# CHAPTER 5: DIAGENESIS AND RESERVOIR POTENTIAL OF VOLCANOGENIC SANDSTONES - CRETACEOUS OF THE SURAT BASIN

# DIAGENESIS AND RESERVOIR POTENTIAL OF VOLCANOGENIC SANDSTONES - CRETACEOUS OF THE SURAT BASIN

## ABSTRACT

The sandstones of the Lower Cretaceous succession of the Surat Basin are characterized by abundant volcanogenic detritus in the form of rock-fragments and feldspars. These compositionally immature sandstones are not regarded as favourable exploration targets for hydrocarbons because of their lithic nature, their shallow burial depths, and hence the low thermal maturity of the intercalated mudrocks which might have constituted hydrocarbon source rocks. However, petrographic and petrophysical examinations show that porosity and permeability exist in varying proportions in all of these stratigraphic units which under certain circumstances could be the host for hydrocarbons and may become the future exploration targets. Teritary meteoric flushing has created significant amounts of secondary dissolution porosity in these sandstones. Knowledge of the diagenetic development of porosity and permeability is essential for understanding the complex geologic evolution of reservoir characteristics, especially in the compositionally immature sandstones.

## INTRODUCTION

Compositionally immature sandstones are generally regarded as unfavourable for hydrocarbon accumulation due to their susceptibility to both physical compaction and chemical alteration and hence rapid loss of porosity and permeability after burial ( Galloway, 1979; Davies et al, 1979; Burns and Ethridge, 1979). Exceptions to this generalization are not uncommon and hydrocarbon production from volcanogenic labile sandstones has been reported from various parts of the world (e.g., Coffman, 1987; Crossey et al, 1984; Hayes et al, 1976; Iijama and Utada, 1971; Magara, 1968; Merino, 1975a, 1975b). In the Surat Basin, significant porosity and permeability exist in some stratigraphic units as demonstrated by the fact that some of them function as aquifers (Exon, 1976, Habermehl, 1980, 1982; Slansky, 1984). However, no hydrocarbons have been reported from the Lower Cretaceous succession of the Surat Basin although their correlative formations in the neighbouring Eromanga Basin contain commercial and sub-commercial oil and gas accumulations (Figure 2.9; see also Armstrong and Barr, 1982).

These compositionally immmature sandstones (Figure 5.1) are buried to depths ranging from a few tens of metres to about 900 metres. Diagenesis has not only reduced porosity in some places within them but has also created substantial amounts of secondary porosity elsewhere through dissolution of pore-filling and grain-replacive cements and detrital framework grains. Meteoric flushing is suggested as the principal agent of secondary porosity development which perhaps was aided by the products of bacterial degradation of organic matter from intercalated mudrocks.

## AUTHIGENIC MINERALS

The principal diagenetic minerals in the Lower Cretaceous sandstones are pore-lining/grain-coating nontronite, pore-filling and grain-replacive zeolite and calcite, and minor kaolinite. Labile components such as heavy minerals, volcanic rock-fragments and feldspars are found to be extensively altered (Figure 5.2C-D) thus releasing $Al^{+++}$ and silica for use in precipitation of clay minerals. The more quartzose Mooga Sandstone (cf. Figure 5.1) has ubiquitious kaolinite pore-fills and minor quartz overgrowths (Figure 5.2). Carbonates are represented mainly by calcite with some ferroan calcite and minor dolomite. The distribution of carbonates are patchy and seems to be grainsize controlled, coarser-grained sandstones tend to contain more carbonate cement. The authigenic zeolite

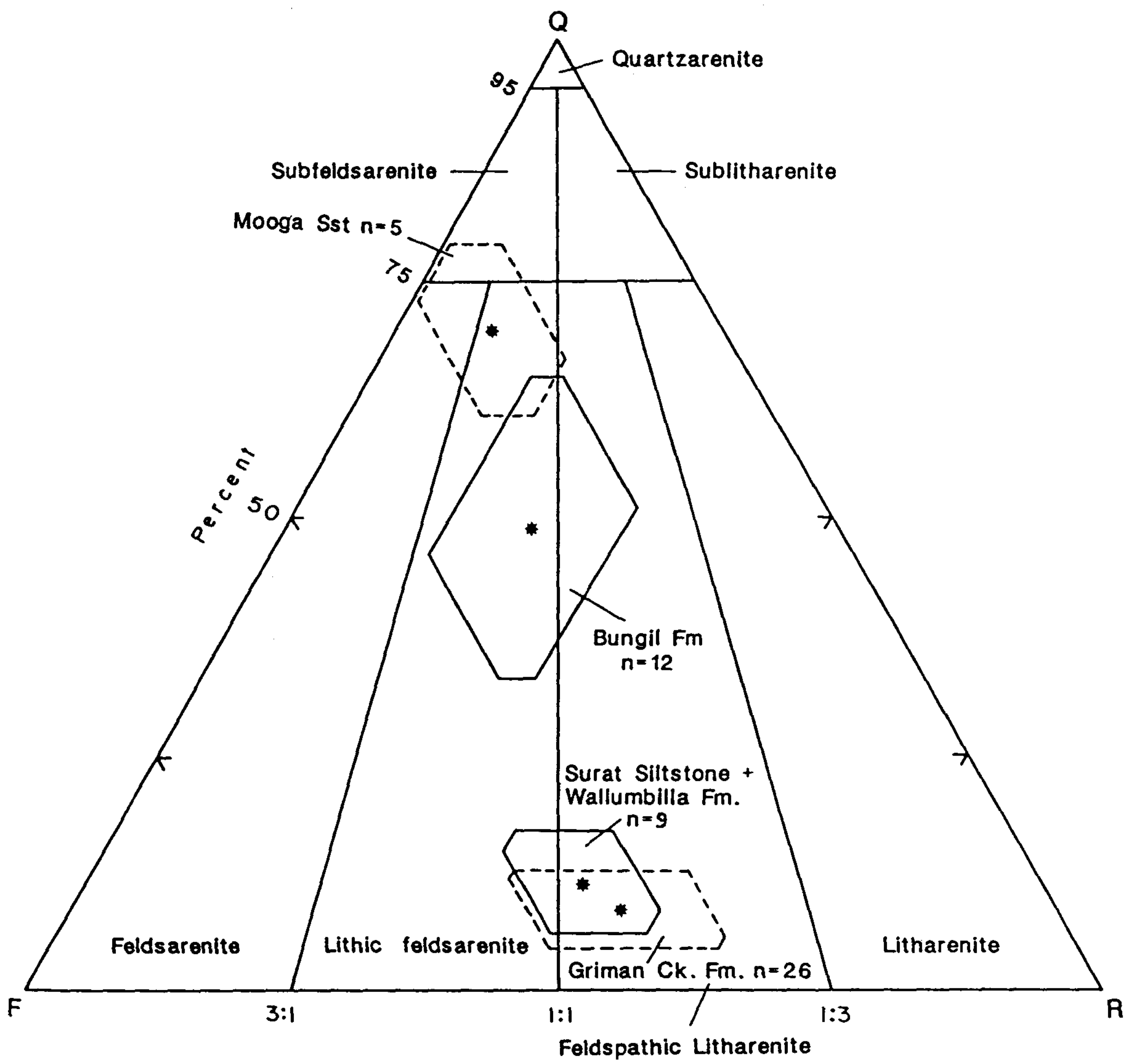



Figure 5.1. Framework grain composition of the Lower Cretaceous sandstones of the Surat Basin (classification after Folk et al, 1970). QFR means (asterisks) are bounded by fields of variation delineating one standard deviation of each component (cf. Ingersoll, 1978).

| Age | Stratigraphic Unit | | Thick. (m) | Diagenetic mineral species | | | | | Core porosity,%[1] | | N | Permeability,[2] md | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Carbonate | Zeolite | Nontronite | Chlorite | Kaolinite | Range | Average | | Range | Average |
| Aptian-mid.-Upp. Alb. | Rolling Downs Group | Griman Ck. Fm. | 480 | ▬ ▬ ▬ | ▬▬ | ▬▬▬ | | ▬ ▬ ▬ | 6-33 | 27 | 26 | 0.001-1495 | 269 |
| Aptian-mid.-Upp. Alb. | Rolling Downs Group | Surat Siltstone | 150 | ▬▬ | | ▬ | | ▬ ▬ | 16-28 | 22 | 2 | 0.001-132 | 66 |
| Aptian-mid.-Upp. Alb. | Rolling Downs Group | Wallumbilla Fm. | 480 | ▬ ▬ ▬ | ▬▬ | ▬▬ | | ▬ ▬ | 17-31 | 25 | 7 | 0.001-82 | 34 |
| Neocom. | | Bungil Fm. | 270 | ▬ ▬ | | ▬ ▬ | | ▬ ▬ ▬ | 15-35 | 27 | 12 | 0.001-2800 | 647 |
| Neocom. | | Mooga Sandstone | 300 | ▬ ▬ | | | ▬ ▬ | ▬▬▬ | 18-31 | 26 | 5 | 0.53-161 | 45 |

Figure 5.2. Diagenetic mineral assemblages and porosity-permeability of the Lower Cretaceous sandstones of the Surat Basin. Length of the bar indicates relative abundance of authigenic minerals; broken bar - patchy distribution throughout the formation. Carbonates comprise mainly calcite with some ferroan calcite and minor dolomite. The Mooga Sandstone also contains minor quartz overgrowth. N - number of samples studied. 1 - Average of the entire Lower Cretaceous succession, 26%. 2 - Average of the Lower Cretaceous succession, 291 md.

is concentrated in the Rolling Downs Group sediments and is represented exclusively by heulandite as confirmed by electron microprobe and EDX analyses (Appendices 2.4 and 2.2.4). The authigenic origin of zeolite is also supported by its delicate shape and geometry of interstitial distribution within the reservoirs (Figures 5.3A, B, D and E). The precipitation of various authigenic phases took place relatively early in the diagenetic history before compaction has signigicantly reduced primary porosity. This is suggested by commonly loose grain-packing and moderate-to-high minus-cement porosity in some samples. Cement stratigraphy suggests that authigenesis of clay minerals (predominantly nontronite, with some montmorillonite) preceded zeolite formation[1] (Figure 5.3A-C and E).

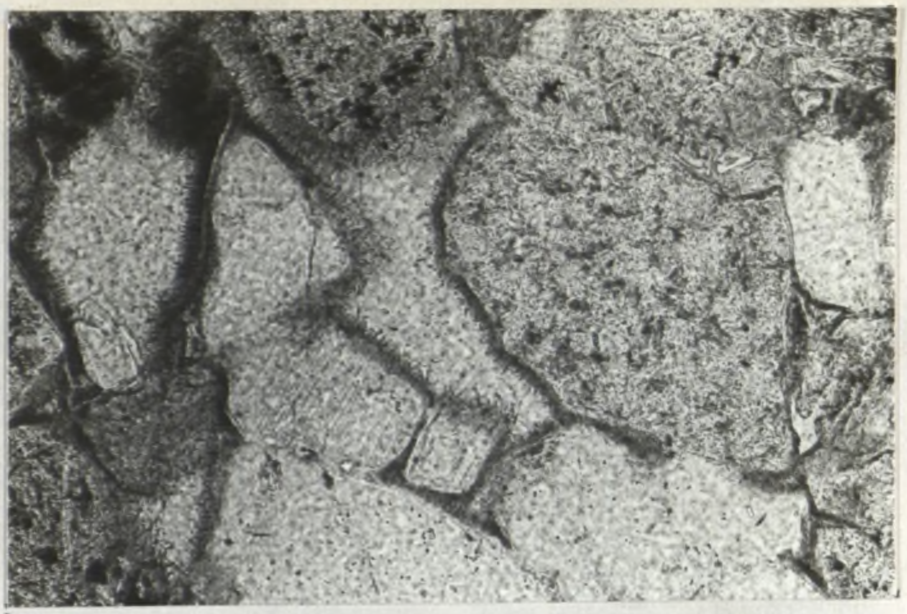
**THE ROLE OF TEMPERATURE AND/OR PORE-FLUID CHEMISTRY ON AUTHIGENIC MINERAL SPECIES**

The formation of zeolite minerals in volcanogenic sediments was largely interpreted as a burial metamorphic phenomenon (zeolite facies) based on the classical works of Coombs (1954, 1960, 1961). In essence, zeolite-facies minerals were regarded as manifesting a response to increased temperature with burial. However, this interpretation of temperature-dependence of zeolite formation was subsequently revised to account for the complexity of the spatial and temporal distribution of the zeolite-facies minerals (Boles and Coombs, 1977; Surdam and Boles, 1979; Surdam et al, 1984). Thus, it was realized that the composition of the volcanic debris and pore-fluid, and the rate of fluid thoroughput are as important as temperature in controlling the formation of zeolites. Davies et al (1979) for instance, showed that precipitation of zeolite (e.g., heulandite) and clays (e.g., smectite and chlorite) in the volcanogenic sediments can take place under near-surface conditions at a temperature of 25°-60° C and as little as 300 m burial within a time period of 2500 years.

[1] A paragenetic sequence of diagenetic events for the Lower Cretaceous Sandstones of the Surat Basin is given in Appendix 8.10.

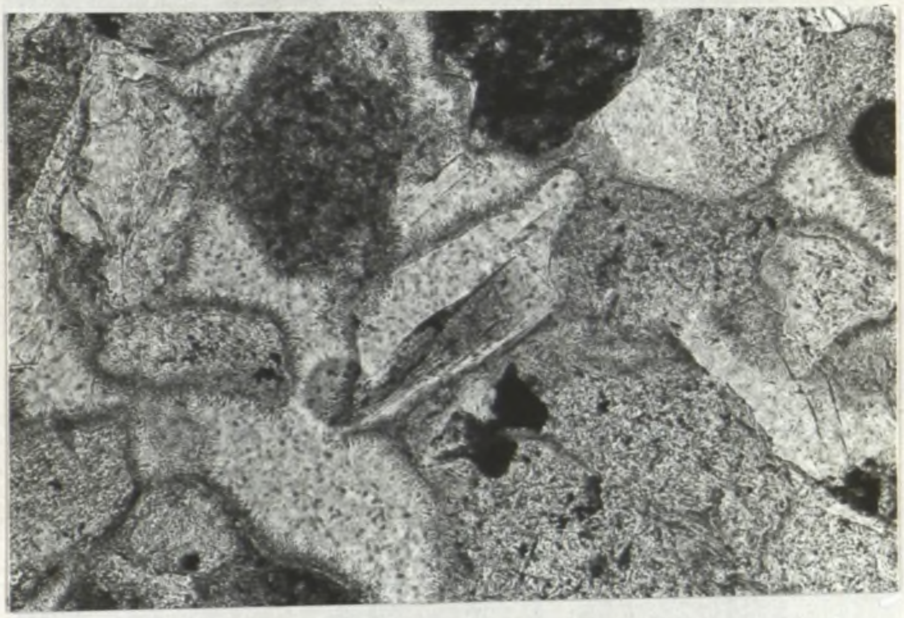
Figure 5.3. A: Thin-section photomicrograph showing nontronite rim which in this case has retarded further diagenetic alterations of the framework grains. Authigenic zeolite (centre-left) has grown subsequently in the pore space formed presumably by the dissolution of a labile framework grain. Griman Creek Formation, GSQ Surat 3/17, depth 213.00 m. Plane light.
B-C: Thin-section photomicrographs of the Griman Creek Formation showing dissolution of an amphibole (centre B and bottom-centre C) giving rise to secondary moldic porosity. The oversized pore in the bottom-centre-left of B is also probably a moldic pore. Note also an elongate authigenic zeolite crystal at top-centre of B. B - GSQ Surat 3/23, depth - 291.50 m. Plane light. C - GSQ Surat 3/12, depth - 154.00 m. Plane light.
D: SEM photomicrograph showing heulandite crystals growing in pore space and on the grain surfaces. Griman Creek Formation, GSQ Surat 3/24, depth - 295.20 m.
E: SEM photomicrograph showing pore-filling heulandite (right). Cement-stratigraphy suggests its formation after the early nontronite grain-coats. Griman Creek Formation, GSQ Surat 3/11, depth - 147.20 m.

A



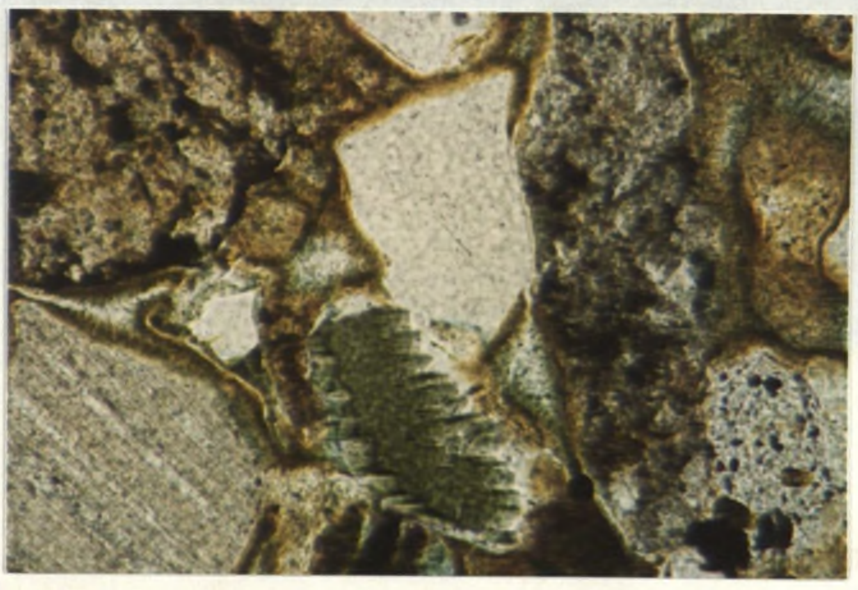
0.1 mm

B



0.1 mm

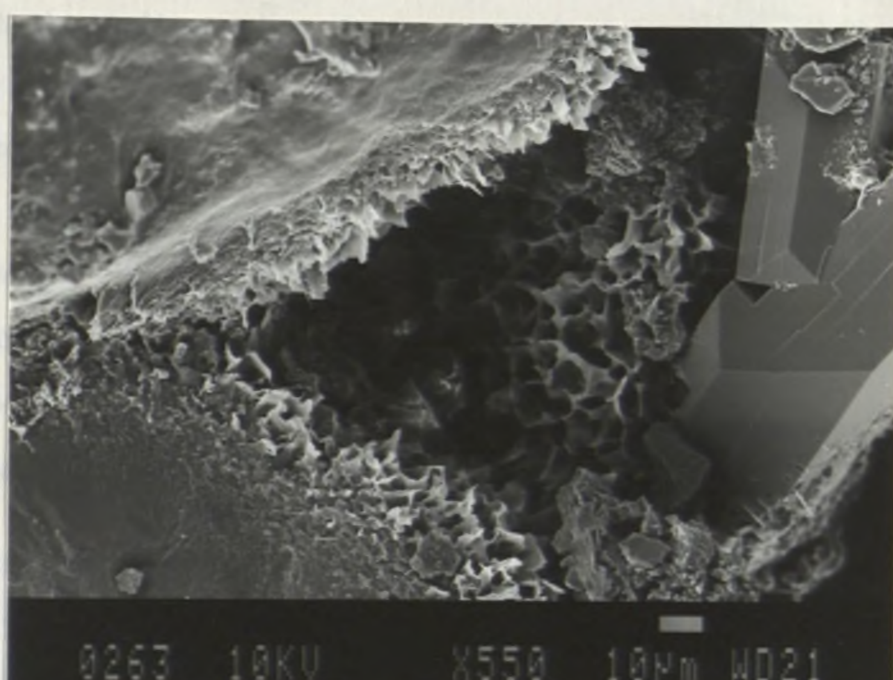
C



0.1 mm

D


E



In the Surat Basin the maximum vitrinite reflectance (Ro) of the Lower Cretaceous sediments hardly exceeds 0.45 - 0.50% and the temperature presumably never exceeded more than 60° C. The present maximum depth of burial is only a few hundred metres and there is no evidence to suggest former appreciably deeper burial. Therefore, temperature seems to have had a subordinate role in the diagenesis of the shallowly buried Surat Basin sandstones. This contradicts the observations of Coombs (1961) and Boles and Coombs (1977) with respect to zeolite formation in other basins. That the pore-fluid chemistry and throughput are the controlling factors for the formation of the diagenetic mineral assemblages in the Lower Cretaceous sandstones of the Surat Basin is also suggested by the fact that the finer-grained rocks contain a less diverse suite of diagenetic minerals than their compositionally similar coarser-grained counterparts. Moreover, coarser-grained sandstones tend to develop more secondary dissolution porosity (cf. Figure 3.6). Such fabric-selective cementation and dissolution indicate that the degree of diagenetic alteration is controlled among other factors by the original porosity and permeability of the sandstone bodies.

In the Rolling Downs Group (cf. Figure 5.2), zeolite has not been observed below a depth of 400 m. On the basis of the few samples available for study below this depth it is suggested that zeolite disappears at this depth and this may reflect either increased temperature or change in pore-fluid chemistry.

## POROSITY AND PERMEABILITY

Measured core porosity in sandstones (throughout the entire Lower Cretaceous succession) varies from 6 to 35% with an average of 26% (Figure 5.2) whereas measured thin-section porosity ranges from 0 to 13% with an average of 5% (Figure 5.4). The difference is arbitrarily taken as a

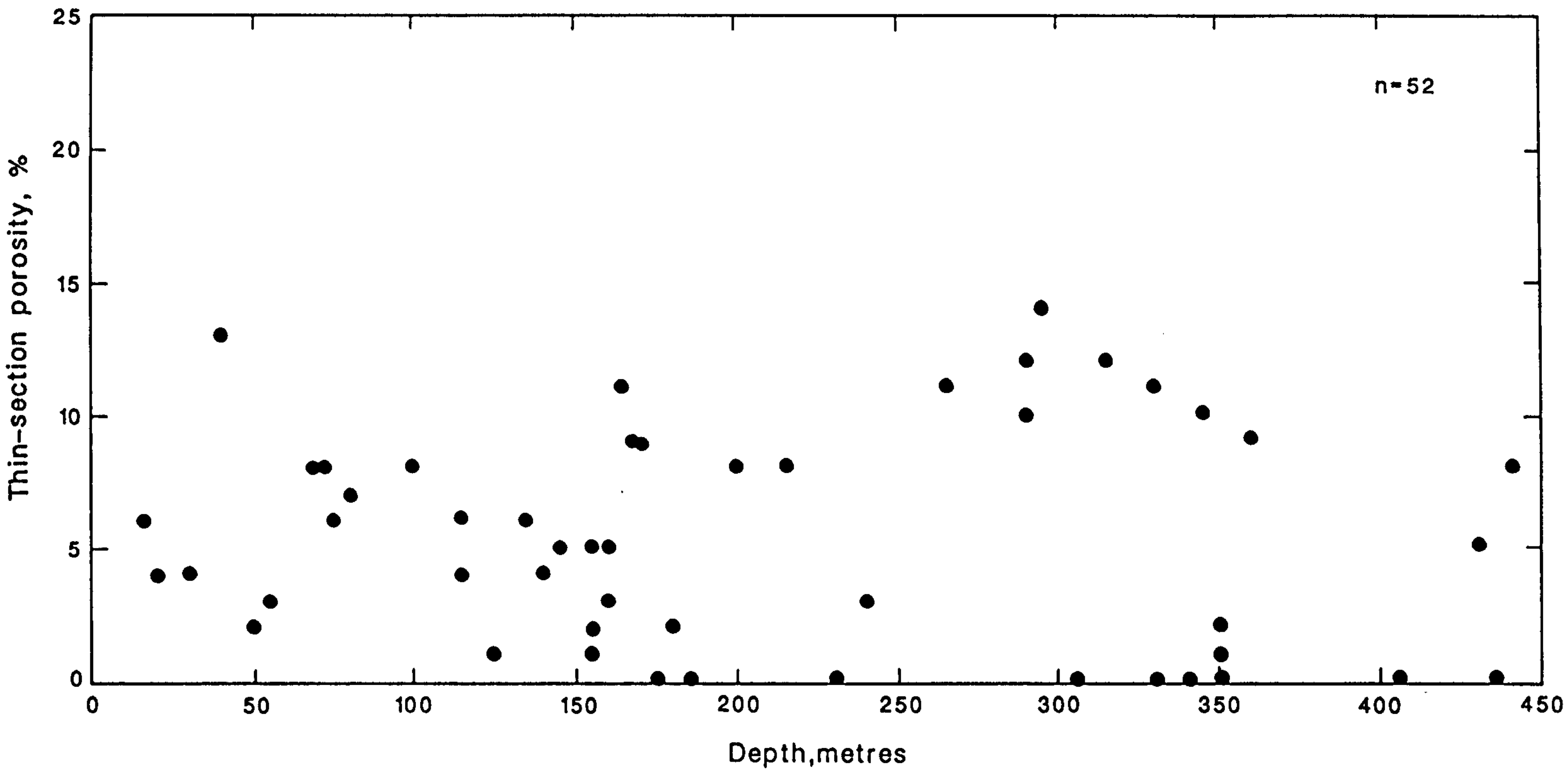



Figure 5.4. Plot of thin-section porosity against depth of the Lower Cretaceous sandstones of the Surat Basin.

measure of microporosity.

Secondary porosity is present in varying proportions throughout the Lower Cretaceous succession. The secondary porosity index (SPI; which is the ratio of the secondary dissolution porosity to the total thin-section porosity) in individual samples reaches up to 0.7 but most samples show a combination of both primary and secondary porosity with the former being the volumetrically more important in the studied samples (Figure 5.5). The inferred paragenetic sequence of diagenetic events (cf. Figure 3.38) suggests that the major phase of development of dissolution porosity in these sandstones did not occur until the inception of the Great Artesian System in the Pio-Pleistocene. The bacterial and/or low-temperature degradation products of organic matter from the intercalated mudrocks (eogenetic zone: Figure 3.38) might also have contributed to the generation of secondary dissolution porosity (discussed in the following section in the text) but it is difficult to isolate its effect from that of meteoric washing.

## MECHANISMS OF SECONDARY POROSITY DEVELOPMENT: A CONCEPTUAL APPROACH

In recent years numerous authors have documented the widespread occurrence of secondary porosity in clastic reservoirs and suggested the products of organic maturation in the adjacent mudrocks as possible agents. Organic maturation is accompanied by the generation of various organic acids and $CO_2$ prior to the onset of hydrocarbon generation. These products facilitate the dissolution of framework grains and/or cements by their corrosive actions. These phenomena offer a sound conceptual mechanism for the development of secondary porosity in sandstone bodies juxtaposed with thermally mature mudrocks. To account for dissolution porosity in the case of the presence of immature kerogen in mudrocks, one or more different machanism(s) have to be invoked.

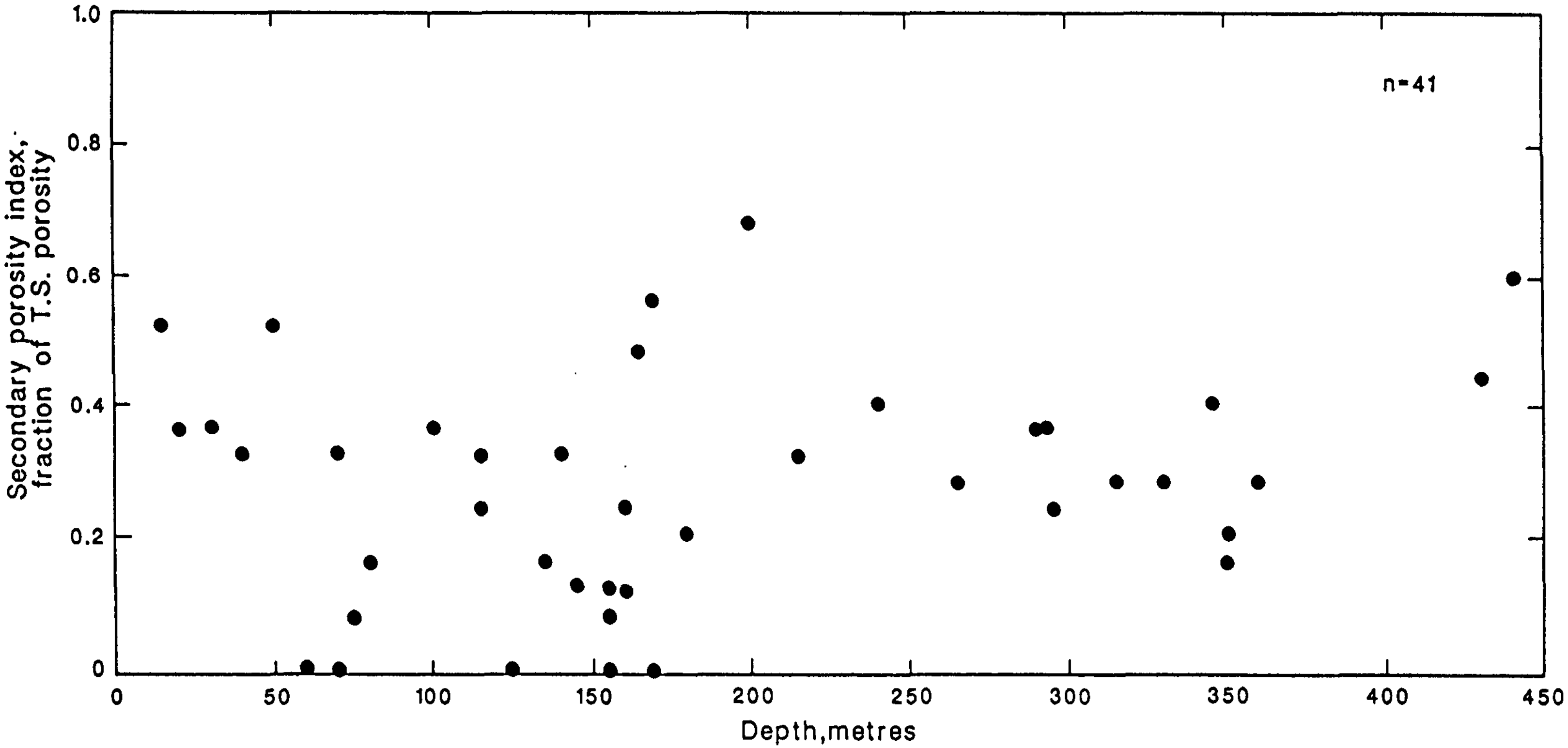



Figure 5.5. Plot of secondary porosity index (SPI) against depth. Lower Cretaceous sandstones, Surat Basin. Samples having zero thin-section porosity have been excluded from the plot.

In the Lower Cretaceous sandstone suites of the Surat Basin, the dissolution porosity may be due to one or both of the following phenomena. Firstly, meteoric flushing of the porous and permeable sandstone bodies by $CO_2$-charged water after the inception of the Great Artesian System in the Plio-Pleistocene (Bowering, 1982) could be a potential agent. Thus the paludal/brackish/shallow marine (cf. Figure 1.2) connate water of these formations was diluted by the fresh water giving rise to lower salinities and pH which aided in the generation of dissolution pores. The Mooga Sandstone is an excellent aquifer throughout the Great Artesian Basin and in places the Griman Creek, Wallumbilla and Bungil Formations and their lateral equivalents also constitute aquifers in both the Surat and Eromanga Basins (Exon, 1976; Habermehl, 1982). The development of secondary dissolution porosity is continuing at the present time in the Great Artesian Basin as suggested by the dissolved $CO_2$ in the formation waters which can be so high in places that corrosion of the steel well-casings of water bores is not uncommon (Habermehl, 1980). Pore-fluid chemistry determined by the types of hydrogeologic regime(s) exerts a first-order control on the diagenetic mineralogy and geologic evolution of porosity. The Surat Basin is an example of a basin presently dominated by the meteoric regime. On a geological time scale meteoric circulation is rapid and groundwater velocity as much as 5 m/year has been reported from the Great Artesian Basin (Habermehl, 1980). Long-term flushing by regional meteoric circulation replaces residual waters with geochemically-evolved meteoric water as dramatically demonstrated by the very low salinity of the dominantly marine Lower Cretaceous sediments of the Great Artesian Basin (Habermehl, 1980, 1982).

Secondly, release of $CO_2$ and organic acids by the bacterial degradation of kerogen in the mudrocks could be another additional mechanism for development of dissolution porosity. The Lower Cretaceous succession contains mudrocks rich in organic matter and microbial degradation is likely to have been a common phenomenon. Moreover, early thermal decomposition of any labile kerogens such as resins and suberins (Chapters 3 and 8) might have contributed to the release of organic acids, particularly in the deeper part of the section. The decomposition products of organic matter, whether bacterial or thermal, include various organic acids (e.g., humic, amino, and carboxylic acids), $CO_2$, and hydrocarbons (Curtis, 1978, fig. 2; 1983; Tissot and Welte, 1978). Crossey et al (1984, 1986) showed that laumontite is soluble in carboxylic acid and feldspar and zeolite solubilities are an order of magnitude higher in difunctional organic acid such as oxalic acid and three orders of magnitude higher in some phenols. Huang and Keller (1972) also showed the enormous solubility of aluminosilicates in humic acids. Although experimental dissolution studies by Crossey et al (1984) focussed mainly on laumontite, the same pattern of solubility may be expected for heulandite. The effect of these acids on sandstone reservoir evolution has been discussed in detail in Chapter 3.

## THE EFFECT OF POROSITY TYPES ON PERMEABILITY AND OTHER PETROPHYSICAL PARAMETERS

A number of petrophysical properties are known to be affected both by the genetic (e.g., primary vs. secondary) and geometric (macro vs. micro) types of porosity present in a sandstone. Knowledge of the porosity type is vital to evaluate its effect on permeability, water saturation and hydrocarbon recovery efficiency. Pittman (1979a, 1979b) offered a triangular porosity classification which combines both the genetic and geometric (i.e., size) aspects of porosity and is very useful in assessing the quality of a clastic reservoir (Figure 5.6). For instance, a sandstone may contain significant proportion of secondary grain-dissolution (moldic) porosity but this may not be accompanied by a corresponding increase in permeability. Moldic porosity has to exceed a critical minimum value to form an interconnected network in order to contribute to the permeability. Isolated dissolution pores in the absence of intergranular pores will manifest little if any permeability due to poor or lack of interconnection (lower coordination number; cf. Wardlaw, 1980) and high pore-to-throat-size ratio. Such a reservoir will require massive hydraulic fracturing to permit hydrocarbon production. Moldic porosity also has implications for enhanced recovery processes of oil. The amount of recoverable oil may be much less than initially estimated if moldic pores are abundant and their distribution patchy (which is commonly the case) because moldic porosity gives rise to high pore-to-throat-size ratio adversely affecting the recovery efficiency (cf. Wardlaw, 1980). Moreover, fabric-selective dissolution porosity gives rise to reservoir heterogeneity by way of forming scattered patches of high porosity/permeability zones which may lead to the premature coning/breakthrough of formation water or secondary/tertiary recovery fluids (cf. Pittman, 1979b). On the other hand, a sandstone containing significant amounts of microporosity will tend to increase water saturation and will cause potential problems with log interpretation and in reservoir stimulation and management (see Chapter 4 for detail). Any hydrocarbon retained in the micropores will require natural or artificial fracturing to allow it to flow. Therefore, formations with significant amounts of dissolution porosity and/or microporosity will necessiate treatment in many respects like carbonate reservoirs with vuggy porosity rather than treatment like conventional clastic reservoirs with dominantly intergranular pores.

Figure 5.6 is a triangular porosity plot of the Lower Cretaceous sandstones of the Surat Basin. It is apparent from this figure that many of the sandstones plot near the microporosity pole which is not surprising

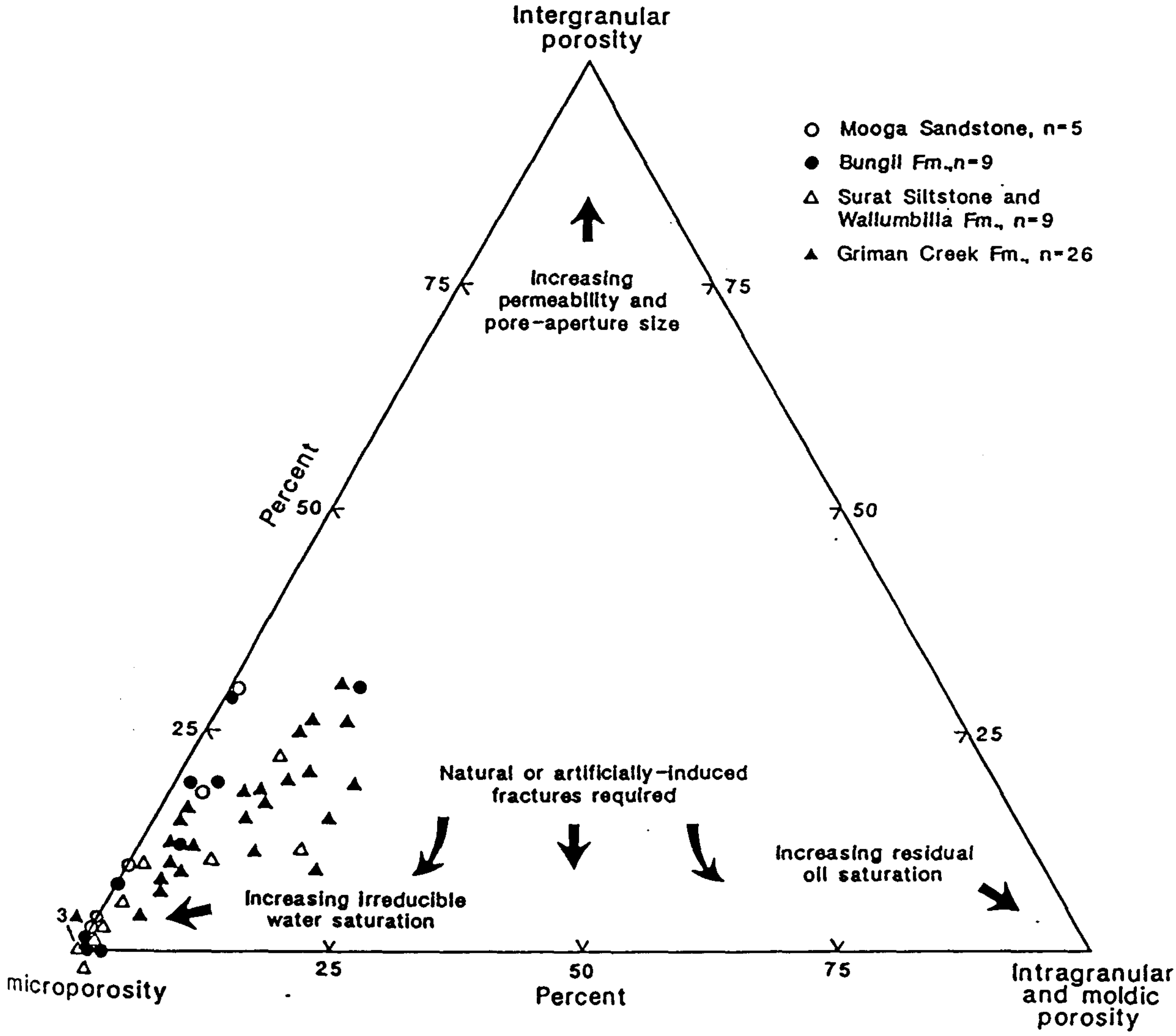



Figure 5.6. Ternary plot of porosity types (plot construction after Pittman 1979a and 1979b with minor modifications). Note that intergranular porosity includes both primary and secondary (cement/matrix-dissolution) varieties whereas intragranular and moldic pores represent grain-dissolution types. Microporosity equals measured core porosity minus measured thin-section porosity.

in view of their lithic detrital composition (cf. Figure 5.1) and presence of various authigenic mineral species (notably clays) that contribute to the microporosity (Chapter 3). However, the proportion of intergranular porosity varies from 0 to 35% (on a 3-component basis) and many samples record more than 10% intergranular porosity (Figure 5.6) rendering them moderate-to-good quality reservoirs.

## DISCUSSION

Reservoir quality sandstones are present in the Surat Basin volcanogenic succession. The absence of hydrocarbons in these formations is due to the shallow burial and hence thermal immaturity of the intercalated organic-rich mudrocks. However, Allen (1976) reported oil and gas shows from the Lower Cretaceous succession of the Surat Basin and the correlative formations in the neighbouring Eromanga Basin have hydrocarbon production and shows (Moore and Pitt, 1984; Figure 2.9 herein). The reported shallow hydrocarbons in the above basins are either derived from the deeper part of the section by leakage through impermeable seals and faults or are biogenic in origin (especially gas). However, no isotope analysis data are yet available to confirm either of these origins. Entrapment of commercial quantities of biogenic gas in geologically young and shallow reservoirs are getting wider recognition (Claypool et al, 1980; Rice and Claypool, 1981) and their contribution to the abovementioned reservoired gas can not be ruled out.

In the event the volcanogenic sandstones contain hydrocarbon, they are likely to require special treatment during drilling, testing and production due to the presence of various water- and acid-sesitive authigenic minerals. They are also prone to give rise to log-derived low resistivity and high water saturation problems due to their commonly high microporosity.

REFERENCES

Allen, J. R., 1976, Surat Basin. In Economic geology of Australia and Papua New Guinea. Austral. Inst. Min. Metall. Monogr. 7, pp. 266-272.

Almon, W. R., and Schultz, A. L., 1979, Electric log detection of diagentically altered reservoirs and diagenetic traps. Trans. Gulf Coast Assoc. Geol. Soc., v. 29, pp. 1-10.

Armstrong, J. D., and Barr, T. M., 1982, Eromanga Basin symposium, summary papers. Petrol. Expln Soc. Austral. and Geol. Soc. Austral., Adelaide, pp. 20-42.

Boles, J. R., and Coomb, D. S., 1977, Zeolite facies alteration of andstones in the Southland Syncline, New Zealand. Amer. Jour. Sci., v. 277, pp. 982-1012.

Bowering, O. J. W., 1982, Hydrodynamics and hydrocarbon migration - a model for the Eromanga Basin. Austral. Petrol. Expln Assoc. Jour., v. 22, pp. 227-236.

Burns, L. K, and Ethridge, F. G., 1979, Petrology and diagenetic effects of lithic sandstones: Paleocene and Eocene Umpqua Formation, southwest Oregon., In Scholle, P. A., and Schluger, P. R., (eds.) Aspects of diagenesis. SEPM Sp. Publ. 26, pp. 307-317.

Claypool, G. E., Threkeld, C. N., and Magoon, L. B., 1980, Biogenic and thermogenic origins of natural gas in Cook Inlet Basin, Alaska. AAPG Bull., v. 64/8, pp. 1131-1139.

Coffman, R. L., 1987, Laumontization and its relationship to carbonate cementation and dissolution within Santa Fe Springs oil field, Los Angeles Basin, California. (Abs.), AAPG Bull., v. 71/5, pp. 540.

Coombs, D. S., 1961, Some recent work on the lower grades of metamorphism, Austral. Jour. Sci. v. 24, pp. 203-215.

Crossey, L. J., Frost, R. B., and Surdam, R. C., 1984, Secondary porosity in laumontite-bearing sandstones. In McDonald, D. A., and Surdam, R. C., (eds.) Clastic diagenesis. AAPG Mem. 37, pp. 225-237.

Crossey, L. J., Surdam, R. C., and Lahann, R., 1986, Application of organic/inorganic diagenesis to porosity prediction. In Gautier, D. L. (ed.) Roles of organic matter in sediment diagenesis. SEPM Sp. Publ. 38, pp. 147-15.

Curtis, C. D., 1978, Possible links between sandstone diagenesis and depth related geochemical reactions occurring in enclosing mudstones. Jour. Geol. Soc. London., v. 135, pp. 107-117.

Curtis, C. D., 1983, Geochemistry of porosity enhancement and reduction in clastic sediments. In Brooks, J. (ed.) Petroleum geochemistry and exploration in Europe. Geol. Soc., Blackwell Sci. Publ., Oxford. pp. 113-125.

Davies, D. K., Almon, W. R., Bonis, S. B., and Hunter, B. E., 1979, Deposition and diagenesis of Tertiary-Holocene volcaniclastics, Guatemala. In Scholle, P. A., and Schluger, P. R., (eds.) Aspects of diagenesis. SEPM Sp. Publ. 26, pp. 281-306.

Exon, N. F., 1976, Geology of the Surat Basin in Queensland. Bureau of Min. Res. Bull., 166, 160 p.

Folk, R. L., Andrews, P. B., and Lewis, D. W., 1970, Detrital sedimentary rock classification and nomenclature for use in New Zealand. NZ Jour. Geol. Geophy. v. 13, n. 4, pp. 937-968.

Galloway, W. E., 1974, Depositional and diagenetic alteration of sandstones in northeast Pacific arc-related basins: implications for greywacke diagenesis. Geol Soc. Amer. Bull., v. 85, pp. 379-390.

Galloway, W. E., 1979, Diagenetic control of reservoir quality in arc-related sandstones: implication for petroleum exploration. In Scholle, P. A., and Schluger, P. R., (eds.) Aspects of diagenesis. SEPM Sp. Publ. 26, p. 251-262.

Habermehl, M. A., 1980, The great Artesian Basin, Australia. Bureau Min. Res. Jour. Austral. Geol. Geophy. v. 5, pp. 9-38.

Habermehl, M. A., 1982, The Eromanga Basin within the Great Artesian Basin. In Eromanga Basin Symposium summary papers, Petrol. Expln Soc. Austral. and Geol. Soc. Austral., Adelaide, pp. 384-397.

Hayes, J. B., 1973, Petrology of indurated sandstones, Leg 18, DSDP. In Kulm, L. D., von Huene, R., et al, Initial reports of the Deep Sea Drilling Project, Leg 18, Washington D. C. U.S. Govt. Printing Office, pp. 915-924.

Hayes, J. B., Harms, J. C., and Wilson, T. Jr., 1976, Contrasts between braided and meandering stream deposits, Beluga and Sterling Formations (Tertiary), Cook Inlet, Alaska. In Miller, T. P. (ed.) Recent and ancient sedimentary environments in Alaska. Alska Geol. Soc., pp. J1-J27.

Huang, W. H., and Keller, W. D., 1972, Organic acids as agents of chemical weathering of silicate minerals. Nature, Physical Sci., v. 239, pp. 149-151.

Iijama, A., and Utada, M., 1971, Present-day zeolitic diagenesis in the Neogene geosynclinal deposits in Niigata oil field, Japan. Amer. Chem. Soc., Advances in chemistry series., v. 101, pp. 342-349.

Ingersoll, R. V., 1978, Petrofacies and petrologic evolution of the Late Cretaceous fore-arc basin, northern and central California. Jour. Geol., v. 86, pp. 335-352.

Magara, K., 1968, Composition and migration of fluids in Miocene mudstone, Nagaoka Plain, Japan. AAPG Bull., v. 52/12, pp. 2466-2501.

Merino, E., 1975 a, Diagenesis in Tertiary sandstones from Kettleman North Dome, California, I, diagenetic mineralogy. Jour. Sedim. Petrol., v.

45/1, pp. 320-336.

Merino, E., 1975 b, Diagenesis in Tertiary sandstones from the Kettleman North Dome, California, II, interstitial solutions: distributions of aqueous species at 100 c and chemical relation to the diagenetic mineralogy. Geochem. Cosmochem. Acta. v. 39, pp. 1629-1645.

Moore, P.S., and Pitt, G. M., 1984, Cretaceous of the Eromanga Basin - implications for hydrocarbon exploration. Austral. Petrol. Expln Assoc. Jour., v. 24, pp. 358-376.

Pirson, S. J., 1963, Handbook of well log analysis for oil and gas formation evaluation. Prentice-Hall Inc., Englewood Cliffs, N.J. 326 p.

Pittman, E. D., 1979 a, Porosity, diagenesis and productive capability of sandstone reservoirs. In Scholle, P. A., and Schluger, P. R., (eds.) Aspects of diagenesis. SEPM Sp. Publ. 26, pp. 159-173.

Pittman, E. D., 1979 b, Recent advances in sandstone Diagenesis. Ann. Rev. Earth Planet. Sci., v. 7, pp. 39-62.

Rice, D. D., and Claypool, G. E., 1981, Generation, accumulation and resource potential of biogenic gas. AAPG Bull., v. 65, pp. 5-25.

Slansky, E., 1984, Clay mineralogy. In Hawke, J. M., and Cramsie, J. W., (eds.) Contributions to the geology of the Great Artesian Basin in New South Wales. Geol. Surv. NSW Bull., 131, pp. 179-203.

Surdam, R. C., and Boles, J. R., 1979, Diagenesis of volcanic sandstones. In Scholle, P. A., and Schluger, P. R., (eds.) Aspects of diagenesis. SEPM Sp. Publ. 26, pp. 227-242.

Surdam, R. C., and Boese, S. W., and Crossey, L. J., 1984, The chemistry of secondary porosity. In McDonald, D. A., and Surdam, R. C., (eds.) Clastic diagenesis. AAPG Mem. 37, pp. 127-149.

Tissot, B. P., and Welte, D. H., 1978, Petroleum formationa and occurrence. Springer-Verlag, Berlin-Heidelberg-New York, 527 p.

Wardlaw, N. C., 1980, The influence of pore structure in rocks on the entrapment of oil. in Miall, A. D. (ed.) Facts and principles of world petroleum occurrence. Can. Soc. Petrol. Geol. Mem. 6, pp. 193-208.

# CHAPTER 6: MULTIPLE LINEAR REGRESSION - A QUANTITATIVE APPROACH TO THE STUDY OF SANDSTONE POROSITY

# MULTIPLE LINEAR REGRESSION - A QUANTITATIVE APPROACH TO THE STUDY OF SANDSTONE POROSITY

## INTRODUCTION

Sandstone porosity is the result of a complex interplay of many variables and has been the subject of numerous studies each emphasizing one or more of the host of controlling parameters. Most of these studies were qualitative or at best semiquantitative in nature and therefore biased to some extent by the a priori insight or intution of the individual researcher(s). Table 1 is a list of parameters that are deemed important by various workers. It is apparent that not all parameters are operating at the same time or place in a specific basin. The objective of the present study is to identify the controlling variables and quantify their effects on porosity in the context of the Surat Basin and if possible to try to predict porosity from the knowledge of these parameters. To this end a stepwise regression analysis was undertaken on 211 cases of core materials by a SPSSX computer package (Procedure REGRESSION, SPSS Inc., 1983) on the Macquarie University VAX mainframe computer system. The basic mathematical model for multiple linear regression is:

$$y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \beta_p x_p + \varepsilon$$

where $x_1$, $x_2$, $x_3$, $\ldots x_p$ are the p independent variables, Y is the dependent variable, $\alpha$, $\beta_1$, $\beta_2$, $\beta_3 \cdots \beta_p$ are the constants and $\varepsilon$ is the the random variable that are normally distributed with 0 mean and constant variance $\sigma^2$. The model assumes that there is a normal distribution of the dependent variable for every combination of values of the independent variables in the model. The estimators of $\beta$'s are $B_1$, $B_2$, $\ldots B_p$ and are called partial regression coefficients. The estimator of $\alpha$ is A and is called the constant term of regression. The coefficients $\alpha$ and $\beta$'s are usually estimated by the method of least squares, by minimizing S, the sum of squares of the deviations, so that the quantity to be minimized is:

$$S = \sum \varepsilon_i^2 = (Y_i - \beta_1 x_{i1} - \beta_2 x_{i2} - \beta_3 x_{i3} \cdots \beta_p x_{ip})^2 .$$

A least square solution to a linear equation of this type can be found by solving a set of normal equations for the coefficients. This can be expressed in matrix form as:

$$[\Sigma X][\beta] = [\Sigma Y] \text{ with a solution } [\beta] = [\Sigma X]^{-1}.[\Sigma Y] ,$$

where $[\Sigma Y]$ is a column matrix of the sums of squares and crossproducts of y with $x_1$, $x_2$, .. $x_p$; $[\Sigma X]$ is a square symmetric $p \times p$ matrix of sums of squares and crossproducts of $x_1$, $x_2$, ...$x_p$, $[\beta]$ is a column matrix of the unknown coefficients and $[\Sigma X]^{-1}$ is the inverse of $[\Sigma X]$. A detailed discussion on the topic can be found in Gunst and Mason (1971), Davis (1973) and Kosch and Link (1971). The following variables were initially selected for the study: COREPOR (core porosity, % dry bulk volume), QUARTZ (detrital mega quart content, whole-rock %), CEMENT (cement including quartz, carbonate, zeolite, and chemically precipitated phyllosilicates; whole-rock %), EPIMAT (epimatrix, whole-rock%; represented mainly by kaolinite; terminology of Dickinson, 1970; see also Appendix 1.1), MEANSIZE (mean grainsize in phi units), SORTING (grainsize sorting in phi standard deviation), DEPTH (depth in metres), AGE (age of the sediment in Ma), DEPENV (depositional environment[1] in an arbitrary scale of 1-6). COREPOR is the dependent variable and the rest are the independent variables.

---

1 Depositional environment: Fluvial, braided - 1; Fluvial, meandering - 2; Lacustrine - 3; Paralic - 4; Shallow marine - 5; Deep marine - 6;

Table 6.1. Factors controlling porosity in clastic reservoirs. Modified from Scherer, 1987.

| | |
|---|---|
| 1. Age | Maxwell, 1960, 1964; Roll, 1974 Schmoker, 1984; Siever, 1983; Scherer, 1987. |
| 2. Composition | Griffiths, 1964; Nagtegaal, 1978; Galloway, 1974, 1979; Hayes, 1979 Loucks et al, 1984 |
| 3. Grainsize | Rogers and Head, 1961; Beard and Weyl, 1973, Pryor, 1973. |
| 4. Sorting | Rogers and Head, 1961; Beard and Weyl, 1973; Pryor, 1973. |
| 5. Rounding | Fraser, 1935; Powers, 1953. |
| 6. Sphericity | Tickell and Hiatt, 1938; Rittenhouse, 1943. |
| 7. Grain orientation | Emery and Griffiths, 1953; Griffiths, 1964. |
| 8. Depth | Athy, 1935; Atwater and Miller, 1965; Selley, 1978; Baldwin and Butler, 1985. |
| 9. Temperature | Maxwell and Verral, 1954; Maxwell, 1964; Galloway, 1974; Selley, 1978; Schmoker, 1984; Loucks et al, 1984. |
| 10. Overpressure | Atwater and Miller, 1965; Selley, 1978. |
| 11. Hydrocarbon saturation | Chepikov et al, 1961; Fuchbauer, 1967; Wilson, 1977; Webb, 1974; Selley, 1978. |
| 12. Formation water chemistry | Renton et al, 1969; Wolf and Chilingarian, 1976, Curtis, 1978; Surdam et al, 1984; Galloway, 1984; Longstaffe, 1984; Franks and Forester, 1984; Siebert et al, 1984. |
| 13. Sand/shale ratio; organic maturation products | Schmidt and McDonald, 1979; Hayes, 1979; Franks and Forester, 1984; Gautier and Claypool, 1984; Surdam et al, 1984; Siebert et al, 1984; Edman and Surdam, 1986; Surdam and Crossey, 1985; Crossey et al, 1986. |

THE ILL-EFFECTS OF MULTICOLLINEARITY ON REGRESSION ANALYSIS

The problem with multicollinear data has been discussed briefly in Chapter 7. A discussion of this problem here is relevant as it relates to the multiple regression.

To evaluate the effect of temperature and geologic age, two more variables TEMP (formation temperature in degress C) and Ro (vitrinite reflectance in oil, %) were included with the data. An examination of the correlation matrix suggests that Temperature and Ro are almost linear functions of depth (r = 1.00 and 0.97 respectively). This is not surprising since temperature was calculated from the geothermal gradient and so was Ro from its regression with depth. This is a problem of multicollinearity and has to be resolved before data analysis is attempted to ensure precision and reliability of the outcome. Multicollinearity usually gives rise to two kinds of problems - one is computational and the other statistical. The computational problem occurs due to rounding-off errors which could lead to the unreliable estimates of regression coefficients. The statistical problem lies in the inflated standard errors of the regression coefficients. This problem reflects the fact that when data are ill-conditioned, some variable(s) are linear combination of others and hence add very little new independent information from which additional statistical information may be gathered. Inflated variances are quite harmful to the use of regression as a basis for hypothesis testing, estimation and forecasting. In extreme cases when any independent variable is a perfect linear combination of other independent variables the correlation matrix becomes singular and a unique unbiased least square solution does not exist. However, this can commonly be detected by an examination of the correlation matrix. Any pairwise correlation of 0.8 or more should be checked for collinearity. But it is also possible to have extreme multicollinearity involving more than two independent variables (e.g some cases when $x_2 = x_3 + x_4$) without having particularly high correlations among pairs of variables (Wesolowsky, 1976; p 50). In such a case multicollinearity can be detected by the eigen values (vectors) calculation; small eigen values (or latent roots) define ill-conditionness of the matrix and large elements of the corresponding eigen vectors are the variables involved in them. SPSSX has a method of warning the user if extreme multicolleariy is present. It does it through the calculation of minimum tolerance of a variable. Tolerance = $1-R_j^2$, where $R_j$ is the multiple correlation coefficient of the jth independent variable when it is considered dependent and its regression with other independent variables are calculated. Tolerance is the proportion of variance not explained by other variables. The default tolerance value in SPSSX is 0.01 which, however, can be preset to any desired value. When independent variables are correlated results may appear anomalous. The overall regression may be significant while none of the individual regression coefficients are significant. It also gives rise to regression coefficients with large standard errors which are unreliable and differ markedly from sample to sample.

The best way to handle the multicollinear data is to remove one (or more) of the variables involved (because they are taken care of by the remaining ones). To deal with this problem I dropped TEMP and Ro and the results show significant improvement of the reliability of the analysis.

## METHOD OF VARIABLE SELECTION

There are numerous methods of variable selection of which the stepwise regression method is one of the most widely used. It is basically a combination of forward selection and backward elimination methods. In stepwise methods the first variable with the highest correlation coefficient with the dependent variable will enter the equation. Then its probability of F to enter (PIN) is compared with the default or set value. The variable must have lower or equal PIN otherwise it is not entered into the equation. If it passes the entry criterion of PIN (or F to enter, FIN), the second variable is selected on the basis of the highest partial correlation coefficient. If it passes the PIN it is also entered into the equation. After the entry of the second variable the first variable already in the equation is tested according to the removal criterion of the probability of F to out (POUT), the default value being 0.10 (or the value of F to out, FOUT). The default value of PIN is 0.05 which must be higher than POUT (or FOUT must be less than FIN). In the next step variables not in the equation are considered for entry depending on the highest partial correlation coefficient. After each step variables already in the equation are considered for removal. This process continues until no variables can be removed by the removal criterion.

## THE RELATIVE IMPORTANCE OF PREDICTOR VARIABLES

There are numerous statistics to assign weight on an individual independent variable. How important an independent variable is when it is the sole predictor of the dependent variable can be answered by inspecting the correlation matrix. The independent variable with the highest correlation coefficient with the dependent variable is the most important. But when the same variable is used to predict the dependent variable along with other predictors the answer is not necessarily straigthforward, especially when the independent variables are correlated among themselves. One of the widely used statistics is the partial correlation coefficient of the predictor variable. It is the correlation between the independent and the dependent variables when the linear effects of other independent variables have been removed from both the dependent and the independent

Table 6.2. Correlation matrix, its 1-tailed significance, multiple correlation coefficient (R), $R^2$, F-value, significance of F and other relevant statistics for variables included in the regression equation. Data represent all samples ( n = 211 cases).

Correlation, 1-tailed Sig:

| | COREPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | DEPTH | AGE | DEPENV |
|---|---|---|---|---|---|---|---|---|---|
| COREPOR | 1.000 | .127 | -.438 | .047 | -.039 | -.103 | -.437 | -.371 | -.118 |
| | .999 | .033 | .000 | .248 | .286 | .068 | .000 | .000 | .044 |
| QUARTZ | .127 | 1.000 | -.194 | .317 | -.340 | .353 | .583 | .625 | -.371 |
| | .033 | .999 | .002 | .000 | .000 | .000 | .000 | .000 | .000 |
| CEMENT | -.438 | -.194 | 1.000 | -.320 | .209 | .007 | -.029 | -.229 | .047 |
| | .000 | .002 | .999 | .000 | .001 | .462 | .340 | .000 | .247 |
| EPIMAT | .047 | .317 | -.320 | 1.000 | -.194 | .000 | .200 | .354 | -.021 |
| | .248 | .000 | .000 | .999 | .002 | .497 | .002 | .000 | .380 |
| MEANSIZE | -.039 | -.340 | .209 | -.194 | 1.000 | -.375 | -.199 | -.404 | .230 |
| | .286 | .000 | .001 | .002 | .999 | .000 | .002 | .000 | .000 |
| SORTING | -.103 | .353 | .007 | .000 | -.375 | 1.000 | .285 | .265 | -.134 |
| | .068 | .000 | .462 | .497 | .000 | .999 | .000 | .000 | .026 |
| DEPTH | -.437 | .583 | -.029 | .200 | -.199 | .285 | 1.000 | .824 | -.315 |
| | .000 | .000 | .340 | .002 | .002 | .000 | .999 | .000 | .000 |
| AGE | -.371 | .625 | -.229 | .354 | -.404 | .265 | .824 | 1.000 | -.261 |
| | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .999 | .000 |
| DEPENV | -.118 | -.371 | .047 | -.021 | .230 | -.134 | -.315 | -.261 | 1.000 |
| | .044 | .000 | .247 | .380 | .000 | .026 | .000 | .000 | .999 |

Equation Number 1 Dependent Variable.. COREPOR CORE POROSITY, %

Variable(s) Entered on Step Number 5.. DEPENV

| | |
|---|---|
| Multiple R | .80682 |
| R Square | .65096 |
| Adjusted R Square | .64244 |
| Standard Error | 4.05121 |

Analysis of Variance

| | DF | Sum of Squares | Mean Square |
|---|---|---|---|
| Regression | 5 | 6274.77321 | 1254.95464 |
| Residual | 205 | 3364.51606 | 16.41227 |

F = 76.46440 Signif F = .0000

------------------------------ Variables in the Equation ------------------------------

| Variable | B | SE B | Beta | Correl | Part Cor | Partial | T | Sig T |
|---|---|---|---|---|---|---|---|---|
| CEMENT | -.609888 | .058077 | -.468601 | -.438095 | -.433319 | -.591423 | -10.501 | .0000 |
| AGE | -.110735 | .015659 | -.574640 | -.370588 | -.291800 | -.442839 | -7.072 | .0000 |
| QUARTZ | .171169 | .017829 | .534411 | .126786 | .396142 | .556915 | 9.600 | .0000 |
| DEPTH | -.007223 | .001682 | -.336340 | -.436761 | -.177211 | -.287306 | -4.295 | .0000 |
| DEPENV | -1.395573 | .409642 | -.153224 | -.117837 | -.140576 | -.231480 | -3.407 | .0008 |
| (Constant) | 44.538497 | 2.215895 | | | | | 20.100 | .0000 |

variables. The coefficients (standardized regression coefficients) also tells us about their relative importance; but again, when independent variables are correlated their regression coefficients also are correlated and this statistic becomes less reliable.

**THE OUTCOME AND INTERPRETATION OF THE ANALYSIS**

The result of the regression analysis shows that the variables having the first-order control on porosity are the CEMENT, QUARTZ, AGE, DEPTH and DEPENV in decreasing order of importance. The multiple regression coefficient is 0.807 with standard error of estimate within 4% of porosity (Table 6.2). Although the standard error is rather high it has a tremendous predrilling predictive capacity to forecast porosity in a basin with so diverse a sediment composition (Chapter 2). The other interesting outcome of this study is the statistically significant association between porosity and detrital quartz content (Table 6.2), an idea put forward by Veevers et al, (1982). The association becomes much stronger in individual formations (Appendx 4.1). Also the DEPENV seems to be related to porosity (COREPOR) - this is a rather significant relationship and supports the idea of the above workers who suggested that fluvial sands of cratonic origin are prone to be good hydrocarbon reservoirs.

Regression was also carried out on different subsets of samples, the outcome of some of which are more encourgaging and stringent from their predictive point of view. For instance regression run on samples containing less than 5% cement gave a multiple correlation coefficient of 0.80 and a standard error of 3.6% porosity (Table 6.3). This is a significant improvement and confirms the findings of Scherer, 1987 who noted that regression done on uncemented or less cemented samples are more reliable. Another significant improvement is its predictive capability in samples containing 50% or more detrital quartz. Interestingly the two predictor variables selected by stepwise methods are DEPTH and DEPENV

Table 6.3. Correlation matrix, its 1-tailed significance, multiple correlation coefficient (R), $R^2$, F-value, significance of F, and other relevant statistics for varibales included in the regression equation. Data represent samples containing less than 5% cement ( n = 176 cases).

* * * *   M U L T I P L E   R E G R E S S I O N   * * * *

Correlation, 1-tailed Sig:

| | COREPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | DEPTH | AGE | DEPENV |
|---|---|---|---|---|---|---|---|---|---|
| COREPOR | 1.000 | .087 | -.013 | -.091 | .044 | -.068 | -.568 | -.565 | -.023 |
| | .999 | .127 | .433 | .116 | .283 | .183 | .000 | .000 | .382 |
| QUARTZ | .087 | 1.000 | .201 | .255 | -.283 | .346 | .521 | .558 | -.375 |
| | .127 | .999 | .004 | .000 | .000 | .000 | .000 | .000 | .000 |
| CEMENT | -.013 | .201 | 1.000 | -.087 | .119 | -.015 | .201 | -.008 | -.187 |
| | .433 | .004 | .999 | .126 | .057 | .421 | .004 | .459 | .007 |
| EPIMAT | -.091 | .255 | -.087 | 1.000 | -.190 | .024 | .186 | .318 | -.053 |
| | .116 | .000 | .126 | .999 | .006 | .377 | .007 | .000 | .243 |
| MEANSIZE | .044 | -.283 | .119 | -.190 | 1.000 | -.392 | -.151 | -.355 | .217 |
| | .283 | .000 | .057 | .006 | .999 | .000 | .022 | .000 | .002 |
| SORTING | -.068 | .346 | -.015 | .024 | -.392 | 1.000 | .229 | .249 | -.146 |
| | .183 | .000 | .421 | .377 | .000 | .999 | .001 | .000 | .027 |
| DEPTH | -.568 | .521 | .201 | .186 | -.151 | .229 | 1.000 | .829 | -.356 |
| | .000 | .000 | .004 | .007 | .022 | .001 | .999 | .000 | .000 |
| AGE | -.565 | .558 | -.008 | .318 | -.355 | .249 | .829 | 1.000 | -.313 |
| | .000 | .000 | .459 | .000 | .000 | .000 | .000 | .999 | .000 |
| DEPENV | -.023 | -.375 | -.187 | -.053 | .217 | -.146 | -.356 | -.313 | 1.000 |
| | .382 | .000 | .007 | .243 | .002 | .027 | .000 | .000 | .999 |

Variable(s) Entered on Step Number 4.. DEPENV

| | |
|---|---|
| Multiple R | .79326 |
| R Square | .62926 |
| Adjusted R Square | .62059 |
| Standard Error | 3.57810 |

Analysis of Variance

| | DF | Sum of Squares | Mean Square |
|---|---|---|---|
| Regression | 4 | 3715.86993 | 928.96748 |
| Residual | 171 | 2189.27942 | 12.80280 |

F = 72.55969 Signif F = .0000

------------------------------ Variables in the Equation ------------------------------

| Variable | B | SE B | Beta | Correl | Part Cor | Partial | T | Sig T |
|---|---|---|---|---|---|---|---|---|
| DEPTH | -.008863 | .001599 | -.470541 | -.567858 | -.258110 | -.390288 | -5.543 | .0000 |
| QUARTZ | .166789 | .016665 | .582692 | .086561 | .466010 | .607773 | 10.008 | .0000 |
| AGE | -.099146 | .015682 | -.545357 | -.565453 | -.294390 | -.435283 | -6.322 | .0000 |
| DEPENV | -1.149935 | .413736 | -.142639 | -.022760 | -.129416 | -.207901 | -2.779 | .0061 |
| (Constant) | 42.426593 | 2.306091 | | | | | 18.398 | .0000 |

Table 6.4. Correlation matrix, its 1-tailed significance, multiple correlation coefficient (R), $R^2$, F-value, significance of F, and other relevant statistics for variables included in the regression equation. Data represent samples containing $\geqslant$50% detrital quartz (n = 50 cases).

* * * * M U L T I P L E  R E G R E S S I O N * * * *

Correlation, 1-tailed Sig:

| | COREPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | DEPTH | AGE | DEPENV |
|---|---|---|---|---|---|---|---|---|---|
| COREPOR | 1.000 | -.396 | -.422 | -.141 | -.043 | -.214 | -.703 | -.646 | .099 |
| | .999 | .002 | .001 | .165 | .384 | .067 | .000 | .000 | .246 |
| QUARTZ | -.396 | 1.000 | .228 | -.045 | -.355 | .296 | .618 | .464 | -.406 |
| | .002 | .999 | .056 | .379 | .006 | .018 | .000 | .000 | .002 |
| CEMENT | -.422 | .228 | 1.000 | -.126 | .108 | .039 | .486 | .424 | -.084 |
| | .001 | .056 | .999 | .191 | .227 | .393 | .000 | .001 | .282 |
| EPIMAT | -.141 | -.045 | -.126 | 1.000 | .146 | -.195 | -.013 | .097 | .136 |
| | .165 | .379 | .191 | .999 | .156 | .088 | .464 | .252 | .173 |
| MEANSIZE | -.043 | -.355 | .108 | .146 | 1.000 | -.439 | .006 | -.008 | .144 |
| | .384 | .006 | .227 | .156 | .999 | .001 | .483 | .477 | .160 |
| SORTING | -.214 | .296 | .039 | -.195 | -.439 | 1.000 | .121 | .089 | -.151 |
| | .067 | .018 | .393 | .088 | .001 | .999 | .202 | .269 | .148 |
| DEPTH | -.703 | .618 | .486 | -.013 | .006 | .121 | 1.000 | .893 | -.411 |
| | .000 | .000 | .000 | .464 | .483 | .202 | .999 | .000 | .002 |
| AGE | -.646 | .464 | .424 | .097 | -.008 | .089 | .893 | 1.000 | -.304 |
| | .000 | .000 | .001 | .252 | .477 | .269 | .000 | .999 | .016 |
| DEPENV | .099 | -.406 | -.084 | .136 | .144 | -.151 | -.411 | -.304 | 1.000 |
| | .246 | .002 | .282 | .173 | .160 | .148 | .002 | .016 | .999 |

Variable(s) Entered on Step Number 2.. DEPENV

| | |
|---|---|
| Multiple R | .73298 |
| R Square | .53727 |
| Adjusted R Square | .51758 |
| Standard Error | 2.97143 |

Analysis of Variance

| | DF | Sum of Squares | Mean Square |
|---|---|---|---|
| Regression | 2 | 481.82456 | 240.91228 |
| Residual | 47 | 414.98264 | 8.82942 |

F = 27.28518 Signif F = .0000

------------------------------ Variables in the Equation ------------------------------

| Variable | B | SE B | Beta | Correl | Part Cor | Partial | T | Sig T |
|---|---|---|---|---|---|---|---|---|
| DEPTH | -.012336 | .001685 | -.796431 | -.702991 | -.726217 | -.729830 | -7.319 | .0000 |
| DEPENV | -1.641303 | .784722 | -.227599 | .099373 | -.207534 | -.291809 | -2.092 | .0419 |
| (Constant) | 36.889151 | 2.456325 | | | | | 15.018 | .0000 |

(Table 6.4). The standard error of estimate here is significantly low (within 3% of porosity) with multiple R = 0.73. As for the subset of variables with less than 50% quartz the predictor variables in decreasing order of importance are CEMENT, AGE, QUARTZ, DEPTH and DEPENV (Appendix 4.1). Although R is 0.82, standard error is rather high (4.19% of porosity), the predictive capacity of this regression equation is less stringent than for the quartzose sandstone (i.e. quartz>50%) suggesting that porosity reduction phenomena in compositionally immature sandstones are more complex. Samples with more than 5% cement show three predictor variables - CEMENT, AGE, and DEPENV (Appendix 4.1). It may be noted here that when Ro was included along with the above variables SPSSX gave no warning message about the ill-conditionness of the correlation matrix, because the default tolerance (0.01) allows for a very high value of multiple R of the independent variable when it is considered the dependent variable and it is regressed on the other independent variables. Interestingly, SPSSX in such a case included Ro instead of DEPTH as a predictor variable and the resulting multiple R and standard error of estimate were found to be exactly the same. This finding indicates that one of the collinear variables can satisfactorily be represented by the other. This point is discussed in more detail in considering the effect of time (geologic age) and temperature on porosity (Chapter 3).

REFERENCES


Athy, L. F., 1930, Density, porosity, and compaction of sedimentary rocks. AAPG Bull., v. 14, pp. 1-24.

Atwater, G. I., and Miller, E. E., 1965, The effect of decrease in porosity with depth on future development of oil and gas reserves in South Louisiana (Abs.). AAPG Bull., v. 49, pp. 334

Baldwin, B., and Butler, C. O., 1985, Compaction curves. AAPG Bull., v. 69, pp. 622-626.

Chepikov, K. P., Yermolova, Y. P., and Orlova, N. A., 1961, Corrosion of quartz grains and examples of the possible effect of oil on the reservoir properties of sandy rocks. Doklady Academy of Sciences, USSR. Earth Sciences Section, v. 4, pp. 1111-1113 (in English).

Crossey, L. J., Surdam, R. C., and Lahann, R., 1986, Application of organic/inorganic diagenesis to porosity prediction. In Gautier, D. L., (ed.) Roles of organic matter in sediment diagenesis. SEPM Sp. Publ. 38. pp. 147-155.

Curtis, C. D., 1978, Possible links between sandstone diagenesis and depth related geochemical reactions occurring in enclosing mudstones. Journ. Geol. Soc. London, v. 135, pp. 107-117.

Dickinson, W. R., 1970, Interpreting detrital modes of greywacke and arkose. Jour. Sedim. Petrol., v. 40, pp. 695-707.

Edman, J. D., and Surdam, R., C., 1896, Organic-inorganic interactions as a mechanism for porosity enhancement in the Upper Cretaceous Ericson Sandstone, Green River Basin, Wyoming. In Gauiter, D. L., Roles of organic matter in sediment diagenesis. SEPM Sp. Publ. 38, pp. 85-109.

Emery, K. O., and Griffiths, J. C., 1953, Reconnaisance investigation into relationships between behaviour and petrographic properties of some Mississippian sediments. Pennsylvania State Univ. Mineral Indust. Experimental Station Bull., 62, pp. 67-80.

Franks, S. G, and Forester, R. W., 1984, Relationship among secondary porosity, pore-fluid chemistry and carbon dioxide, Texas Gulf Coast. In McDonald, D. A., and Surdam, R. C. (eds.) Clastic diagenesis. AAPG Mem. 37, pp. 63-79.

Fraser, H. J., 1935, Experimental study of the porosity and permeability of clastic sediments. Jour. Sedim. Petrol. V. 43, pp. 910-1010.

Fuchtbauer, H., 1967, Influence of different types of diagenesis on sandstone prosity. Proc. 7th World Petrol. Congress. pp. 359-369.

Galloway, W. E., 1974, Depositional and diagenetic alteration of sandstones in Northeast Pacific arc-related basins: implications for greywacke genesis. Geol. Soc. America, Bull. v. 85, pp. 379-390.

Galloway, W. E., 1979, Diagenetic control of reservoir quality in arc-related sandstones: implications for petroleum exploration. SEPM Sp. Publ. 26, pp. 251-262.

Galloway, W. E., 1984, Hydrogeologic regimes of sandstone diagenesis. In McDonald, D. A., and Surdam, R. C., (eds.) Clastic diagenesis. AAPG Mem. 37. pp. 3-13.

Gautier, D. L., and Claypool, G. E., 1984, Interpretation of methanic diagenesis in ancient sediments by analogy with process in modern diagenetic environments. In McDonald, D. A., and Surdam, R. C., (eds.) Clastic diagenesis. AAPG Mem. 37. pp. 111-123.

Griffiths, J. C., 1964, Statistical approach to the study of potential oil reservoir sandstones, In Parks, G. A., (ed.) Computers in the mineral industries. Stanford Univ. Publ. in Geol. Sci., v. 9, pp. 637-668.

Hayes, J. B., 1979, Sandstone diagenesis - the hole truth. In Scholle, P. A., and Schluger, P. R., (eds.) Aspect of diagenesis, SEPM Sp. Publ. 26, pp. 127-140.

Longstaffe, F. J., 1984, The role of meteoric water in diagenesis of shallow sandstones: stable isotope studies of the Milk River aquifer and gas pool, Southern Alberta. In McDonald, D. A., and Surdam, R. C., (eds.) Clastic diagenesis. AAPG Mem. 37. pp. 81-97.

Loucks, R. G., Dodge, M. M., and Galloway, W. E., 1984, Regional controls on diagenesis and reservoir quality in Lower Tertiary sandstones along the Texas Gulf Coast. In McDonald, D. A., and Surdam, R. C., (eds.) Clastic diagenesis. AAPG Mem. 37., pp. 15-45.

Maxwell, J. C., 1964, Influence of depth, temperature and geologic age on porosity of quartzose sandstone. AAPG Bull. v. 48/5, pp. 697-709.

Nagtegaal, P. J. C., 1978, Sandstone framework instability as a function of burial diagenesis. Journ. Geol. Soc. London, v. 135, pp. 101-105.

Powers, M. C., 1953, A new roundness scale for sediment particles. Jour. Sedim. Petrol., v. 23, pp. 117-119.

Pryor, W. A., 1973, Permeability-porosity patterns and variations in some Holocene sand bodies. AAPG BUll. v. 57/1, pp. 162-189.

Renton, J. J., Heald, M. T., and Cecil, C. B., 1969, Experimental investigation of pressure solution of quartz. Jour. Sedim. Petrol., v. 39, pp. 1107-1117.

Rittenhouse, G., 1943, A visual method of estimating two-dimensional sphericity. Jour. Sedim. Petrol., v. 13, pp. 79-81.

Rogers, J. J., and Head, W. B., 1961, Relationship between porosity, median size, and sorting coefficients of synthetic sands. Jour. Sedim. Petrol., v. 31, pp. 467-470.

Roll, A., 1974, Langfristige reduktion der machtigkeit von sedimentgesteinen und ihre auswirkung - eine ubersight. Geol. Jahrbuch, Pt. 1, v. 14, pp. 2-76.

Scherer, M., 1987, Parameters influencing porosity in sandstones: a model for sandstone porosity prediction. AAPG Bull. v. 71/5, pp. 485-491.

Schmidt, V., and McDonald, D. A., 1979, Secondary reservoir porosity in the course of sandstone diagenesis. AAPG contg. edun. course note series. 12, 125 p.

Schmoker, J. W., 1984, Empirical relation between porosity and thermal maturity: an approach to regional porosity prediction. AAPG Bull., v. 68, pp. 1697-1703.

Selley, R. C., 1978, Porosity gradients in North Sea oil-bearing sandstones. Jour. Geol. Soc. London, v. 135, pp. 119-132.

Siebert, R. M., Moncure, G. K., and Lahann, R. W., 1984, A theory of framework grain dissolution in sandstones. In In McDonald, D. A., and Surdam, R. C., (eds.) Clastic diagenesis. AAPG Mem. 37, pp. 163-178.

Surdam, R. C., Boese, S. W., and Crossey, L. J., 1984, The chemistry of secondary porosity. In McDonald, D. A., and Surdam, R. C., (eds.) Clastic diagenesis. AAPG Mem. 37, pp. 127-149.

Surdam, R. C., and Crossey, L. J., 1985, Organic-inorganic reactions during progressive burial: key to porosity and permeability enhancement and preservation. Phil. Trans. Roy. Soc. London, A 315, pp. 135-156.

Tickell, F. G., and Hiatt, W. N., 1938, Effect of angularity of grain on porosity and permeability of unconsolidated sands. AAPG Bull., v. 22, pp. 1272-1274.

Veevers, J. J., Jones, J. G., and Powell, C. McA., 1982, Tectonic framework of Australia's sedimentary basins., Austral. Perol. Expln Assoc. Jour. v. 22. pp. 283-300.

Webb, J. E., 1974, Relation of oil migration to secondary clay cementation, Cretaceous sandstones, Wyoming. AAPG Bull., v. 58/11, pp. 2245-2249.

Wesolowsky, G. O., 1976, Multiple regression and analysis of variance: an introduction for computer users in management and economics. John Wiley & Sons. New York, 292 p.

Wilson, H. H., 1977, "Frozen-in" hydrocarbon accumulations or diagenetic traps - exploration targets. AAPG Bull., v. 61/4, pp. 483-491.

Wolf, K. H., and Chillingarian, G. V., 1976, Diagenesis of sandstones and compaction. In Chillingarian, G. V., and Wolf, K. H., (eds.) Compaction of coarse-grained sediments. II, Elsevier, Amsterdam, pp. 69-444.

# CHAPTER 7: FACTOR ANALYSIS OF PETROGRAPHIC AND PETROPHYSICAL DATA

# FACTOR ANALYSIS OF PETROGRAPHIC AND PETROPHYSICAL DATA

## INTRODUCTION

Factor analysis is a term used for a group of multivariate statistical procedures designed to analyze the interrelationship within a set of correlated variables or objects (cases). The goal is to investigate the number of independent variables or factors which are linear combinations of the original variables and the dimensionality of multiple observations. In terms of matrix algebra the objective is to find the rank of the data matrix $M_{nxp}$ by analyzing its minor product moment (or major product moment in case of Q-mode factor analysis), where n = number of cases, p = number of variables. The minor product moment $M'.M = A_{(pxp)}$ is a square symmetric matrix which can be a variance-covariance or correlation matrix. One of the first steps in determinig the number of independent factors (vectors, principal components, or principal axes) is to find the rank of the matrix $A_{(pxp)}$. Geological application of factor analysis is generally confined to two broad categories: Q-mode and R-mode. The former investigates the interrelationship between objects (cases) whereas the latter between the variables. The present study is a R-mode factor analysis since it deals with the interrelationships within a set of variables.

The data matrix $M_{(n\,x\,p)}$, $(n \geqslant p)$ can be conceived of as a p-dimensional space in which each point can be expressed in terms of p coordinates (variables). The eigen vectors (factors, principal components) are the linearly independent (orthogonal) vectors and the number of non-zero eigen vectors is the rank of a matrix. The matrix $A_{(pxp)}$ can have $\leqslant p$ number of eigen vectors along which the total variance are distributed. Factor analysis reduces the number of the linearly independent vectors (eigen vectors) so that they account for the maximum variance. So in essence it is the reduction of dimensionality of space. Davis (1973), Koch and Link (1971), and Joreskog et al (1976) described factor analysis in geological sciences and more intensive discussion on the topic can be obtained from Harman (1967), Rummel (1970), Marriott (1974), and Kim and Mueller (1978). Le Maitre (1982) has given a recent treatment of its application in geology.

In the present work the different compositional, textural and petrophysical parameters of sandstones were measured and the purpose of conducting factor analysis is to elucidate the interrelationships among them which might then be expressed in terms of a few geologically meaningful factors - e.g., diagenetic, depositional, fluid flow etc. The following variables were selected for factor analysis: QUARTZ (detrital megaquartz content, whole-rock %), TSPOR (thin-section porosity, whole-rock %), CEMENT (diagenetic cement including carbonate, quartz, zeolite, and chemically precipitated phyllosilicates; whole-rock %), EPIMAT (epimatrix, represented mainly by kaolinite, whole-rock %; terminology of Dickinson, 1970; see also Appendix 1.1), MEANSIZE (mean grainsize in phi units), SORTING (grainsize sorting in phi standard deviation), LOGPERM (decimal logarithm of permeability in md), AGE (age of the sediment in Ma), DEPTH (depth below surface, metres), DEPENV (depositional environment).[1] Analysis was carried out on 211 cases of GSQ core materials containing the abovementioned ten variables using a SPSSX computer package (PROCEDURE FACTOR, SPSS Inc., 1983) in the Macquarie University VAX mainframe computer system.

---

1 Depositional Environment: An arbitrary scale of 1 - 6 was choosen to quantify the depositional environments. There are some a priori observations and insight as to the relationship of this parameter with other variables which were subsequently confirmed by an examination of the correlation matrix. The scale is as follows: Fluvial, low-sinuosity (braided) - 1; Fluvial, high-sinuosity (meandering) - 2; Lacustrine - 3; Paralic - 4; Shallow marine - 5; Deep marine - 6.

CHOICE OF VARIABLES AND DATA CONSIDERATIONS

Correlation matrix (or covariance matrix for unstandardized data matrix) is the starting point for factor analysis. Since the purpose is to clarify the interrelationships among variables the first thing is to look for significant correlation coefficients among them. Variables with small correlation coefficients with other variables are meaningless and their inclusion should be reconsidered. The factor model assumes that correlation between variables results from the sharing of common factors. If any variable lacks significant correlation cofficients with others it is unlikely that they share common factors. An examination of the correlation matrix and 1-tailed significance of the correlation matrix shows that about 71% of the coefficients are significant at <0.05 level of significance (Table 7.1) and more than 37% are higher than 0.3 in absolute value. Apart from the correlation matrix there are a few test statistics which are widely used to scrutinize the usefulness of the factor model before anlysis is undertaken. They are the following:

1. Bartlett's test of sphericity - relies on a statistic based on the chi-square transformation of the determinant of the correlation matrix. For the factor model to be appropriate this test statistic must have a high value with a small level of significance. The data in question show this statistic to be 956 and the associated significance level is too small (Table 7.1). Hence we can not accept the hypothesis that the correlation matrix is an identity (i.e., when the off-diagonal terms are zero) on which the test statistic is based.

2. Kaiser-Mayer-Olkin's Measure of Sampling Adequacy (KMO MSA). The value of this statistic varies from 0 to 1. Kaiser (1974) suggests MSA to be higher than 0.5 for an appropriate factor model. KMO MSA can likewise be calculated for the individual variables which are shown on the diagonal

Table 7.1. Correlation matrix , KMO MSA, Bartlett's test of sphericity and 1-tailed significance of correlation matrix. Data represent all formations, n = 211 cases.

CORRELATION MATRIX:

| | TSPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | LOGPERM | AGE | DEPTH | DEPENV |
|---|---|---|---|---|---|---|---|---|---|---|
| TSPOR | 1.00000 | | | | | | | | | |
| QUARTZ | .42261 | 1.00000 | | | | | | | | |
| CEMENT | -.19782 | -.19373 | 1.00000 | | | | | | | |
| EPIMAT | .01897 | .31668 | -.32009 | 1.00000 | | | | | | |
| MEANSIZE | -.24188 | -.34048 | .20882 | -.19374 | 1.00000 | | | | | |
| SORTING | .02160 | .35343 | .00667 | .00046 | -.37511 | 1.00000 | | | | |
| LOGPERM | .73528 | .45442 | -.46744 | .10445 | -.33886 | .06462 | 1.00000 | | | |
| AGE | -.05535 | .62499 | -.22916 | .35432 | -.40392 | .26499 | .07790 | 1.00000 | | |
| DEPTH | -.08753 | .58306 | -.02855 | .20041 | -.19891 | .28509 | -.05547 | .82437 | 1.00000 | |
| DEPENV | -.22840 | -.37100 | .04732 | -.02120 | .22976 | -.13423 | -.27659 | -.26061 | -.31537 | 1.00000 |

KAISER-MEYER-OLKIN MEASURE OF SAMPLING ADEQUACY = .65284

BARTLETT TEST OF SPHERICITY = 955.62441, SIGNIFICANCE = .00000

THERE ARE 24 (26.7%) OFF-DIAGONAL ELEMENTS OF AIC MATRIX > 0.09

1-TAILED SIG. OF CORRELATION MATRIX:

' . ' IS PRINTED FOR DIAGONAL ELEMENTS.

| | TSPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | LOGPERM | AGE | DEPTH | DEPENV |
|---|---|---|---|---|---|---|---|---|---|---|
| TSPOR | . | | | | | | | | | |
| QUARTZ | .00000 | . | | | | | | | | |
| CEMENT | .00196 | .00237 | . | | | | | | | |
| EPIMAT | .39208 | .00000 | .00000 | . | | | | | | |
| MEANSIZE | .00020 | .00000 | .00115 | .00237 | . | | | | | |
| SORTING | .37754 | .00000 | .46162 | .49735 | .00000 | . | | | | |
| LOGPERM | .00000 | .00000 | .00000 | .06523 | .00000 | .17512 | . | | | |
| AGE | .21189 | .00000 | .00040 | .00000 | .00000 | .00005 | .12998 | . | | |
| DEPTH | .10271 | .00000 | .34003 | .00173 | .00186 | .00001 | .21141 | .00000 | . | |
| DEPENV | .00042 | .00000 | .24708 | .37975 | .00039 | .02577 | .00002 | .00006 | .00000 | . |

of the anti-image correlation matrix (AIC) (Table 7.2). Variable(s) showing MSA <0.5 should be reconsidered for inclusion. MSA for the correlation matrix here is 0.65 (Table 7. 1) and this value for most of the individual variables are > 0.5 (Table 7. 2), so there is no reason to believe that the factor model is doubtful.

3. Partial correlation coefficients of individual variables - it is the correlation between pairs of variables when the linear effects of other variables are removed from both of them. If variables share common factors these coefficients should be small. The negative of the partial correlation coefficients are shown on the off-diagonal elements of the AIC matrix (cf. Table 7.2). If proportions of higher coefficients are high the factor model is in doubt. An examination of the AIC matrix shows that all variables have rather low partial correlation coefficients.

Cosideration of the above test statistics strongly suggests that the assumed factor model is justifiable (i.e. the interrelationships between variables are due to sharing of common factors) and we can confidently embark on the analysis.

MULTICOLLINEARITY AND ILL-CONDITIONED CORRELATION MATRIX

It has been shown in the multiple regression analysis (Chapter 6) that DEPTH is an important predictor of sandstone porosity in the Surat Basin. The association of depth and porosity is a geolgical fact and has been stressed by numerous workers: e.g. Athy (1930), Atwater and Miller (1965), Beard and Weyl (1973), Selley (1978) and Baldwin and Butler (1985). Likewise, geologic age (time), and temperature were shown to be very important variables controlling sandstone porosity. It is interesting to note that in the literature there is a wide difference in opinion as to the relative importance of the abovementioned three variables - namely depth, temperature and age. While nobody argues against their 'role' in the

Table 7.2. Anti-image correlation matrix and the reproduced correlation matrix. Data represent all samples, n = 211 cases.

ANTI-IMAGE CORRELATION MATRIX:

| | TSPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | LOGPERM | AGE | DEPTH | DEPENV |
|---|---|---|---|---|---|---|---|---|---|---|
| TSPOR | .62067 | | | | | | | | | |
| QUARTZ | -.33357 | .75445 | | | | | | | | |
| CEMENT | -.12371 | -.15706 | .56316 | | | | | | | |
| EPIMAT | .05554 | -.25095 | .25002 | .66598 | | | | | | |
| MEANSIZE | .13492 | -.16256 | .06219 | .08783 | .62380 | | | | | |
| SORTING | .15065 | -.30658 | .00620 | .15395 | .37494 | .57579 | | | | |
| LOGPERM | -.55439 | -.26104 | .45925 | .11473 | .14854 | .04878 | .63456 | | | |
| AGE | .24413 | -.30385 | .22934 | -.12881 | .41351 | .15780 | -.00289 | .62842 | | |
| DEPTH | -.02460 | -.20449 | -.10574 | .12111 | -.24077 | -.11481 | .18050 | -.70517 | .64414 | |
| DEPENV | -.00861 | .09775 | .06579 | -.07138 | -.12049 | -.05063 | .15375 | -.08577 | .21043 | .81990 |

MEASURES OF SAMPLING ADEQUACY (MSA) ARE PRINTED ON THE DIAGONAL.

REPRODUCED CORRELATION MATRIX:

| | TSPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | LOGPERM | AGE | DEPTH | DEPENV |
|---|---|---|---|---|---|---|---|---|---|---|
| TSPOR | .78702* | .05384 | .12369 | .05581 | .10121 | -.07739 | -.06610 | .02652 | .08206 | .10317 |
| QUARTZ | .36876 | .74320* | .09465 | .02012 | .19140 | -.06050 | -.00576 | -.02800 | .00391 | .09428 |
| CEMENT | -.32151 | -.28638 | .65277* | .22731 | -.01126 | -.14885 | .02019 | -.00376 | -.01149 | .05973 |
| EPIMAT | -.03684 | .29656 | -.54739 | .65955* | -.01528 | .08671 | -.04401 | -.12151 | -.09742 | -.08822 |
| MEANSIZE | -.34309 | -.53188 | .22008 | -.17846 | .39122* | -.08718 | .06282 | .00837 | .15711 | -.12085 |
| SORTING | .09899 | .41392 | .15552 | -.08625 | -.28794 | .41532* | -.00920 | -.11658 | -.16034 | .23706 |
| LOGPERM | .80138 | .46018 | -.48764 | .14845 | -.40167 | .07382 | .86861* | .03231 | .04026 | .04326 |
| AGE | -.08188 | .65299 | -.22540 | .47583 | -.41229 | .38157 | .04559 | .86377* | .02215 | .03861 |
| DEPTH | -.16959 | .57915 | -.01706 | .29783 | -.35602 | .44543 | -.09572 | .80222 | .80782* | .00419 |
| DEPENV | -.33157 | -.46529 | -.01241 | .06702 | .35061 | -.37128 | -.31985 | -.29922 | -.31956 | .40968* |

THE LOWER LEFT TRIANGLE CONTAINS THE REPRODUCED CORRELATION MATRIX; THE DIAGONAL, COMMUNALITIES; AND THE UPPER RIGHT TRIANGLE, RESIDUALS BETWEEN THE OBSERVED CORRELATIONS AND THE REPRODUCED CORRELATIONS.

THERE ARE 26 (57.0%) RESIDUALS (ABOVE DIAGONAL) THAT ARE > 0.05

geologic evolution of porosity there is no consensus as to their relative importance. Different workers stress one or the other of the three. As for the quantitative study of their interrelationship, very few studies have been published so far. The few works that have came to the writer's attention (e.g. Scherer, 1987) stress either one or more (and not all!). This seeming paradox can be resolved by the simple consideration of the fact that in an actively subsiding basin with little or no uplift all of these three parameters are highly correlated with each other. This is the nature of their geological relationship. But this gives rise to the problem of multicollinearity when computer data-analysis of all parameters including these three are attempted. When depth, temperature and age were included in the factor analysis, the problem of multicollinearity arose and the correlation matrix became ill-conditioned which gives rise to statistical and computational problems. In my data matrix the problem of collinearity is extreme because of the fact that formation temperature was calculated using the average basin-wide geothermal gradient. Temperature in this case becomes the exact linear combination of depth (whereas Ro and age are near-collinear). The ill-conditionness probably also has a contribution from the petrographic modal analysis data which are closed (total of 100%) and to some extent are mutually exclusive giving rise to a component of induced negative correlation. To minimize the closure problem I have included quartz as the only framework grain-type following the suggestion of Griffiths (1967) and Scherer (1987). The best way to deal with the other problem of collinearity (arising from linear combination of variables) is to drop one (or more) of the variables involved. If the multicollinearity is strong enough (pairwise correlation coefficient = 1.00 as in the case of depth - temperature, or 0.96 in depth - Ro) and if this is the characteristic of the population, this approach of removal is a good strategy (Gunst and Mason, 1980, p. 121). Moreover, it seems rather

Table 7.3. PC-extracted eigen values. factor (loading) matrix, and initial and final communalities. All samples, n = 211 cases.

EXTRACTION 1 FOR ANALYSIS 1, PRINCIPAL-COMPONENTS ANALYSIS (PC)

INITIAL STATISTICS:

| VARIABLE | COMMUNALITY | * | FACTOR | EIGENVALUE | PCT OF VAR | CUM PCT |
|---|---|---|---|---|---|---|
| | | * | | | | |
| TSPOR | 1.00000 | * | 1 | 3.39519 | 34.0 | 34.0 |
| QUARTZ | 1.00000 | * | 2 | 1.95325 | 19.5 | 53.5 |
| CEMENT | 1.00000 | * | 3 | 1.25052 | 12.5 | 66.0 |
| EPIMAT | 1.00000 | * | 4 | .97307 | 9.7 | 75.7 |
| MEANSIZE | 1.00000 | * | 5 | .70273 | 7.0 | 82.7 |
| SORTING | 1.00000 | * | 6 | .64569 | 6.5 | 89.2 |
| LOGPERM | 1.00000 | * | 7 | .55884 | 5.6 | 94.8 |
| AGE | 1.00000 | * | 8 | .21787 | 2.2 | 97.0 |
| DEPTH | 1.00000 | * | 9 | .18783 | 1.9 | 98.8 |
| DEPENV | 1.00000 | * | 10 | .11502 | 1.2 | 100.0 |

FACTOR MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| QUARTZ | .85662 | | |
| AGE | .76223 | .50745 | |
| DEPTH | .65008 | .61892 | |
| MEANSIZE | -.61250 | | |
| DEPENV | -.50187 | | |
| SORTING | | | |
| LOGPERM | .56009 | -.74460 | |
| TSPOR | | -.74448 | |
| EPIMAT | | | -.69017 |
| CEMENT | | | .59279 |

FINAL STATISTICS:

| VARIABLE | COMMUNALITY | * | FACTOR | EIGENVALUE | PCT OF VAR | CUM PCT |
|---|---|---|---|---|---|---|
| | | * | | | | |
| TSPOR | .78702 | * | 1 | 3.39519 | 34.0 | 34.0 |
| QUARTZ | .74320 | * | 2 | 1.95325 | 19.5 | 53.5 |
| CEMENT | .65277 | * | 3 | 1.25052 | 12.5 | 66.0 |
| EPIMAT | .65955 | * | | | | |
| MEANSIZE | .39122 | * | | | | |
| SORTING | .41532 | * | | | | |
| LOGPERM | .86861 | * | | | | |
| AGE | .86377 | * | | | | |
| DEPTH | .80782 | * | | | | |
| DEPENV | .40968 | * | | | | |

logical, despite reservations by some workers (e.g. Wesolowsky, 1976), since the collinear variable is taken care of by the remaining one(s). To condition the ill-conditioned correlation matrix I have omitted TEMP and Ro from the data matrix.

Grainsize (MEANSIZE) and sorting (SORTING) parameters are represented by mean grainsize in phi units and phi standard deviation which are the most commonly used measures of grainsize and sorting (Griffiths, 1967). The factor model assumes that the data be from a multivariate normal population. Grainsize and permeability have been proven to be log-normally distributed (Krumbein, 1936, Archie, 1950). That is why mean grainsize in phi units and the decimal logarithm of permeability (LOGPERM) were preferred instead of mm. and md. respectively.

## AN OVERVIEW OF THE CORRELATION MATRIX AND THE METHOD OF FACTOR EXTRACTION

The correlation matrix (Table 7.1) displays the interrelationships among the variables. There is a strong association between SORTING and MEANSIZE. The correlation is negative suggesting that as grainsize increases (i.e., MEANSIZE in phi units decreases numerically) sorting decreases (i.e., numerically SORTING in phi standard deviation increases). This association is reflected in factor 1 of both Varimax and Oblimin rotation (Table 7.4). Also DEPENV shows negative correlation (significance level = 0.000) with quartz (Table 7. 1) which indicates that as 'environmental wetness' increases quartz content decreases (cf. Davies and Ethridge, 1975). This is a very significant revelation of the correlation matrix - an idea proposed by Jones and Veevers (1983) and Jones et al (1984) in their foreland basin model. This concept has been elaborated in Chapter 9. This relationship of depositional environment and detrital quartz content is represented by factor 1 (Table 7. 4). A close association between AGE and QUARTZ is also noticeable. This positive

Table 7.4. Varimax rotated factor matrix, and oblimin rotated factor pattern and structure matrices. All samples, n = 211 cases.

Varimax rotation.

ROTATED FACTOR MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| DEPTH | .85008 | | |
| AGE | .81855 | | |
| QUARTZ | .73048 | | |
| SORTING | .59668 | | |
| DEPENV | -.50638 | | |
| MEANSIZE | -.48447 | | |
| LOGPERM | | .90314 | |
| TSPOR | | .88637 | |
| EPIMAT | | | .79421 |
| CEMENT | | | -.71636 |

OBLIMIN ROTATION

PATTERN MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| DEPTH | .87149 | | |
| AGE | .82540 | | |
| QUARTZ | .71138 | | |
| SORTING | .60923 | | |
| DEPENV | -.49956 | | |
| MEANSIZE | -.46574 | | |
| LOGPERM | | -.89779 | |
| TSPOR | | -.89127 | |
| EPIMAT | | | -.78765 |
| CEMENT | | | .71138 |

STRUCTURE MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| DEPTH | .83269 | | |
| AGE | .82865 | | |
| QUARTZ | .78245 | | |
| SORTING | .58502 | | |
| MEANSIZE | -.52944 | | |
| DEPENV | -.52748 | | |
| LOGPERM | | -.91275 | |
| TSPOR | | -.88617 | |
| EPIMAT | | | -.79787 |
| CEMENT | | | .72537 |

FACTOR CORRELATION MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| FACTOR 1 | 1.00000 | | |
| FACTOR 2 | -.16682 | 1.00000 | |
| FACTOR 3 | -.10705 | .06465 | 1.00000 |

correlation arises from the character of the specific basin in interest and may not be applied universally. The association arises from the fact that in the Surat Basin volcanogenic components increase upsequence at the expense of detrital quartz (cf. Chapter 2). This is, however, a natural step in the history of arc-related foreland basin dvelopment and perhaps embodies a component of universality. Another relationship of this kind which arises from the nature of the data is the positive correlation between AGE and formation DEPTH. In a subsiding basin with litle or no uplift this is a natural association. Depth of burial increases with age and so does temperature. These associations are represented by factor 1 in both varimax and oblimin rotation (Table 7.4).

Factor 2 (both varimax and oblimin solution, Table 7. 4) represents the very strong association between thin-section porosity (TSPOR) and permeability (LOGPERM) (r = 0.73).

The epimatrix (EPIMAT) and CEMENT shows negative correlation (r = -0.32, sig. lev. = 0.000) as expected. This is a common association as they both compete for the pore spaces and to some extent are mutually exclusive. This association is represented by factor 3 (Table 7. 4).

As noted before both varimax and oblimin rotation produces very similar factor pattern matrices but oblique rotation is favoured because of the ease of its geological interpretability.

The first step in the factor analysis is the extraction of factors (eigen values or latent roots). A variety of extraction methods exist among which the principal component analysis (PCA) is the most widely used. In the present study PCA was employed (Table 7. 3). However, another extraction technique, namely the maximum likelihood (ML), was also tried and led to the same number and comparable magnitude of eigen vectors as PCA. PCA is a different technique from many other factor analyses with which it has been equated in the literature by various workers and deserves some comments here. The total variance of a variable x may be represented by:

$$\sigma_x^2 = \sigma_c^2 + \sigma_e^2$$

where, $\sigma_c^2$ is common variance or communaltiy; it represents that part of the variance x which is in common with other variables and is involved in the covariance between them; $\sigma_e^2$ is the residual variance or the uniqueness. It is the variance of x unaccounted for by the factors and is not shared by other variables. In PCA, factors are determined so as to account for the maximum variance of the variables and the residuals are assumed to be small; this latter assumption is not true for other modes of factor analysis. The proportion of variance accounted for by the common factors is called the communality and it is 1 for all variables in PCA (Table 7.3). The variance that is not explained by common factors is attributed to the unique factor and is called the uniqueness of the variable. Since the total variance is explained by the common factors, the uniqueness is zero in PCA. In essence PCA is a separate technique from true factor analysis. Other modes of factor analysis allow for a considerable amount of uniqueness to be present in the data and utilize only that part of the variable that takes part in correlation with other variables. In both methods the residuals are assumed to be uncorrelated with the factors. In PCA there is no assumption about the correlation among the residuals whereas in true factor analysis it is assumed to be correlated among themselves. PCA involves no assumptions about the original variables, no hypotheses that need to be tested, and no underlying model (Marriott, 1974, p. 18). PCA is a variance-orientated exercise whereas factor analysis is a covariance- or correlation-orientated process (Joreskog et al, 1976). Although PCA is a separate technique, many factor analyses start with PCA as the factor extraction phase. Factor extraction employing the PCA can be useful in two senses: firstly, by means of rigid rotation of the axes it can be used to transform the original set of variables into a new set of variables called factors, (also called principal components or principal coordinates) which display a decresing amount of variance and are uncorrelated with each other. When plotted against each other these coordinates provide the optimum way of viewing the data. Secondly, it is often the case that the first few principal components (or coordinates) account for a high proportion of variance and the remaining ones so little that they can be discarded thereby reducing the number of processes or phenomena that could be involved in causing the variation within the original set of data. Thus, in essence, PCA is a method of reducing the dimensionality of the problem.

THE NUMBER OF IMPORTANT FACTORS

The extraction phase involves the extraction of eigen values and eigen vectors. Usually PCA extracts as many factors as there are variables so that the cumulative percentage of variance is always 100%. But the variances are distributed in such a manner that the first few factors account for most of the total variance. When all factors are included in the solution of a variable all of its variance is accounted for and there is no need for a unique factor in the model. The proportion of variance of each variable accounted for by the common factors is called the communality and it is 1 for all variables (Table 7. 3). This is the starting point (initial statistics) of PCA. It calculates the uncorrelated (orthogonal) factors from the linear combination of the correlated variables. SPSSX extracts factors with eigen values greater than 1. Although this may not seem a good practice it is logical in PC extraction since factors with a variance less than 1 are no better than a single variable - each variable has a total variance (communality) of 1. A plot of the total variance of

```
         3.395 +     *
               !
               !
               !
E              !
I              !
G              !
E              !
N              !
V        1.953 +          *
A              !
L              !
U              !
E        1.251 +               *
S              !
          .973 +                    *
          .703 +                         *
          .559 +                              *    *
               !
          .188 +                                        *    *
          .115 +                                                  *
          .000 +----+----+----+----+----+----+----+----+----+----+
                    1    2    3    4    5    6    7    8    9   10

  PC EXTRACTED    3 FACTORS.
```

Figure 7.1. Plot of PC-extracted eigen values (scree plot).

each factor (scree plot of Cattell, 1966 - called so because it resembles the profile of rubble at the foot of a mountain) is very useful in determining the optimum number of factors. The scree plot (Figure 7.1) shows a distinct break between the steep slope of the large factors and the gradual levelling off of the rest of the factors. The scree plot shows that a 3-factor model would be sufficient to explain the data which account for 66% of the total variance (Table 7.3).

After extraction of the three factors, factor loadings are calculated so that each variable can be represented as linear combinations of three factors: $x = \alpha F1 + \beta F2 + \gamma F3$ , where $\alpha$, $\beta$, $\gamma$, are the factor loadings. The matrix of factor loadings is called the factor pattern matrix. Factor loadings indicate how much weight is assigned to each variable. When factors are uncorrelated with each other as in PC extraction, factor loadings are also the correlation coefficients between the varibale and the factor; the correlation matrix is called the factor structure matrix which in this case is the same as the factor pattern matrix (Tables 7.3 and 7.4). After factor loadings are calculated it can be seen how well a 3-factor model fits the data in hand; or in other words, how much of the total variance associated with each variable can be accounted for by the 3-factor model. This is done by adding the variances caused by each of three factors (Table 7.3) as follows:

Variance caused by factor 1 = $\sum$(corr. coeff. between variable and factor)$^2$.

For the variable quartz they are:

variance due to factor 1 = $(0.856)^2$

variance due to factor 2 = $(0.029)^2$

variance due to factor 3 = $(0.092)^2$

total variance = $(0.856)^2 + (0.029)^2 + (0.092)^2$ = 78.7%.

This is the new communality (as opposed to original communality in the 10-factor model which was 1 for each variable) and is shown in the final statistics (Table 7. 3). The data show that most variables have more than 60% of their variances accounted for by a 3-factor model (communality, final statistics; Table 7. 3). To see how well a 3-factor model explains the data, the correlation coefficients between the variables can be calculated from the estimated correlation coefficients between the factors and the variables. The estimated correlation coefficients and the residuals are shown in the reproduced correlation matrix (Table 7.2). The magnitudes of the residuals shows how well the model explains the data: large residuals indicate a poor fit of the model. There are 57% residuals which are >0.05 in absolute value and most are below 0.10, suggesting that the model is adequate to represent the data.

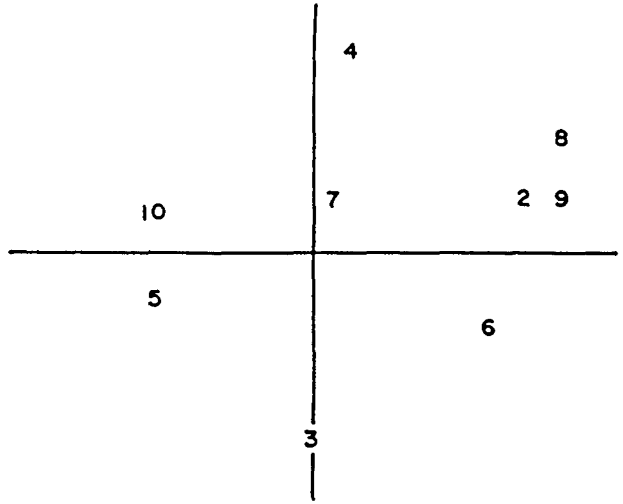
Once the factors are extracted each variable can be represented in a 3-dimensional space, each coordinate represented by each of the three factors. The coordinates for each variable are called factor loadings and are shown in the factor pattern matrix. The projection of each variable on the principal axes/coordinates/factors are called the factor scores.

FACTOR ROTATION

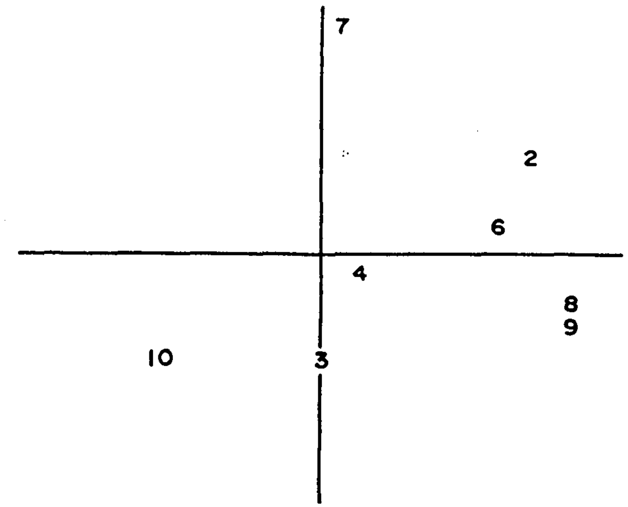
The unrotated factor pattern matrix shows the relationship between the factors and variables. Often the factors and variables are correlated in such a manner that meaningful interpretation is almost impossible because most factors are correlated with many variables: i.e., most factors have high loadings on many variables (Table 7. 3; loadings below 0.45 in absolute value have been supressed). The purpose of rotation is to achieve factors which will have high loadings on fewer variables and low loadings on the others. In such a case only a subset of variables are better represented by an individual factor (with which they have higher

Figure 7.2. Plots of varimax rotated factors. All formations, n = 211 cases.

HORIZ. FACT. I, VERT. FACT 3




HORIZ. FACT. I, VERT. FACT. 2




HORIZ. FACT. 2, VERT. FACT. 3

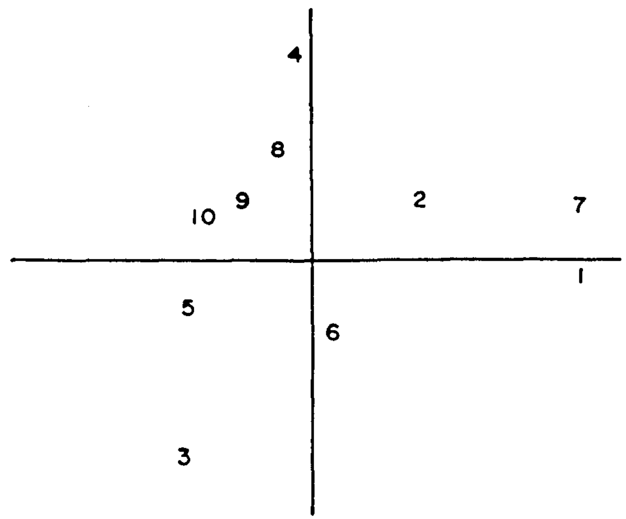
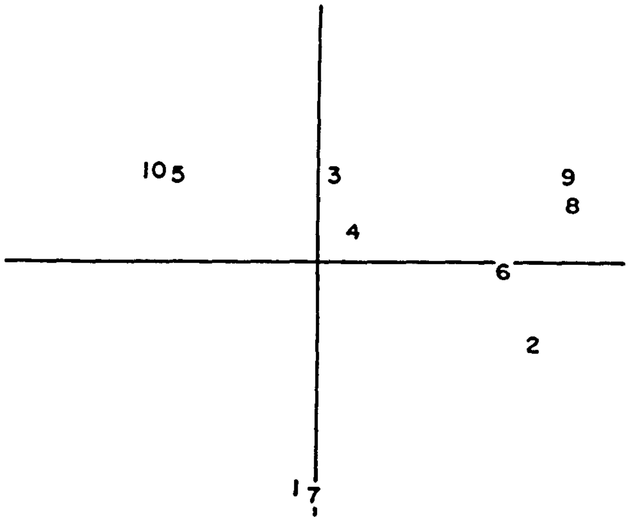
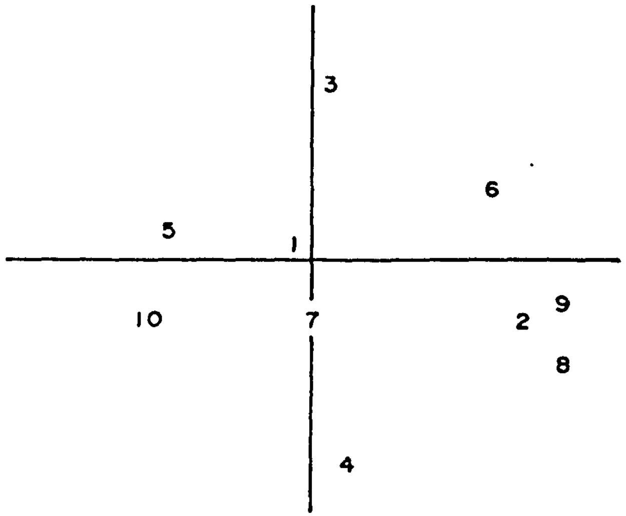


Figure 7.3. Plots of oblimin rotated factors. All formations, n = 211 cases.

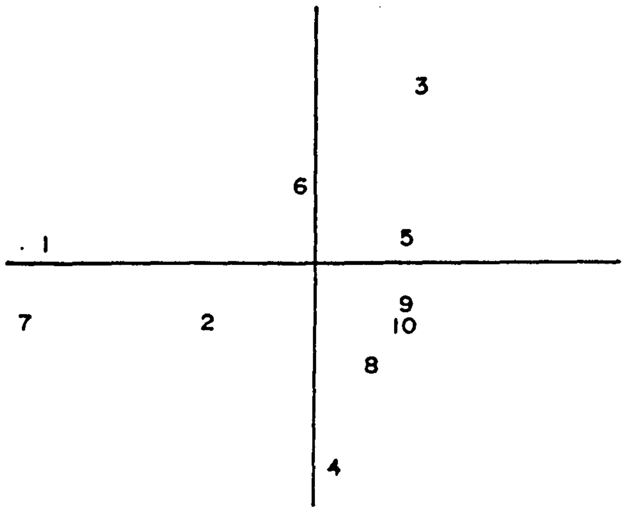
HORIZ. FACT. 1, VERT. FACT. 2




HORIZ. FACT. 1, VERT. FACT. 3




HORIZ. FACT. 2, VERT. FACT. 3



loadings), whereas other subsets are better represented by another factor(s). There are numerous ways of factor rotation but all of them fall into two categories: orthogonal rotation (when the axes are maintained at right angles during rotation) and oblique rotation (when they are not maintained orthogonally). Rotation does not affect the goodness of fit of a factor solution and although the factor loadings matrix (factor pattern matrix) changes the communalities, but the percentages of total variances do not change. One of the most widely used orthogonal rotations is the varimax. This method attempts to minimize the number of variables that have high loadings on a factor. The rotated factor matrix (both varimax and oblimin, Table 7.4) clearly shows that factor 1 has high loadings on DEPTH, AGE, QUARTZ, SORTING, DEPENV and MEANSIZE while it (i.e., factor 1) has small loadings on the other two factors (the factor loadings and correlations are sorted in numerically descending order and coefficients less than 0.45 in absolute value have been suppressed). Variables LOGPERM and TSPOR have high loadings on factor 2 and EPIMAT and CEMENT have high loadings on factor 3. The plot of varimax rotated factors (Figure 7.2) shows that most variables are clustered towards the axes (principal coordinates). This is a way of judging the success of rotation.

With the other method of rotation (oblique rotation) the factor pattern matrix shows comparable loadings on variables as in the varimax rotation (Table 7.4). The plots of factor loadings (Figure 7.3) also show good clustering around the principal axes. Unlike varimax rotation, oblimin rotation gives rise to factors that are correlated among themselves (the factor correlation matrix is not an identity). Also the factor loadings are no longer the correlation between the factors and variables. Variables with high loadings, however, have high correlation coefficients with the factors.

THE GEOLOGICAL MEANING OF THE FACTORS

Judging the relative merits of factor pattern matrices of both varimax and oblimin rotation I favoured the oblimin rotation because of its ease of interpretation. The variables DEPTH, AGE, QUARTZ, SORTING, DEPENV, and MEANSIZE have high loadings on factor 1 which can be regarded as the 'provenance, depositional and compactional factor'. The variables LOGPERM and TSPOR have high loadings on factor 2 which can be regarded as the 'fluid flow factor'; and the variables EPIMAT and CEMENT having high loadings on factor 3 can be conceived of as the 'cementation factor'. My choice of oblique rotation is warranted by the fact that in nature all these three factors seem to be correlated to some extent with each other. More often than not natural phenomena are complexly inter-related and it is therefore unlikely that the above three factors would be statistically uncorrelated.

Factor analysis was also carried out on different subsets of samples and individual stratigraphic formations (Appendix 5.1). However, some formations are represented by fewer samples, and others show test-statistics (e.g., KMO-MSA, Bartlett's test of sphericity) which do not justify the further application of factor analysis. The correlation matrices, anti-image correlation matrices (AIC), unrotated and rotated varimax and oblimin factor pattern matrices of the subsets of samples and formations on which factor analysis was performed are shown in Appendix 5.1. As can be expected, depending on the interrelationships of the variables within the individual formation, the unrotated and rotated factor pattern and structure matrices vary from formation to formation. It is apparent from the outcome that factor analysis can be done on geological data and meaningful results can be obtained, and that it is not merely a method for 'making the invisible visible' (Cattell, 1965).

REFERENCES


Archie, G. E., 1950, Introduction to petrophysics of reservoir rocks. AAPG Bull., v. 34, pp. 943-961.

Athy, L. F., 1930, Density, porosity, and compaction of sedimentary rocks. AAPG Bull., v. 14, pp. 1-24.

Atwater, G. I., and Miller, E. E., 1965, The effect of decrease in porosity with depth on future development of oil and gas reserves in South Louisiana (Abs.). AAPG Bull., v. 49, pp. 334.

Baldwin B., and Butler, C. O., 1985, Compaction curves. AAPG Bull., v. 69, pp. 622-626.

Beard, D. C., and Weyl, P. K, 1973, Influence of texture on porosity and permeability of unconsolidated sand. AAPG Bull., v. 57/2, pp. 349-369.

Cattell, R. B., 1965, Factor analysis: an introduction to essentials. Biometrics, v. 21, pp. 190-215.

Cattell, R. B., 1966, The meaning and strategic use of factor analysis. In Cattell, R. B., (ed.) Handbook of multivariate experimental psychology. Rand McNally, Chicago, pp. 174-243.

Davies, D. K., and Ethridge, F. G., 1975, Sandstone composition and depositional environments. AAPG Bull., v. 59/2, pp. 239-264.

Davis, J. C., 1973, Statistics and data analysis in geology. John Wiley & Sons, 550 p.

Dickinson, W. R., 1982, Compositions of sandstones in circum-Pacific subduction complexes and forearc basins. AAPG Bull., v. 66, pp. 121-137.

Griffiths, J. C, 1967, Scientific methods in analysis of sediments. McGraw Hill. 508 p.

Gunst, R. F., and MAson, R. L., 1980, Regression analysis and its application: a data-oriented approach. Marcel Dekker, New York, 402p.

Harman, H. H., 1976, Modern factor analysis. Univ. Chicago Press. 487 p.

Kaiser, H. F., 1974, An index of factorial simplicity. Psychometrica, v. 39, pp. 31-36.

Kim, J. O., and Muller, C. W., 1978, Introduction to factor analysis. Stage Press, Beverly Hills. 88 p.

Krumbein, W. C., 1936, Application of logarithmic moments to size-frequency distribution of sediments. Jour. Sedim. Petrol., v. 6, pp. 35-47.

Jones, G. J., and Veevers, J. J., 1983, Mesozoic origins and antecedents of Australia's Eastern Highlands. Jour. Geol. Soc. Austral., v. 30, pp. 305-322.

Jones, J. G., Conaghan, P. J., McDonnel, K. L., Flood, R. H., and Shaw, S. E., 1984, Papuan Basin analogue and foreland basin model for the Bowen- Sydney Basin. In Veevers, J. J. (ed.) Phanerozoic earth history of Australia. Clarendon Press, Oxford, pp. 243-262.

Joreskog, K. G., Klovan, J. E., and Reyment R. A., 1976, Geological factor analysis. Elsevier Sci. Publ., 178 p.

Koch, G. S. and Link, R. F., 1970, Statistical analysis of geological data. vol. II., John Willey & Sons, 438 p.

Le Maitre, R. W., 1982, Numerical petrology - statistical interpretation of geochemical data. Elsevier Sci. Publ., 281 p.

Mariott, F. H. C., 1974, The interpretation of multiple observations. Academic Press, 117 p.

Rummel, R. J., 1970, Applied factor analysis. Northwest Univ. Press, Evanston, 617 p.

Scherer, M., 1987, Parametres influencing porosity in sandstones: a model for sandstone porosity prediction. AAPG Bull., v. 71/5, pp. 485-491.

Selley, R. C., 1978, Porosity gradients in North Sea oil-bearing sandstones. Jour. Geol. Soc. London, v. 135, pp. 119-132.

SPSS Inc., 1983, SPSSX user guide. 806 p.

Wesolowsky, G. O., 1976, Multiple regression and analysis of variance: an introduction for computer users in management and economics. John Willey & Sons, New York, 292 p.

# CHAPTER 8: A REVIEW OF THE HYDROCARBON POTENTIAL OF SOME SOURCE ROCKS WITH SPECIAL REFERENCE TO THE SURAT BASIN: IMPLICATIONS FOR PETROLEUM EXPLORATION

# A REVIEW OF THE HYDROCARBON POTENTIAL OF SOME SOURCE ROCKS WITH SPECIAL REFERENCE TO THE SURAT BASIN: IMPLICATIONS FOR PETROLEUM EXPLORATION


## ABSTRACT

Oil and gas in most Australian basins are thought to have been derived mainly from land-plant-sourced organic matter, the overall gas-prone nature of the Australian petroleum provinces being due principally to the presence of continental source rocks. However, oil, gas and condensate have been discovered in various basins around the world in situations where they have been sourced from terrestrially-derived organic matter and at maturity levels normally regarded as prohibitive to hydrocarbon generation according to conventional wisdom. The petrological and geochemical nature of some terrestrially-derived organic matter of the Surat Basin suggest that it can produce significant amounts of liquid hydrocarbon at a very early stage of maturation. Additionally, abundant quantities of methane and possibly some higher (i.e., $C_{2+}$ ) hydrocarbons could be generated from hydrogen-poor humic organic matter in the diagenetic stage before it reaches the threshold of oil generation. In the light of these new data and concepts, a multiple source for the Surat Basin reservoired oil and gas is suggested. Knowledge of this kind may be useful in the exploration for new fields in this basin and in other partially explored and unexplored frontier basins with similar geologic and geochemical characteristics.


## INTRODUCTION

Most Australian crude oils and gas are generally thought of as being derived from land-plant-sourced organic matter (Powell and McKirdy, 1975, 1976; Thomas, 1982; Thomas et al, 1982; Smith and Cook, 1984). Apart from a few basins, Australian hydrocarbon provinces are generally gas-prone, a fact consistent with the predominance in these provinces of

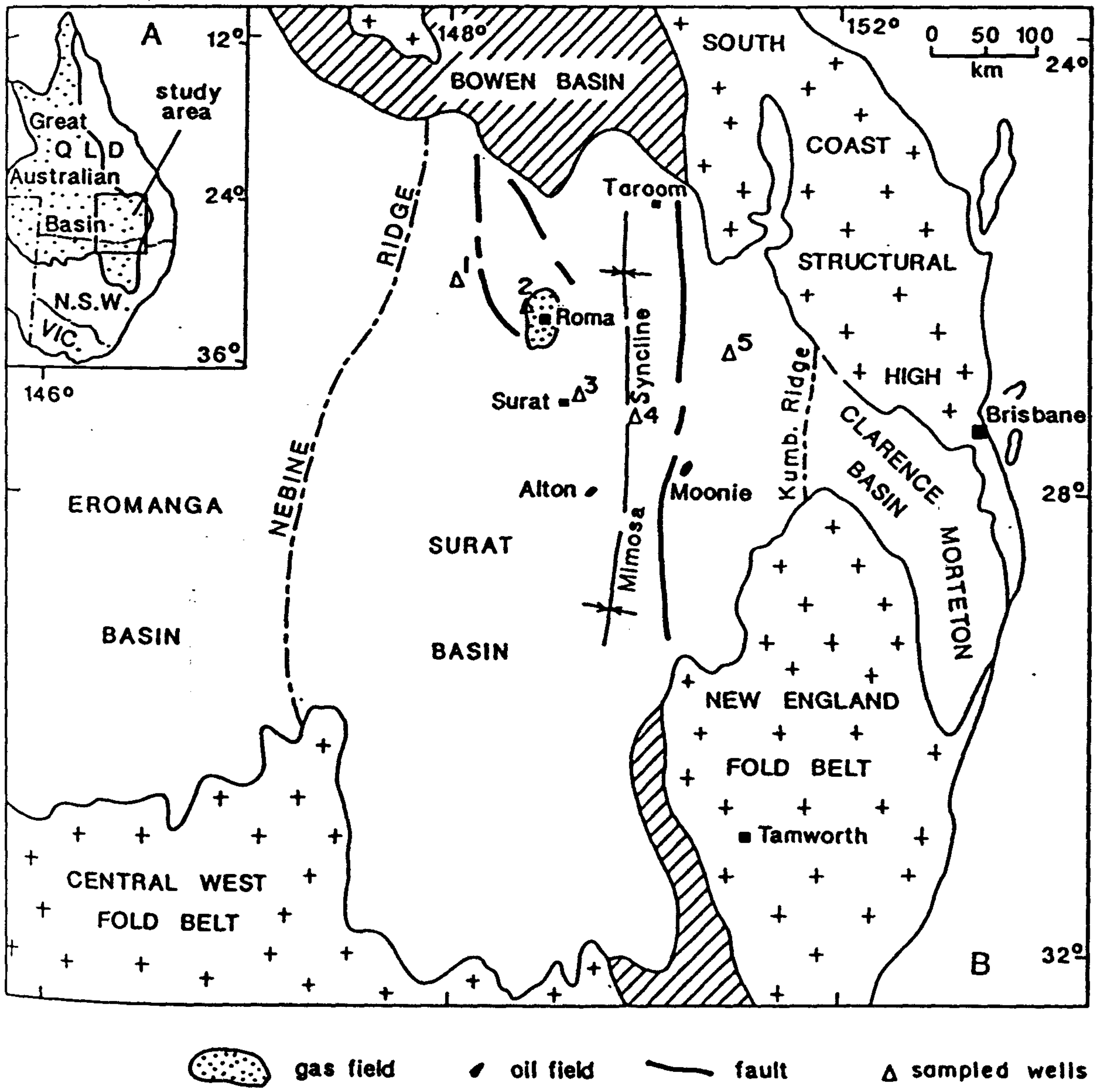



Figure 8.1. Location (A) and major structural elements (B) of the Surat Basin. From Exon (1976) with modifications.

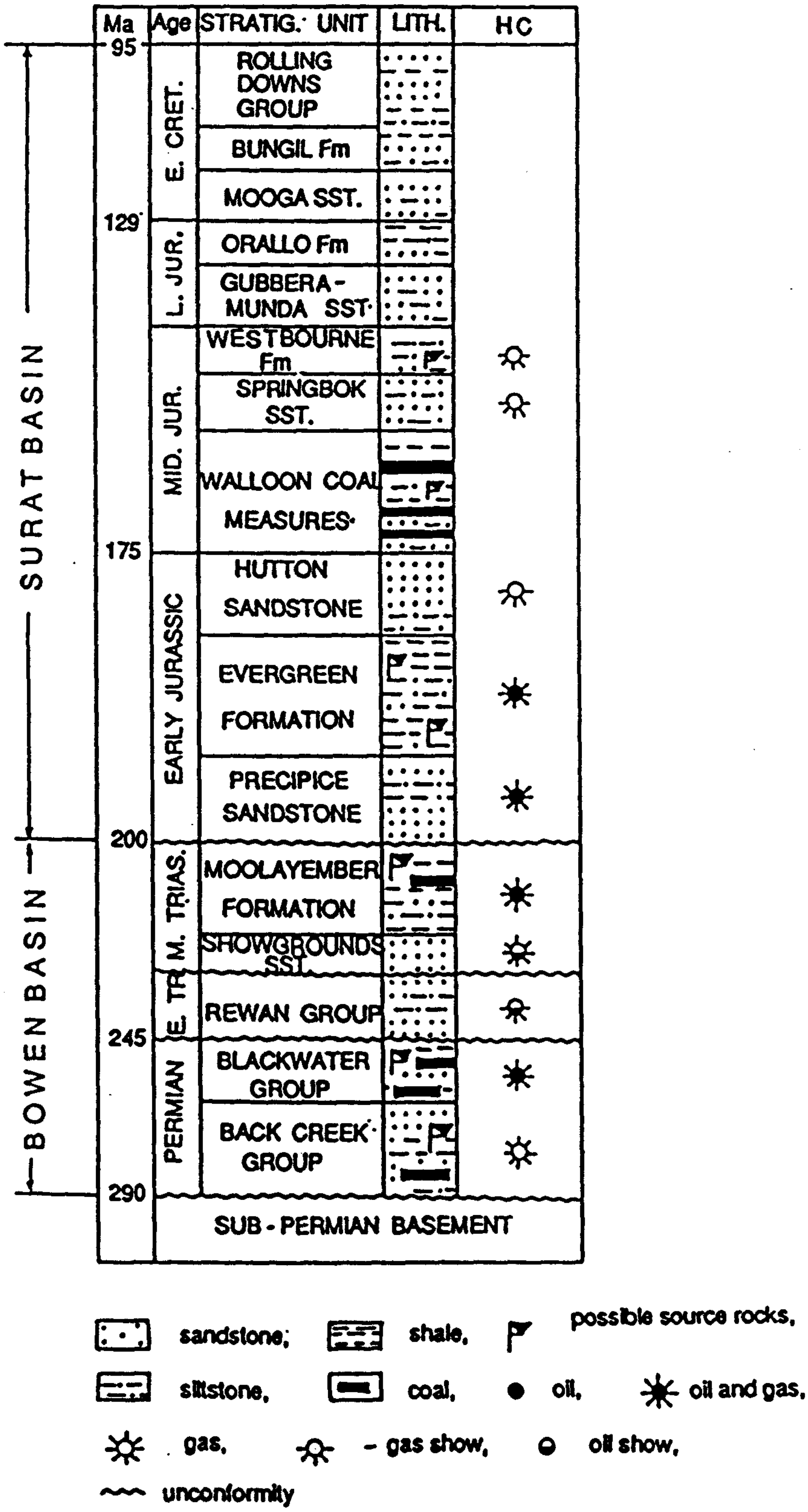



Figure 8.2. Generalised stratigraphic column of the Surat and Bowen Basins showing the occurrence of hydrocarbons and possible source rocks. Adapted from Thomas et al (1982). HC - hydrocarbon.

terrestrial source rocks and associated land-plant-derived organic matter whose potential to generate liquid hydrocarbons is subordinate compared to their gas generative potential. In the Surat Basin (Figure 8.1) the probable source of reservoired oil and gas is argued to be the Permian Gondwanan coals and coal-bearing strata of the underlying Bowen Basin (Thomas, 1982; Thomas et al, 1982; Philp and Gilbert, 1982). However, organic-rich oil-prone source rocks are present throughout the Mesozoic succession of the Surat Basin (Figure 8.2) some of which are marginally mature to mature and certainly have reached the threshold of hydrocarbon generation in various parts of the basin (Khorasani, 1987). In this context, the present Chapter constitutes a review of the hydrocarbon potential of the Jurassic source rocks.

## THE TYPES OF ORGANIC MATTER AND THEIR HYDROCARBON GENERATION POTENTIAL

Sedimentary organic matter, depending on elemental composition, may be broadly classified into three types: Type I, II and III (Figure 8.3, Table 8.1). Commonly a fourth type is also recognised (Table 8.1, Figure 8.3; cf. Harwood, 1977). Type I and Type II kerogens are believed to generate oil whereas Type III and IV mainly gas (cf. Table 8.1). As can be seen from Table 8.1 terrestrially-derived organic matter is characterized by a wide range of petrographic and elemental composition with correspondingly variable oil and gas potential.

### Oil potential of liptinite

Terrestrial organic matter, responsible for the generation of waxy oils in various Mesozoic and Tertiary basins globally (cf. Hedberg, 1968), is believed to originate from the lipid-rich resistant parts of land-plant materials, particularly wax, cuticles and pollens. These plant remains, along with resins and suberins, are the principal precursors of the liptinite/exinite-group macerals. Compared to vitrinites and inertinites, liptinites are characterized by a higher aliphatic fraction (and high H/C ratio; cf. Table 8.1) and lower aromatic content. The compositional differences between the various plant materials and kerogen types are best seen in the plot of H/C and O/C ratios in the van Krevlen diagram (Figures 8.3 and 8.4).

Cuticles comprise the protective outer covering of stems, leaves, cones and fruits of certain land-plants and are composed of waxes as indicated by an abundance of normal paraffins in the range $C_{22}$-$C_{36}$ (Hedberg, 1968). Thick cuticles are characteristic of conifers growing in the middle to high latitudes (Thomas, 1982) and the leaf of the New Zealand Kauri (also a conifer) is a good modern example. Pollen grains and spores contain large quantities (50-60%) of fat/sporopollenin present mainly in the outer cell wall or exine (Shaw, 1970). Exine is one of the most resistant materials in the organic world. Cuticles and pollens/spores respectively give rise to the cutinite and sporinite macerals.

The principal macerals of the liptinite group are shown in Table 8.1. Of particular importance are the macerals resinite and suberinite which, compared to other liptinite macerals, behave quite differently under thermal stress. Resinites have differing origins, but are derived mainly from resins and waxes, with some contributions from balsam, copals, latex, oils and fats. Resins form in secretion cells of certain land-plants, particularly in the wood of conifers. Resinites can be classified into two broad categories: terpenes and lipids (Table 8.1). Terpene resinite is comprised essentially of terpenes in addition to esters, phenols, higher alcohols and a mixture of different resin acids. Lipid resinites on the other hand consist of fats and waxes. They are generated by almost all seed plants and as much as 70% of the dry substance of the seed could be of lipid resins (Stach et al, 1982, p. 253-259). With the

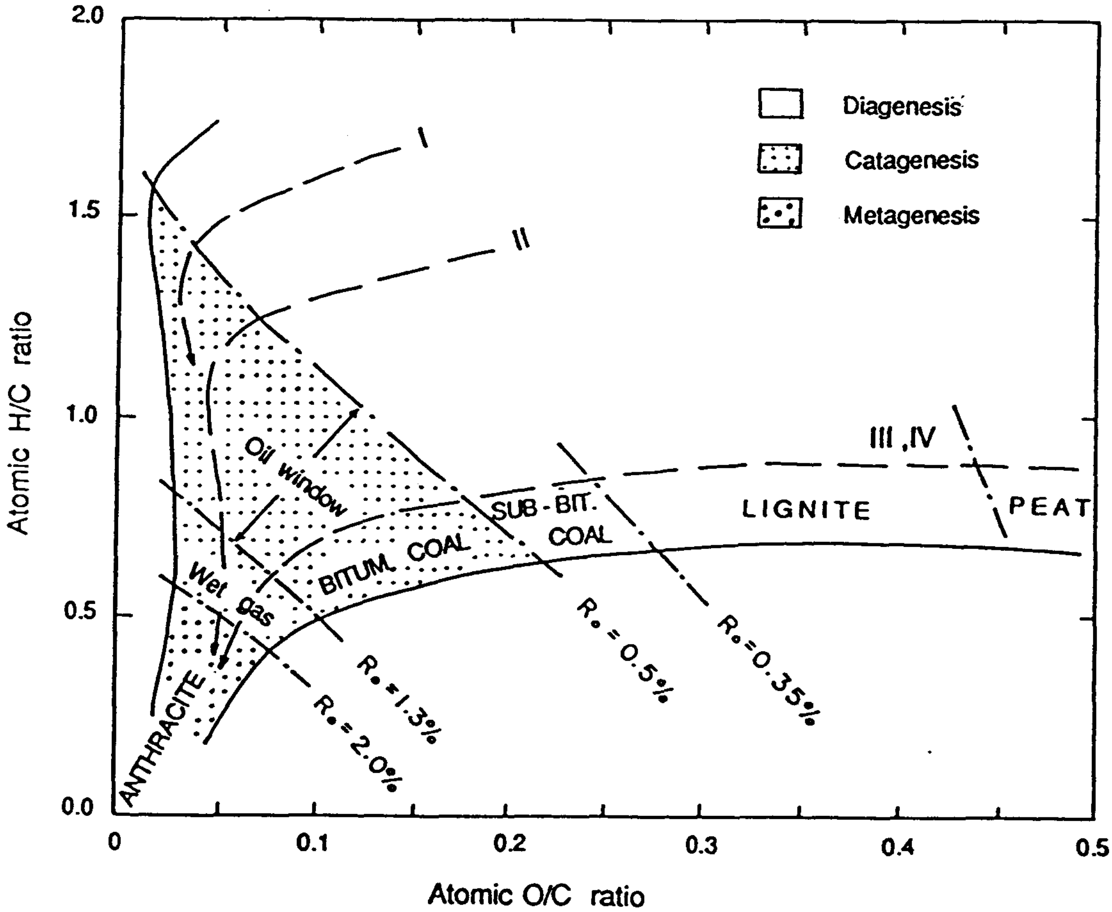



Figure 8.3. General scheme of kerogen evolution in the van Krevlen diagram. Arrows show evolution paths of principal kerogen types. Adapted from Tissot and Welte (1978; fig. II.5.1) and Durand and Pratte (1983; fig. 1).

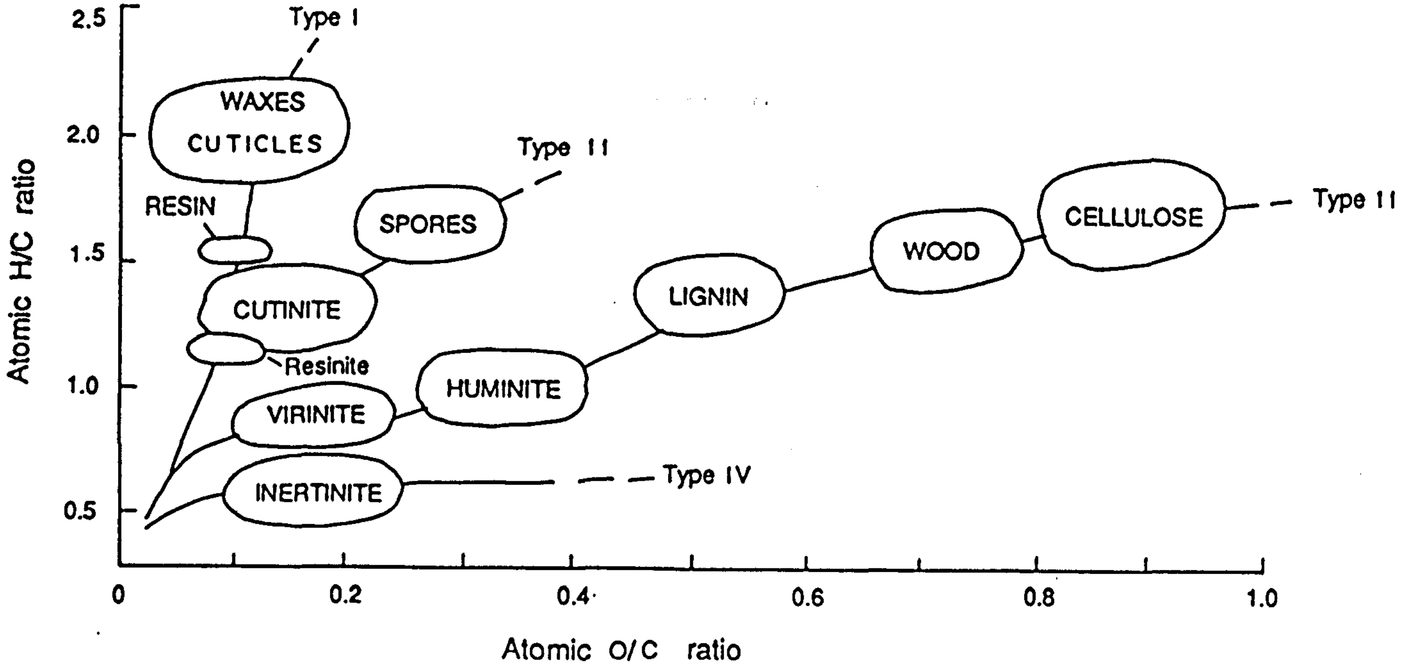



Figure 8.4. Elemental composition of selected plant and coal materials in the van Krevlen diagram. Modified from Tissot and Welte (1978; fig. II.7.6); composition of resin based on data from Shanmugam (1985) and that of resinite from Stach et al (1982).

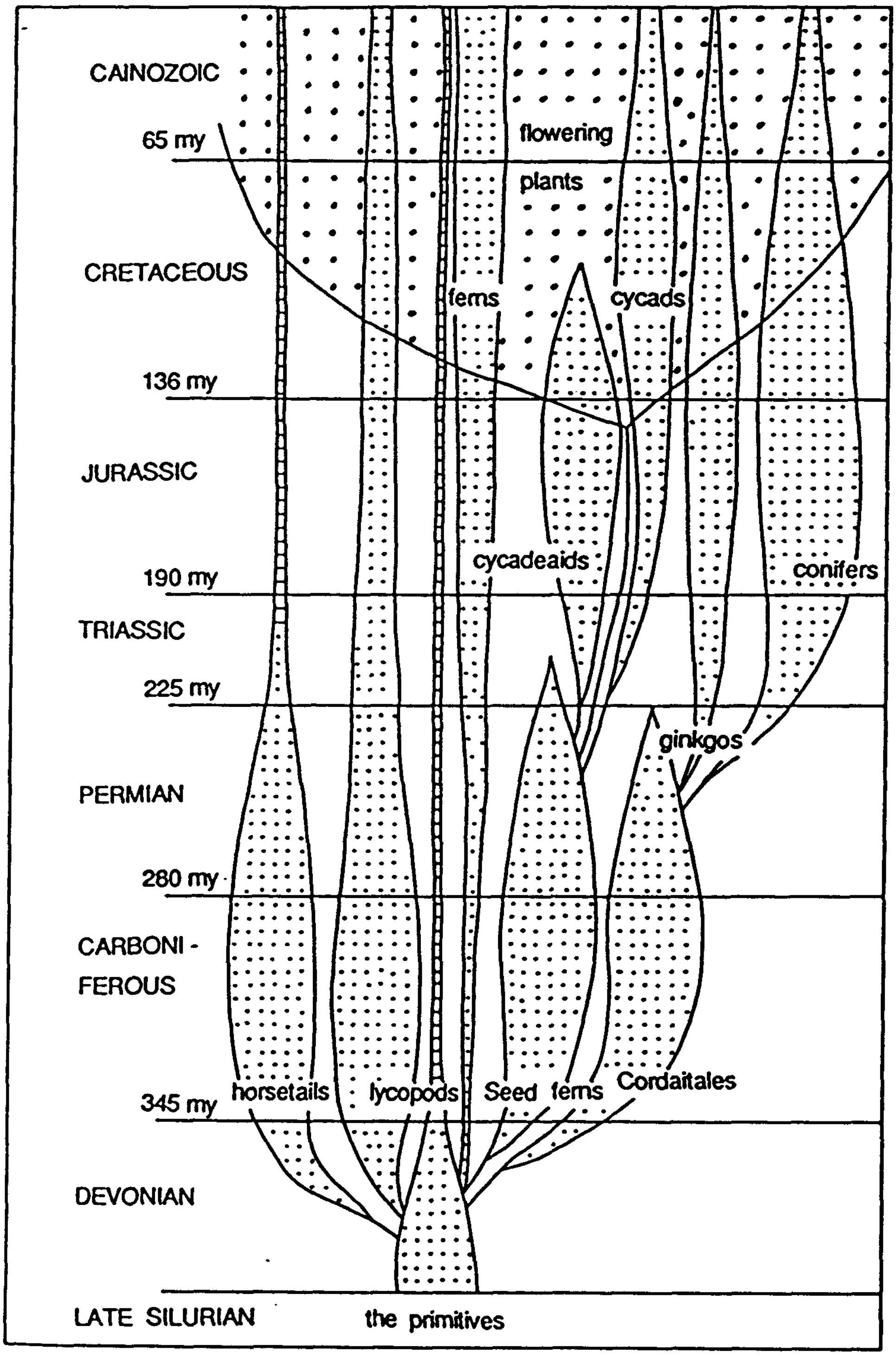



Figure 8.5. Evolution of the land-plants. After Bellamy (1978).

evolution of land-plants the amount and composition of resinites also varied. For instance, Mesozoic and younger coals tend to be resin-rich because of the abundance of conifers in the contributing flora (cf. Figure 8.5). In Carboniferous bituminous coal, the terpene resinites are lower in amounts and show less variability probably because plants in Carboniferous times rarely formed terpenic cell secretions (Stach et al, 1982, p. 252-254), as can be expected by the absence of conifers during that Period (Figure 8.5).

Table 8.1. A general classification of sedimentary organic matter. From Hunt (1979, fig. 7-5) with modifications.

| SAPROPELIC | | | HUMIC | |
|---|---|---|---|---|
| **Kerogen (transmitted light)** | | | | |
| Algal | Amorphous | Herbaceous | Woody | Coaly |
| **Coal macerals (Reflected light)** | | | | |
| Liptinite (Exinite) | | | Vitrinite | Inertinite |
| Alginite | Amorphous | Sporinite | Telinite | Fusinite |
| | | Cutinite | Collinite | Semifusinite |
| | | Resinite (lipid and terpene) | Vitrodetrinite | Micrinite |
| | | | | Macrinite |
| | | Suberinite | | Sclerotinite |
| | | Liptodetrinite | | Inertodetrinite |
| **Kerogen (elemental analysis/evolutionary pathways)** | | | | |
| Type I | Type I/II | Type II | Type III | Type IV |
| H/C ratio: | | | | |
| 1.7 - 0.3 | | 1.4 - 0.3 | 1.0 - 0.3 | 0.45 - 0.3 |
| O/C ratio: | | | | |
| 0.1 - 0.02 | | 0.2 - 0.02 | 0.4 - 0.02 | 0.3 - 0.02 |
| **Organic source** | | | | |
| Lacustr. | Marine | Terrestr. | Terrestr. | Terres./recycled |
| **Fossil fuels** | | | | |
| Predominantly oil, oil-shales, boghead and cannel coals. | | Oil and gas | Gas, condesate, and humic coal. | Minor gas, and coal. |
| **Threshold of liquid hydrocarbon generation, (Vit. Ref., %)** | | | | |
| 0.50 | 0.50 | 0.35 - 0.50[1] | 0.60 - 0.70 | 0.70 |

Footnote to Table 8.1

1 Depends on the composition of Type II kerogen; cf. Khorasani, 1987; Powell and Snowdon, 1983.

The maceral suberinite is derived from suberin which consists of glycerine esters of high molecular weight unsaturated and saturated fatty acids and oxy-fatty acids. Suberin is found in corkified cell walls which occur mainly in barks and also at the surface of roots, on stems and fruits acting as a protection against desiccation. Primitive plants such as Pteridophytes which were predominant during the Carboniferous did not form cork cells. Cork cells are especially characteristic of woody plants. Most of the liptinite macerals in contrast to those of vitrinite are relatively stable up to the sub-bituminous stage (Stach et al, 1982, p. 245). The first coalification jump of liptinites at approximately the boundary nbetween the sub-bituminous and high volatile bituminous coal stage (Ro = 0.5%; cf. Table 8.2) may reflect their thermal breakdown and may accompany the generation and release of hydrocarbons.

*Response of resinites and suberinites to thermal stress*

Certain liptinite-group macerals such as resinites, although resistant to chemical attack and possesing good potential for preservation, tend to break down at a lower levels of thermal exposure (Powell et al, 1978; Snowdon, 1980). Khorasani (1987) reported thermal alterations of certain resinites (terpene) at a maturation level of 0.45 - 0.60% Ro with the generation of hydrocarbons. Yield of high amounts of hydrocarbons by resinous components at comparable maturity levels has also been reported by Powell et al (1978) (see also Powell and Snowdon, 1983). The above evidence corresponds well with the microscopy observations by Stach et al (1982, p. 255) who noted the presence of a strongly fluorescing yellow material in coal derived from resinous cell fillings at the boundary between lignite and sub-bituminous coal (Ro = 0.35 - 0.37%) and still visible in the high volatile bituminous A stage (0.80% Ro). Cook and Struckmeyer (1986) also reported the presence of oil droplets and

| Main stages of evolution | | | Vitrinite reflectance (%) | Coal Rank, | | Oil window | |
|---|---|---|---|---|---|---|---|
| Tissot & Welte, (1978) | Vassoevich (1969, 1974) | Main HC generated | | ASTM | IHBCP | Vassoevich, 1974, Dow, 1977; Tissot & Welte, 1978, Hunt, 1979 | This Study |
| Diagenesis<br>$R_o$ ~0.5% | Proto - Catagenesis | Methane | 0.5 | Peat<br>Lignite<br>Sub - bitumin. C, B | Peat<br>Brown coal | | 0.35 |
| Catagenesis | Meso- Catagenesis | Oil | 1.3 | Sub - bitumin. A<br>High volat. bitum. C, B, A | hard coal | 0.5 – 1.3 | 0.35 – 1.3 |
| $R_o$~2% | | Wet gas | 2.0 | Med. vol. bit.<br>Low vol. bit. | | | |
| Metagenesis<br>$R_o$~ 4% | Apo - Catagenesis | Methane | 4.0 | Semi - Anthracite<br>anthracite | | | |
| Metamorphism | | | | Meta - anth. | | | |

Table 8.2. Main stages of the evolution of organic matter. Adapted from Tissot and Welte (1978; fig. II.1.2). ASTM - American Society for Testing and Materials. IHBCP - International Handbook of Coal Petrography.

fluorescing material similar to crude oil in coal in a reflectance range as low as 0.35 - 0.50% Ro. Lipid resinites, however, are believed to be more resistant and would not produce significant amounts of oil until a more advanced stage of maturation (Khorasani, 1987).

Like terpene resinites, suberinite is also thermally unstable. Khorasani (1987) noted severe alterations of suberinite at a reflectance range of 0.35 - 0.45% Ro with the generation of substantial amounts of highly waxy hydrocarbons. That both suberinite and terpene resinites are prone to early thermal decomposition is evidenced by the association of high $S_1/C_{org.}$ values (ranging from 7 to 75 mg/g) in immature isorank coals with alteration of suberinite and terpene resinites (Khorasani, 1987). Such early thermal decomposition of terpene resinites may explain the productivity of some petroliferous basins (e.g., Beaufort MacKenzie Basin, Canada) which are characterized by anomalously low levels of maturation (Snowdon and Powell, 1982).

*Geochemical characteristics of oil derived from liptinite-rich source rocks*

In contrast to high-wax oils derived mainly from cutinite and sporinite, resin-sourced oils are richer in naphthenes and aromatics than in paraffins (Guennel, 1981). Although resin-sourced oils are characterized by a high pristane/phytane ratio, they are low in wax content and are therefore dissimilar to the more common terrestrially-derived waxy paraffinic oil (Snowdon, 1980). Moreover, low API (American Petroleum Institute) gravity, lack of n-alkanes and other properties of resin-derived oils are also characteristic of biodegradation and water-washing (cf. Shanmugam, 1985) which makes it difficult to decipher their origin where meteoric flushing of the reservoir has taken place. Resin-derived oils are known from the Beaufort - MacKenzie Basin in Arctic Canada (Snowdon, 1980; Snowdon and Powell, 1982) and there is an indication of their presence in Gippsland Basin oil (which is biodegraded in varying degrees; cf. Burns et al, 1987) in offshore southeast Australia (cf. Shanmugam, 1985).

Hydrocarbon potential of vitrinite and inertinite

Apart from their distinctive geochemical composition, vitrinite and inertinite can be distinguished by their origin from different plant substances and organs. Vitrinites are coalification products of humic substances which essentially originate from lignin, cellulose and some tannins. Lignins contain an aromatic nucleus and are more resistant to microbial attack than cellulose while tannins (which possess phenolic properties) enhance the preservation potential of peat due to their resistance to decay.

Inertinites originate mainly from the humic-acid fraction of plant materials. The formation and properties of humic acids are dependent on the geochemical environment (e.g., Eh, pH) of the mire. Vitrinite has a higher H/C ratio than inertinite and a correspondingly lower O/C ratio. Inertinite is the most hydrogen-poor of all macerals (Table 8.1).

The hydrocarbon potential of organic matter is a function of the amount of aliphatic materials present. Vitrinite and inertinite are characterized by a high aromatic content. Although aromatics appear to be nothing more than cyclic alkenes, they are unusually stable and therefore have no hydrocarbon potential. Depending on the amount of aliphatic fraction, vitrinites are commonly thought to have only gas potential whereas inertinite is capable of producing no hydrocarbons or at most a trace of gas (Hunt, 1979, p. 274). However various authors in recent years favoured the hydrocarbon generating capacity (notably oil) of both vitrinite and/or inertinite (Durand and Paratte, 1983; Smyth, 1983; Smith and Cook, 1984; Tissot, 1984)

There are both geological and geochemical grounds which seem to support the oil generative capacity of vitrinite and inertinite. The geological reasoning hinges on the fact that in some basins the amount of reservoired oil can not be accounted for if liptinite is considered to be the only possible maceral capable of producing oil. Thus Smith and Cook (1984) suggested that much of the petroleum in the Gippsland Basin is probably derived from vitrinite (in addition to liptinite). Likewise, mass balance considerations in respect of the Cooper Basin oil led Smyth (1983) to suggest that inertinite (in addition to vitrinite and liptinite) must be an effective oil generator. She argued that the total amount of liptinite and vitrinite in the dispersed organic matter (DOM) are not sufficient to explain the volume of the reservoired oil there. If, however, the liptinte and the vitrinite in the DOM as well as in the coal are considered to be the potential oil generator (cf. Cook, 1982; Durand and Paratte, 1983; Cook and Struckmeyer, 1986), then there is no problem in accounting for the Cooper Basin oil.

Proponents of the view that both vitrinite and inertinite can be effective oil generators put forward much experimental evidence such as the following:

1) based on laboratory pyrolysis work Rohrback et al (1984) concluded that humic organic matter (represented by recent peat and presumably comprising vitrinite and inertinite precursors) is an equally effective oil and gas source as liptinite-rich sapropelic organic matter (e.g., algal mats);

2) inertinite is known to pass through a coalification jump in the range of Ro = 0.2-0.9% which is believed to be accompanied by hydrocarbon generation (Smith and Cook, 1980).

3) the coal liquification products from both vitrinite and inertinite are similar in composition (although the quantity differs) (Heng et al, 1983);

4) hydrous pyrolysis and hydrogenation research by Evans et al (1984), Rigby et al (1986) and Smith et al (1987) show that the hydrocarbon generation potential (especially the longer-chain n-alkanes) of vitrinites and inertinites are comparable and that the latter could be equally as effective a source for n-alkanes as the former.

Some of the abovementioned experimental evidence is inconclusive and is therefore open to question. In some cases alternative explanations are available. For instance, laboratory pyrolysis of recent peat (point 1) to simulate the maturation of ancient humic material in geologic situations may not be representative due to the time-dependent evolution of precursor plant materials of peat (discussed later). The coalification jump of inertinite (point 2) as reported by Smith and Cook (1980) may be due to the presence of associated sub-microscopic degraded algal materials (alginite) (cf. Taylor et al, 1988) that are commonly not discernible under light microscopy except perhaps in fluroscence mode. Moreover, such alginites are likely to produce oil at fairly early stage of maturation as noted by Taylor et al (1988) which may also explain the coalification jump (Smith and Cook, 1980) at a fairly early stage. Both coal liquification and hydrous pyrolysis of organic matter (points 3 and 4) are extreme chemical processes and therefore do not simulate the maturation that occurs under geologic conditions.

Probably the best criteria to evaluate the hydrocarbon potential is the elemental composition of organic matter. Therefore, inertinite being the most hydrogen-poor of all macerals is unlikely to have any hydrocarbon potential except possibly some methane (Hunt, 1979, p. 274; Taylor et al, 1988). With regard to vitrinite it has an intermediate value of H/C ratio and therefore has a moderate hydrocarbon generating potential. It can generate abundant gas with some condensate. The perhydrous variety is likely to be more oil-prone. The apparent association of oil fields in certain basins with predominantly vitrinitic organic matter may reflect the inhomogeneity of vitrinite and its association with sub-microscopic alginite (cf. Taylor and Liu, 1984).

HYDROCARBON POTENTIAL OF COAL

One of the main arguments against accepting coal as a viable source rock is its supposedly poor expulsion capacity (due to high sorptive properites). Thus Evans et al (1984) on the basis of experimental hydrogenation suggest that hydrocarbon is generated in coal but is not expelled before an advanced stage of maturation (Ro > 0.65%). Furthermore isotopic study of gas from DOM and coal seams led Rigby and Smith (1981) to suggest that DOM rather than seam coal is the main source of the Cooper Basin oil and gas. This is in contrast to Cook and Struckmeyer (1986) who, on the basis of microscopy evidence, have pointed out that seam coals can source hydrocarbons and concluded that it is a more important source of hydrocarbons than the DOM (see also Taylor et al, 1988). Durand and Paratte (1983) suggested easy expulsion of hydrocarbons from coal during burial and proposed that retention of hydrocarbons within the microporosity is unlikely. Stainforth (1984) has also considered both coal and DOM as sources for the Gippsland Basin hydrocarbons. The close association of coal and coal-bearing strata to oil accumulations in various basins, especially the Tertiary deltaic succession as in the Niger Delta (Evamy et al, 1978; Nwachukwu and Chukwura, 1986; Bustin, 1988) and the Mahakam Delta (Combaz and de Matharel, 1978; Durand and Oudin, 1979; Vandenbourke et al, 1983) indicates that certain types of coal have produced both oil and gas in specific basins (Durand and Paratte, 1983; Tissot, 1984; Thompson et al, 1985). Furthermore, mass-balance calculations in some basins (cf. Smyth, 1983) lend support to the view that seam coal can contribute to hydrocarbon generation (Taylor et al, 1988). Therefore, from the geological point of view it is evident that some coals are capable of generating hydrocarbons.

**Type of hydrocarbons - oil or gas**

Although coal is equated with Type III kerogen it is essentially a mixture of different macerals with diverse geochemical and petrological characteristics. As mentioned above, coal and coaly sediments have generally been considered a source of gas but not of oil (Tissot and Welte, 1978, p. 145-147). Many such studies regarding the oil potential of coal were based mainly on European and North American Carboniferous coals which, compared to the southern hemisphere (Gondwanan and younger) coals, were formed from different plant types and in different climatic and depositional settings. In this connection the petrologic and geochemical compositions of the coal macerals are deemed very critical in determining the amounts and types of hydrocarbons produced.

The composition of coal results from a complex interplay of such interrelated variables as the nature of the contributing flora, climate, geologic setting and depositional environments. Depending on composition, coals and coal-bearing strata of different age and geographic location are known to have produced both oil and gas. For instance, European coal of Westphalian age yielded huge amounts of gas in the North Sea, Netherlands and northern Germany region without any significant oil accumulation except in the East Midlands (England) where several small fields of high waxy oils are derived from coals (Tissot, 1984). In Australia, Mesozoic and Tertiary coals are claimed to generate both oil and gas whereas Permian coal has yielded mainly gas (Thomas, 1982) with some oil.

In an attempt to compare Australian coals of different basins and ages Cook (1975) reported that Gondwanan coals are extremely rich in

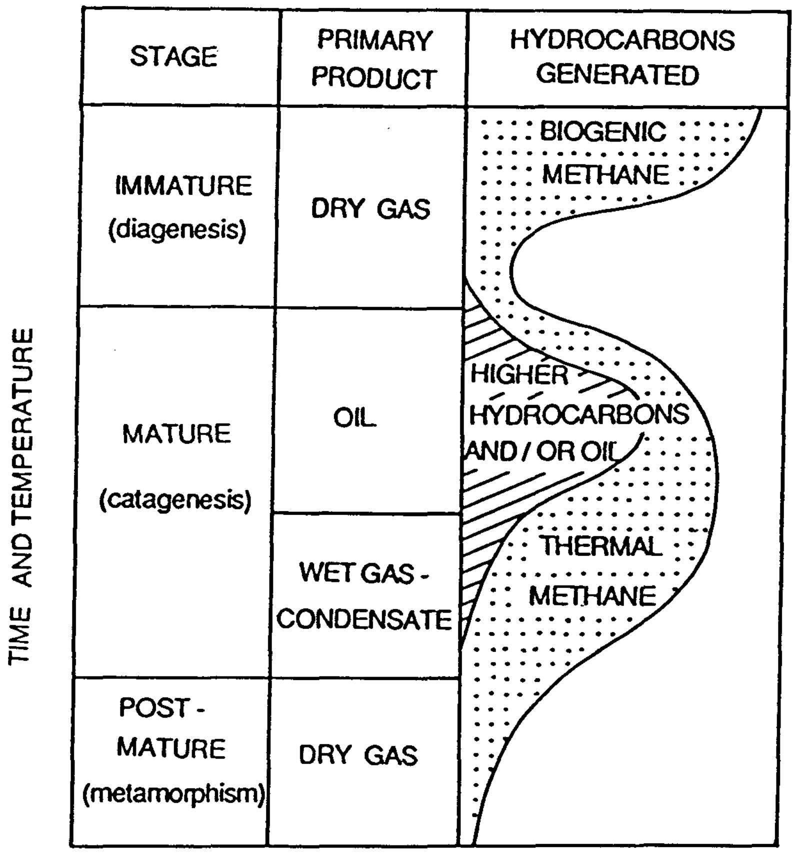



Figure 8.6. Schematic diagram showing the different stages of organic maturation and generation of hydrocarbons. After Rice and Claypool (1981, fig. 1).

inertinite but poor in liptinite. Vitrinite content is highly variable ranging from 5% to 30% with some rare seams containing higher amounts, but in general its content is low. Amongst the liptinites which comprise a minor component of the Australian Permian coals (5% average; Hunt, 1985, p. 18) megaspores (typical of Carboniferous coals of North America and a source for hydrogen-rich lipid material) are missing and cuticles are very thin. In contrast, Australian Jurassic coals are rich in vitrinite and liptinite (especially cutinite and resinite); inertinite occurs only in traces and the vitrinite contains a high proportion of low-reflectance material and is perhydrous (probably vitrinite 2 of Buiskool Toxopeus, 1983). Some of the differences in maceral composition may be related to floral changes. Thus the generally low liptinite content of the Permian coals reflects a flora that had a relatively low rate of spore production and was characterized by leaves with relatively thin cuticles. Jurassic coals on the other hand contain abundant cutinite and resinite which presumably are derived from conifers.

In terms of currently accepted notions, hydrogen-rich macerals of the liptinite/exinite group are thought to be responsible for the generation of oil (Thomas, 1982; Snowdon and Powell, 1982; Powell and Snowdon, 1983) as opposed to vitrinite which produces predominantly gas and possibly some condensate.

## PRINCIPAL ZONE OF GAS FORMATION

Methane can be generated by a variety of processes and within a wide range of thermal maturity starting from the early diagenetic/biogenic stage through the oil window up to the metagenetic stage by cracking of kerogen and earlier formed hydrocarbons (Figure 8.6). Generation from each of these stages involves specific mechanisms. For instance, studies by Monnier at al (1983) in Canadian Arctic Basins show that from Type III organic matter it begins at an early stage of maturation prior to the onset of oil generation (Ro = 0.5%) and presumably due to loss of methoxyl groups. By contrast, generation of methane in the catagenetic stage involves the breaking of stronger C-C bonds. Moreover, the amounts of gas generated from Type III kerogen at the marginally mature to mature stage can be as much as three times higher than that generated from Type II kerogen (Powell and Snowdon, 1983). No dramatic change in the amount of gas yield occurs for Type III kerogen from the mature to overmature zone but there is an increase in gas yield during this transition for Type II kerogen (Monnier at al, 1983). These authors have also shown that in the case of Type III organic matter significant gas generation begins at a reflectance level of Ro = 0.55% which is prior to the onset of liquid hydrocarbon generation and reaches a maximum at the onset of oil generation (Ro = 0.70%). This is in contrast to the widely held notion that the principal zone of gas formation for all types of organic matter is the overmature stage by the extensive cracking of kerogen and previously formed hydrocarbons (Tissot and Welte, 1978, p. 70, 169). Isotope studies of gas from undersaturated reservoired oil by Burns et al (1984) showed that in the Gippsland Basin which has abundant coal and Type III kerogen at all levels of maturity, there is insignificant gas generation in the early to peak maturity stage to saturate the major oil fields. Their interpretation is contingent upon the assumption that the gas is derived from the same source as the oil and was derived at the same time. Biodegradation (against which the authors caution) and in-reservoir maturation may be other complicating factors. This may also explain the lower maturity range suggested by Smith and Cook (1984) for the Gippsland Basin hydrcarbons (measured at Ro = 0.4 - 0.8% compared to 1.0 - 1.1% derived from gas isotope data by Burns et al, 1984). It may be mentioned, however, that hydrocarbon accumulation is a factor of many variables and any early generated hydrocarbons must be accompanied by the presence of suitable traps in the absence of which hydrocarbons will be dissipitated. Therefore each basin has to be studied on a case-by-case basis in the overall geologic and geochemical context.

## LIMITATIONS AND SHORTCOMINGS OF SOME CONVENTIONAL PETROLOGIC AND ORGANIC GEOCHEMICAL PARAMETERS

The conventional petrographic analysis of organic matter in terms of coal macerals does not provide infallible criteria for source rock evaluation. Transmitted light microscopy categorization of algal, amorphous, herbaceous, woody and coaly organic matter can be especially misleading when equated with elemental analyses. For instance, although amorphous kerogen is commonly equated with Type I and II kerogen and is considered to have high oil potential, Durand and Monin (1980) showed that its elemental composition may spread over the entire field of the van Krevlen diagram (see also Powell et al, 1982). Likewise, macerals identified by reflected light microscopy may not be assignable to specific organic matter types in the van Krevlen diagram. Taylor and Liu (1984), on the basis of transmission electron microscopy, have shown the heterogeneity of vitrinite some of which contains abundant bacterial lipids and may well plot on or close to the field of Type II kerogen rather than the field of Type III kerogen with which it is commonly equated. Inertinite from the Cooper Basin has also been found to be associated with several percent of sub-microscopic alginite, commonly not discernible with light microscopy (Taylor et al, 1988). The importance of this alginite is significant to account for the reservoired oil in the Cooper Basin (cf. Smyth, 1983).

Use of Ro as a maturation indicator - a reappraisal

Although vitrinite reflectance is one of the most popular and widely used indices of organic maturation it suffers from the following shortcomings:

1) the problem of distinguishing vitrinite from other macerals having intermediate characteristics; Buiskool Toxopeus (1983) has shown that even in the absence of reworked materials at least two groups of vitrinite can exist in coals (see also Brown et al, 1964). The hydrogen-poor vitrinite 1 shows higher Ro and no fluorescence whereas the hydrogen-rich vitrinite 2 shows a lower Ro value and depending on maturation level may show some weak fluorescence. The identification problem becomes more difficult in Type I and II kerogens in which the commonly identified vitrinite may not be land-plant-derived and compositionally may resemble vitrinite 2 of Buiskool Toxopeus (1983);

2) the reliability of Ro is questionable at low levels of maturity, especially below Ro = 0.3% (Heroux et al, 1978);

3) the lithology of the host rock is known to influence Ro values: at the same maturation stage, reflectance of vitrinite increases from sandstone through siltstone and shale to coal (Heroux et al, 1978);

4) oxidation reduces Ro value and

5) Ro suffers from problems of interlaboratory calibration (cf. Heroux et al, 1978; Tissot et al, 1987).

Elemental composition

Classification of kerogen types based on the H/C and O/C ratios despite wide acceptance has not gone unchallenged. Thus Smith et al (1987) noted that the hydrocarbon potential, especially the n-alkane content as determined by hydrogenation and hydrous pyrolysis, appears to be unrelated to either the chemical, elemental or petrographic compositions. They argued that the chemical structure is of critical importance. Despite wide differences in their elemental compositions (as reflected on the H/C and O/C ratios), these workers observed no regular differences in the n-alkane contents of the hydrogenation products of Australian vitrinites and inertinites (Smith et al, ibid.).

## Laboratory pyrolysis of source rocks

Experimental laboratory pyrolysis, especially the Rock-Eval pyrolysis (Espitalie et al, 1977) to simulate the geochemical evolution of organic matter, has become a routine practice despite the fact that it may not be suitable for certain types of organic matter at certain maturity levels. Tissot (1984) points out that results of such analyses compare well with those observed along natural evolution paths provided the source rock comprises Type I and II kerogen and it comes from the catagenetic stage. On the other hand, Type III kerogen and coal, especially from the diagenetic stage, show a different behaviour; their artificial evolution does not follow the natural evolution path. Tissot (1984) explained that in artificial simulations the elimination of $O_2$ takes place as $H_2O$ (a $H_2$-consuming process) in contrast to preferential elimination as $CO_2$ (an $O_2$-consuming process) during geologic evolution (see also Monin et al, 1980).

Conclusions based on pyrolysis carried out on recent terrestrial sediments to assess the hydrocarbon potential of their ancient counterparts should be interpreted with caution because of the time-dependent change of the composition of organic matter as a function of floral evolution. For example, Rohrback et al (1984), on the basis of laboratory pyrolysis work concluded that hydrogen-poor recent peat (on which they experimented) is nearly as efficient a source of petroleum as the hydrogen-rich algal mat (Type I kerogen). This contradicts the conventional view that humic organic matter is gas-prone. The abovementioned apparently conflicting views may well be due to the fact that Tertiary floras (and therefore peat) are richer in resins, suberins, cutins and other hydrogen-rich components than their ancient counterparts. Such organic matter is likely to produce liquid hydrocarbon at a much lower level of thermal stress compared to other types of terrestrial organic matter (cf. Figure 8.7).

**HYDROCARBON GENERATION FROM A MULTICOMPONENT SYSTEM**

Sedimentary organic matter consists of a complex mixture of different types of macerals (Table 8.1) the relative abundance of particular varieties of which will determine whether a source rock has significant oil potential or will generate mainly gas. Terrestrial organic matter in coal maceral terms may be considered a three-component system and can be plotted in a ternary diagram with the vertices consisting respectively of the terpene resinites and suberinites, macerals of the liptinite/exinite family (excluding the terpene resinite and suberinite), and vitrinite plus inertinite (Figure 8.7). Such a diagram shows the relative importance of various macerals which, depending on the level of organic maturation, are expected to produce different amounts and type (oil and/or gas) of hydrocarbons. It also shows the pulsatory/episodic nature of hydrocarbon generation from terrestrial source rocks consisting of a diverse suite of macerals. As can be seen from Figure 8.7, terrestrial organic matter can generate both oil and gas and in a wide range of thermal maturity as a function of its petrologic/geochemical composition. Suberinite and terpene resinites being the most labile of macerals can produce significant amounts of oil at a very early stage of maturation whereas other liptinite macerals and vitrinite/inertinite will require a fairly advanced stage of maturation to produce hydrocarbons. The detailed chemical composition of vitrinite also influences its behaviour under thermal stress. For example: because the perhydrous vitrinite

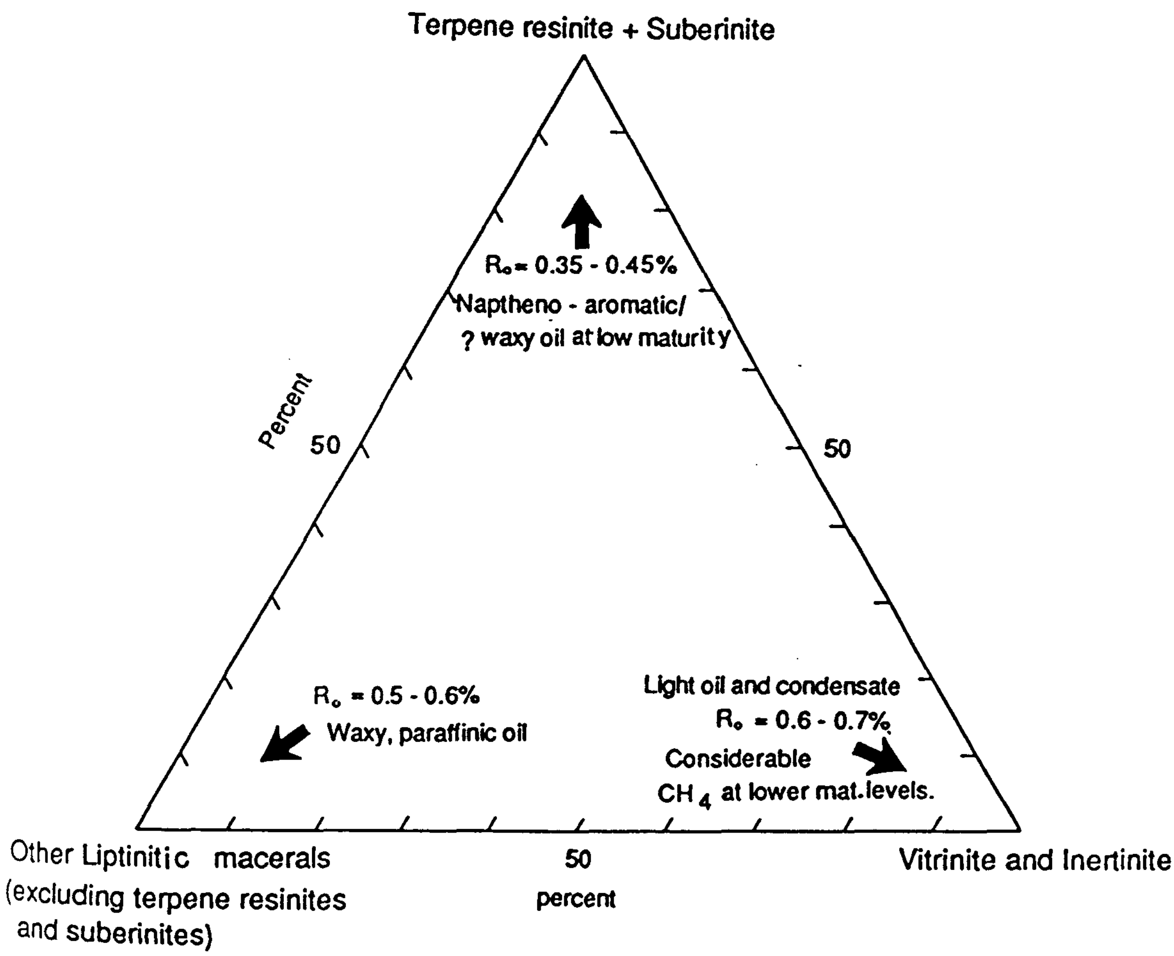



Figure 8.7. Ternary diagram showing the different types of terrestrially-derived organic matter and their thresholds of liquid hydrocarbon generation (shown in vitrinite reflectance values). See text for explanation. $R_o$ values for terpene resinites and suberinites from Khorasani (1987) and Powell and Snowdon (1983). Values for other macerals are from Hunt (1979), Tissot and Welte (1978), and Powell and Snowdon (1983).

(characteristic of the Walloon coals) has a higher H/C ratio than typical vitrinites, it can be expected to generate more oil than its hydrogen-poor counterpart in the Permian coal measures of the underlying Bowen Basin.

BOUNDARIES OF THE OIL WINDOW

The petroleum generation model elaborated by Vassoevich et al (1974) and Dow (1977) indicates that the principal zone of oil formation occurs between Ro values of 0.6% to 1.2% and that the principal zone of condensate formation occurs at somewhat higher levels of thermal alteration extending up to 1.6% Ro. In fact the boundaries of the oil window are diffuse rather than sharply defined. As mentioned before, depending on the composition of the organic matter, the onset of oil generation can be expected to take place at a very early stage (Ro = 0.35-0.45%) when kerogen contains thermally unstable exinitic macerals, or relatively late (Ro = 0.6-0.7%) in case of other maceral types (cf. Figure 8.7 and Table 8.2).

POTENTIAL SOURCE ROCKS OF THE SURAT BASIN HYDROCARBONS

Thomas et al (1982) considered the Permian Blackwater and Back Creek Groups of the underlying Bowen Basin to be the prime source for most of the Surat Basin hydrocarbons. Because of their supposed low to marginal maturity they have discounted the Lower Jurassic Evergreen Formation (cf. Figure 8.8) and the overlying Jurassic coals and coal-bearing strata of the Walloon Coal Measures as possible source(s) for oil and gas.

But, as has been suggested before, in a basin with diverse organic matter type petroleum generation takes place in different phases rather than in a single pulse; certain hydrogen-rich macerals generate hydrocarbons at low levels of organic maturity. The Evergreen Formation and the Walloon Coal Measures with liptinite-rich source rocks (especially those rocks rich in suberinite and resinite) certainly have generated hydrocarbons. Moreover, the Westbourne Formation contains locally up to

30% total organic carbon (TOC). The organic matter is hydrogen-rich and falls between Types I and II kerogen in the modified van Krevlen diagram and has a reflectance of Ro = 0.5 - 0.6% in some places (cf. Almond, 1986; John, 1986). No information as to the maceral types is available but even in the absence of low maturity labile macerals (cf. Figure 8.7), this formation has reached the threshold of the conventional oil window. This conjecture is supported by the fact that very minor gas production has been reported from the Westbourne Formation and the underlying Springbok Sandstone in the Roma Shelf area[1] (Figures 8.1 and 8.2) (Allen, 1976; Groves, 1976). The possibility of more than one source of the Surat Basin oils as proposed by Philp et al (1982) (based on oil-to-source-rock correlation) may suggest that both the Bowen and Surat Basin source rocks have contributed to the reservoired hydrocarbons.

Macerals of the Evergreen Formation

Although the minor coals within the Evergreen Formation are vitrinite-rich, the DOM is rich in liptinite (Figure 8.9) and TOC values of up to 3.8% have been reported from this formation (Almond, 1986; John, 1986). The liptinite content of the DOM is moderate to high with most of the DOM containing more than 50% liptinite (Golin and Smyth, 1986). More liptinite-rich organic matter is likely to be present in the Evergreen Formation which has paralic/brackish environmental affinities (Exon, 1976, p. 46, 88; see also Golin and Smyth, 1986). Such organic matter can be deposited by a similar mechanism to that which evidently operated in the Tertiary Mahakam Delta source rocks of Indonesia (see Thompson et al, 1985). Thompson et al (ibid.) argued that in strongly tide-dominated

---

[1] The reported gas could also be of biogenic and/or diagenetic (non-biogenic) origin. It is characteristically dry, consisting of methane only without any higher hydrocarbons (cf. Allen, 1976). No isotope analysis data are available so far as to the genetic nature of this gas.

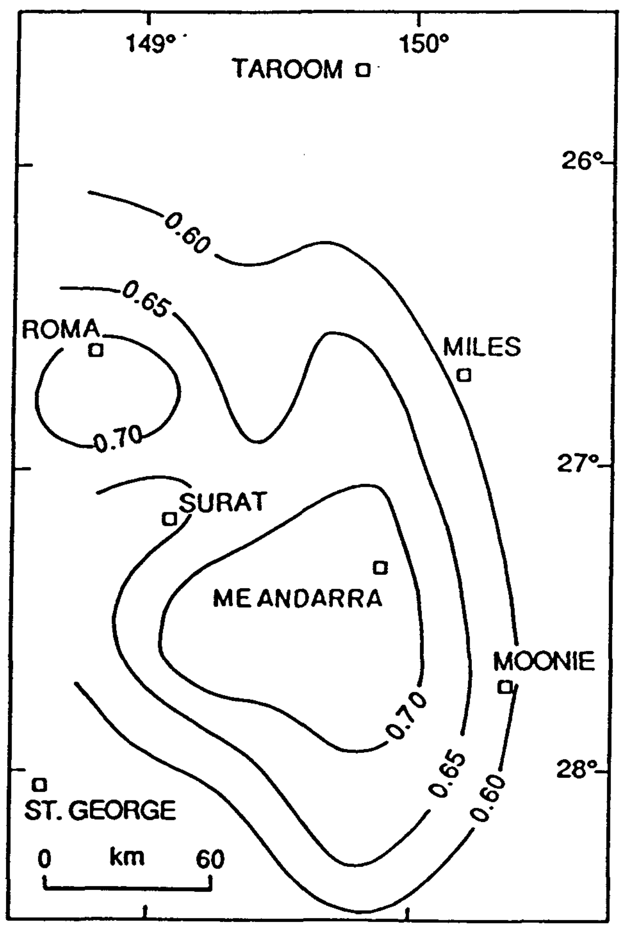



Figure 8. 8. Vitrinite reflectance of the Evergreen Formation. After Thomas et al (1982, fig. 9).

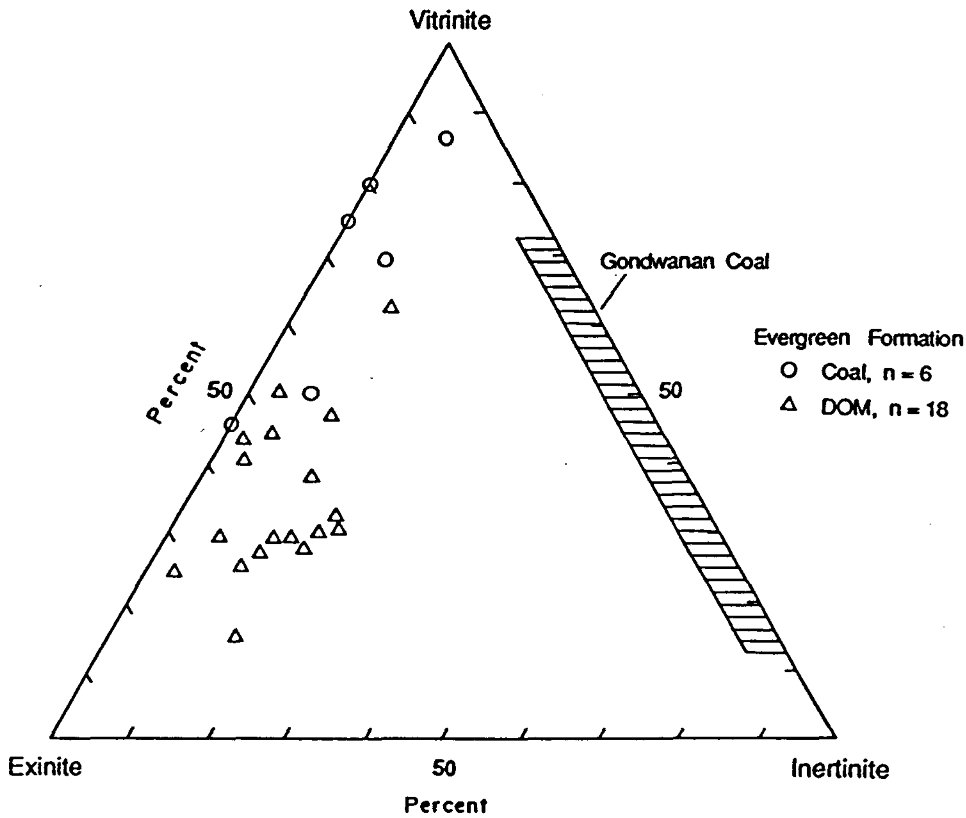



Figure 8.9. Macerals of the Evergreen Formation. After Golin and Smyth (1986). Gondwanan coal based on data from Cook (1975) and Stach et al (1982). DOM - Dispersed organic matter.

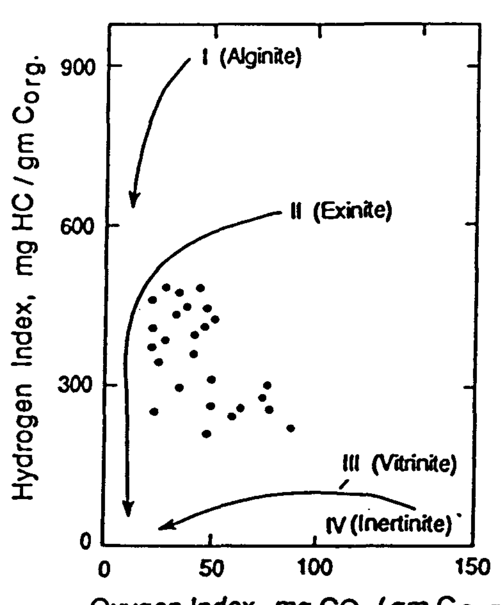



Figure 8.10. Type of organic matter in the Walloon coals based on Rock-Eval pyrolysis data plotted on a modified van Krevlen diagram (after Khorasani, 1987; fig. 3). Evolution paths (arrows) of major coal macerals are shown for comparison.

deltas/coastal plain environments peats are rarely preserved as autochthonous accumulations. Once eroded, humic acid gels (formed from the bacterial degradation products of plant material) go into solution whereas the resistant remains such as waxes, cuticles, resins and lignified woody fragments become part of the traction/suspended load to be deposited in intertidal or shallow neritic depths as allochthonous/hypauthochthonous peats. The process of separation of soluble and insoluble organic matter in this fashion results in the accumulation of liptinite-rich peats and carbonaceous shales in lacustrine and shallow-marine environments. A similar mechanism of source rock enrichment might have been responsible for the accumulation of the Latrobe Group source rocks in the Gippsland Basin and local concentration of liptinite-rich kerogen may also be expected to have occurred in the Evergreen Formation.

Moran and Gussow (1963) were the first to suggest the Evergreen Formation as a source for the Surat Basin oil and on the evidence of the presence of Jurassic spores in oils from the Jurassic, Permian and Triassic reservoirs De Jersey and Allen (1966) concluded that the Evergreen Formation is a significant source of oil in the Surat and Bowen Basins. Subsequently Mathews et al (1971) pointed out that oils known to occur within the Evergreen Formation must have been derived from the Evergreen Formation itself. On the other hand on the basis of conventional maturity parameters (e.g., Ro), biomarker composition and gas chromatography - mass spectrometry Thomas (1982), Thomas et at (1982), Philp et al (1982) and Philp and Gibert (1986) discounted the Evergreen Formation as a possible source of oil. If, however, Ro = 0.5-0.6% is taken as the threshold of oil generation then most of the Evergreen Formation is marginally mature to mature (Figure 8.8) and must have generated hydrocarbons.

**Oil-prone source rocks of the Walloon Coal Measures**

Walloon coals are the richest source rocks within the Jurassic section and in terms of liptinite content (as much as 30%; Khorasani, 1987) are richer than the coals and coaly organic matter of the Upper Cretaceous and Tertiary Latrobe Group (5-20% liptinite; Smith and Cook, 1984) which are regarded as the sources of the 3 billion barrels of recoverable oil in the Gippsland Basin (Shanmugam, 1985; see also Burns et al, 1984, and Stainforth, 1984). Walloon coals have the highest liquid yields upon destructive distillation of any Australian coals (Smith, 1980). They are also rich in perhydrous vitrinite which has an unusually higher hydrogen index (a measure of H/C ratio; Figure 8.10) than expected for normal vitrinites of similar rank (see also Golin and Smyth, 1986). Furthermore, inertinite content is very low and does not exceed 4-5% by volume.

The unusual richness of the Walloon Coal Measures (Figure 8.10) is a function of plant type and depositional environments. The coal is derived mostly from conifer materials represented by the family Araucariaceae (Gould, 1974, 1980) deposited in dysaerobic peat-forming environments where mouldering and/or dehydration-oxidation of humic matter was not favoured (Khorasani, 1987). The liptinite macerals comprise mainly cutinite, resinite and sporinite. Suberinite is very abundant, representing as much as 20-30% by volume of many Walloon coals (see also Cook, 1982). The vitrinite reflectance of the Walloon coals varies from Ro = 0.5% at the top of the coal measures to a maximum of Ro = 0.6% at the bottom of the unit which is consistent with the sub-bituminous coal rank. Such source rocks containing significant labile liptinite macerals are likely to have contributed to hydrocarbon generation (Khorasani, 1987).

DISCUSSION

Liptinite-rich terrestrial organic matter has excellent potential for oil generation. However, under thermal stress the different macerals of the liptinite group behave differently from each other. Suberinites and terpene resinites being the most labile will produce significant amounts of oil at a very early stage much above the threshold of the conventional oil window (Figure 8.7, Table 8.2). The other macerals of the liptinite group (e.g., cutinite, sporinite) are more resistant to thermal stress and would not produce oil until a fairly advanced stage of maturation (Figure 8.7). The composition of organic matter results from a complex interplay of contributing flora, climate and environments of deposition. An overriding influence of any of these factors can give rise to source rocks rich in specific type(s) of organic matter. A paralic/marine depositional environment, for instance, by reworking littoral peats may concentrate exinitic macerals even though the contributing floras are poor in similar precursor materials.

Although vitrinite has now been recognised as a source of oil, oil generation is probably restricted to the perhydrous variety. However, oil generation, if any, does not take place in vitrinite-rich kerogen until an advanced stage of maturation. It can produce significant amounts of gas (and possibly some condensate) at early maturation levels before it reaches the threshold of the conventional oil window which may explain the prolific gas-prone nature of Tertiary deltas with predominantly humic source rocks of relatively low maturity (e.g., the Niger, Mahakam and Bengal Deltas). In the catagenetic zone vitrinite also produces abundant methane and possibly some light oil.

The hydrocarbon potential of inertinite is restricted to minor gas, if any. The indication that in specific basins inertinite might have contributed to oil generation (cf. Smyth, 1983) is due to the association of hydrogen-rich sub-microscopic alginite rather than inertinite itself (Taylor et al, 1988).

Biogenic methane is a significant contributor to commercial gas accumulations in many basins around the world. It can be generated from any type of organic matter soon after deposition and within a short geologic time (Figure 8.6). However, its commercial accumulation depends upon the availability of traps and in the absence of synsedimentary structures is restricted to stratigraphic traps. The fact that, globally, more than 20% of all known gas reserves are biogenic in origin (cf. Rice and Claypool, 1981) testifies to the importance of this phenomenon in gas accumulation.

The problem of assigning hydrocarbon source(s) in composite basins is always complex and the Surat/Bowen Basins are no exception. Organic-rich mature humic source rocks are abundant in the underlying Bowen Basin which itself is oil and gas productive (Figure 8.2). The Permian coal measures of this basin are highly inertinite-rich and the liptinite content is less than 5%. Although the Gondwanan coal is inertinite-rich, depending on depositional environments, concentration of liptinite in potential source rocks, especially in the DOM, may locally exist (cf. Thompson et al, 1985).

The presence of thrust faults in the eastern flank of the Surat Basin (Figure 8.1) led Thomas et al (1982) to suggest vertical migration of oil and gas in that area from the underlying Permian System whereas they proposed extensive lateral migration to explain the presence of oil and gas fields in Roma Shelf area. If a broader oil window is accepted (cf. Table 8.2) with certain exinitic macerals capable of generating hydrocarbons at lower maturation levels, then some of the Surat Basin oil and gas must have come from the Jurassic System.

## CONCLUSIONS

Oil-generative source rocks rich in organic matter are present throughout the Mesozoic succession of the Surat Basin although the Cretaceous System lies wholly above the threshold of the oil window. Some formations of the Surat Basin succession are rich in certain exinite group macerals: notably suberinite and terpene resinites. These labile macerals are capbale of generating liquid hydrocarbons at a much lower levels of thermal maturity compared to other macerals. Additionally, significant quantities of gas can be generated from oxygen-rich Type III organic matter before they reach the catagenetic stage. The coals and coaly organic matter in the Permian Blackwater and Back Creek Groups which are thought to produce the Surat Basin oil/gas are very rich in inertinite, the oil-generating potential of which is minor. These source rocks might have produced abundant gas with some condensate. A broader oil window as suggested in this paper indicates that the Evergreen Formation, the Walloon Coal Measures and, in some places, the Westbourne Formation have reached the threshold of oil generation. These findings could be of critical importance in formulating future exploration strategies in the Surat Basin and other frontier areas with comparable geologic and geochemical characteristics.

REFERENCES

Allen, R. J., 1976, Surat Basin. In Leslie, R. B., Evans, H. J., and Knight, C. L., (eds.) Economic geology of Australia and Papua New Guinea. Australas. Inst. Min. Metall. Monogr. 7, pp. 269-272.

Almond, C. S., 1986, Stratigraphic drilling report - GSQ Mitchell 2. Qld. Govt. Min. Jour. v. 87, n. 1018, pp. 353-360.

American Society for Testing and Materials (ASTM), Standard for coal and coke, Committee D-5, 1975-1976. 1916 Race St., Philadelphia, Pa. 19103.

Bellamy, D., 1978, Botanic man. Hamlyn, London. 208 p.

Brown, H. R., Taylor, G. H., and Cook, A. C., 1964, Prediction of coke strength from the rank and petrographic composition of Australian coals. Fuel, v. 43, part 1, pp. 43-54.

Buiskool Toxopeus, J. M. A., 1983, Selection criteria for the use of vitrinite eflectance as a maturity tool. In Brooks, J., (ed.) Petroleum geochemistry and exploration in Europe. Blackwell, Oxford. pp. 295-307.

Burns, B. J., James, A. T., and Emmet, J. K., 1984, The use of gas isotopes in determining the source of some Gippsland Basin oils. Austral. Petrol. Expln Assoc. Jour., v. 24, pp. 217-221.

Burns, B. J., Bostwick, T. R., and Emmet, J. K., 1987, Gippsland terrestrial oils - recognition of compositional variations due to maturity and biodegradation effects. Austral. Petrol. Expln. Assoc. Jour., v. 27, pp. 73-83.

Bustin, R. M., 1988, Sedimentology and characteristics of dispersed organic matter in Tertiary Niger Delta: origin of source rocks in a deltaic environment. AAPG Bull. v. 72, pp. 277-298.

Combaz, A., and de Matharel, M., 1978, Organic sedimentation and genesis of petroleum in Mahakam Delta, Borneo. AAPG Bull., v. 62, pp. 1684-1695.

Cook, A. C., 1975, The spatial and temporal variation of the type and rank of Australian coals. In Cook, A. C., (ed.) Australian black coals. Australas. Inst. Min. and Metall., Illawara Branch, Australian Black Coal Symposium, Wollongong. pp. 63-84.

Cook, A. C., 1982, Organic facies in the Eromanga Basin. In Eromanga Basin Symposium, summary papaers. Petrol. Expln Soc. Austral. and Geol. Soc. Austral. pp. 234-257.

Cook, A. C., and Struckmeyer, H., 1986, The role of coal as a source rock. In Glenie, R. C., (ed.) Second Southeastern Asutralian oil exploration symposium. Petrol. Expln Soc. Austral. pp. 419-432.

De Jersey, N. J., and Allen, R. J., 1966, Jurassic source for oil of Surat Basin, Queensalnd, Australia. AAPG Bull. v. 50, pp. 2479-2481.

Dow, W. G., 1977, Kerogen studies and geochemical interpretations. Jour. Geochem. Expln. v.7, pp. 79-99.

Durand, B., and Monin, J. C., 1980, Elemental analysis of kerogen. In Durand, B., (ed.) Kerogen: insoluble organic matter from sedimentary rocks. Editions Technip, Paris. pp. 113-142.

Durand, B., and Oudin, J. L., 1979, Exemple de migration des hydrocarbures dans une serie deltaique: de delta de la Mahakam, Kalimantan, Indonesie. Proceed. 10th World Petrol. Congr. Bucharest. v. 2. pp. 3-11.

Durand, B., and Paratte, M., 1983, Oil potential of coals: a geochemical approach. In Brooks, J., (ed.) Petroleum geochemistry and exploration in Europe. Blackwell, Oxford-London. pp. 255-265.

Edman, J. D., and Surdam, R. C., 1986, Organic-inorganic interactions as a mechanism for porosity enhancement in the Upper Cretaceous Ericson Sandstone, Green River Basin, Wyoming. In Gautier, D. L., (ed.) Roles of organic matter in sediment diagenesis. SEPM Sp. Publ. 38, pp. 85-109.

Espitalie, J. M., Menning, J. J., and Leplat, P., 1977, Source rock characterisation method for petroleum exploration. 9th Offshore Technology Conference OTC 2935, v. 3, pp. 439-444.

Evamy, B. D., Harembaure, J., Kamerling, P., Knaap, W. A., Molloy, F. A., and Rowlands, P. H., 1978, Hydrocarbon habitat of Tertiary Niger Delta. AAPG Bull. v. 62, pp. 1-39.

Exon, N. F., 1976, Geology of the Surat Basin in Queensland. Bureau Min. Res., Geol. Geophy. Bull. v. 166, 160 p.

Golin, V., and Smyth, M., 1986, Depositional environment and hydrocarbon potential of the Evergreen Formation, ATP 145P, Surat Basin, Queensland. Austral. Petrol. Explon Assoc. Jour. v. 26, pp. 156-171.

Gould, R. E., 1974, The fossil flora of the Walloon Coal Measures, a survey. Proceed. Roy. Soc. Qld. v. 85, pp. 33-41.

Gould, R. E., 1980, The coal-forming flora of the Walloon Coal Measures. Coal Geol. v.1, pp.83-105.

Groves, R. D., 1976, Roma Shelf petroleum fields. In Leslie, R. B., Evans, H. J., and Knight, C. L., (eds.) Economic geology of Australia and Papua New Guinea. Australas. Inst. Min. Metall. Monogr. 7, pp. 280-302.

Guennel, G. K., 1981, Oil from pollen and spores. In Brooks, J., (ed.) Organic maturation studies and fossil fuel exploration. Academic Press, London. pp. 303-318.

Harwood, R. J., 1977, Oil and gas generation by laboratory pyrolysis of kerogen. AAPG Bull. v. 61, pp. 2082-2102.

Hedberg, D. H., 1968, Significance of high-wax oils with respect to genesis of petroleum. AAPG Bull. v. 52, pp. 736-750.

Heng, S., Collin, P. J., and Wilson, M. A., 1983, Hydrogenation of maceral concentrates from Bayswater Coal: effect of temperature on the yield and mean chemical composition of the product. Fuel. v. 62, pp. 1359-1368.

Heroux, Y., Chagnon, A., and Bertrand, R., 1978, Compilation and correlation of major thermal maturation indicators. AAPG Bull. v. 63, pp. 2128-2144.

Hunt, J. M., 1979, Petroleum geochemistry and geology. Freeman, San Francisco. 617 p.

Hunt, J. W., 1985, Studies in Gondwana coal geology. Unpublished Ph.D thesis. Macquarie University. V. 1, 187 p.

International Handbook of Coal Petrography. 1971. Paris, Centre Nationale de la Recherche Scientifique.

John, B. H., 1986., Stratigraphic drilling report - GSQ Roma 8. Qld. Govt. Min. Jour. v. 87, n. 1012, pp. 104-115.

Khorasani, G. K., 1987, Oil-prone coals of the Walloon Coal Measures, Surat Basin, Australia. In Scott, A. C., (ed.) Coal and coal-bearing strata: recent advances. Geol. Soc. Spec. Publ. v. 32, pp. 303-310.

Mathews, R. T., Burns, B. J., and Johns, R. B., 1971, An approach to identification of source rocks. Austral. Petrol. Expln Assoc. Jour. v.11, pp. 115-120.

Monin, J. C., Durand, B., Vandenbroucke, M., and Huc, A. Y., 1980, Experimental simulation of the natural transformation of kerogen. In Douglas, A. G., and Maxwell, J. R., (eds.) Advances in organic geochemistry. Physics and chemistry of the Earth. v. 12, pp. 517-530.

Monnier, F., Powell, T. G., and Snowdon, L. R., 1983, Qualitative and quantitative aspects of gas generation during maturation of sedimentary organic matter: examples from Canadian frontier basins. In Bjoroy, M., Albrecht, C., Corning, C., deGroot, K., Eglington, G., and Speers, G., (eds.) Advances in organic geochemistry 1981. pp. 487-495. John Wiley, Cheichester.

Moran, W. R., and Gussow, W. C., 1963, The history of the discovery and the geology of the Moonie Oil Field, Queensland, Australia. Proceed. 6th World Petrol. Congr. Geophysics and Geology Section 1, pp. 595-609.

Nwachukwu, J. I., and Chukwura, P. I., 1986, Organic matter of Agbada Formation, Niger Delta, Nigeria. AAPG Bull. v. 70, pp. 48-55.

Philp, P. R., Gilbert, T. D., and Friedrich, J., 1982, Geochemical correlation of Australian crude oils. Austral. Petrol. Expln Assoc.

Jour. v. 22, pp. 189-199.

Philp, P. R., and Gilbert, T. D., 1986, A geochemical investigations of oils and source rocks from the Surat Basin. Austral. Petrol. Expln. Assoc. Jour. v. 26, pp. 172-186.

Powell, T. G., and McKirdy, D. M., 1975, Geologic factors controlling crude oil composition in Australia and Papua New Guinea. AAPG Bull. v. 59, pp. 1176-1197.

Powell, T. G., and McKirdy, D, M., 1975, Geochemical character of crude oils from Australia and Papua New Guinea. In Leslie, R. B., Evans, H. J., and Knight, C. L., (eds.) Economic geology of Australia and Papua New Guinea. Australas. Inst. Min. Metall. Monogr. 7, pp. 18-29.

Powell, T. G., Foscolos, A. E., Gunther, P. R., and Snowdon, L. R., 1978, Diagenesis of organic matter and fine clay minerals. Geochem. Cosmochem. Acta. v.42, pp. 1181-1197.

Powell, T. G., Creany, S., and Snowdon, L. R., 1982, Limitations of use of organic petrographic techniques for identification of petroleum source rocks. AAPG Bull. v. 66, pp. 430-435.

Powell, T. G., and Snowdon, R. L., 1983, A composite hydrocarbon generation model. Erdol und Kohle, Erdgas, Petrochemie vereinigt mit Brennstoff-chemie. v. 36, pp. 163-169.

Rice, D. D., and Claypool, G. E., 1981, Generation, accumulation and resource potential of biogenic gas. AAPG Bull. v. 65, pp. 5-25.

Rigby, D., and Smith, J. W., 1981, An isotopic study of gases and hydrocarbons in the Cooper Basin. Austral. Petrol. Expln Assoc. Jour. v. 21, pp. 222-229.

Rigby, D., Gilbert, T. D., Batts, B. D., and Smith, J. W., 1986, The generation and release of hydrocarbons from Victorian brown coal lithotypes. In Glenie, R. C., (ed.) Second southeastern Australian oil exploration Symposium. Petrol. Expln Soc. Austral. Technical papers, pp. 433-438.

Rohrback, B. G., Peters, K. E., and Kaplan, I. R., 1984, Geochemistry of artificially heated humic and sapropelic sediments II: oil and gas generation. AAPG Bull. v.68, pp. 961-970.

Shanmugam, G., 1985, Significance of coniferous rain forests and related organic matter in generating commercial quantities of oil, Gippsland Basin, Australia. AAPG Bull. v. 69, pp. 1241-1254.

Shaw, G., 1970, Sporopollenin. In Harborne, J. B., (ed.) Phytochemical phylogeny. Academic Press, London. pp. 31-58.

Smith, G. C., and Cook, A. C., 1980, Coalification paths of exinite, vitrinite and inertinite. Fuel. v.59, pp. 641-646.

Smith, G. C., and Cook, A. C., 1984, Petroleum occurrence in the Gippsland Basin and its relation to rank and organic matter type. Austral.

Petrol. Expln Assoc. Jour. v. 24, pp. 196-216.

Smith, I. W., 1980, The flash pyrolysis method for converting coal to oil. Coal Geol. v. 1, pp. 133-138.

Smith, J. W., Gilbert, T. D., and Batts, B. D., 1987, A quest for a new parameter in petroleum exploration geochemistry. Austral. Petrol. Expln Assoc. Jour. v. 27, pp. 98-105.

Smyth, M., 1983, Nature of source material for hydrocarbons in Cooper Basin, Australia. AAPG Bull. v. 67, pp. 1423-1426.

Snowdon, L. R., 1980, Resinite - a potential petroleum source in the Upper Cretaceous/Tertiary of the Beaufort-MacKenzie Basin. In Miall, A. D., (ed.) Facts and principles of world petroleum occurrence. Canad. Soc. Petrol. Geol. Mem. 6, pp. 504-521.

Snowdon, L. R., and Powell, T. G., 1982, Immature oil and condensate - modification of hydrocarbon generation model for terrestrial organic matter. AAPG Bull. v. 66, pp. 775-788.

Stainforth, J. G., 1984, Gippsland hydrocarbons - a perspective from the Basin edge. Austral. Petrol. Expln Assoc. Jour. v. 24, pp. 98-105.

Stach, E., Mackowsky, M. Th., Teichmuller, M., Taylor, G. H., Chandra, D., and Teichmuller, R., 1982, Hand book of Coal Petrology. Gebruder Borntrager, Berlin - Stuttgart. 535 p.

Taylor, G. H., and Liu, S., 1984, Characteristics and properties of macerals. Proceed. Austral. Coal Sci. Conf. Gippsland Institute of Advanced Education. pp. 38-41.

Taylor, G. H., Liu, S. Y., and Smyth, M., 1988, New light on origin of Cooper Basin oil. Austral. Petrol. Expln Assoc. Jour. v. 28, pp. 303-309.

Thomas, B. M., 1982, Land-plant source rocks for oil and their significance in Australian Basins. Austral. Petrol. Expln Assn Jour. v. 22, pp. 164-178.

Thomas, B. M., Osborne, D. G., and Wright, A. J., 1982, Hydrocarbon habitat of the Surat/Bowen Basin. Austral. Petrol. Expln Assoc. Jour. v.22, pp. 213-226.

Thompson, S., Cooper, B. S., Morley, R. J., and Barnard, P. C., 1985, Oil generating coals. In Thomas, B., et al (eds.) Petroleum geochemistry in exploration of the Norwegian Shelf. Graham and Tartman, London. pp. 59-73.

Tissot, B. P., and Welte, D. H., 1978, Petroleum formation and occurrence. Springer-Verlag, Berlin. 527 p.

Tissot, B. P., 1984, Recent advances in petroleum geochemistry applied to hydrocarbon exploration. AAPG Bull. v. 68, pp. 545-563.

Tissot, B. P., Peter, R., and Ungerer, Ph., 1987, Thermal history of sedimentary basins, maturation indices, and kinetics of oil and gas generation. AAPG Bull. v. 71, pp. 1445-1466.

Vandenbroucke, M., Durand, B., and Oudin, J. L., 1983, Detecting migration phenomena in geological series by means of $C_1$ - $C_{35}$ hydrocarbon amounts and distribution. In Bjoroy, M., Albrecht, C., Corning, C., deGroot, K., Eglington, G., and Speers, G., (eds.) Advances in organic geochemistry, 1981. John Wiley, Cheichester. pp. 147-145.

Vassoevich, N. B., Akramkhodzhaev, A. M., and Geodekyan, A. A., 1974, Principal zone of oil formation. In Tissot, B. P., and Beinner, F., (eds.) Advances in organic geochemistry, 1973. Editions Technip, Paris. pp. 309-314.

# CHAPTER 9: COMPARATIVE HYDROCARBON GEOLOGY OF TWO MESOZOIC CIRCUM-PACIFIC FORELAND BASINS AS A FUNCTION OF SEDIMENT PROVENANCE: SURAT BASIN, EASTERN AUSTRALIA AND WESTERN CANADA BASIN

# COMPARATIVE HYDROCARBON GEOLOGY OF TWO MESOZOIC CIRCUM-PACIFIC FORELAND BASINS AS A FUNCTION OF SEDIMENT PROVENANCE: SURAT BASIN, EASTERN AUSTRALIA AND WESTERN CANADA BASIN

## ABSTRACT

The Surat Basin in Queensland and New South Wales, Australia, is a foreland basin which was formed in response to a magmatic arc during early Jurassic to mid-Cretaceous time. It has a maximum basin-fill of about 2.5 km of Jurassic and Lower Cretaceous sediments. The first commercial production of oil in Australia came from this basin in the early 1960s.

The Western Canada Basin is a retro-arc foreland basin with up to 3.5 km of sediments deposited during the Middle Jurassic to Late Cretaceous. The basin was developed on the cratonward side of an arc/cordillera by plate convergence. It is a composite basin with sediments ranging in age from Devonian to Tertiary, and is one of the prolific petroliferous basins of the world. The famous Athabasca - Peace River - Lloydminister tar sands alone contain a reserve of about $3x10^{12}$ barrels of oil, which exceeds three times the recoverable reserves of the world's known oil.

The main sediment source was, in both basins, a rising arc/cordillera which shed a cratonward tapering clastic wedge into the flanking foreland basins. Sedimentation, in both cases, was episodic and the patterns of sedimentation in each present striking similarities. During the waxing phase of magmatism/orogeny in the arc/cordillera, the foreland subsided in response to the flexural loading of the foreland fold - thrust belt (although the evidence of major flexural loading in the case of the Surat Basin is less than in the Western Canada Basin) and to downward drag by the subducting plate. Continental synorogenic sediments were rapidly emplaced in mainly terrestrial environments into the subsiding

foreland. These sediments are lithic-labile in nature and because of their physical and chemical reactivity are prone to be 'tight' and thus of little hydrocarbon reservoir potential. During the waning phase(s) of orogenesis/volcanism in the arc/orogen the foreland gently rose in response partly to the cessation of drag (decoupling) by the subducting plate and to isostatic rebound (tectonic relaxation). The supracrustal volcano-sedimentary cover in the arc/orogen was dissected to the plutonic - metamorphic core which supplied quartz-lithic debris to the foreland with additional contribution of quartzose sediments from the cratonic source. Reworking of the sediments of both sources in periods of relative tectonic quiescence made them mineralogically and texturally more mature. As a consequence they are prone to have good reservoir characteristics.

Hydrocarbons are generally associated with the characteristically more porous quartzose facies in contrast to the labile facies which is relatively 'tight'. With a few exceptions the above generalizations hold true for both basins.

## INTRODUCTION

Veevers et al (1982) and Jones and Veevers (1983) suggested the dual orogenic vs. cratonic sediment sources for the Palaeozoic and Mesozoic foreland basins in eastern Australia. They postulated that the craton-derived quartzose facies is prone to constitute good reservoirs for hydrocarbons and conversely that the arc-derived labile facies tends to be relatively 'tight' but, being finer-grained and associated with more organic-rich sediments, prone to have good hydrocarbon source potential. Jones et al (1984) have elaborated this dual sediment provenance in the Permo-Triassic Bowen - Sydney Foreland Basins in the context of a more general foreland basin model (see also Conaghan et al, 1982; and Jones et al, 1987). The present study applies and extends these ideas in a comparison of the Jurassic - Cretaceous of the Surat Basin with that of the Western Canada Basin. The terminology that I employ here in reference to basin-type, palaeomorphology, and evolutionary development follows that of Jones et al (1984) and Veevers et al (1982).

## SURAT BASIN

The Surat Basin is the segment of the Great Australian Basin that extends across southeastern Queensland and northeastern New South Wales (Figures 9.1 and 9.4). It is a composite basin and unconformably overlies the Permo-Triassic Bowen - Sydney Basin. The Lower Jurassic to mid-Cretaceous succession of the Surat Basin averages 1.5 km in thickness, increasing to 2.5 Km in the Mimosa Syncline (Figure 9.1), and comprises an asymmetric wedge-shaped sediment body that thins towards the Australian craton in the west (Figure 9.5). The basin is partitioned from the Eromanga Epicratonic Basin in the west by a linear basement culmination known as the Nebine Ridge. To the east it is separated from the Clarence - Moreton Basin by the Kumbarilla Ridge (Figure 9.1). The first commercial hydrocarbon in Australia was discovered in the Surat Basin at Moonie, Queensland (Figure 9.1), in the early 1960s. The most comprehensive synthesis of the Surat Basin is that of Exon (1976). Much of the detailed information cited in the present work is drawn from this monograph and from the petrologic work of the writer.

### Geologic history

The Surat Basin was formed in Early Jurassic time in response to a magmatic arc located along the line of what is now the Barrier Reef in offshore Queensland. A convergent plate boundary existed several hundred km east of the arc where the Pacific plate subducted under eastern Gondwanaland.

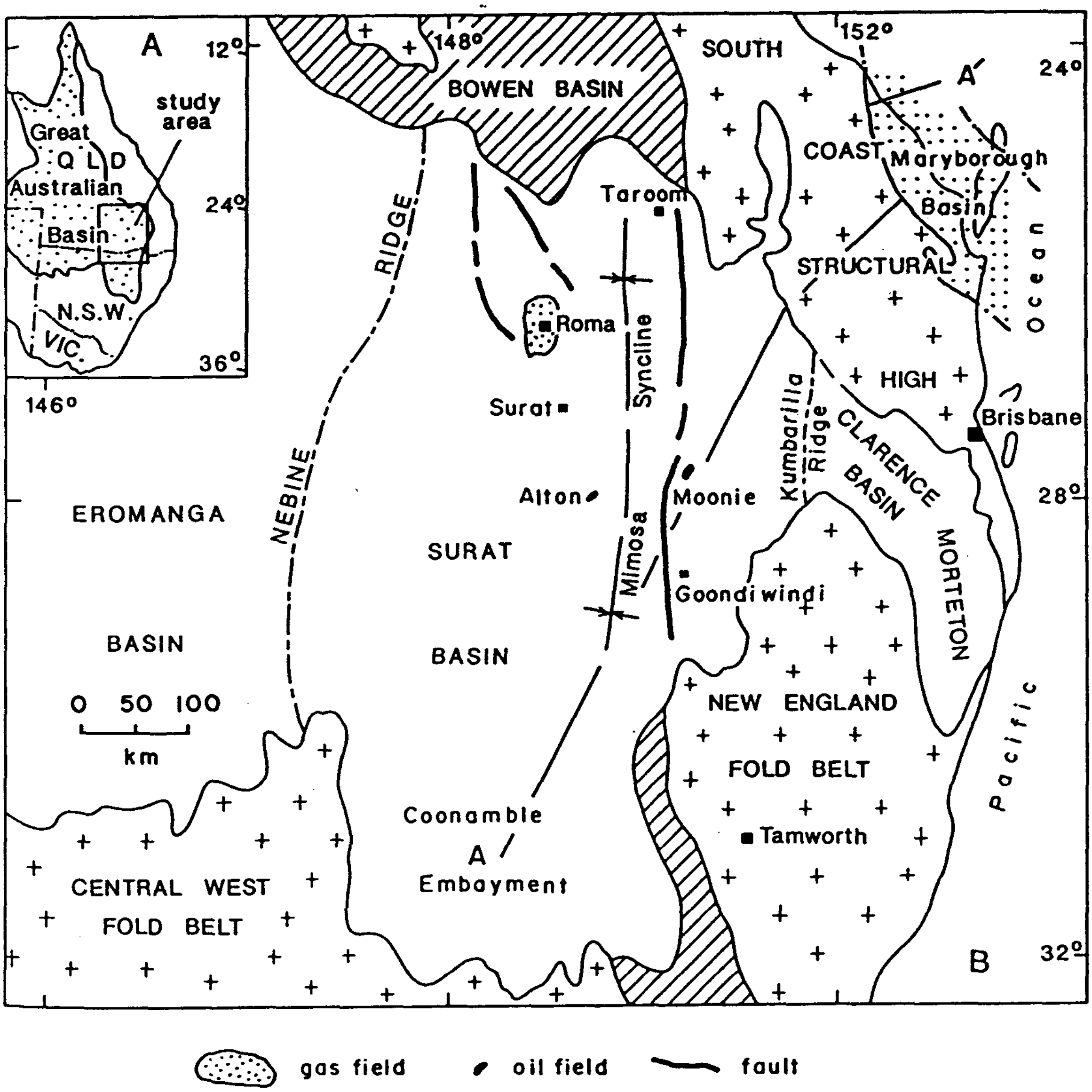


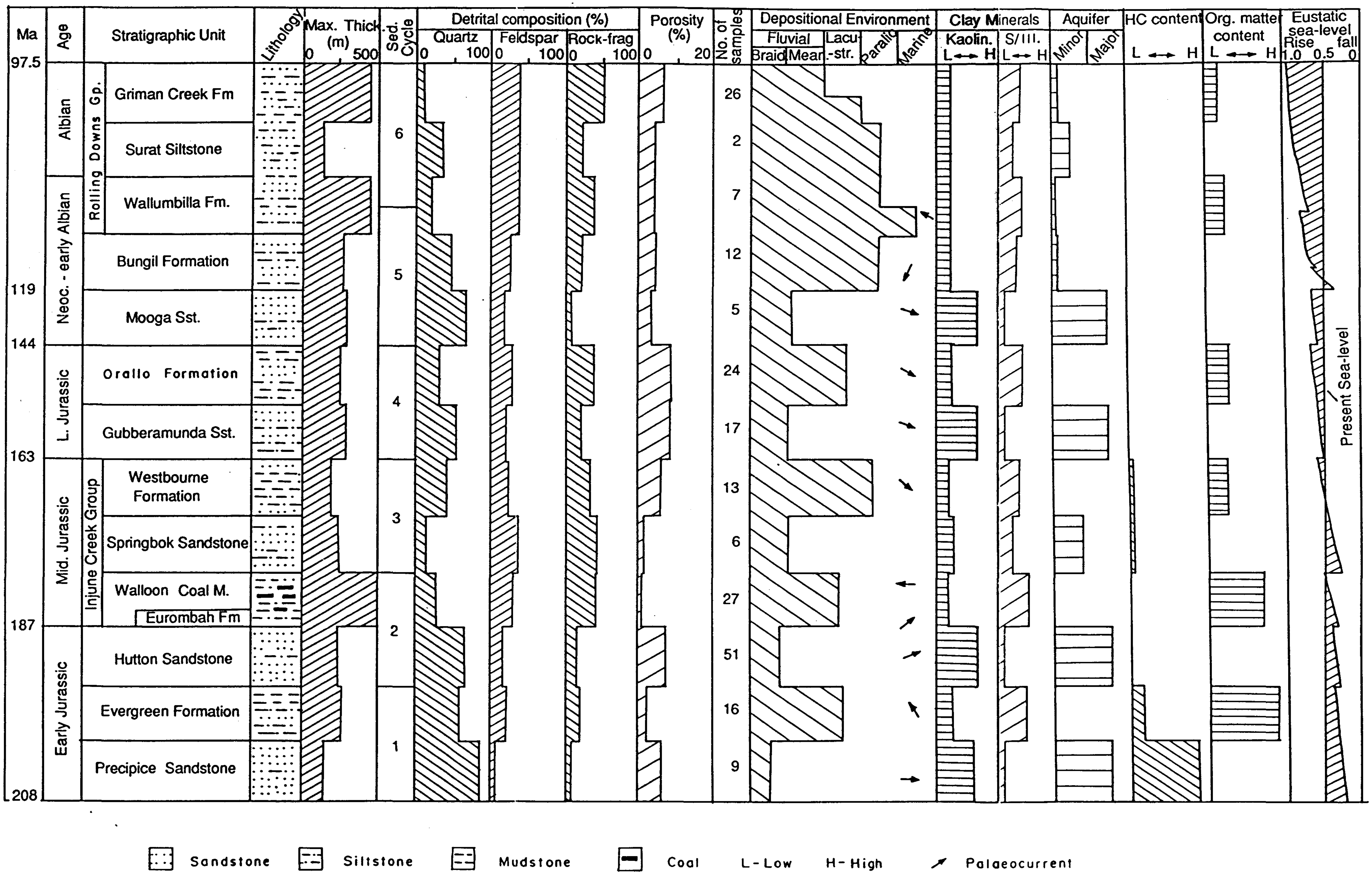

Figure 9.1. Regional setting (A) and major structural elements (B) of the Surat Basin. From Exon (1976) with modifications. Maryborough Basin is stippled for clearer definition. A-A' is the line of time-space transect of Figure 9.3.

Sedimentation in the Surat Basin commenced during the Early Jurassic and continued uninterrupted through to the end of the Albian (Figure 9.2). The Jurassic sediments were deposited in predominantly terrestrial environments with the exception of the Evergreen Formation whose environmental affinities are probably shallow-marine. The marine influence became gradually pronounced in the Early Cretaceous and by Aptian time the sea had transgressed westward across the Nebine Ridge into the Eromanga Basin as exemplified by the marine fauna in the upper part of the Bungil and lower part of Wallumbilla Formations (Figures 9.2 and 9.3). During the early Albian the marine connection between the Surat Basin and the more proximal Maryborough Basin (Figures 9.1, 9.3 and 9.4A) was severed as a result of mild tectonism and a drop in global sea-level (Day et al, 1983). The paralic Surat Siltstone and fluvio-lacustrine Griman Creek Formation were deposited at this time. Sedimentation in the Surat Basin ceased in the latest Albian.

The Cenomanian (95-90 Ma) is regarded as a phase of trasition when the plate boundary in Eastern Australia underwent major rearrangement from dominantly subductive to major transcurrence resembling the present western North American margin (cf. Jones and Veevers, 1983). After this transitional episode the plate boundary in the offshore Queensland region moved eastward away from mainland Australia, the sea withdrew northwards and henceforth surficial quartzose sediments dominated the Australian craton (Figure 9.3).

The sedimentary succession of the Surat Basin is only gently deformed. Structural features are mainly due to differential compaction of the underlying Bowen Basin succession and/or renewed movements along old faults (Exon, 1976).

Figure 9.2. Generalised stratigraphic column of the Surat Basin showing the detrital mineralogy, depositional environments, and hydrocarbon source and reservoir potentials. Detrital composition represents QFL percentage recalculated to 100%. Thin-section porosity is expressed as whole-rock percentage. Detrital mineralogy and porosity data are based on a consistent count of 1000 points per slide on 215 thin-sections and are expressed as means for each formation; column documenting number of samples refers to thin-section data-base for petrography and porosity. Eustatic sea-level curve and arbitrary scale from Vail et al (1977). Clay mineralogy from Exon (1976), Slansky (1977, 1984) supplemented by XRD, EDX, and SEM analyses by the author. Q - detrital quartz grains; F - feldspar grains; L - total lithic fragments; S/Ill. - Smectite (including montmorillonite and nontronite) and mixed-layer smectite-illite; HC - hydrocarbon. Organic matter content includes coal as well as dispersed organic matter. Sedimentary cycles are those of Exon and Burger (1981). Palaeocurrent data from Conaghan and Hawlader (unpublished reconnaissance field data, 1986; cf. Appendix 1.14) supplemented by data for the Precipice Sandstone approximated from Martin (1981, fig. 4), and for the Hutton Sandstone and Birkhead Formation approximated from the subsurface of central Eromanga Basin (Watts, 1987, fig. 11).



Ma
Age
Stratigraphic Unit
Lithology
Max. Thick. (m)
0 500
Sed. Cycle
Detrital composition (%)
Quartz 0 100
Feldspar 0 100
Rock-frag 0 100
Porosity (%)
0 20
No. of samples
Depositional Environment
Fluvial
Braid
Mean
Lacu-str.
Paralic
Marine
Clay Minerals
Kaolin. L H
S/Ill. L H
Aquifer
Minor
Major
HC content
L H
Org. matter content
L H
Eustatic sea-level
Rise fall
1.0 0.5 0
97.5
119
144
163
187
208
Albian
Neoc. - early Albian
L. Jurassic
Mid. Jurassic
Early Jurassic
Rolling Downs Gp.
Injune Creek Group
Griman Creek Fm
Surat Siltstone
Wallumbilla Fm.
Bungil Formation
Mooga Sst.
Orallo Formation
Gubberamunda Sst.
Westbourne Formation
Springbok Sandstone
Walloon Coal M.
Eurombah Fm
Hutton Sandstone
Evergreen Formation
Precipice Sandstone
6
5
4
3
2
1
26
2
7
12
5
24
17
13
6
27
51
16
9
Present Sea-level
Sandstone
Siltstone
Mudstone
Coal
L - Low
H - High
Palaeocurrent

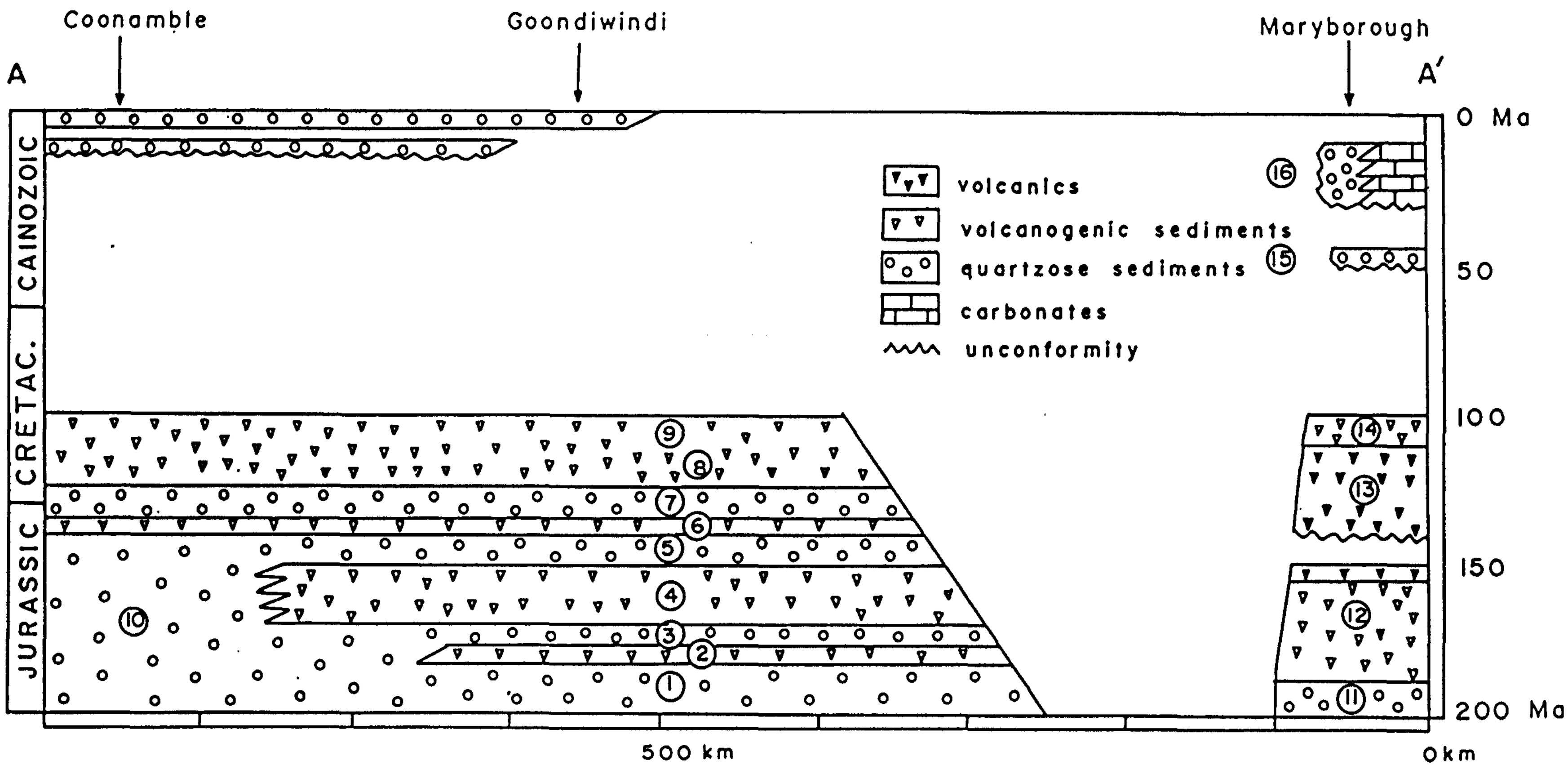



Figure 9.3. SW - NE time-space diagram of the Surat and Maryborough Basins showing the distribution of preserved lithofacies and of lacunae (shown blank). Location of transect is shown in Figure 9.1. Note the interfingering of craton-derived quartz-rich and orogen-derived labile petrofacies. Circled numbers indicate stratigraphic units: 1 - Precipice Sandstone, 2 - Evergreen Formation, 3 - Hutton Sandstone, 4 - Injune Creek Group, 5 - Gubberamunda Sandstone, 6 - Orallo Formation, 7 - Mooga Sandstone, 8 - Bungil Formation, 9 - Rolling Downs Group, 10 - Pilliga Sandstone, 11 - Myrtle Creek Sandstone, 12 - Tiaro Coal Measures, 13 - Grahams Creek Formation, 14 - Maryborough Formation and Barrum Coal Measures, 15 - Fairymead Beds, 16 - Elliot Formation. Redrawn from Jones and Veevers (1983).

Sediment composition, provenance, and depositional environments

The stratigraphy of the Surat Basin is shown in Figure 9.2, which also summerises the gross aspects of sediment composition, organic matter and hydrocarbon content, depositional environments, reservoir characteristics, and inferred relationship to eustatic events as discussed in the following section. Terrestrial sedimentation took place throughout the Jurassic beginning with the deposition of the fluviatile Precipice Sandstone upon the deformed and eroded Permo-Triassic Bowen - Sydney Basin which constitutes the 'basement'. Throughout most of the basin the Precipice Sandstone consists of medium- to coarse-grained, porous and permeable quartzose sandstone with ubiquitous large-scale crossbedding. Palaeocurrent directions from crossbedding show a consistent west-to-east pattern. The main sediment source lay to the west and south of the Great Australian Basin in the Precambrian Shield areas (Martin, 1981). About 70% of the Roma gas and Moonie oil occur within porous intervals in the lower part of the Precipice Sandstone.

The Evergreen Formation is the only Jurassic unit of possible marine environmental affinity as evidenced by the presence of numerous acritarchs and chamositic oolites in the upper part of the Formation (Exon, 1976). The detrital composition is variable but on a QFR diagram plots as a feldspathic litharenite (cf. Figure 2.4A). The overlying Hutton Sandstone is relatively quartzose (cf. Figure 2.4A) with variable amounts of feldspar, volcanic and metasedimentary rock-fragments. The rest of the stratigraphic units display a similar compositional and provenance pattern; i.e, the intercalation and interfingering of craton-derived quartzose and orogen-derived labile facies (cf. Figure 9.3).

Until the time of accumulation of the Mooga Sandstone the depositional enviroments throughout the basin were mainly fluvial and fluvio-lacustrine with the exception of a probable shallow-marine incursion during deposition of the upper Evergreen Formation. The encroachment of the sea in the Neocomian and Early Aptian ended this initial regime of terrestrial sedimentation in the Surat Basin (Figure 9.2).

There had been a considerable degree of difference in the style and rate of sedimentation between the Jurassic and Early Cretaceous. Firstly, Jurassic sedimentation was slower, only about 40 m/Ma, while in the Early Cretaceous it reached as much as 150 m/Ma (Exon, 1976). Secondly, the marine influence in the Lower Cretaceous succession is much more pronounced than in its Jurassic counterpart (i.e., Evergreen Formation). Thirdly, there had been a considerable increase in volcanogenic detritus in the Cretaceous sediments (Figures 9.2 and 9.3). This change in provenance and depositional environment can be linked to the increased activity of the magmatic arc and probably relative rise of sea-level. The rapid deposition of these volcanogenic sediments in a predominantly marine setting precluded much reworking thereby preserving their compositional and textural immaturity. The less pronounced marine influence and relatively less lithic content of the Jurassic succession is in accord with the contemporary subdued activity of the orogen and relatively low global sea-level (Figure 9.2).

Hydrocarbon reservoirs and source rocks

Most of the hydrocarbon reservoirs in the Surat Basin occur within the quartzose fluviatile Precipice Sandstone, the basal formation in the Surat Basin succession. The relatively quartz-rich sediments within the Evergreen Formation also form reservoirs in many fields. Other quartzose formations with good reservoir potential are the Hutton, Gubberamunda and Mooga Sandstones (Figure 9.2). That they do not contain hydrocarbons is explained by the absence of an effective seals above them and lack of thermally mature source rocks. However, they are excellent aquifers and produce bicarbonate artesian waters. Less important aquifers also occur within the Injune Creek Group, Bungil Formation and the Rolling Downs Group (Figure 9.2).

In the Surat Basin the stratigraphic distribution of the reservoir rock/aquifer and potential hydrocarbon source rock/coal follows a distinct pattern. Despite considerable variation in the relationship between porosity and sandstone mineralogy (due principally to the presence of secondary dissolution porosity; cf. Chapter 3), there appears to be a statistically significant association between sandstone porosity and detrital composition (as respresented by detrital quartz content). Quartz content is found to be a first-order variable controlling the porosity of the Surat Basin sandstones (Figure 9.2, see also Chapter 6). Contrastingly, the finer-grained labile paralic/shallow-marine formations are organic-rich and constitute potential petroleum source rocks (Figure 9.2). It may be mentioned here that significant secondary porosity exists in some immature labile sandstones of the Surat Basin (cf. Chapters 4 and 5) but due to its patchy distribution and the presence of various sensitive authigenic mineral assemblages, would require special treatment during reservoir development and management in the event they contain any hydrocarbons (cf. Chapter 4).

As can be seen from Figure 9.2, organic-rich potential source rocks and coal are present throughout the Mesozoic succession of the Surat Basin. But because of their supposed thermal immaturity they have often been discounted as likely source rocks and the commonly inertinite-rich Permian coal and coaly organic matter of the underlying Bowen Basin have been argued to be the prime source for most of the Surat Basin hydrocarbons (Thomas et al, 1982). However, On the basis of a synthesis of a vast amount of published information, the author has suggested (cf. Chapter 8) that the Evergreen Formation and the Walloon Coal Measures might have partly contributed to the Surat Basin reservoired oil and gas and that, in certain places, the organic-rich Westbourne Formation has reached the threshold of oil window.

*Cyclicity and global sea-level stand*

Exon and Burger (1981) noted the essentially cyclic nature of the Surat Basin succession and related these events to the eustatic sea-level changes of Vail et al (1977). Each cycle begins with the deposition of fluviatile coarse-grained sandstone and siltstone and ends with lacustrine/paralic mudstone and coal and/or marine sediments (Figure 9.2). Such cycles are not unique to the Surat Basin and can be recognised in other Late Palaeozoic - Mesozoic basins in eastern Australia (e.g., the foreland Bowen - Sydney Basins and the epicratonic Cooper/Eromanga Basins), and in other foreland basins elsewhere in the world. Exon and Burger (ibid.) suggested that a sharp drop in sea-level would lower the base-level of erosion resulting in deposition of the high-energy fluviatile sediments. Conversely the gradual rise of sea-level would elevate the base-level giving way to meandering stream and finally to fluvio-deltaic, paralic and marine sedimentation with the encroaching seas. However, Jones and Veevers (1983) pointed out that although such an explanation is adequate to account for the difference in grainsize and sedimentary structures, it does not explain the different sediment composition. In the Surat Basin the high-energy fluviatile sandstones are quartzose. They contrast with the volcanogenic labile sandstone units within the finer-grained formations which have 'wetter' environmental affinities having been deposited in paralic - shallow-marine environments. The contrasting detrital composition of the basin-fill reflects a change in provenance which Jones and Veevers (1983) and Jones et al (1984) explain in terms of synchronous activity of both orogen and foreland; times of orogeny are also the times of foreland subsidence (i.e., transgression), and conversely the waning phase of orogeny/magmatism is accompanied by a gentle rise in the foreland (i.e., regression). This explanation is also supported by the palaeocurrent and petrological studies of Conaghan et al (1982) in the Permo - Triassic Sydney foreland Basin of eastern Australia. Any change in global sea-level associated with these episodes of foreland basin evolution may result from either eustasy or tectonism or a combination of both. However, commonly there is an association of first-order sea-level change with major episodes of tectonism - a phenomenon called the 'Haug effect' (cf. Johnson, 1971, 1972).

*Clay minerals*

A major contrast in the suite of authigenic minerals is also noticeable between the quartzose and lithic-labile petrofacies (Figure 9.2). The quartzose facies contains mainly kaolinite and the labile facies contains mainly smectite, mixed-layer smectite-illite, illite and some chlorite (cf. Exon, 1976; Byrnes, 1975; Slansky, 1977, 1984; and Chapters 3, 4 and 5 herein). The contrast in clay mineralogy reflects the difference in the mode of alteration of the sediments during and after deposition. In the Surat Basin kaolinite is not restricted exclusively to the quartzose sandstones (Figure 9.2): coarser-grained labile sandstones with good initial porosity and permeability facilitated post-depositional flux of meteoric water which altered the labile components into kaolinite (cf. Arditto, 1982, 1983). However, the quartzose sandstones invariably contain abundant kaolinite whereas smectite and mixed-layer clays are characteristic of the labile facies. This first-order association, despite variations in depositional and postdepositional environments reflects the contrasting provenance of the quartzose and labile petrofacies (Jones and Veevers, 1983). Time-temperature-induced illitization of smectite of the labile facies is not prevalent which is in agreement with the relatively shallow burial and low thermal maturity of the Surat Basin succession since the maximum vitrinite reflectance level observed there is 0.7% (Thomas et al, 1982).

*Hydrocarbon traps*

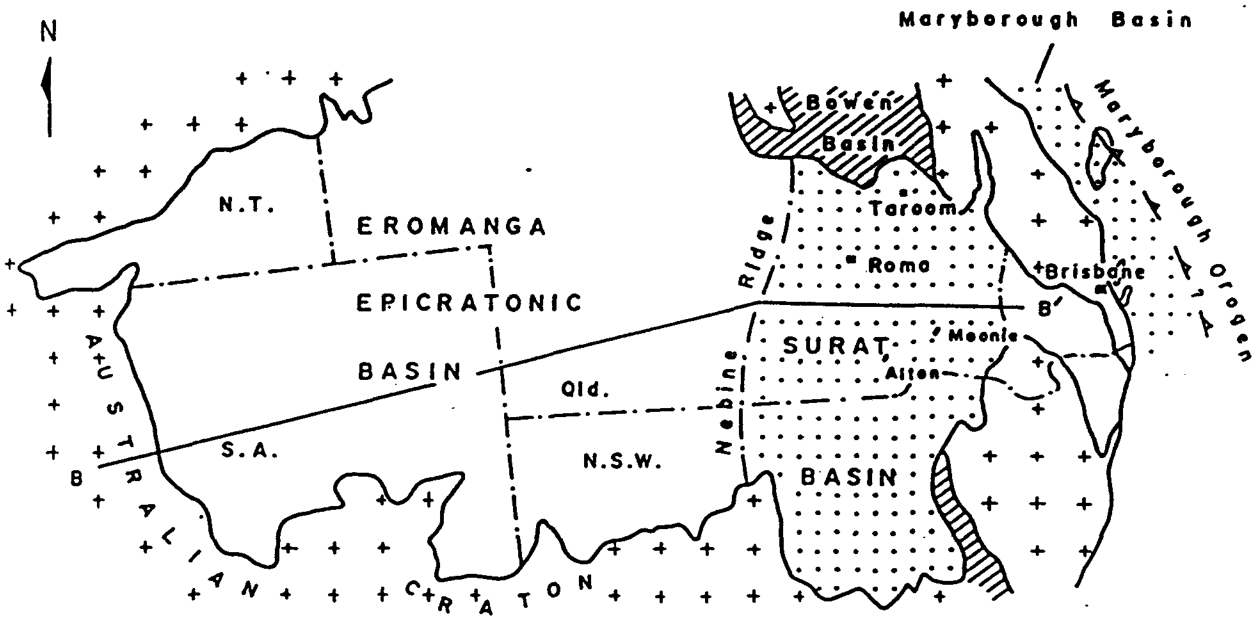
There is considerable geographic variation as to the genetic nature of traps and the liquid vs. gaseous phase of reservoired hydrocarbons in the Surat Basin. The traps are mainly stratigraphic-structural in the Roma Shelf (cratonic flank) (Traves, 1971) whereas in the east they are structural and commonly fault-bounded. Significant lateral migration of hydrocarbons evidently took place within the cratonic flank hydrocarbon fields but hydrocarbons migrated both vertically (facilitated by the presence of faults) and laterally in the eastern orogenic flank fields (e.g., Moonie; cf. Thomas et al, 1982).

**WESTERN CANADA BASIN**

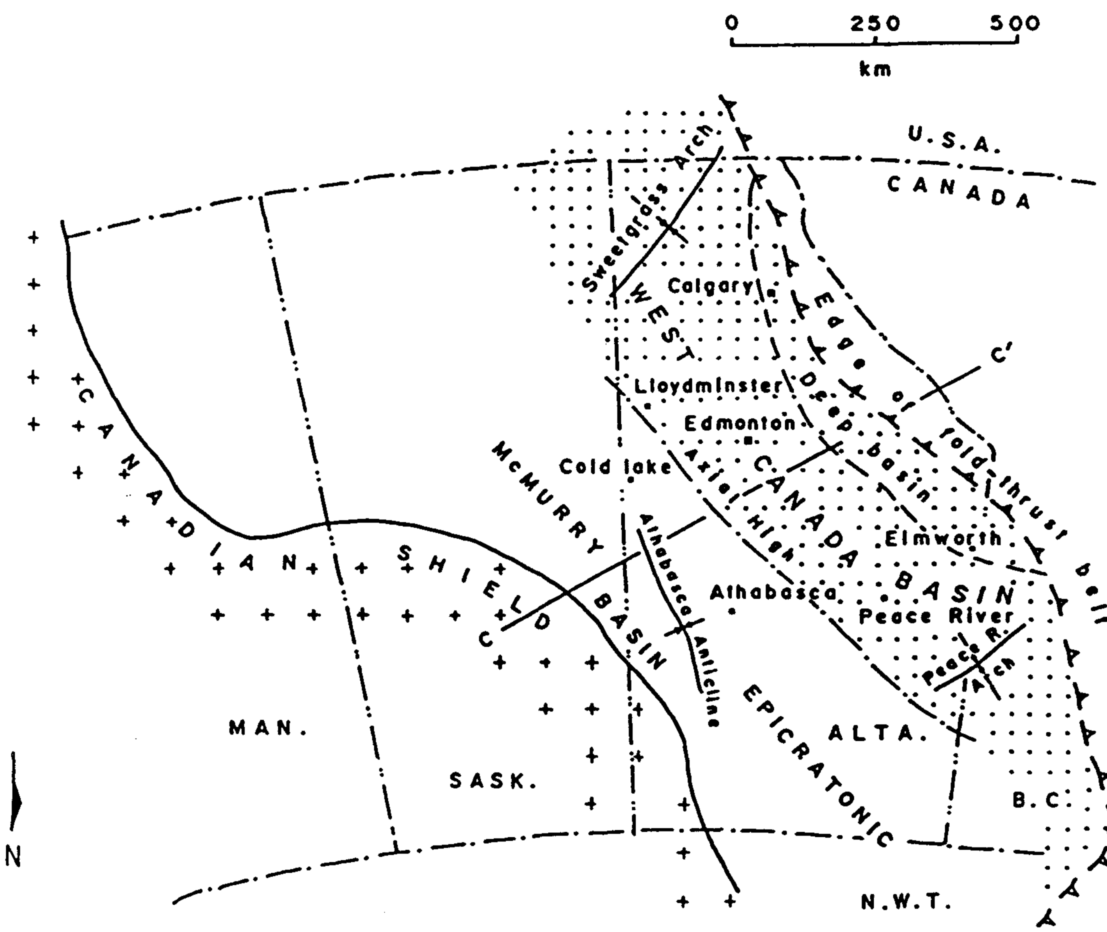
The Western Canada Basin is situated in northeast British Columbia, Alberta and southeast Saskatchewan, and extends farther south into the United States (Figures 9.4 and 9.5). It is a part of the more extensive foreland basin to the Rocky Mountain Fold Belt and extended from the Arctic to the Gulf of Mexico in the Late Cretaceous (cf. Hancock and Kauffman, 1979; Weimer, 1984). It is a composite basin with sediments ranging in age from Devonian to Tertiary. The Mesozoic section reaches a maximum thickness of 3.5 km. The present study focuses only on the Lower Cretaceous part of the succession which accounts for more than 44% of the hydrocarbons (excluding the tar sands) of the entire Phanerozoic succession of the Western Canada Basin (Masters, 1984). The Jurassic section has not been addressed here mainly because of the relatively sparse availability of

Figure 9.4. Surat Basin, eastern Australia (A), and Western Canada Basin (B), drawn at same scale for comparison. Place names and hydrocarbon fields mentioned in the text are indicated. BB′ and CC′ are lines of cross-sections in Figure 9.5.

B


N
Maryborough Basin
Bowen Basin
Taroom
Roma
Brisbane
Maryborough Orogen
N.T.
EROMANGA
EPICRATONIC
BASIN
Ridge
Nebine
SURAT
Moonie
Alton
BASIN
Qld.
N.S.W.
S.A.
B
B'
AUSTRALIAN CRATON
0 250 500
km

B


U.S.A.
CANADA
Sweetgrass Arch
Calgary
WEST
Edge of fold-thrust belt
Deep basin
C'
Lloydminster
Edmonton
Cold lake
Axial High
CANADA
Elmworth
BASIN
McMURRY BASIN
Athabasca Anticline
Athabasca
Peace River
Peace R. Arch
CANADIAN SHIELD
C
EPICRATONIC
ALTA.
MAN.
SASK.
B.C.
N.W.T.
N

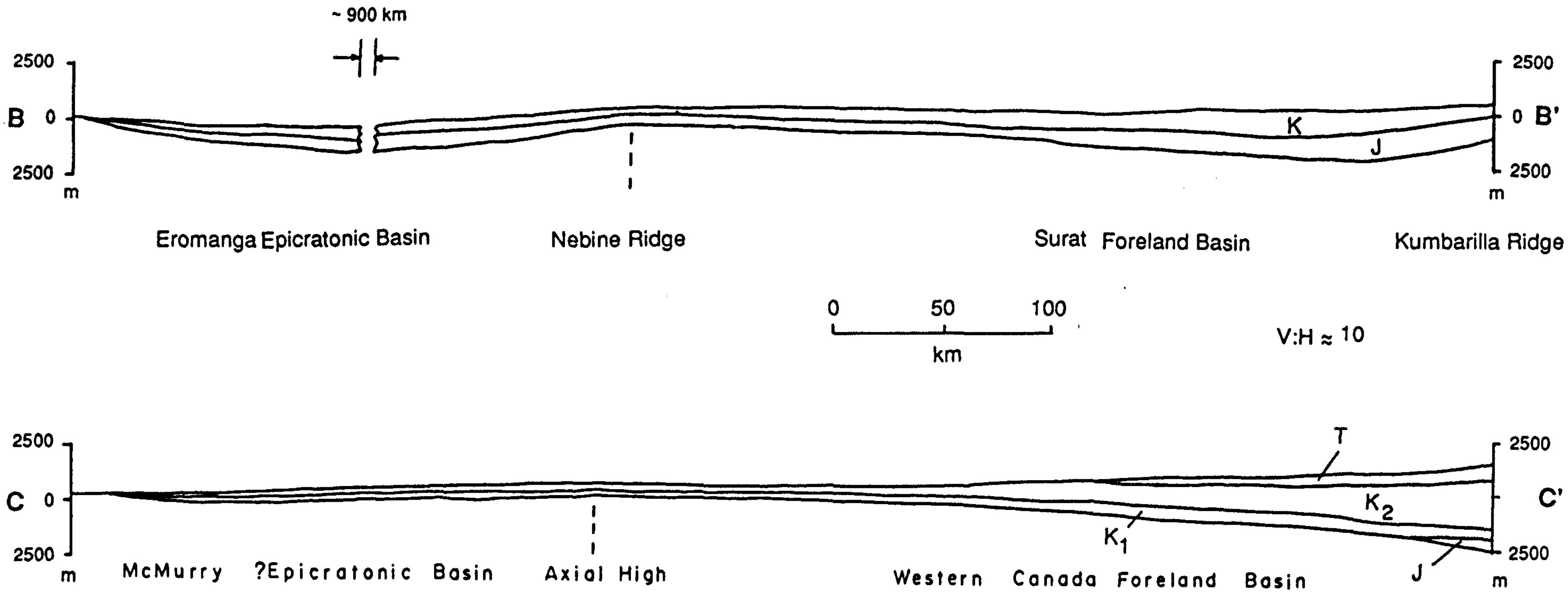



Figure 9.5. Schematic transverse cross-section of the Surat and Western Canada Basins, drawn at same scale for comparison. J - Jurassic, K - Cretaceous, $K_1$ - Lower Cretaceous, $K_2$ - Upper Cretaceous. Location of sections is shown in Figure 9.4.

published data. However, in regard to the sediment-provenance of the Jurassic formations, they are mainly orogen-sourced, and constitute the oldest of the three clastic wedges formed in response to the Columbian and Laramide Orogenies. In this Chapter I deal only with the second of these wedges (i.e., the Blairmore - Mannville), the terminal wedge associated with the Columbian Orogeny.

Geologic history

The Western Canada Basin was formed as a retro-arc foreland basin in Middle Jurassic time in response to a magmatic arc which lay along what is now the North American Coast Range. An extensive orogenic province within the cordillera extended from the southwestern United States northward through British Columbia, southern Yukon Territory and southern Alaska. The orogeny, called the Columbian (Sevier or Nevadan) Orogeny, lasted until Middle Campanian (Dickinson et al, 1983). A schematic west - east cross-section showing the palaeotectonics is shown in Figure 9.6.

Orogenic activity was characterized by major plutonic emplacement originally expressed as a volcanic archipelago along the western margin of the continent. However, volcanism appears to have played a subordinate role in terms of its contribution to the sediment-fill of the foreland basin. The foreland received clastic sediments mainly from the intervening fold - thrust belt with occasional input of igneous detritus from the arc. The two oldest clasic wedges of the foreland basin are latest Jurassic through earliest Cretaceous (Kootenay and Nikanassin Groups) and Early Cretaceous through mid-Cretaceous (Bullhead and Fort St. John Groups and their equivalents; Figure 9.7) in age. These wedges were themselves subsequently folded and thrust-faulted in latest Cretaceous - Tertiary times during the Laramide Orogeny. This cratonward movement of the loci of the fold - thrust belt is believed to have taken place in response to the

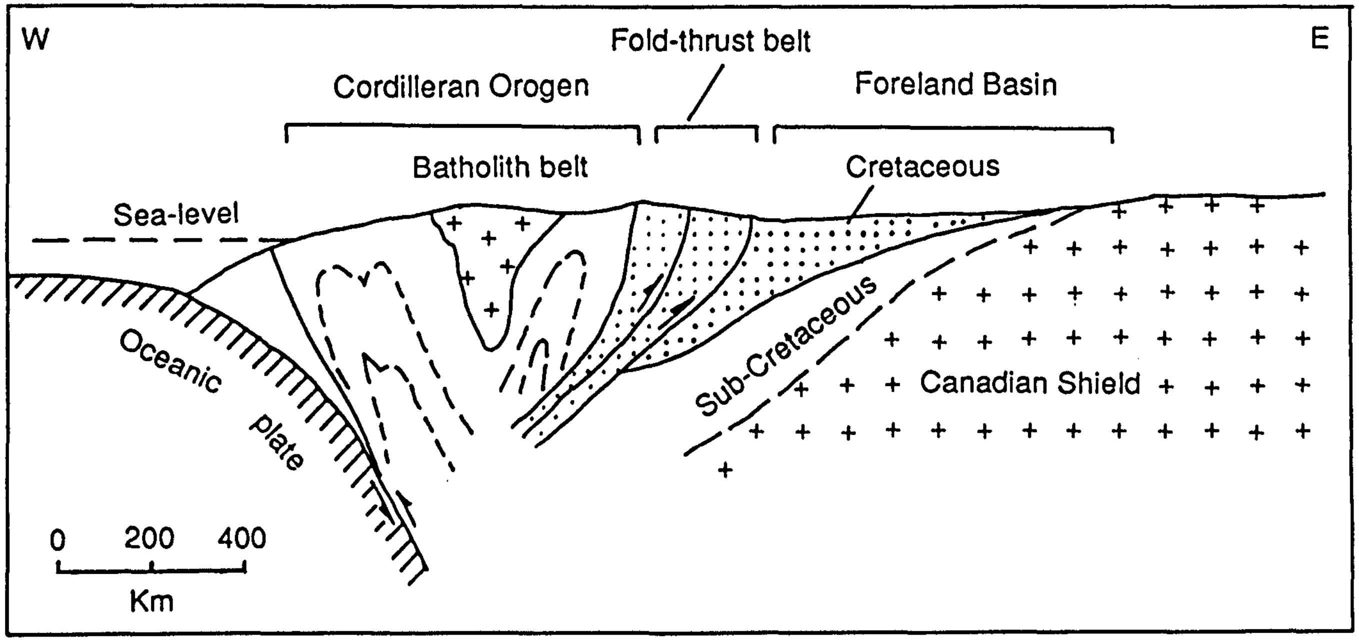
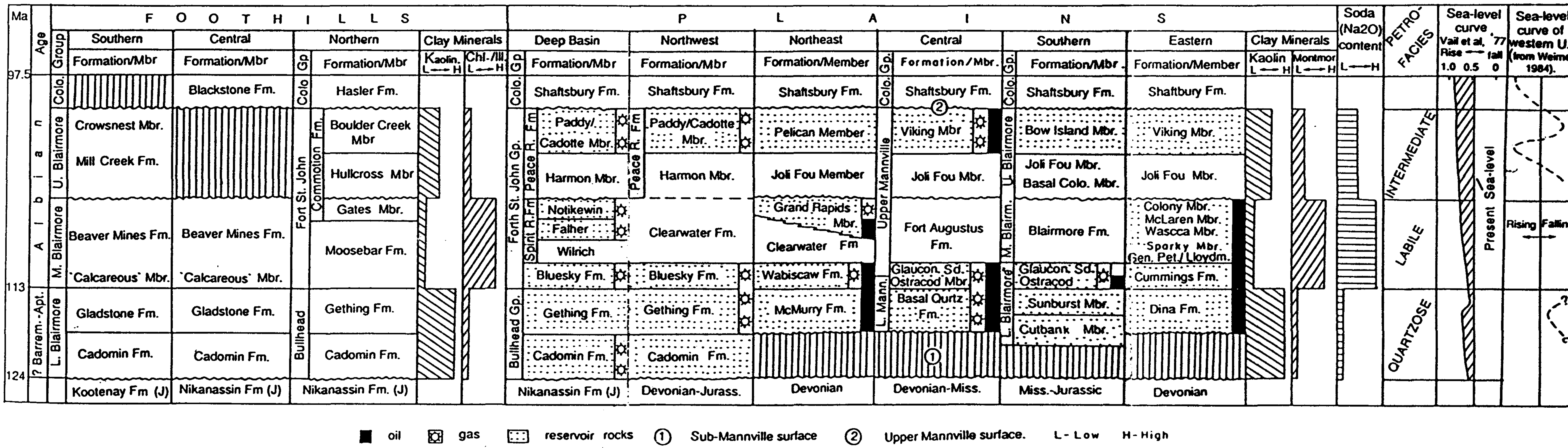



Figure 9.6. Schematic west - east cross-section of the Western Canada Basin showing the tectonic setting during the Cretaceous (after Dickinson, 1976 and Jackson, 1984).

Figure 9.7. Generalised stratigraphic correlation chart of the Lower Cretaceous succession of the Western Canada Basin showing the distribution of major petrofacies and hydrocarbon occurrence. Adapted from Mellon (1967), Masters (1984), and Smith et al (1984). Soda ($Na_2O$) content from Cameron (1966). Time scale after Palmer (1983). Depositional environments are not specified in this chart, but formations in the Foothills domain are predominantly non-marine, whereas those in the Plains region include both marine and non-marine (see text). Stratigraphic reference areas are shown in Figure 9.8.


Ma
Age
Group
97.5
113
124
F O O T H I L L S
P L A I N S
Southern
Central
Northern
Clay Minerals
Kaolin. L—H
Chl.-/Ill. L—H
Deep Basin
Northwest
Northeast
Central
Southern
Eastern
Kaolin L—H
Montmor L—H
Soda (Na2O) content L—H
PETRO-FACIES
Sea-level curve Vail et al. '77 Rise — fall 1.0 0.5 0
Sea-level curve of western U.S. (from Weimer, 1984).
Formation/Mbr
Formation/Member
Formation/Mbr.
Colo. Gp
Colo.
U. Blairmore
M. Blairmore
L. Blairmore
Albian
? Barrem.-Apt.
Blackstone Fm.
Hasler Fm.
Shaftsbury Fm.
Shaftbury Fm.
Crowsnest Mbr.
Mill Creek Fm.
Boulder Creek Mbr
Hullcross Mbr
Gates Mbr.
Fort St. John
Commotion Fm.
Moosebar Fm.
Beaver Mines Fm.
'Calcareous' Mbr.
Gladstone Fm.
Gething Fm.
Cadomin Fm.
Bullhead
Kootenay Fm (J)
Nikanassin Fm (J)
Nikanassin Fm. (J)
Forth St. John Gp.
Peace R. Fm.
Spirit R.Fm.
Paddy/ Cadotte Mbr.
Paddy/Cadotte Mbr.
Harmon Mbr.
Notikewin
Falher
Wilrich
Clearwater Fm.
Bluesky Fm.
Bullhead Gp.
Devonian-Jurass.
Pelican Member
Joli Fou Member
Grand Rapids Mbr.
Clearwater Fm
Wabiscaw Fm.
McMurry Fm.
Devonian
Upper Mannville
L. Mann.
Viking Mbr
Joli Fou Mbr.
Fort Augustus Fm.
Glaucon. Sd. Ostracod Mbr
Basal Qurtz Fm.
Devonian-Miss.
L. Blairmore
Bow Island Mbr.
Joli Fou Mbr.
Basal Colo. Mbr.
Blairmore Fm.
Glaucon. Sd. Ostracod
Sunburst Mbr.
Cutbank Mbr.
Miss.-Jurassic
Viking Mbr.
Colony Mbr.
McLaren Mbr.
Wascca Mbr.
Sparky Mbr.
Gen. Pet./Lloydm.
Cummings Fm.
Dina Fm.
INTERMEDIATE
LABILE
QUARTZOSE
Present Sea-level
Rising
Falling
oil
gas
reservoir rocks
① Sub-Mannville surface
② Upper Mannville surface.
L- Low
H- High

shallow subduction of the younger Pacific plate under the North American plate (Dickinson and Snyder, 1978).

Sediment composition and depositional environments

A stratigraphic correlation chart for the Lower Cretaceous units of the Western Canada Basin is shown in Figure 9.7. The Lower Cretaceous begins with the deposition of the Lower Mannville Group and equivalent sediments on the unconformity of the Sub-Mannville surface which is believed to have been generated as a result of a global sea-level drop, and a concomitant lull of orogenic activity in the western cordillera (Smith et al, 1984).

During the Early Cretaceous the basin was partitioned by a northwest-trending ridge on the unconformity surface. East of the ridge called the 'Axial High' (see Jackson, 1984, his figs. 7 and 8) lay the 'McMurray Basin' whose formation is attributed to the subsurface leaching of the Devonian salt (Masters, 1984). In essence this Axial High can be regarded as a morphological foreswell that partitioned the foreland basin from the epicratonic McMurray Basin. The fluvio-deltaic sandstones of the McMurray and Dina Formations accumulated in the Mcmurry Basin and are interpreted to have been derived from the crystalline and preexisting sedimentary rocks of the Canadian Shield in the east. This is supported by the detrital composition (Carrigy, 1963) and palaeocurrent directions (Eisbacher et al, 1974). At a slightly earlier time in the Foothills, the Cadomin Formation consisting of conglomerate, coarse-grained sandstone, siltstone and some coal accumulated in a piedmont alluvial environment (Figure 9.7). Thickness and clast-size of the conglomerates indicate a western, cordilleran provenance. The dominant lithic component is chert some of which consists of a microcrystalline aggregate of quartz and feldspar with phenocrysts of feldspar suggestive of a volcanic origin

(Rapson, 1965). Contribution from a volcanic source is also evidenced by the presence of greenish pebbles of rhyolite with feldspar phenocrysts (Stott, 1968).

The overlying Gething Formation in the Plains (Figure 9.7) has a comparable composition with 32% quartz, 29% chert, and varying amounts of rock-fragments. Chert content can be as much as 90% and probably represents recrystallized volcanic rock-fragments (Stott, 1968).

The Ostracod Member and the overlying Glauconitic Sand Member of the central Alberta Plains and the equivalent Bluesky/Wabiskaw Formations in the Elmworth/Athabasca areas (Figures 9.7 and 9.8) may be considered as a transitional interval in between the Lower and Upper Mannville Group sediments both in terms of tectonic setting and depositional environment. In the eastern flank of the basin this interval is more quartzose and thin. It thickens in a westerly direction with a concomitant increase in the proportion of lithic components. There is indication of a considerable degree of marine influence in this interval. The Clearwater Sea (cf. Clearwater Formation and equivalents, Figure 9.7) encroached from the north and was accompanied by a change in composition of the sediments deposited at this time. Volcanic detritus first appeared and clay mineralogy changed from dominantly kaolinitic in the underlying Lower Mannville Group sediments to more smectitic in the Upper Mannville Group sediments (Figure 9.7; see also Putnam and Pedskalny, 1983).

The Clearwater Formation comprises predominantly shale with minor intercalated sandstones. The sandstone units comprise mainly feldspathic litharenite (Putnam and Pedskalny, 1983). The lithic grains are volcanic rock-fragments and chert, and the plagioclase is dominantly andesine. In the south and north coeval strata are mainly quartzose (Mclean and Putnam, 1983).

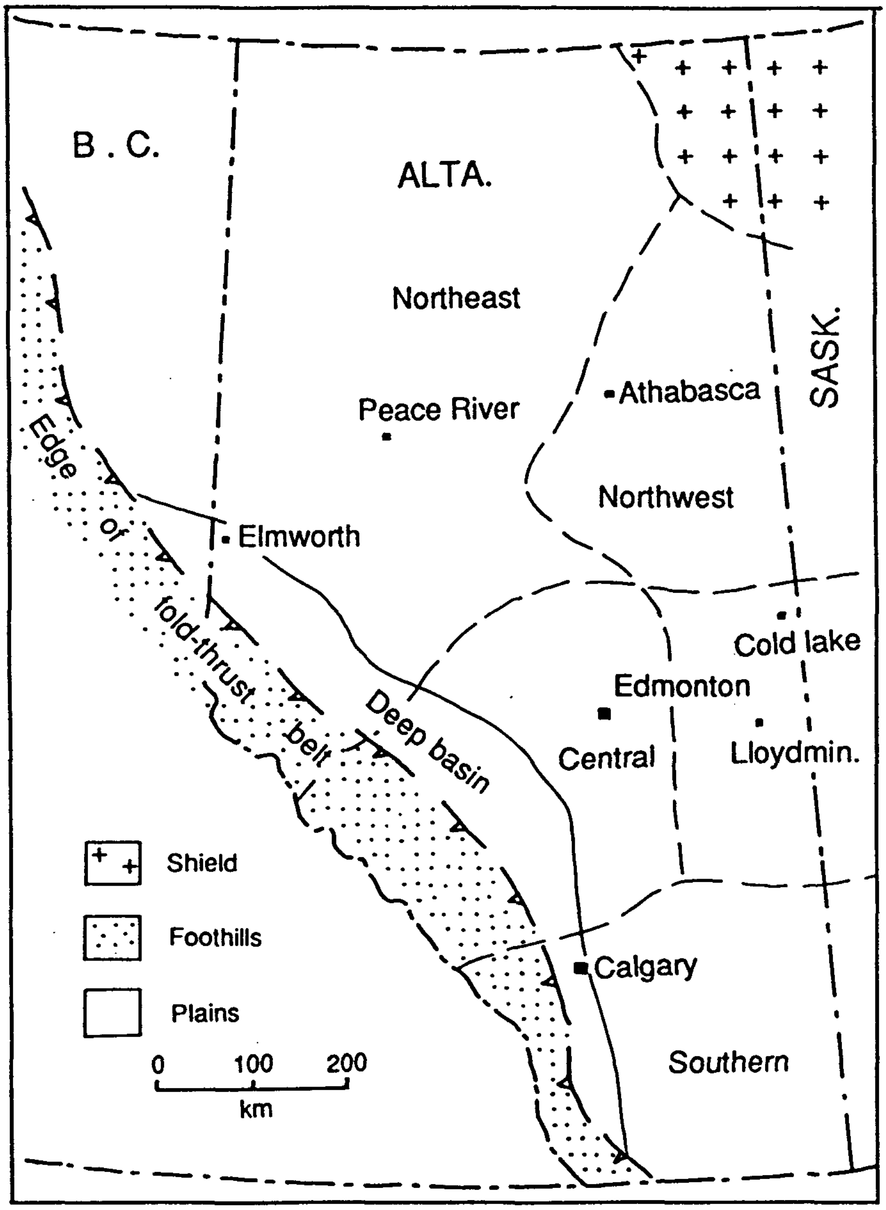


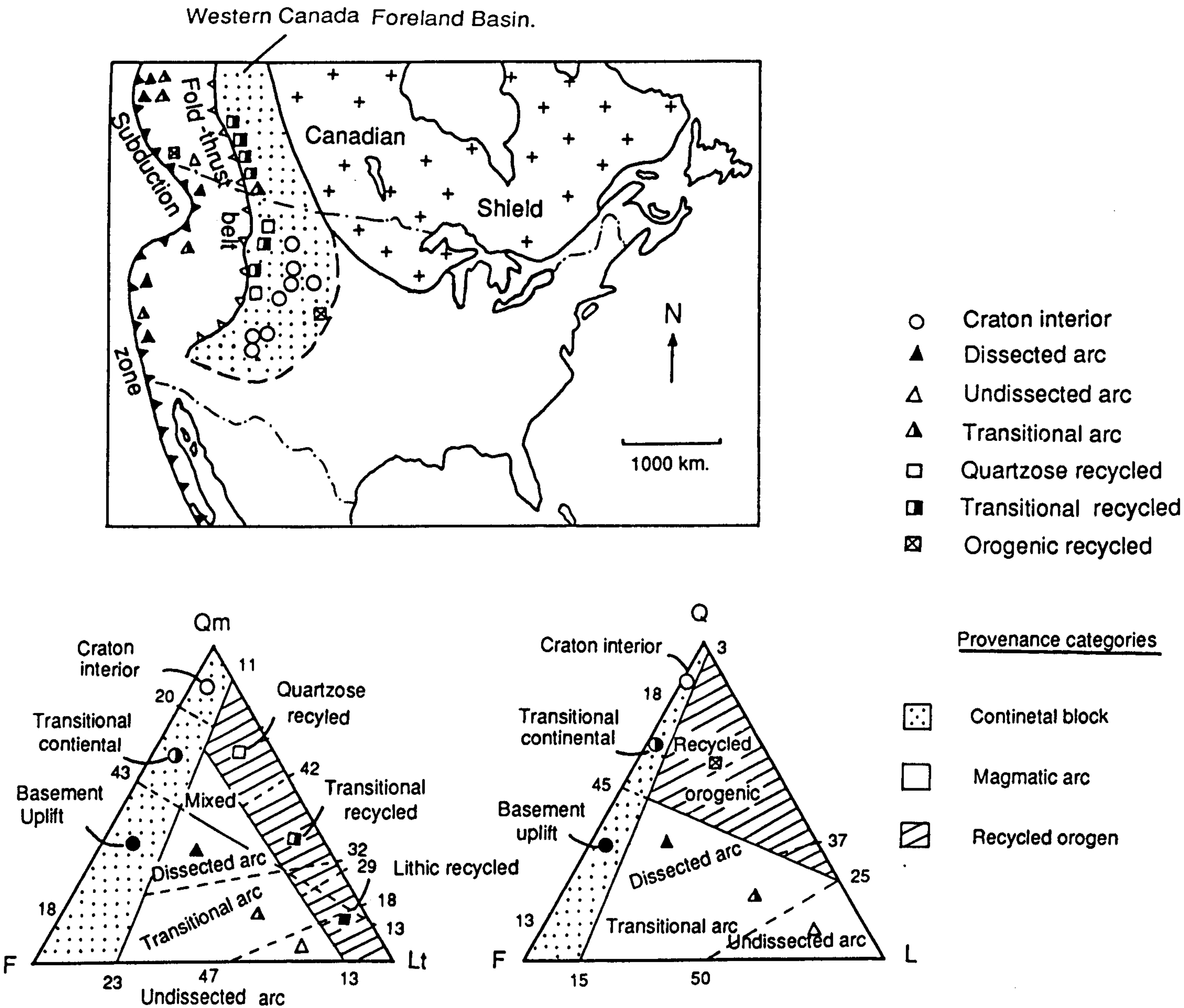

Figure 9.8. Stratigraphic reference areas for Figure 9.7. From Jackson (1984).

A first-order contrast is noticeable in the detrital composition of the Lower and Upper Mannville Group sediments and their equivalents (Figure 9.7) which may be explained in terms of change in provenance. In the western flank of the basin, the Lower Mannville Group sediments are of Cordilleran provenance. During their emplacement the foreland fold - thrust belt apparently acted as a drainage divide and little or no igneous detritus from the magmatic arc was deposited in the foreland as evidenced by the general lack of volcanogenic sediments there but which are abundant in the numerous forearc and intra-arc basins to the west (Figure 9.9). The eastern flank of the basin received sediments from the preexisting sedimentary rocks on the flank of the Canadian Shield and from the shield rocks themselves.

The Upper Mannville Group and stratigraphically equivalent sediments are characterized by a marked change in composition. Plagioclase, biotite and smectite make their first appearence in sympathy with an upsequence increase in the chlorite and smectite content (Figure 9.7). They contain larger amounts of volcanic detritus and plagioclase suggestive of a provenance different to that which sourced Lower Mannville Group sediments. It appears that the shielding effect of the fold - thrust belt was not effective and/or there might have been an intense pulse of widespread volcanic activity in the orogen such that igneous detritus bypassed the thrust-belt to contribute to the foreland basin-fill.

Following inundation of the foreland by the Clearwater Sea, intensified arc activity supplied a pulse of volcanogenic sediments as evidenced by the Falher Member (Figure 9.7). Sediment supply began to exceed both the relative rise of sea-level and the rate of basin subsidence and the shoreline prograded northward. A brief drop in relative sea-level concomitant with the cessation of activities in the cordillera caused minor erosion of the Upper Mannville Group rocks producing the unconformity known

Figure 9.9. Palaeotectonic setting of North America during the Late Jurassic - Cretaceous time showing the detrital composition of the sandstone suites in QFL and QmFLt diagrams (adapted from Dickinson et al, 1983). Q - total quartzose grains, including polycrystalline lithic fragments such as chert and quartzite; F - monocrystalline feldspar grains; L - unstable polycrystalline lithic fragments of igneous, sedimentary, and metasedimentary parentage; Qm - monocrystalline quartz grains; Lt - total polycrystalline lithic fragments, including quartzose varieties. The prevalence of craton interior petrographic suites on the eastern side of the foreland basin in the USA and their apparent absence in the Canadian part of the basin is an artifact of data availability.


Western Canada Foreland Basin.
Canadian
Shield
Subduction
zone
Fold-thrust
belt
N
1000 km.
Craton interior
Dissected arc
Undissected arc
Transitional arc
Quartzose recycled
Transitional recycled
Orogenic recycled
Qm
Craton interior
Transitional contiental
Basement Uplift
Quartzose recyled
Transitional recycled
Lithic recycled
Mixed
Dissected arc
Transitional arc
Undissected arc
F
Lt
11
20
43
42
32
29
18
13
18
23
47
13
Q
Craton interior
Transitional continental
Basement uplift
Recycled
orogenic
Dissected arc
Transitional arc
Undissected arc
F
L
3
18
45
37
25
13
15
50
Provenance categories
Continetal block
Magmatic arc
Recycled orogen

as the Upper Mannville Surface (cf. Figure 9.7). This is one of the regional unconformities that developed throughout the whole of the Western Interior Basin of North America and has been attributed by Weimer (1984) to a global sea-level fall. In a second major southward advance of the Boreal Clearwater Sea the marine shales of the Hermon and Joli Fou Members were deposited. At the same time the Gulfian Sea advanced from the south and eventually joined with the Boreal Sea to form the the Western Interior Seaway of North America (Hancock and Kauffman, 1979; Weimer, 1984).

The late Albian Paddy-Cadotte and the Viking Members overlie the shales of the Joli Fou and Hermon Members (Figure 9.7). The Viking and Paddy-Cadotte Members have a western cordilleran provenance. Average grainsize of the sandstones in the Paddy-Cadotte Members increases towards the source area in the west (Smith et al, 1984). The principal detrital components in the Cadotte Sandstone in northeast British Columbia are: quartz 45-50%; chert 30-35%; and subsidiary clay clasts, organic matter and feldspar (Thomas and Miller, 1980). The end of Paddy-Cadotte deposition is marked by a major transgression which ultimately inundated the entire Western Interior Basin from Alaska to the Gulf of Mexico. The advance of this transgression can be seen at the top of the Paddy-Cadote Members capped by the marine shale of the Shaftsbury Formation (cf. Figure 9.7). The laterally equivalent sandstones of the Viking Member fall in the category of litharenite with chert comprising the dominant rock-fragments. The detrital composition is: chert 10-15%, pelitic rock-fragments 3.7-14.8%, feldspar 0.9-14.6% and quartz 31.8-64% (Reinson and Foscolos, 1986).

Provenance

Most of the sandstones in the orogenic flank show a transitional recycled orogenic provenance (cf. Dickinson et al, 1983) but the sandstones on the eastern side of the basin show a cratonic provenance (Figure 9.9).

However, undissected arc petrographic suites are locally common (though not depicted on Figure 9.9), especially for the Middle Blairmore Group interval and its equivalents. The average sandstone composition of the Lower Cretaceous Blairmore Group in the Foothills and its correlatives in the Plains is shown in Table 9.1. Note the Lv content in particular which emphasises the dramatic change in provenance affinities across the Lower/Middle Blairmore boundary (cf. Figure 9.7). A similar change in the lithic content is noticeable in the Plains at the Lower and Upper Mannville boundary.

Table 9.1. Detrital composition of Lower Cretaceous sandstones of the Foothills and the Plains of the Western Canada Basin

| Stratig. Unit | N | Q | F | L | Qm | F | Lt | Qp | Lv | Ls |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | FOOTHILLS[1] | | | | | |
| U. Blairmore | 16 | 46 | 6 | 48 | 32 | 6 | 62 | 23 | 18 | 49 |
| M. Blairmore | 58 | 22 | 24 | 54 | 16 | 24 | 60 | 8 | 59 | 33 |
| L. Blairmore | 8 | 74 | 0 | 26 | 38 | 0 | 62 | 55 | 0 | 45 |
| | | | | | PLAINS | | | | | |
| Viking[2] | 40 | 83 | 9 | 8 | 68 | 9 | 23 | 68 | -[4] | 32 |
| Clearwater/ Grand Rap.[3] | 26 | 28 | 19 | 53 | 23 | 18 | 59 | 9 | 48 | 43 |
| McMurray[3] | 2 | 96 | 2 | 2 | 96 | 1 | 3 | 25 | 0 | 75 |

N - Number of analyses. Q - Stable quartzose grains, including both monocrystalline quartz grains (Qm), and polycrystalline lithic fragments (Qp), which are chiefly chert grains; F - Monocrystalline feldspar grains, including plagioclase and K-feldspar; L - Unstable polycrystalline lithic fragments, including volcanic and metavolcanic types (Lv), and sedimentary and metasedimentary types (Ls); Lt - Total lithic fragments including unstable lithic fragments (L), and quartzose lithic fragments (Qp).

Footnote to Table 9.1

[1] From Dickinson and Suczek, 1979, based on data in Mellon, 1967.
[2] From Reinson and Foscolos, 1986.
[3] From Mellon, 1967.
[4] Not reported separately.

Resolution of provenance of the Lower Mannville Group sediments of the Western Canada Basin is difficult on the basis of mineralogy alone because of the petrographic compositional similarity of the two possible source areas, namely the foreland fold - thrust belt and the sedimentary cover on the western flank of the craton. Cordilleran provenance for the Upper Mannville Group sediments is obvious due to the presence of considerable amounts of volcanogenic detritus. During the time of accumulation of the Upper Blairmore Group and its equivalents the arc was presumably partly dissected to its metamorphic/plutonic core and a significant amount of metasedimentary and igneous detritus was shed from the cordillera. Metasedimentary detritus is absent from the lower part of the Upper Mannville Group sediments (Mellon, 1967). Compositionally, the Upper Blirmore Group and equivalent sediments are intermediate in character between those of the quartzose Lower Blairmore/Lower Mannville Groups and the volcanogenic-labile Middle Blairmore Group (Figure 9.7). This intermediate compositional nature is in accord with the geochemistry of the sediments studied by Cameron (1966) who attributed the different soda ($Na_2O$) content of the sedimentary succession to the different amount of volcanic detritus (Figure 9.7). The characteristic high $Na_2O$ content of the volcanic graywackes reported from different parts of the world presumably reflect the albitization of the feldspars in the course of diagenesis (cf. Pettijohn et al, 1973, p. 211).

Reservoir characteristics and hydrocarbon occurrence

Sandstone porosity is a result of a complex interplay of numerous variables such as detrital mineralogy, texture, depositional environment, rate of burial, geothermal and pressure gradients, age, hydrodynamics, chemistry of the pore fluid, and the nature of the intecalated strata (cf. Chapter 6). The mode and distance of sediment transport and depositional environment by means of controlling grainsize influence the initial porosity much more than does the detrital mineralogy. However, sandstones of different composition react quite differently with the changing geochemical conditions after burial as exemplified by the different porosity gradient with depth as a function of mineralogic composition (cf. Figure 3.4).

Sandstones of the orogenic flank of the Western Canada Basin are mostly litharenite and sublitharenite. The spatial trend of orogenward increase of labile components is accompanied by deteriorating reservoir characteristics which although attributed by some authors (e.g., Masters, 1979, 1984) to the increased clay content, compaction and cementation, is likely also to have been enhanced by labile mineralogic composition (cf. Mclean, 1979). The quickly buried labile sediments on the orogenic flank are generally tight and hydrocarbon occurrence there is restricted to the unconventional low-porosity and low-permeability reservoirs. Contrastingly the quartzose sandstones of the cratonic flank commonly constitute more porous and permeable conventional reservoirs. (cf. Table 9.2, Figure 9.7). Similarly any change in sediment composition is accompanied by a corresponding change in the reservoir properties. This is well illustrated by the fluvio-deltaic McMurray Formation in the Athabasca area where the sandstone shows a distinct variation in reservoir properties as a function of its detrital composition (Table 9.3).

Table 9.2. Comparison of average porosity and permeability of Lower Cretaceous sandstones in the Deep basin and in the Peace River/Alberta Shelf area (from Smith et al, 1984).

| Formation/Member | Deep basin | | Peace River/Alberta Shelf | |
|---|---|---|---|---|
| | Por. (%) | Perm. (md)[1] | Por.(%) | Perm.(md) |
| Paddy | 11.7 | 81.9 | 24 | 300 |
| Cadotte | 7.8 | 2.4 | 22 | 250 |
| Notikewin | 8.7 | 81.8 | 19 | ---[3] |
| Falher(undiff.)[2] | 8.1 | 0.001 | 22 | ---[3] |
| Bluesky | 7.4 | 8.3 | 18 | 200 |
| Gething | 6.9 | 2.8 | 17 | 10 |
| Cadomin | 6.1 | 1.22 | 16 | 75 |

Footnote to Table 9.2

[1] Permability in the Deep basin area is measured from flow test and indicates in situ permeability.

[2] Only the sandstones are taken into account in the Falher Member; the conglomerates are much more porous and permeable and are commercial producers.

[3] Data not reported.

Table 9.3. Occurrence of hydrocarbon in the Athabasca Tar Sands (McMurray Formation and its equivalents) as a function of sandstone mineralogy, texture, clay minerals and depositional environments (from Carrigy, 1971).

| Depos. Envir. | Pre-deltaic (alluvial) | Deltaic (lacustr.-lagoon.) | Post-deltaic (marine) |
|---|---|---|---|
| Texture | med.-c.gr. well sorted sand. | v.f.-f.gr. well sorted sand. | sand, silt, and clay; poorly sorted; locally well sorted clean sand. |
| Composition | qtz. 95% K-feldspar <5% muscovite <1% | qtz. 90% k-feldspar <5% muscovite <5% | qtz. 50% chert and volcanic rock-fragments 25% glauconite 20% feldspar 5% |
| Clay minerals | Kaolinite, Illite. | kaolinite, illite, smectite. | smectite, illite, kaolinite, chlorite. |
| Oil content | very good, max. of 35% by vol. | poor to good, 5-30% by vol. | very poor, variable, local bodies of rich tar sands. |

A Similar trend can be seen in the Deep basin area as well. Figure 9.7 shows the distribution of hydrocarbon as a function of major petrofacies. It is evident that the hydrocarbons are commonly associated with the quartzose facies. The occurrence of hydrocarbons within the labile petrofacies are restricted either to unconventional tight reservoirs (e.g., Falher Member) or to sedimentologically controlled transgressive, reworked and relatively more quartzose sandstones (e.g. Bluesky/Wabiskaw Formations and Paddy-Cadotte/Viking Members) within the labile and intermediate facies.

*Clay minerals*

Although the type of clay mineral is a function of numerous interrelated variables such as initial sediment composition, and depositional and postdepositional geochemical environments, certain first-order associations between clay mineral types and detrital sediment composition are noticeable in the Western Canada Basin as observed by Carrigy and Mellon (1964), Carrigy (1971) and Bayliss and Levinson (1976). Kaolinite has been found to be the dominant clay mineral associated with the quartzose sandstones whereas smectite, illite, chlorite and minor kaolinite characterize sandstones with moderate to abundant amounts of volcanic detritus (Figure 9.7). Such a trend of distinct clay mineral suites associated with contrasting sandstone petrofacies is not unique to the Western Canada Basin. For instance, Jones (1972) has found that kaolinite is associated with the "craton-derived quartzarenite facies" and likewise chlorite with the "orogen-derived litharenite facies" in the Forest of Dean Foreland Basin in England.

DISCUSSION

Table 9.4 summarises the analogous morphotectonic elements and major comparative features of the two sedimentary basins. In both the Surat and Western Canada Basins the main sediment source was the arc/orogen. The orogen and the foreland acted in synchrony and this activity was in concert with the first-order global sea-level changes. Times of orogeny/magmatism in the cordillera/arc were contemporaneous with relative high sea-level stand, increased rate of basin subsidence and higher sedimentation rate in the foreland. The synorogenic clastics that accumulated during this tectonically active or prograde phase have poor reservoir potential because they are mineralogically and texturally immature due to rapid burial commonly against rising sea-level, and with a few exceptions (e.g. sedimentologically controlled clean beach/bar sand bodies within the labile and intermediate facies) the labile facies sandstones have poor reservoir quality. Having accumulated in an environmentally 'wet' situation (i.e., under conditions of relatively high water-table), the presence of coal and a high organic matter content is characteristic of this facies (Figure 9.10). Cratonward in the more axial parts of the foredeep, marine conditions might prevail, (e.g. in the southern extension of the Western Canada Basin in the Cretaceous Western Interior Basin), the rate of clastic alluviation is slower and some type II organic matter may accumulate, this being a good source of liquid hydrocarbons. Farther cratonward still, in the epicratonic basin, restricted marine circulation may be established due in part perhaps to the presence of the foreswell, in which case oil-prone prolific source rocks containing type II kerogen will be deposited (e.g. Athabasca, Cold lake and Lloydminister tar sand districts; cf. Figure 9. 10).

Table 9.4. Analogous morphotectonic elements and comparative features of the Surat and Western Canada Basins.

Footnote to Table 9.4.

1 As mentioned in the text, the formation of the 'McMurray Basin' is attributed to the subsurface leaching of Devonian salt. If the Axial High lacks a history of tectonic movements linked to that of the foreland basin, my attribution of the McMurray Basin as an epicratonic basin is semantically arguable. Nevertheless its role in controlling the dispersal pattern of orogenic vs. cratonic sediment across it is immense, at least during the time-interval of accumulation of the Lower Mannville Group sediments.

2 Palaeoclimate from Quilty (1984), and Leckie and Foscolos (1986).

| Morphotectonic Elements | Eastern Australia | Western Canada |
| --- | --- | --- |
| Orogen | Maryborough | Rocky Mountains |
| Foreland basin | Surat Basin | Western Canada Basin |
| Foreswell | Nebine Ridge | Axial High |
| Epicratonic basin | Eromanga Basin | McMurray Basin[1] |
| Craton/Neocraton | Australian Craton | Canadian Shield |

| Comarative features | Surat Basin | Western Canada Basin |
| --- | --- | --- |
| Age | J-K | J-K |
| Basin Width | | |
| Foreland | ~350 Km | ~350 Km |
| Epicratonic | ~1100 Km | ~300 Km |
| Sediment thickness | 2.5 Km | 3.5 Km |
| Climate[2] | cool, temperate | humid - subhumid. |
| Depos. Environ. | J mainly non-marine, K- marine; intercalation of 'dry' fluvial and 'wet' paralic/marine facies. | J - Early K non-marine, Late K mainly marine; intercalations of 'dry' and 'wet' facies. |
| Lithology | mainly clastics, minor pyroclastics and coal. | mainly clastics, minor pyroclastics, and coal. |
| HC traps | structural; folded- and faulted-anticlines on the orogenic flank; and struct.-stratig. on the cratonic flank. | steeply-dipping folded- and faulted-anticlines on the orogenic flank, and struct.-stratig. traps on the cratonic flank. |
| HC Source Type | dominantly land-plant-derived type III org. matter and coal. | dominantly land-plant-derived type III org. matter and coal. Proportion of type II org. matter increases cratonward. |
| Maturation of HC. | submature to mature; $R_o$ max = 0.7% | mature to supermature $R_o$ max = 1.6 - 2.0% |

In the Western Canada Basin during the waning phase of orogeny the dissected arc/orogen acted as a significant sediment source in addition to cratonic input from the east. In contrast to the waxing phase, sediments of the waning phase were of plutonic and metamorphic provenance affinity (cf.Mellon, 1967; his fig. 47). Time dependent evolution of petrofacies from quartz-poor volcanolithic to quartz-feldspathic as a function of the dissection of the arc has been noted by numerous workers (Ingersoll, 1978; Dickinson et al, 1982; Ingersoll, 1983) and additionally may reflect geochemical evolution of the arc magmatism from mafic/intermediate to more silicic (cf. Korsch, 1984). Furthermore, the sediments of this phase, being deposited in a period of relative tectonic quiescence, underwent intense reworking (enhanced by the humid and sub-humid climate) rendering them somewhat mineralogically and texturally mature (cf. Davies and Ethridge, 1975; Houseknecht, 1980).

With regard to sediment provenance in the Surat Basin, reconnaissance palaeocurrent data (Conaghan and Hawlader, unpublished data; Appendix 1.14) suggest similar patterns of orogenic vs. cratonic sources (applicable especially to the non-marine Jurassic and very basal part of the Cretaceous succession; cf. Figure 9.2) as shown by Conaghan et al (1982) in the Permo - Triassic Sydney foreland Basin of eastern Australia. The relatively quartzose sandstones of the Surat Basin show consistent orogenward palaeocurrent patterns whereas the labile formations show either cratonward or axial (but, with the exception of the Euromabh Formation, not orogenward) patterns (Figure 9.2; see also Chapter 2). Indeed, the dynamic fluvial basin-fill model of Conaghan et al (ibid.) seems to have general applicability to a temporal succession of three foreland basins in eastern Australia, each of which was formed in response to successive abrupt eastward relocations ('jumps') of a magmatic arc away from the craton with the superposition of each younger foreland basin over the previous fore-arc basin, and similarly, each younger epicratonic basin over the previous foreland basin (cf. Veevers et al, 1982). One of the important differences between the two foreland basins analyzed here is that the Western Canada Basin was formed in response to shallow subduction of the Pacific Plate under the North American Plate with the development of the intervening low angle thrust-sheets which gradually migrated cratonward as subduction continued and provided a continous sediment source for the flanking foredeep. On the other hand, in the Surat Basin, the steep subduction of old, dense oceanic crust of the Pacific plate and associated back-arc extension is probably indicated by the lack of evidence of the presence of low angle thrust-sheets. No significant fold-thrust belt barrier therefore intervened between arc/orogen and foreland, thus explaining the overwhelmingly volcanogenic character of the labile basin-fill shed from the magmatic arc.

In both basins hydrocarbon reservoirs are mainly associated with the quartzose facies and petroleum source rocks with the labile facies. The first-order influence of detrital mineralogy on sandstone porosity is well documented in the Surat Basin (Chapter 6). Quantitative study of this relationship for the Western Canada Basin is sparse but qualitative information is suggestive of a similar pattern. Conventional hydrocarbon occurrence in both basins follows the same general trend. However, as petroleum accumulation is influenced by many factors, under certain circumstances hydrocarbon can be entrapped in low-porosity and low-permeability tight sandstones, siltstones and even shales within the mineralogically immature labile faices. However, because of their unique characteristics they necessiate especial treatment during drilling, reservoir development/management, and hydrocarbon production. Hence such reservoirs can be regarded as unconventional. In the Deep basin area of

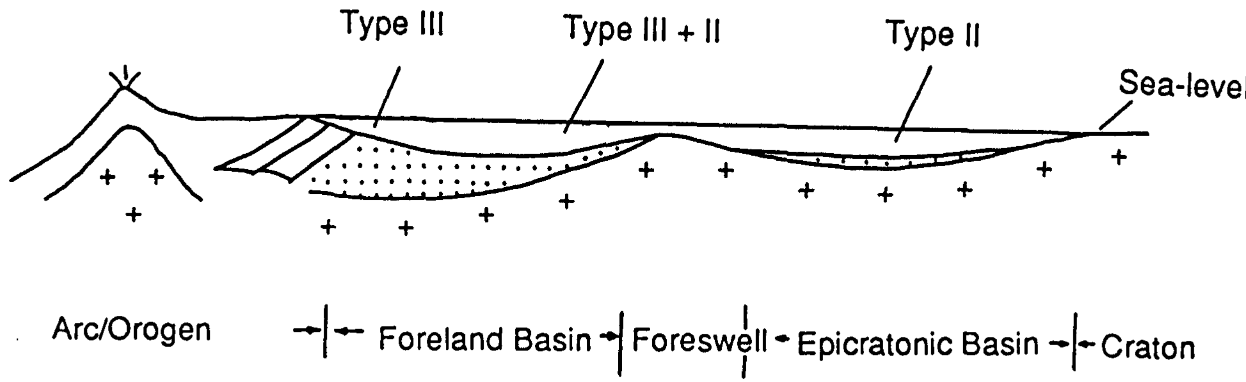



Figure 9.10. Schematic cross-section of a foreland basin showing the distribution of different organic matter types across the foreland and epicratonic basins during a relatively high water table. Note how kerogen type changes from dominantly land-plant-derived type III in the orogenic flank with the appearance of type II kerogen (in addition to type III) in the cratonic flank within the foreland basin. Moreover, high sea-level stand may establish restricted circulation and anoxia beyond the foreswell in the epicratonic basin favouring better preservation of oil-prone type II kerogen.

the Western Canada Basin (Figure 9.4) many reservoirs within the orogen-derived clastics are of this unconventional type (Masters, 1984; see also Spencer, 1985).

With regard to hydrocarbon source rocks, terrestrial land-plant-derived type III dispersed organic matter and coal are characteristic of both basins (Thomas et al, 1982; Welte et al, 1984). In the Western Canada Basin a trend of cratonward increase of the relative proportion of the oil-prone type II organic matter has been observed (D. H. Welte, written comm., 1986). This is paralleled by a corresponding increase in total organic carbon content (Weiss, 1985). This trend is more pronounced in the Upper Cretaceous shales, accentuated perhaps by the marine trangressions of the Western Interior Seaway. Published data are sparse as to any systematic geographic/stratigraphic change of the quality and quantity of organic matter in the Surat Basin, but such a trend as mentioned for the Western Canada Basin is a possibility (cf. Boreham and Powell, 1987). The inferred pattern of geographic distribution of organic matter type in a typical foreland basin is schematically shown in Figure 9.10.

## CONCLUSIONS

Detrital mineralogy exerts a first-order control on sandstone porosity. Mineralogically mature quartozose sandstone retains high porosity at depth. Conversely, labile sandstones being physically and chemically unstable, tend to lose porosity quickly upon burial thereby establishing a shallow economic basement. Sedimentation in foreland basins is characterised by dual provenance: orogenic vs. cratonic. Cratonic sandstones, being quartz-rich, are prone to constitue good hydrocarbon reservoirs whereas the orogenic labile sediments tend to be tight, the finer-grained members of which are prone to be of good hydrocarbon source potential. Notwithstanding inherent complexities, these general patterns hold true for both the Surat and Western Canada Basins. The comparative approach employed in this paper suggests that basins with similar tectonic and geologic settings may be expected to have similar suites of petrofiacies with distinct patterns of hydrocarbon reservoir and source rock characteristics. Study of these relationships can be useful in assessing the hydrocarbon potential of frontier or less explored basins from knowledge of basins of comparable tectonic/geologic history with proven hydrocarbon potential.

REFERENCES

Arditto, P. A., 1982, Deposition and diagenesis of the Jurassic Pilliga Sandstone in the southeastern Surat Basin, New South Wales. Jour. Geol. Soc. Austral. v. 29, pp. 191-203.

Arditto, P. A., 1983, Mineral-groundwater interactions and the formation of authigenic kaolinite within the southeastern intake beds of the Great Australian (Artesian) Basin, N.S.W. Sedim. Geol., v. 35, pp. 249-261.

Bayliss, P., and Levinson, A. A., 1976, Mineralogical review of the Alberta oil sand deposits (Lower Cretaceous Mannville Group), Bull. Can. Petrol. Geol., v. 25.,n.2.,pp. 211-224.

Boreham, C. J., and Powell, T. G., 1987, Sources and preservation of organic matter in the Cretacous Toolebuch Formation, eastern Australia. Organic Geochem., v. 11/6, pp. 433-449.

Byrnes, J. G., 1975, Great Australian Basin smectite and possible easter sources., Geol. Surv. N.S.W., Unpubl. Rpt. 75/12 GS 1975/119, 8 p.

Cameron, E. M., 1966, A geochemical method of correlation for the Lower Cretaceous strata of Alberta., Geol. Surv. Can. Bull. 137, 30 p.

Carrigy, M. A., 1963, Petrology of coarse grained sands in the lower part of the McMurray Formation. In Carrigy M. A. (ed.) 'The Clark Volume', A collection of papers on the Athabasca Oil Sands., Res. Coun. Alta. pp. 31-54.

Carrigy, M. A.,and Mellon. G. B., 1964, Authigenic clay mineral cements in Cretaceous and Tertiary sandstones of Alberta. Jour. Sedim.

Petrol., v. 34, pp.461-472.

Carrigy, M. A., 1971, Deltaic sedimentation in Athabasca tar sands., AAPG Bull., v. 55/8, pp. 1155-1169.

Conaghan, P. J., Jones, J. G., Mcdonnell, K. L, and Royce, K., 1982, A dynamic fluvial model for the Sydney Basin. Jour. Geol. Soc. Austral., v. 29, pp. 55-70.

Davies, D. K., and Ethridge, F. G., Sandstone composition and depositional environment. AAPG Bull., v. 59/2, pp. 239-264.

Day, R. W., Whitaker, W. G., Murray, C. G., Wilson, I. H., and Grimes, K. G., (1983), Queensland Geology - a companion volume to the 1:2 500 000 scale geological map (1975). Geol. Surv. Qld. 194 p.

Dickinson, W. R., 1976, Plate tectonic evolution of sedimentary basins. AAPG contg educ. course note series 1. 83 p.

Dickinson, W. R., and Snyder, W. S., 1978, Plate tectonics of the Laramide Orogeny. Geol. Soc. Amer. Mem. 151, pp. 355-366.

Dickinson, W. A. and Suczek, C. A., 1979, Plate tectonics and sandstone composition. AAPG Bull., v. 63, pp. 2164-2182.

Dickinson, W. R., Ingersoll, R. V., Cowan, D. S., Helmold, K. P., and Suczek, C. A., 1982, Provenance of Franciscan graywackes in coastal California. Geol. Soc. Amer. Bull., v. 93, pp. 95-107.

Dickinson, W. R., Beard, L. S., Brakenridge, G. R., Erjavee, J. L., Ferguson, R. C., Inman K.F., Knepp R.A., Lindberg F.A., and Ryberg, P.T., 1983, Provenance of North American Phanerozoic sandstones in relation to tectonic setting. Geol. Soc. Amer. Bull., v. 94, pp. 222-235.

Eisbacher, G. H., Carrigy, M. A., and Campbell, R. B., 1974, Paleodrainage pattern and late-orogenic basins of the Canadian Cordillera. SEPM Sp. Publ. 22, pp. 143-166.

Exon, N. F., 1976, Geology of the Surat basin in Queensland., Bureau Min. Res. Bull. 166, 160 p.

Exon, N. F., and Senior, B. R., 1976, The Cretaceous of the Eromanga and Surat Basins., Bureau Min. Res. Jour. Austral. Geol. Geophy., v. 1, pp. 33-50.

Exon, N. F., and Burger, D., 1981, Sedimentary cycles in the Surat Basin and global changes in sea-level., Bureau Min. Res. Jour. Austral. Geol. Geophy., v. 6, pp. 153-159.

Hancock, J. M., and Kauffman, E. G., 1979, The great transgressions of the Late Cretaceous. Jour. Geol. Soc. London., v. 136, pp. 175-186.

Houseknecht, D. W., 1980, Comparative anatomy of a Pottsville lithic arenite of the Pochahontas Basin, southern West Virginia: petrogenetic, depositional, and stratigraphic implications. Journ. Sedim. Petrol., v. 50, pp. 3-20.

Houston, B. R., 1972, Petrology of subsurface samples of Mesozoic arenites of the Bowen and Surat Basins. In Gray, A. R. G., 'Stratigraphic drilling in the surat and Bowen Basins, 1967-70'. Geol. Surv. Qld. Rpt. 71, 106 p.

Ingersoll, R. V., 1978, Petrofacies and petrologic evolution of the Late Cretaceous forearc basin, northern and central California. Jour. Geol., v. 86, pp. 335-352.

Ingersoll, R. V., 1983, Petrofacies and provenance of Late Mesozoic forearc basin, northern and central California. AAPG Bull., v. 67, n.7, pp. 1125-1142.

Jackson, P. C., 1984, Paleogeography of the Lower Cretaceous Mannville Group of Western Canada. In Masters, J. A., (ed.) `Elmworth', case study of a deep basin gas field'. AAPG Mem. 38, pp. 49-77.

Johnson, J. G., 1971, Timing and coordination of orogenic, epeirogenic, and eustatic events. Geol. Soc. Amer. Bull., v. 82, pp. 3263-3298.

Johnson, J. G., 1972, Antler Effect equals Haug Effect. Geol. Soc. Amer. Bull., v. 83, pp. 2497-2498.

Jones, J. G., Conaghan, P. G., and McDonnell, K. L., 1987, Coal measures of an orogenic recess: Late Permian Sydney Basin, Australia. Palaeogeogr. Palaeoclimatol. and Palaeoecol., v. 58, pp. 203-219.

Jones, J. G.; Conaghan, P. J., McDonnell, K. L., Flood, R. H., and Shaw, S. E., 1984, Papuan Basin analogue and a foreland basin model for the Bowen - Sydney Basin. In Veevers, J. J. (ed.) Phanerozoic earth history of Australia. Cleardon Press, Oxford., pp. 243-262.

Jones, J. G., and Veevers, J. J., 1982, A Cainozoic history of Australia's Southeast Highlands. Jour. Geol. Soc. Austral., v. 29, pp. 1-12.

Jones, J. G., and Veevers, J. J., 1983, Mesozoic origins and antecedents of Australia's Eastern Highlands. Jour. Geol. Soc. Austral., v. 30, pp. 305-322.

Jones, P. C., 1972, Quartzarenite and litharenite facies in the fluvial foreland deposits of the Trenchard Group (Westphalian), Forest of Dean, England. Sediment. Geol., v. 8, pp. 117-198.

Korsch, R. J., 1984, Sandstone composition from the New England Orogen, Eastern Australia: implications for tectonic setting. Jour. Sedim. Petrol., v. 54/1, pp. 192-211.

Leckie, D. A., and Foscolos, A. E., 1986, Paleosols and Late Albian sea level flactuations: preliminary obsevations from the northeastern British Columbia foothills. Current Research, Part B. Geol. Surv. Canada. Paper 86-1B, pp. 429-441.

Martin, K. R., 1981, Deposition of the Precipice Sandstone and the evolution of the Surat Basin in the Early Jurassic. Austral. Petrol. Expln Assoc. Jour., v 21, pp. 16-23.

Masters, J. A., 1979, Deep basin gas trap, Western canada. AAPG Bull., v.

63, pp. 152-181.

Masters, J. A., 1984, Lower Cretaceous oil and gas in the Deep basin of Western Canada. In Masters, J. A., (ed.) `Elmworth'- case study of a Deep basin gas field. AAPG , Mem. 38. pp. 1-33.

Mclean, J. R., 1979, Regional considerations of the Elmworth field and Deep basin. Bull. Can. Petrol. Geol., v. 27/1, pp. 53-62.

Mclean, J. R., and Putnam, P. E., 1983, Composition of heavy oil reservoirs: the Lloydminister Formation, Lloydminister area, and the Clearwater Formation, Cold Lake area. In Mclean, J. R., and Reinson, G. E., (eds.) Sedimentology of selected Mesozoic clastic sequences. Proceedings of the corexpo '83, Calgary. Canad. Soc. Petrol. Geol. pp. 81-93.

Mellon, G. B., 1967, Stratigraphy and petrology of the Lower Cretaceous Blairmore and Mannville Groups, Alberta Foothills and Plains. Res. Coun. Alta. Bull. 21, 270 p.

Palmer, A. R., 1983, The decade of North American geology - 1983 geologic time scale. Geol., v. 11, pp. 503-504.

Pettijohn, F. J., Potter, P. E., and Siever, R., 1973, Sand and Sandstone. Sringer-Verlag, New York, 618 p.

Putnam, P. E., and Pedskalny, M. A., 1983, Provenance of Clearwater Formation reservoir sandstones, Cold Lake, Alberta, with comments on feldspar composition. Bull. Canad. Petrol. Geol., v. 31, pp. 148-160.

Quilty, P. G., 1984, Phanerozoic climates and environments of Australia. In Veevers, J. J. (ed.) Phanerozoic earth history of Australia., Clarendon Press, Oxford., pp. 48-57.

Rapson, J. E., 1965, Petrology and derivation of Jurassic-Cretaceous clastic rocks, soutrhern Rocky Mountains, Canada. AAPG Bull., v. 49/9, pp. 1426-1452.

Reinson, G. E., and Foscolos, A. E., 1986,Trends in sandstone diagenesis with depth of burial, Viking Formation, southern Alberta. Bull. Canad. Petrol. Geol. v. 34/1, pp. 126-152.

Slansky, E., 1977, Clay minerals and the quality of artesian waters in the Great Australian Basin in N. S. W., Search, v. 8/9, pp. 322-324.

Slansky, E., 1984, Clay mineralogy. In Hawke, J. M., and Cramsie, J. W., (eds.) Contributions to the geology of the Great Artesian Basin in New South Wales. Geol. Surv. N. S. W. Bull. 31, pp. 179-203.

Smith, D. G., Zorn, C. E.,and Sneider, R. M., 1984, The paleogeography of the Lower Cretaceous of Western Alberta and Northeastern British Columbia in and adjacent to the Deep basin of the Elmworth area. In Masters, J. A., (ed.) `Elmworth', case study of a Deep basin gas field. AAPG Mem. 38, pp. 79-114.

Spencer, C. W., 1985, Geologic aspects of tight gas reservoirs in the Rocky Mountain region. Jour. Petrol. Tech., July 1985, pp. 1308-1314.

Stott, D. F., 1968, Lower Cretaceous Bullhead and Fort St. John Groups, between Smoky and Peace Rivers, Rocky Mountains Foothills, Alberta, British Columbia., Geol. Surv. Canad. Bull. 152, 279 p.

Thomas, B. M., Osborne, D. G., and Wright, A. J., 1982, Hydrocarbon habitat of the Surat-Bowen Basins. Austal. Petrol. Expn Assoc. Jour. v. 22, Pt. 1, pp. 213-226.

Thomas, M., and Miller, B., 1980, Diagenesis and rock-fluid interaction in the Cadotte Member from a well in northwestern British Columbia. Bull. Canad. Petrol. Geol., v. 28/2, pp. 173-199.

Tissot, B. P., and Welte, D. H., 1978, Petroleum Formation and Occurrence. Springer-Verlag, Berlin-Heidelberg-New York. 527 p.

Traves, D. M., 1971, Stratigraphic traps in the Roma area, Queensland, Australia. Proceed. 8th World Petrol. Congr., Applied Science, London. pp. 275-284.

Vail, P. R., Mitchum, R. M., and Thompson, S., 1977, Seismic stratigraphy and global changes of sea-level, Pt.4. Global cycles of relative changes of sea-level. In Payton, C. E., (ed.) Seismic stratigraphy - applications to hydrocarbon exploration. AAPG Mem. 26, pp. 83-97.

Veevers, J. J., Jones, G. J., and Powell, C. MA., 1982, Tectonic framework of Australia's sedimentary basins. Austal. Petrol. Expn Assoc. Jour., v. 22, pp. 283-300.

Weimer, R. J., 1984, Relation between unconformities, tectonics, and sea level changes, Cretaceous of Western Interior, USA. In Schlee, J. S., (ed.) Interregional unconformities and hydrocarbon accumulation. AAPG Mem. 36, pp. 7-35.

Weiss, H. M., 1985, Geochemische und petrographische untersuchungen am organischen material Kretazicher sedimentgestine aus dem Deep Basin, WestKanada. Ph.D thesis (Unpubl.). Tech. Univ. Aachen, 261 p.

Welte, D. H., Schaefer, R. G., Stoessinger, W., and Radke, M., 1984, Gas generation and migration in the Deep basin of Western Canada. In Masters, J. A., (ed.) `Elmworth', case study of a deep basin gas field. AAPG Mem. 38, pp. 35-47.

# APPENDICES

# APPENDIX 1.1. THIN-SECTION POINT-COUNT FORMAT

*Appendix 1.1. Thin-section point-count format for provenance and porosity characteristics of the Surat Basin sandstones*

| Grain-types | | Designated code |
|---|---|---|
| | **DETRITAL QFR CATEGORIES** | |
| **MEGAQUARTZ** | | |
| COMMON/PLUTONIC | unstrained/slightly strained (<5° stage-rotation (add m if mono- and p if polycrystalline) | Qcu |
| | moderate/highly strained (>5° stage-rotation) (add m if mono- and p if polycrystalline) | Qcs |
| VOLCANIC | unstrained (add 1 or 2 to indicate confidence level) | Qvu(1)/(2) |
| | strained ( " " " " ) | Qvs " " |
| VEIN | monocrystalline | Qvm |
| | polycrystalline | Qvp |
| POLYCRYSTALLINE | unimodal | Qpu |
| | bimodal | Qpb |
| | polymodal | Qpp |
| **MICROQUARTZ** (with or without rads; add r if present) | | |
| CHERT | clear/cloudy (<5% impurities) | qcc |
| | silty/argillaceous (>5% impurities) | qcs |
| METACHERT | | qcm |
| MICROVEIN | | qvm |
| CHALCEDONY | | qcd |
| **FELDSPAR** (add s if skeletal, r if replaced, ch/ca/phy etc. to indicate replacing mineral) | | |
| PERTHITIC/ANTIPERTHITIC (add rg if regular, and ig if irregular) | | Fp |
| UNTWINED/CARLSBAD-TWINNED (add p if plag., k if orthoclase, i if indeterminate, ns if non-skeletal, and (1) or (2) confidence level) | | Fu |
| ALBITE/PERICLINE-TWINNED PLAGIOCLASE (add z if zoned, and ns if non-skeletal) | | Fa |
| CROSS-TWINNED K-SPAR | | Fx |
| GLOMEROPORPHYRITIC | | Fg |
| RADIAXIAL | | Fr |
| QUARTZ-FELDSPAR INTERGROWTHS (add c if cuniform, m if myrmekitic, p if poikilitic, g if granular) | | Fi |
| **PLUTONIC/METAPLUTONIC ROCK-FRAGMENT** | | P |

| | | |
|---|---|---|
| <u>VOLCANIC/HYPABYSSAL</u> (add r if replaced, and ch/ca/etc. to indicate replacing mineral, and p if phenocrysts present) | | |
| VITRIC | non-clastic (or apparently so) | Vv |
| | clastic, with or without shards (add s if present) | Vvk |
| | pumiceous | Vvu |
| | vesicular | Vvv |
| | semiopaque (add (1) or (2) confidence level) | Vvo |
| MICROLITIC | | Vm |
| MICROGRANULAR (add k if clastic; x, h, or i if xeno-, hypidio-, or idiomorphic respectively) | | Vx |
| FELSITIC | | Vf |
| SILICEOUS-GRANULAR | | Vsi |
| VAPOUR-PHASE QUARTZ | | Vvpq |
| LATHWORK | | Vl |
| SPHERULITIC | | Vsp |
| MESOCRYSTALLINE-GRANULAR | | Vg |
| OTHER | | Vo |
| <u>CARBONATE ROCK-FRAGMENTS</u> (add r if replaced, and ca/ch/etc. to indicate replacing mineral) | | CR |
| <u>TECTONITE</u> (i.e., foliated metamorphics) | | |
| | slate/phyllite/semischist | Tp |
| | quartz-mica schist/gneiss | Ts |
| | ribbon/mylonitic quartz-schist | Tq |
| | calc-schist | Tca |
| | chlorite-schist | Tch |
| | other | Tco |
| <u>METAMORHIC OTHER</u> (i.e., non-foliated types, e.g., hornfelses, metaquartzite) | | Mh, Mkq, etc. |
| <u>SEDIMENTARY CLASTIC</u> (extraclastic only; metamorphic foliation weak or absent) | | |
| QUARTZOSE | quartz-sandstone | Ksq |
| | quartz-siltstone | Kzq |
| LABILE | labile-sandstone | Ksl |
| | labile-siltstone | Kzl |
| ARGILLITE/MUDROCK (add r if rads present) | | ka |

## EXTRACLASTIC DETRITAL GRAINS OF AMBIGIOUS/UNCERTAIN PROVENANCE AFFINITTY

| | |
|---|---|
| EQUANT/SEMI-EQUANT MASSIVE CHLORITE/?CHAMOSITE (add (1)/(2) confidence level) | Achm |
| NON-ORGANIC, NON-MINEROGENIC OPAQUES/SEMIOPAQUES LACKING GENETICALLY DIAGNOSTIC INTERNAL TEXTURAL CRITERIA OF SOURCE-ROCK AFFINITY | Aso |
| WHOLLY REPLACED/PSEUDOMORPHED ROCKFRAGMENTS (add ca/ch/etc. to indicate replacing mineral) | Ar |
| POLYMINERALIC ROCKFRAGMENTS OF INDETERMINATE SOURCE-ROCK AFFINITY | Ai |
| PSEUDOMATRIX (add s if sedimentary, t if tectonite, etc. where possible) | Apm |

## DETRITAL NON-QFR GRAIN CATEGORIES: EPICLASTIC/INTRCLASTIC

**MICA**

| | |
|---|---|
| BIOTITE (add d if degraded, and ch if chloritised) | Zb |
| MUSCOVITE (" " " " " " ) | Zw |
| CHLORITE FLAKES (detrital) | Zch |
| DEGRADED INDETERMINATE (add ch if chloritised, o if oxidised) | Zdi |

**HEAVY MINERALS**

| | |
|---|---|
| PYROBOLES (add a if amphibole or p if pyroxene, r if replaced, and ca/ch etc. to indicate replacing mineral) | HP |
| DETRITAL OPAQUE/SEMI-OPAQUE HEAVY MINERALS | HO |
| TRANSLUCENT/TRANSPARENT HEAVY MINERALS (add z if zircon, g if garnet, t if tourmaline, r if rutile, and e if epidote, etc.) | HT |

| | |
|---|---|
| **SEDIMENTARY INTRACLASTS** (add pm/om if now pseudomatrix/orthomatrix) | I |
| **PROTOMATRIX** (unrecrystallized lutum) | PR |
| **ORTHOMATRIX** | OM |

## DETRITAL NON-QFR CATGORIES: ALLOCHEMICAL/AUTHIGENIC

| | |
|---|---|
| **BIOCLASTS** (add m if mollusk, b if brach., e if echinoid etc.) | B |
| **OOLITES** (add ca if carbonate, cham if chamosite, etc.) | OO |
| **DETRITAL ORGANICS** (add (1)/(2) to indicate confidence level) | DO |
| **GLAUCONIE** (add p if pellet-like; add (1)/(2) confidence level) | G |
| **PSEUDOMATRIX** (add cham, etc. to indicate grain-type) | Pmal |
| **SUPERFICIAL OOLITIC COATINGS OF EPICLASTIC GRAINS** (add cham, glau, etc) | FP |

## VOID-FILLING PHYLLOSILICATE (EPIMATRIX)

(add r if apparently replacing feldspar or other minerals; add (1A), (2B), etc. to indicate genetic nature of occlued pores; cf. separate pore-codes)

| | | |
|---|---|---|
| TYPE 1 | Dickite | Ed |
| TYPE 2a | Kaolin, clear, fine-grained | Eka |
| TYPE 2b | Kaolin, discoloured, fine-grained | Ekb |
| TYPE 2c | Kaolin, coarse-grained, fanwork | Ekc |
| TYPE 3 | Sheetwork ?smectite | Ess |
| TYPE 4 | Illite | Eil |
| TYPE 5 | Other | Eo |

## OTHER VOID-LINIG/FILLING CHEMICALLY PRECIPITATED CEMENT

(add code to indicate genetic pore-type occluded where appropriate, especialy where pore-type is of intragranular nature)

| | | |
|---|---|---|
| PHYLLOSILICATE CEMENT (add t if coats, r if hairy, and ch, il, etc. to indicate mineralogy) | | Xp(t)/(r) |
| QUARTZ OVERGROWTH | | Xfo |
| CARBONATE | calcite (red stain) | Xca |
| | ferroan calcite (mauve stain) | Xfca |
| | dolomite (no stain) | Xdol |
| | siderite (no stain) | Xsd |
| | ferroan dolomite (light blue stain) | Xfdol |
| | ankerite (dark blue stain) | Xank |
| SERICITE | | Xse |
| CHLORITE/CHAMOSITE | | Xch/Xcham |
| GLAUCONIE | | Xglau |
| AUTHIGENIC PYRITE | | Xpyr |
| CHERT/MICROQUARTZ | | Xqc |
| GRANULAR MESOQUARTZ | | Xqg |
| ZEOLITE (add subscript to indicate mineralogy) | | Xz |
| IRON OXIDES/HYDROXIDES | | Xfeox |
| OTHER | | Xo |

Appendix 1.1 (contd.)

**NATURAL MACROPORES**
(add b/p if occluded by bitumen/paraffin)

| | | |
|---|---|---|
| **INTERGRANULAR PRIMARY** | | 1A |
| **INTERGRANULAR SECONDARY** | | |
| | grain-dissolution | 2Agd |
| | matrix-dissolution | 2Amd |
| | cement-dissolution | 2Acd |
| **INTRAGRANULAR PRIMARY** | | |
| | biogenic cellular/chamber/pore | 1Bb |
| | non-biogenic | 1Bn |
| **INTRAGRANULAR SECONDARY** | | |
| | fracture | 2Bf |
| | dissolution (add skf if within skeletal feldspar) | 2Bd |
| | shrinkage (add glau etc. to indicate grain-type) | 2Bs |
| | splay/rotational-fracture | 2Br |
| **ROCK-FRACTURE** | | |
| | bedding-parallel | 3bp |
| | bedding-normal | 3bn |
| | bedding-oblique | 3bo |
| **ORGANIC BURROWS** | | |
| | bedding-parallel | 4bp |
| | bedding-normal | 4bn |
| | bedding-oblique | 4bo |
| **CAVERNOUS** | | 5 |

# APPENDIX 1.2. OPERATIONAL THIN-SECTION CRITERIA FOR DISCRIMAINATION BETWEEN SOME LITHIC GRAIN-TYPES OF INTERGRADATIONAL PETROGRAPHIC CHARACTER

Appendix 1.2. Operational thin-section criteria for discrimination between some lithic grain-types of commonly intergradational petrographic character (from Conaghan, unpubl.[1]).

| Grain-type | Designated code | Opacity | Colour |
| --- | --- | --- | --- |
| CHERT, clear/cloudy | qcc (qccr, if radio-larians present) | Very low to moderate | colourless, orange or reddish-brown, or pale-green in plane polarized light (PPL); light- to mid-grey or creamy-grey in crossed polarized light (XP); radiolarians show conspicuous polka-dot pattern both in PPl and XP because they are typically colourless and internally more coarsely crystalline than surrounds. |
| CHERT, silty/argillaceous | qcs (qcsr if rads. present) | low to moderate | variable; predominantly mid- to dark brown or olive-brown in PPL; light- to dark-grey in XP, but birefringent pattern typically has more speckled appearance than qcc because of higher impurity content of phyllosilicate and/or clastic quartz/feldspar silt/sand; radiolarians show polka-dot pattern as for qccr |

| Grain-type | Designated code | Opacity | Colour |
| --- | --- | --- | --- |
| SEDIMENTARY (clastic), argillite | Ka (Kar if rads. present) | moderate to high | similar to qcs, but colour-field can appear more conspicuously heterogeneous (speckled in situations where clastic content is coarser-grained |
| METACHERT | qcm | very low to moderate | typically colourless; some phases or patches appear dusty/cloudy with pale brown colouration due to presence of disseminated fine-grained chlorite blebs |
| VOLCANIC (felsitic)[2] | Vf | low to moderate | commonly light-brown in PPL; in XP colour is conspicuously more heterogeneous (in mid- and light-greys) and more fuzzy/cloudy than qcc and qcs. |
| VOLCANIC (vitric) | Vv | extremely variable within and between samples | in PPL colour of groundmass variable between specimens, ranging from near-clourless to semi-opaque, but commonly light-to medium-brown; common to abundant opaque specs/microlites give dusty/speckled appearance; in XP, where groundmass not isotropic, interference colours are typically grey in |

| Grain-type | Designated code | Opacity | Colour |
|---|---|---|---|
| | | | microgranular or fibrous (spherulitic, axiolitic etc.) birefringent textures |
| SEDIMENTARY (clastic) labile | K1 | low to moderate with irregular pattern reflecting inherent grainsize/ compositional heterogeneity | variable; bulk colour commonly light-brown, reddish-brown, or grey in PPL, but pattern is homogeneous reflecting inherent clastic character; in XP colours are commonly greyish for most components, except detrital quartz and authienic carbonate |

| Grain-type | Minearalogy and clastic/authigenic content |
|---|---|
| CHERT, clear/cloudy | semi-equigranular undulose-extinction units predominate and comprise bundles of fibrous microquartz (chalcedony) and/or overlapping/superimposed micron-sized polyhedral crystals of microquartz[3]; radiolarinas are commonly infilled by larger fan-shaped arrays of chalcedony; clastic impurities low to absent (<5%) comprising mainly detrital phyllosilicate (muscovite, biotite, chlorite) flakes/shreds, and quartz and feldspar silt; blebs, lenticles and/or irregular clots of semiopaque/opaque earthy material and/or organic matter present in varying amounts in the macroscopically darker-coloured grains |

| *Grain-type* | *Minearalogy and clastic/authigenic content* |
|---|---|
| | of this category; blebs and filamentous meshworks or authigenic chlorite also common but in small amounts |
| CHERT, silty/argillaceous | microquartz mineralogy as for qcc; clastic mineral content 5-10%, comprising similar mineral assemblages as in qcc; detrital feldspar and quartz grains consist predominantly of of silt but range up to medium sand size; other compositional characteristics similar to those of qcc except that authigenic chlorite present as blebs, filamentous meshworks, or pervasive fields is commonly more abundant |
| SEDIMENTARY (clastic) argillite | clastic content moderate to high (>10%) and comprising similar mineral assemblages to those of qcs; microquartz mineralogy similar to qcs |
| METACHERT | Polyhedral megaquartz with variably undulose to sharp extinction; chlorite blebs commonly present disseminated throughout the quartz moasaic, between, rather than within, quartz crystals. |
| VOLCANIC, felsitic | intergrowths of ragged, fuzzy/cloudy, semi-equant feldspar crystals or feldspar and quartz, in some cases with well-defined phenocrysts/microphenocrysts of volcanic quartz and/or feldspar; fuzzy/cloudy appearance of crystals is due to presence of dense concretions of bead-like and tabular vacuoles (ca. 0.002 mm diam.) which in places from clot-like clusters that are characteristically opaque/semi-opaque and greenish-rusty-orange in PPL. |

| Grain-type | Minearalogy and clastic/authigenic content |
|---|---|
| VOLCANIC, vitric | where not isotropic (i.e., glass), groundmass mineralogy is dominated by various devitrification assemblages in either microgranular or fibrous arrays of feldspar and quartz with common specs/blebs/microlites of opaque minerals; phenocryst/microphenocryst minerals predominantly volcanic quartz (commonly resorbed, partially resorbed), deuterically-altered feldspar and altered/partially altered biotite and pyroboles; vesicular cavities and miarolitic cavities filled by early generations of fibrous/bladed intergrowth rims of quartz (paramorphic after tridymite/cristobalite) and alkali feldspar, and by later more coarsely crystalline growths of vapour-phase quartz and vug quartz, with or without chalcedony, zeolite, and chlorite; devitrification of shards gives characteristically axiolitic fibrous intergrowths of alkali feldspar and quartz (paramorhic after tridymite/cristobalite); deuteric/authigenic blebs/patches of green chlorite and/or caledonite common throughout groundmass in many samples |
| SEDIMENTARY (clastic), labile | content of megaquartz typically low (<10%) and consisting virtually exclusively of volcanic quartz; other clastic grain-types are predominantly silicic and/or feldsparphyric volcanic rock-fragments and plagioclase phenocrysts; accessory grain-types include fragments of tectonite and sedimentary rocks, especially argillite and chert; binding media most commonly comprise void-filling chlorite, chert and megaquartz (including quartz overgrowth) cements (in grainstones), and pelitic/semi-isotropic matrices in packstones and wackestones; carbonate commonly replaces feldspar phenocrysts and feldsparphyric |

| Grain-type | Minearalogy and clastic/authigenic content |
| --- | --- |
| | volcanic rock-fragments and occludes interstitial space between such grains, in some cases probably replacing pre-existing binding media. |

| Grain-type | Grain/crystal size[4] |
| --- | --- |
| CHERT, clear/cloudy | extinction units of microquartz <0.02 mm and ranging in apparent size down to ca. 0.006 mm; clastic and authigenic impurities range up into coarser silt sizes |
| CHERT, silty/argillaceous | as for qcc; clastic quartz and feldspar present predominantly as silt disseminated in cherty-pelitic matrix, but in some cases clastic grains range up to medium sand size in mudstone/wackestone textural relationship relative to the cherty-pelitic matrix. |
| SEDIMENTARY (Clastic), argillite | as for qcs. |
| METACHERT | megaquartz crystals typically >0.02 mm. and ranging up to ca. 0.06 mm; chlorite blebs typically 0.02 mm in length. |
| VOLCANIC (felsitic) | extinction units are commonly semi-equant/equant in individual specimens but show a very large size range from ca. 0.2 mm or more to a lower limit of ca. 0.03 mm. |

| Grain-type | Grain/crystal size |
|---|---|
| VOLCANIC (Vitric) | where groundmass still not isotropic, constituent crystals commonly of variable size between samples but less so within individual samples except where sample contains spherulitic patches or vesicular/miarolitic cavity infills; where groundmass consists of equigranular crystal mosaic (as opposed to spherulitic/fibrous fabrics) crystal size is typically cryptocrystalline (<0.01 mm) or finely microcrystalline (0.01-0.05 mm). |
| SEDIMENTARY (Clastic), labile | variable; clastic grains range from silt size through sand in to gravel sizes in control samples; at finer end of the grainsize spectrum this grain-type category (Kl) is gradational with Ka and finer-grained varieties of Vvk; it is operationally separated from Ka where predominant grainsize of the clastic framework is more than 0.03 mm, and from the finer-grained varieties of Vvk on the basis of the presence in the latter of glass shards/shard ghosts/axiolites etc. (see comments in 'Other Remarks' for Vvk). |

| Grain-type | Texture/fabric |
| --- | --- |
| CHERT, clear/cloudy | shape of individual microquartz extinction units typically complex with irregular interlocking boundaries between neighbours; fabric of microquartz extinction units/bundles typically semi-equigranular, constituting a conspicuous cherty mosaic that is continous throughout; phyllosilicate shreds commonly sub-aligned and sub-parallel to stratification where the latter is definable on the basis of independent textural/compositional criteria. |
| CHERT, Silty/argillaceous | texture/fabric of microquartz as for qcc but typically higher clastic/authigenic impurity content and opacity render cherty mosaic less conspicuous and discernibly pervasive; clastic impurities commonly define bedding lamination by common alignment of elongate/platy grains; variation in relative concentration, and changes in grainsize and/or clastic mineralogy; bedding-parallel alignment of fine phyllosilicate flakes can cause partial mass-extinction effect. |
| SEDIMENTARY (clastic), argillite | as for qcs, but higher clastic content and opacity render cherty mosaic almost undiscernible; bedding-parallel alignment of fine phyllosilicate flakes can cause partial mass-extinction effect. |

| Grain-type | Texture/fabric |
|---|---|
| METACHERT | fabric is typically equigranular to semi-equigranular and hypidioblastic/idioblastic with a strong tendency for the polyhedral megaquartz crystals to show triple point relationships with neighbours; disseminated chlorite blebs between polyhedral quartz crystals can show strong mutual alignment parallel to texturally-defined bedding foliation in the host metachert or random orientations; where specimens shows evidence of structural deformation (brecciation, shear lamellae etc.) a more platy crystal habit may locally characterize the quartz crystals. |
| VOLCANIC (felsitic) | typically mosaics of very ragged-edged ill-defined equant/semi-equant anhedral crystals defining a xenomorphic fabric; better defined phenocryst/microphenocryst of volcanic quartz (commonly showing resorbtion effects) or altered feldspar may be present within the groundmass; a more elongate crystal shape characterize this grain-type category in situations where it arises as cavity-wall lining and/or cavity-wall devitrification product in eutaxites. |
| VOLCANIC, Vitric | textural character of groundmass extremely variable, particularly between samples, and comprising either near-isotropic/isotropic glass, microgranular crystalline mosaics, |

| Grain-type | Texture/fabric[5] |
| --- | --- |
| | and simple or complex fibrous/spherulitic arrays, or combinations/associations of these textural varieties with or without eutaxitic fabrics (including fluidal layering and occluded elongate/flat vesicular and miarolitic cavities) and, where devitrified glass shards are present, axiolites; volcanic quartz and (commonly altered) feldspar usually present as phenocrysts/microphenocrysts which commonly exhibit more conspicuously broken shpaes where demonstrably (through presence of glass shards) volcaniclastic; pumice lenticles in ignimbrites and much of the groundmass in other ?non-clastic silicic lavas consists predominantly of felsitic crystalline mosaics but this textural category herein differentiated into seperate grain-type category (i.e., Vf) |
| SEDIMENTARY (Clastic), labile | variable, ranging from texturally mature grainstones through immature packstones to wackestones. |

| Grain-type | Internal relief | Biogenic features |
| --- | --- | --- |
| CHERT, Clear/cloudy | little or none except that associated with foreign mineral impurities, especially phyllosilicate flakes/shreds. | radiolarians common, but ranging from complete absence to very abundant; small burrow-like structures occur rarely. |
| CHERT, Silty/argillaceous | moderate to pronounced because of large content of clastic and authigenic impurities, especially phyllosilicate minerals (detrital muscovite, biotite, chlorite, and authigenic chlorite). | as for qcc; siliceous spicules also occur rarely. |
| SEDIMENTARY (Clastic), argillite | as for qcs. | as for qcs. |
| METACHERT | as for qcs; major cause of internal relief is presence of disseminated blebs of chlorite. | ?zeolite/?albite-infilled ellipsoidal-shaped features seen in one specimen may be radiolarian ghosts. |

| Grain-type | Internal relief | Biogenic features |
|---|---|---|
| VOLCANIC, Felsitic | usually fairly pronounced: at lower magnification relief is due to presence of clot-like clusters of vacuoles, rare accessory mineral inclusions, ?and by presence of chlorite blebs; at higher magnification relief is caused by the above together with a background of more evenly disseminated vacuoles. | not applicable |
| VOLCANIC, Vitric | where groundmass is not isotropic internal relief is usually moderate to moderately high. | not applicable |
| SEDIMENTARY (Clastic), labile | variable; commonly low to moderate | none observed (other than sporadic radiolarians within component clastic grains of chert and argillite) |

| Grain-type | Structural characteristics |
|---|---|
| CHERT, Clear/cloudy | bedding foliation defined by compositional/textural lamination common; networks of intersecting quartz veins/microveins common to abundant, commonly defining breccia-like fracture patterns; variably mild to strong ductile deformation evident in many grains because of uniform flattening of radiolarinas and other primary textural features. |
| CHERT, Silty/argillaceous | as for qcc; vein- and fracture-filling minerals include ?searlesite and or ?albite and a fine grained white mica (probably pyrophllite) in addition to quartz. |
| SEDIMENTARY (Clastic), argillite | as for qcs. |
| METACHERT | texturally-defined layering in some specimens probably represent bedding lamination; most specimens appear rather homogenous texturally, but brecciation fabrics with associated quartz veins and microveins are common. |
| VOLCANIC, felsitic | specimens typically appear texturally rather homogeneous except for spoaradic presence of phenocrysts/microphenocryst. |

| Grain-type | Structural characteristics |
| --- | --- |
| VOLCANIC, Vitric | variable; eutaxitic foliation commonly present and caused by presence of flattened pumice lenticles, flat vesicular and miarolitic cavities, and/or fluidal layering; otherwise, samples rather homogeneous structurally. |
| SEDIMENTARY (Clastic), labile | sporadic quartz veins/microveins; evidence of ductile deformation not observed. |

| Grain-type | Distinguishing characterisitcs |
| --- | --- |
| CHERT, clear/cloudy | where present radiolarians provide best genetically diagnostic clue to (oceanic) sedimentary origin, together with optical clarity, low internal relief, bright grey/creamy-grey interference colours, complex interfingering shpae and undulose character of extinction units, and conspicuous orange-red or otherwise pale near-absent colour; ubiquitous microveins give good circumstantial evidence. |
| CHERT, silty/argillaceous | where present, radiolarians and siliceous spicules provide best genetically diagnostic clue to (oceanic) sedimentary origin; other distinguishing characterisitcs as for qcc except that optical clarity is commonly less, internal relief higher, and birefringent colour pattern less homogeneously grey because of slightly higher clastic content; predominance of tiny aligned flakes of mica (including white mica) is characteristic. |

| Grain-type | Distinguishing characterisitcs |
|---|---|
| SEDIMENTARY (Clastic), argillite | where present, radiolarians and spicules provide best genetically diagnostic clue to (oceanic) sedimentary origin; optical clarity is typically low with a strongly pelitic character and tiny aligned detrital falkes of mica, including white mica; control samples show radiolarians infilled by burial metamorphic minerals (including chlorite, ?zeolite/?albite, prehnite/pumpellyite) in addition to microquartz and fine-grained mosaics of vug-megaquartz. |
| METACHERT | low internal relief together with semi-equigranular hyoidiomorphic crystalline mosaic of decimicron-sized straight- to (apparent) undulose extinguishing polyhedral quartz crystals is diagnostic. |
| VOLCANIC, felsitic | distinctive characteristics are: cloudy/dusty appearance with moderate/high fine-scale relief associated principally with the fine-scale inclusions/impurities (vacuoles, microlites, chlorite blebs, blebs of iron-oxide etc.) which charge (overprint) a mosaic of conspicuously xenomorphic, deci- to fine-centimicron-sized extremely ragged/fuzzy-edged crystals of untwinned feldspar and quartz (probably paramorphic after tridymite/cristobalite) that individually give well-defined mass-extinction; enclosed sporadic phenocrysts/microphenocrysts of beta quartz and/or (commonly cloudy, deuterically-altered) plagioclase are genetically important diagnostic clues. |

| Grain-type | Distinguishing characterisitcs |
|---|---|
| VOLCANIC, vitric | textural characteristics vary considerably from sample to sample, covering the spectrum from glassy/near-glassy (isotropic/semi-isotropic) to microgranular crystal mosaics, with/without genetically-diagnostic clues as to volcanic origin such as included phenocrysts/microphenocrysts of plagiocalse and beta quartz (or fragments thereof) and glass shards or their devitrified ghosts (including crowded arrays of curvilinear axiolites) where groundmass/matrix is microgranular (and grain-type identity can be potentially confused with a variety of cryptocrystalline/microcrystalline grain-types of sedimentary/meta-sedimentary origin such as, qcc, qcs, qcm, and ka), best clues as to volcanic rather than other origins are: the more polygonal equant/semi-equant shapes of the constiutent crystals with relatively sharply defined boundaries (contrasting with the more complex interfingering shapes of the microgranular extinction units/bundles in qcc, and qcs); the commonly moderate to high differential relief between these crystals reflecting presumbaly the intimate intergrowth of quartz and feldspar (contrasting with the low differential relief in qcc, qcs, and qcm); the noticeably less bright grey extinction colours in XP (contrasting with the brighter colours of qcc, qcs, and qcm); the common presence of disseminated microlites of other higher-relief minerals (including common |

| Grain-type | Distinguishing characterisitcs |
|---|---|
| | equant crystals of opaques) and blebs/clots of iron-oxide; and, with the exception of blebs of (?mainly authigenic) chlorite, the lack of abundant/common fine phyllosilicate flakes, most especially white mica (in contrast to qcs, and Ka); also, though not as reliable a criterion, the generally better optical clarity (less pelitic appearance in PPL (in contrast to Ka)); demonstrable flow-banding, spherulitic and other distinctively igneous textures/fabrics are clearly also valuable diagnostic criteria where present. |
| SEDIMENTARY (Clastic), labile | distinguishing characterisitcs are presence of clastic textures exhibiting either wackestone, packstone, or grainstone depositional fabrics in which there is a predominance of feldspar, lithic and other labile grain constituents operationally coarser than 0.03 mm (but commonly coarser than 0.06 mm), and (operationally) few or no glass shards; where the depositional fabrics are those of wackestone/packstone, the matrix is typically pelitic with low optical clarity, and where grainstone, the cements commonly comprise chlorite, chert, zeolite, and quartz-overgrowth on the relatively minor grains of clastic megaquartz. |

| Grain-type | Other Remarks |
| --- | --- |
| CHERT, Clear/cloudy | controls samples show that clear/colourless chert of optically identical character to the groundmass of the radiolarian-bearing sedimentary cherts examined here occur also as the predominant constituent in hydrothermal siliceous sinter (geyserite); chert-like constituents in silisic volcanic rocks have subtle differences to cherts of the above two origins. |
| CHERT, Silty/argillaceous | with progressively higher clastic content the conspicuous, complex, interfingering pattern of the cherty extinction units is lost and the petrographic characteristics begin to converge with those of grain-type categories Ka and Vv. |
| SEDIMENTARY (Clastic), argillite | petrographic characteristics are indistinguishable from the intergrain matrix element of wackestone and packestone varieties of grain-type category Kl, but clastic grains of Ka are distinguished from those of Kl operationally on the basis of the presence within the latter of a predominance of labile clastic constituents coarser than 0.03 mm exhibiting packestone, wackestone, or grainstone primary depositional fabrics; despite some petrographic convergence of the characteristics of Ka with those of Vv, the microcrystalline matrix/groundmass elements of Vv is typically more optically clear in PPL than is that of Ka except for isolated clusters/patches or more extensive |

| Grain-type | Other Remarks |
|---|---|
| | areas of vesicule concentration in the former, which, especially in oxidized/weathered specimens, appear opaque/near-opaque in both PPL and XP. |
| METACHERT | Control specimens are optically clear apart from sporadic disseminated chlorite blebs in some, but optical clarity is presumably less in examples originating from less pure cherts; one pebble of probably hydrothermal chert (siliceous sinter) contains phases of granular hypidiomorphic microquartz of very similar petrographic character to what is described here as metachert and is only subtly different from the latter by way of being less strongly hypidiomorphic and with extinction units that give more conspicuously undulose extinction. |
| VOLCANIC, felsitic | control samples show that this textural/compositional category arises principally as a devitrification phase in eutaxitic volcaniclastic where it forms preferentially within flattened pumice lenticles and peripheral to lenticular vesicles and/or miarolitic cavities, but also in other apparently random locations within the glassy matrix of such rocks and within the groundmass of some siliceous lavas; in all such cases it can occur transitionally with areas that are better described as vapour-phase quartz[2], as well as with mosaics of more fibrous crystals (commonly spherulitic or semi-spherulitic) of apparently the same mineral assemblage. |

| Grain-type | Other Remarks |
| --- | --- |
| VOLCANIC, vitric | presence of shards and axiolitic or other types of shard ghosts allows interpretation as to volcaniclastic origin, together with presence of abundant/common fine sliver-shaped or otherwise broken crystal fragments of beta quartz and small cleavage fragments of feldspar (beta quartz recognised in the absence of preserved information as to crystal geometry on the basis of its inclusion-free and sharp extinguishing characteristics); in the absence of shards/shard ghosts/axiolites, the presence of abundant/common broken and especially sliver-shaped crystal fragments of the latter minerals (with or without biotite) set in a glassy/cryptocrystalline/microcrystalline matrix is good circumstantial evidence as to volcaniclastic rather than epiclastic sedimentary origin (note too that the matrix in control samples of many air-fall and ash-flow tuffs is crypto- rather than microcrystalline, and, where microcrystalline, the crystal mosaics resemble more those of qcc/qcs in that the crystals/extinction bundles show complex mutually interfingering relationships rather than the simple polyhedral shapes mentioned previously under 'Distinguishing characteristic'). |

| Grain-type | Other Remarks |
|---|---|
| SEDIMENTARY (Clastic), labile | Examples of this grain-type category are almost invariably of predominantly volcanic provenance and are commonly transitional with Ka at the finer grained end of the size spectrum, and with Vvk at all other size levels with respect to the constituent clastic grains of the latter; Kl is separated operationally from Ka where the constituent clastic grains are predominantly coarser than 0.03 mm, and packstone/wackestone varieties of Kl are separated from Vvk on the basis of absence (in the former) of glass shards/shard ghosts/axiolites and the presence of typically more pelitic, turbid matrix than is characteristic of Vvk; control field samples of New England sedimentary rocks show that much of what is described here as Kl most likely arises from 'volcanic greywackes' of predominantly turbidite origin, volcanic-lithic sandstones (grain-stones) of terrestrial/paralic origin, and crystal/lithic tuffs of both subareial and subaqueous origin. |

FOOTNOTES TO APPENDIX 1.2.

1 Constrained by thin-section studies of pebbles from arc-derived Sydney Basin conglomerates and stratigraphically controlled field samples of likely source rock types from the New England Fold Belt, N. S. W. and elsewhere, including deposits of hydrothermal chert (siliceous sinter) from the Central Volcanic Region, North Island, New Zealand.

2 Includes the grain-type which has been identified as vapour-phase quartz (vvpq); this is superficially similar to Vf but cloudy appearance in PPL is commonly more intense, commonly with a rusty-brown hue (due to disseminated vacuoles and associated specks/blebs of iron-oxide); extinction colours in XP are typically those of quartz (and hence a generally brighter grey or creamy-grey than typical of Vf even though masked by the discolouration); additionally, crystal size is commonly coarser than Vf, and although the fabric is still xenomorphic and the crystal boundaries somewhat ragged/irregular, these boundaries are more distinct and thus better defined than those in Vf; control samples show that this compositional/textural category arises as a deuterically altered devitrification phase in fluidal silicic lavas and vapour-phase cavity infills in flattened vesicles/miarolitic cavities in eutaxitic volcaniclastics; in the latter situation it can exhibit gradational, but more commonly sharply discontinuous, relationship with terminal (i.e., post-vapour phase) infills of vug quartz; Vvpq is superficially similar to hydrothermal vein quartz but differs from it by being characteristically finely crystalline, less composite and undulose in its extinction pattern in respect of individual crystals, lacking the comb structure of vein quartz, and by virtue of its typically greater concentration of vacuoles which do not occur in the train-like pattern common in some examples of

vein quartz, and in respect of the commonly conspicuous rusty-brown discolouration caused by these vacuoles and associated disseminated specks of iron-oxide.

3 Cf. Folk and Weaver (1952).

4 Crystal size scales and terminology are those of Pettijohn (1975, table 3-12) and Friedman (1965).

5 Sedimentary fabric terminology (mudstone, wackestone, packstone and grainstone) is that of Dunham (1962).

References cited in Appendix 1.2.

Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture. In Ham, W. E. (ed.) Classification of carbonate rocks. Amer. Assoc. Petrol. Geol. Mem. 1, pp. 108-121.

Folk, R., and Weaver, C. E., 1952, A study of the texture and composition of chert. Amer. Jour. Sci., v. 250, pp. 498-510.

Friedman, G. M., 1965, Terminology of crystallization textures and fabrics in sedimentary rocks. Jour. Sedim. Petrol., v. 35, pp. 643-655.

Pettijohn, F. J., 1975, Sedimentary rocks. Harper & Row, New York.

## APPENDIX 1.3. AMOUNTS OF MONO AND POLYCRYSTALLINE QUARTZ, VOLCANIC, SEDIMENTARY AND METAMORPHIC ROCK-FRAGMENTS

Appendix 1.3. Amounts of mono and polycrystalline quartz, volcanic, sedimentary and metamorphic rock-fragments in the Surat Basin sandstones based on a consistent count of 1000 points in each thin-section[1].

| Sample No. | Q | Qm | Qp | L | Lv | Ls | Lm |
|---|---|---|---|---|---|---|---|
| | ←——— | | | Whole-rock percentage | | | ———→ |
| <u>Griman Creek Formation</u> | | | | | | | |
| Surat 3/1 | 4.80 | 4.40 | 0.40 | 35.80 | 34.00 | 0.60 | 1.20 |
| " 2 | 3.90 | 3.80 | 0.10 | 36.00 | 33.90 | 0.80 | 1.30 |
| " 3 | 2.60 | 2.40 | 0.20 | 42.90 | 41.90 | 0.60 | 0.40 |
| " 4 | 2.10 | 1.80 | 0.30 | 35.20 | 33.30 | 0.40 | 1.50 |
| " 5 | 4.70 | 4.70 | 0.00 | 38.30 | 35.40 | 1.60 | 1.30 |
| " 6 | 3.20 | 2.70 | 0.50 | 32.00 | 30.10 | 0.40 | 1.50 |
| " 7 | 4.10 | 4.00 | 0.10 | 33.40 | 32.40 | 0.30 | 0.70 |
| " 9 | 9.10 | 8.70 | 0.40 | 38.10 | 35.10 | 1.50 | 1.50 |
| " 10 | 3.80 | 3.30 | 0.50 | 39.30 | 35.40 | 2.50 | 1.40 |
| " 11 | 4.10 | 3.70 | 0.40 | 50.20 | 46.80 | 2.20 | 1.20 |
| " 12 | 6.30 | 6.30 | 0.00 | 51.70 | 48.20 | 1.80 | 1.70 |
| " 13 | 5.30 | 5.30 | 0.00 | 58.60 | 56.00 | 1.10 | 1.50 |
| " 14 | 5.90 | 5.60 | 0.30 | 39.30 | 35.90 | 1.60 | 1.80 |
| " 15 | 2.40 | 2.30 | 0.10 | 38.80 | 36.10 | 0.80 | 1.90 |
| " 16 | 4.70 | 4.60 | 0.10 | 40.80 | 38.60 | 0.60 | 1.60 |
| " 17 | 6.10 | 6.00 | 0.10 | 41.10 | 38.50 | 1.20 | 1.40 |
| " 18 | 5.80 | 5.10 | 0.70 | 33.30 | 31.60 | 0.80 | 0.90 |
| " 20 | 6.10 | 5.80 | 0.30 | 43.20 | 39.90 | 1.70 | 1.60 |
| " 21 | 7.50 | 6.70 | 0.80 | 17.90 | 16.60 | 0.40 | 0.90 |
| " 22 | 10.50 | 8.80 | 1.70 | 19.40 | 18.50 | 0.50 | 0.40 |
| " 23 | 8.90 | 8.20 | 0.70 | 27.90 | 26.80 | 0.50 | 0.60 |

| Sample No. | | Q | Qm | Qp | L | Lv | Ls | Lm |
|---|---|---|---|---|---|---|---|---|
| | | ← Whole-rock-percentage → | | | | | | |
| " | 24 | 12.50 | 11.60 | 0.90 | 18.30 | 16.10 | 1.70 | 0.50 |
| " | 25 | 6.10 | 5.60 | 0.50 | 31.00 | 29.60 | 0.90 | 0.50 |
| " | 26 | 7.60 | 6.80 | 0.80 | 23.70 | 22.20 | 0.40 | 1.10 |
| " | 27 | 6.30 | 5.80 | 0.50 | 29.40 | 27.90 | 0.50 | 1.00 |
| " | 28 | 8.70 | 8.10 | 0.60 | 33.70 | 31.50 | 1.40 | 0.80 |
| <u>Surat Siltstone</u> | | | | | | | | |
| Surat | 3/29 | 8.80 | 8.10 | 0.70 | 25.70 | 23.60 | 1.40 | 0.70 |
| " | 30 | 15.00 | 13.90 | 1.10 | 11.40 | 11.00 | 0.40 | 0.00 |
| <u>Wallumbilla Formation</u> | | | | | | | | |
| Surat | 1/4 | 12.30 | 12.00 | 0.30 | 14.40 | 13.90 | 0.30 | 0.20 |
| " | 5 | 7.20 | 6.90 | 0.30 | 25.90 | 23.60 | 1.40 | 0.90 |
| " | 8 | 4.10 | 3.80 | 0.30 | 22.30 | 21.70 | 0.30 | 0.30 |
| " | 9 | 6.70 | 6.00 | 0.70 | 31.70 | 28.10 | 2.80 | 0.80 |
| Surat | 3/31 | 2.80 | 2.80 | 0.00 | 36.50 | 35.70 | 0.50 | 0.30 |
| " | 32 | 4.90 | 4.90 | 0.00 | 28.60 | 26.80 | 1.60 | 0.20 |
| " | 33 | 8.30 | 7.70 | 0.60 | 27.50 | 24.10 | 1.80 | 1.60 |
| <u>Bungil Formation</u> | | | | | | | | |
| Mitch. | 2/1 | 38.50 | 37.00 | 1.50 | 9.90 | 7.50 | 2.10 | 0.30 |
| " | 3 | 41.90 | 41.40 | 0.50 | 9.20 | 7.60 | 1.50 | 0.10 |
| " | 4 | 46.60 | 45.40 | 1.20 | 6.80 | 6.00 | 0.60 | 0.20 |
| Roma | 8/1 | 47.90 | 45.30 | 2.60 | 12.50 | 9.50 | 2.70 | 0.30 |
| " | 2 | 34.40 | 34.00 | 0.40 | 10.00 | 9.60 | 0.40 | 0.00 |
| " | 3 | 9.00 | 8.30 | 0.70 | 12.00 | 10.00 | 1.70 | 0.30 |
| " | 4 | 31.90 | 31.80 | 0.10 | 10.90 | 9.70 | 1.20 | 0.00 |
| Surat | 1/13 | 17.40 | 16.20 | 1.20 | 13.70 | 13.10 | 0.50 | 0.10 |
| " | 15 | 20.60 | 20.00 | 0.60 | 15.80 | 15.30 | 0.30 | 0.20 |
| " | 16 | 25.50 | 24.50 | 1.00 | 18.90 | 18.30 | 0.60 | 0.00 |
| " | 17 | 27.50 | 26.70 | 0.80 | 22.60 | 22.30 | 0.30 | 0.00 |

| Sample No. | | Q | Qm | Qp | L | Lv | Ls | Lm |
|---|---|---|---|---|---|---|---|---|
| | | ← Whole-rock percentage → | | | | | | |
| " | 18 | 31.60 | 30.10 | 1.50 | 25.80 | 25.20 | 0.60 | 0.00 |
| Mooga Sandstone | | | | | | | | |
| Mitch. | 2/61 | 29.90 | 29.20 | 0.70 | 11.10 | 7.70 | 3.10 | 0.30 |
| Roma | 8/5 | 50.80 | 50.70 | 0.10 | 2.70 | 2.20 | 0.30 | 0.20 |
| " | 7 | 47.50 | 47.40 | 0.10 | 1.80 | 1.40 | 0.00 | 0.40 |
| " | 8 | 50.40 | 50.30 | 0.10 | 1.60 | 1.20 | 0.20 | 0.20 |
| " | 9 | 42.80 | 40.60 | 2.20 | 10.30 | 9.50 | 0.70 | 0.10 |
| Orallo Formation | | | | | | | | |
| Mitch. | 2/6 | 14.70 | 12.80 | 1.90 | 33.20 | 28.50 | 3.80 | 0.90 |
| " | 7 | 6.00 | 4.80 | 1.20 | 41.40 | 37.20 | 4.00 | 0.20 |
| " | 9 | 13.20 | 10.90 | 2.30 | 41.00 | 33.30 | 5.80 | 1.90 |
| " | 10 | 23.30 | 22.20 | 1.10 | 23.50 | 19.30 | 3.60 | 0.60 |
| " | 11 | 39.00 | 37.00 | 2.00 | 16.10 | 13.50 | 2.20 | 0.40 |
| " | 12 | 34.20 | 33.20 | 1.00 | 12.10 | 9.60 | 1.80 | 0.70 |
| " | 13 | 43.10 | 40.0 | 3.10 | 13.00 | 11.40 | 1.50 | 0.10 |
| " | 14 | 34.60 | 32.70 | 1.90 | 21.10 | 18.60 | 1.30 | 1.20 |
| " | 15 | 18.70 | 17.90 | 0.80 | 31.80 | 25.20 | 5.40 | 1.20 |
| " | 16 | 25.90 | 25.20 | 0.70 | 26.20 | 18.50 | 6.20 | 1.50 |
| " | 17 | 29.10 | 27.90 | 1.20 | 25.50 | 21.80 | 3.10 | 0.60 |
| Roma | 8/10 | 5.80 | 5.40 | 0.40 | 62.00 | 54.90 | 5.90 | 1.20 |
| " | 11 | 10.40 | 8.10 | 2.30 | 56.60 | 51.90 | 3.80 | 0.90 |
| " | 12 | 10.10 | 9.10 | 1.00 | 38.20 | 34.00 | 3.20 | 1.00 |
| " | 13 | 13.00 | 12.20 | 0.80 | 45.00 | 39.00 | 4.70 | 1.30 |
| " | 14 | 52.00 | 50.10 | 1.90 | 9.50 | 8.90 | 0.50 | 0.10 |
| " | 15 | 41.40 | 39.40 | 2.00 | 18.80 | 17.80 | 0.90 | 0.10 |
| " | 16 | 22.50 | 20.50 | 2.00 | 33.20 | 31.10 | 2.10 | 0.00 |
| " | 17 | 8.50 | 7.60 | 0.90 | 49.80 | 43.30 | 5.00 | 1.50 |
| " | 18 | 16.30 | 15.80 | 0.50 | 29.50 | 24.20 | 4.80 | 0.50 |

| Sample No. | | Q | Qm | Qp | L | Lv | Ls | Lm |
|---|---|---|---|---|---|---|---|---|
| | | ← Whole-rock percentage → | | | | | | |
| Chin. | 4/1 | 40.00 | 38.60 | 1.40 | 18.80 | 16.80 | 1.80 | 0.20 |
| " | 2 | 21.50 | 20.20 | 1.30 | 27.70 | 23.90 | 3.00 | 0.80 |
| Roma | 8/20 | 14.40 | 13.60 | 0.80 | 30.90 | 24.20 | 5.50 | 1.20 |
| " | 19 | 16.90 | 16.40 | 0.50 | 27.10 | 21.10 | 4.80 | 1.20 |
| <u>Gubberamunda Sandstone</u> | | | | | | | | |
| Mitch. | 2/18 | 55.80 | 53.50 | 2.30 | 5.30 | 4.50 | 0.60 | 0.20 |
| " | 19 | 51.30 | 49.20 | 2.10 | 6.50 | 5.80 | 0.40 | 0.30 |
| " | 20 | 48.50 | 46.10 | 2.40 | 8.30 | 7.50 | 0.40 | 0.40 |
| " | 21 | 58.90 | 55.50 | 3.40 | 6.60 | 6.10 | 0.30 | 0.20 |
| Roma | 8/21 | 33.20 | 31.30 | 1.90 | 13.10 | 10.30 | 1.90 | 0.90 |
| " | 22 | 35.10 | 33.30 | 1.80 | 7.70 | 5.80 | 0.60 | 1.30 |
| " | 23 | 45.70 | 43.50 | 2.20 | 7.30 | 6.00 | 0.90 | 0.40 |
| " | 24 | 46.10 | 44.50 | 1.60 | 10.50 | 8.30 | 1.70 | 0.50 |
| " | 25 | 50.20 | 47.90 | 2.30 | 10.10 | 8.30 | 1.40 | 0.40 |
| " | 26 | 48.30 | 45.60 | 2.70 | 10.00 | 8.70 | 1.00 | 0.30 |
| Chin. | 4/3 | 21.90 | 21.20 | 0.70 | 32.40 | 28.90 | 3.10 | 0.40 |
| " | 5 | 23.80 | 23.20 | 0.60 | 40.80 | 36.00 | 4.60 | 0.20 |
| " | 6 | 19.70 | 19.00 | 0.70 | 39.50 | 34.90 | 3.90 | 0.70 |
| " | 7 | 19.00 | 17.10 | 1.90 | 34.90 | 27.30 | 6.90 | 0.70 |
| " | 8 | 37.90 | 36.00 | 1.90 | 26.30 | 21.70 | 4.10 | 0.50 |
| " | 9 | 30.50 | 28.50 | 2.00 | 28.20 | 21.30 | 5.90 | 1.00 |
| " | 10 | 36.10 | 34.70 | 1.40 | 7.40 | 4.30 | 2.50 | 0.60 |
| <u>Westbourne Formation</u> | | | | | | | | |
| Mitch. | 2/23 | 58.70 | 56.50 | 2.20 | 9.70 | 7.50 | 1.80 | 0.40 |
| " | 24 | 48.20 | 46.60 | 1.60 | 8.10 | 7.00 | 1.00 | 0.10 |
| " | 25 | 38.40 | 36.50 | 1.90 | 26.80 | 18.80 | 7.40 | 0.60 |
| " | 26 | 25.80 | 24.70 | 1.10 | 29.90 | 19.80 | 8.20 | 1.90 |

| Sample No. | | Q | Qm | Qp | L | Lv | Ls | Lm |
|---|---|---|---|---|---|---|---|---|
| | | ← Whole-rock percentage → | | | | | | |
| " | 27 | 27.80 | 26.90 | 0.90 | 26.40 | 19.10 | 6.10 | 1.20 |
| " | 28 | 31.70 | 30.40 | 1.30 | 21.30 | 14.90 | 5.30 | 1.10 |
| " | 29 | 15.40 | 14.80 | 0.60 | 29.10 | 18.60 | 9.70 | 0.80 |
| Roma | 8/28 | 47.10 | 45.60 | 1.50 | 7.80 | 6.00 | 1.20 | 0.60 |
| " | 29 | 33.20 | 32.90 | 0.30 | 16.30 | 11.80 | 3.50 | 1.00 |
| " | 30 | 32.20 | 31.20 | 1.00 | 28.10 | 22.70 | 3.90 | 1.50 |
| Chin. | 4/46 | 13.40 | 12.90 | 0.50 | 31.90 | 23.20 | 7.10 | 1.60 |
| " | 47 | 9.00 | 8.70 | 0.30 | 24.40 | 21.00 | 2.90 | 0.50 |
| " | 48 | 9.80 | 9.30 | 0.50 | 40.30 | 37.00 | 2.70 | 0.60 |
| <u>Springbok Sandstone</u> | | | | | | | | |
| Mitch. | 2/30 | 8.90 | 8.20 | 0.70 | 31.50 | 22.60 | 8.30 | 0.60 |
| " | 63 | 13.30 | 12.70 | 0.60 | 21.30 | 14.40 | 6.60 | 0.30 |
| Roma | 8/32 | 11.80 | 10.90 | 0.90 | 23.70 | 16.60 | 6.30 | 0.80 |
| " | 33 | 10.70 | 9.60 | 1.10 | 25.80 | 18.50 | 6.80 | 0.50 |
| Chin. | 4/49 | 8.60 | 8.30 | 0.30 | 32.40 | 26.00 | 6.00 | 0.40 |
| " | 50 | 4.00 | 4.00 | 0.00 | 50.30 | 45.00 | 4.90 | 0.40 |
| <u>Walloon Coal Measures</u> | | | | | | | | |
| Mitch. | 2/31 | 9.10 | 8.40 | 0.70 | 39.80 | 28.70 | 10.70 | 0.40 |
| " | 62 | 9.50 | 8.60 | 0.90 | 39.70 | 32.70 | 6.60 | 0.40 |
| Roma | 8/34 | 9.60 | 8.70 | 0.90 | 28.10 | 17.00 | 10.20 | 0.90 |
| " | 35 | 18.80 | 18.30 | 0.50 | 31.20 | 17.10 | 13.10 | 1.00 |
| " | 36 | 10.60 | 10.00 | 0.60 | 42.10 | 28.10 | 13.00 | 1.00 |
| " | 37 | 18.10 | 17.10 | 1.00 | 27.90 | 20.60 | 6.60 | 0.70 |
| " | 38 | 24.70 | 24.00 | 0.70 | 20.30 | 10.70 | 8.90 | 0.70 |
| " | 39 | 8.80 | 8.60 | 0.20 | 32.90 | 29.50 | 3.30 | 0.10 |
| " | 40 | 16.20 | 15.40 | 0.80 | 30.50 | 19.60 | 10.70 | 0.20 |
| " | 41 | 15.10 | 14.30 | 0.80 | 34.50 | 23.90 | 10.20 | 0.40 |

| Sample No. | | Q | Qm | Qp | L | Lv | Ls | Lm |
|---|---|---|---|---|---|---|---|---|
| | | ←—— Whole-rock percentage ——→ | | | | | | |
| " | 42 | 10.20 | 10.10 | 0.10 | 23.80 | 15.60 | 8.10 | 0.10 |
| Chin. | 4/11 | 24.60 | 24.10 | 0.50 | 18.40 | 12.70 | 5.60 | 0.10 |
| " | 12 | 19.60 | 19.10 | 0.50 | 37.80 | 28.20 | 9.10 | 0.50 |
| " | 13 | 20.70 | 20.40 | 0.30 | 33.00 | 25.60 | 7.10 | 0.30 |
| " | 14 | 20.70 | 20.20 | 0.50 | 28.80 | 24.40 | 4.40 | 0.00 |
| " | 15 | 16.30 | 15.70 | 0.60 | 34.20 | 26.40 | 7.60 | 0.20 |
| " | 16 | 15.40 | 15.30 | 0.10 | 31.30 | 25.40 | 5.50 | 0.40 |
| | 17 | 16.40 | 16.20 | 0.20 | 34.20 | 25.60 | 8.00 | 0.60 |
| " | 19 | 8.50 | 8.00 | 0.50 | 35.30 | 30.20 | 4.20 | 0.90 |
| " | 20 | 22.20 | 21.20 | 1.00 | 37.20 | 26.80 | 5.00 | 5.40 |
| " | 21 | 37.60 | 33.90 | 3.70 | 34.80 | 27.00 | 5.20 | 2.60 |
| " | 22 | 39.30 | 35.20 | 4.10 | 28.50 | 25.40 | 1.40 | 1.70 |
| " | 23 | 11.50 | 11.00 | 0.50 | 47.20 | 45.30 | 1.60 | 0.30 |
| Chin. | 4/51 | 21.90 | 21.10 | 0.80 | 21.50 | 20.20 | 1.20 | 0.10 |
| " | 52 | 14.70 | 14.30 | 0.40 | 28.30 | 23.30 | 4.50 | 0.50 |
| " | 53 | 11.90 | 11.30 | 0.60 | 33.90 | 27.50 | 5.80 | 0.60 |
| " | 54 | 21.80 | 20.70 | 1.10 | 33.70 | 25.70 | 7.60 | 0.40 |
| Hutton Sandstone | | | | | | | | |
| Mitch. | 2/32 | 22.40 | 20.60 | 1.80 | 25.20 | 19.60 | 0.90 | 4.70 |
| " | 33 | 20.20 | 19.00 | 1.20 | 30.30 | 23.70 | 2.90 | 3.70 |
| " | 33 | 34.40 | 32.10 | 2.30 | 33.30 | 26.40 | 4.80 | 2.10 |
| " | 35 | 23.60 | 22.20 | 1.40 | 27.60 | 19.50 | 2.60 | 5.50 |
| " | 36 | 29.90 | 28.40 | 1.50 | 30.90 | 25.20 | 2.40 | 3.30 |
| " | 37 | 61.10 | 56.60 | 4.50 | 10.00 | 8.60 | 1.30 | 0.10 |
| " | 38 | 38.10 | 36.30 | 1.80 | 23.40 | 20.50 | 1.00 | 1.90 |
| " | 39 | 55.10 | 51.80 | 3.30 | 11.70 | 8.70 | 2.20 | 0.80 |
| " | 40 | 58.30 | 53.50 | 4.80 | 11.40 | 9.90 | 1.20 | 0.30 |

| Sample No. | | Q | Qm | Qp | L | Lv | Ls | Lm |
|---|---|---|---|---|---|---|---|---|
| | | ←——— Whole-rock percentage ———→ | | | | | | |
| " | 41 | 51.60 | 49.80 | 1.80 | 9.10 | 7.00 | 0.70 | 1.40 |
| " | 42 | 53.50 | 52.60 | 0.90 | 4.60 | 3.40 | 0.60 | 0.60 |
| " | 43 | 52.60 | 51.10 | 1.50 | 4.60 | 3.00 | 0.80 | 0.80 |
| " | 44 | 56.30 | 54.70 | 1.60 | 4.00 | 3.00 | 0.30 | 0.70 |
| " | 45 | 56.10 | 53.90 | 2.20 | 3.70 | 2.60 | 0.50 | 0.60 |
| " | 46 | 55.50 | 53.70 | 1.80 | 4.40 | 3.60 | 0.20 | 0.60 |
| " | 47 | 50.00 | 48.50 | 1.50 | 6.20 | 5.10 | 0.20 | 0.90 |
| " | 49 | 49.10 | 48.60 | 0.50 | 6.30 | 5.20 | 0.00 | 1.10 |
| " | 50 | 51.80 | 50.90 | 0.90 | 7.20 | 5.80 | 0.10 | 1.30 |
| " | 51 | 58.40 | 56.80 | 1.60 | 3.00 | 2.20 | 0.20 | 0.60 |
| " | 52 | 45.80 | 44.00 | 1.80 | 7.30 | 4.60 | 0.20 | 2.50 |
| " | 53 | 55.00 | 53.00 | 2.00 | 6.10 | 4.10 | 0.60 | 1.40 |
| " | 54 | 57.70 | 55.40 | 2.30 | 4.90 | 4.30 | 0.10 | 0.50 |
| " | 55 | 64.30 | 62.10 | 2.20 | 5.00 | 3.50 | 0.00 | 1.50 |
| " | 56 | 60.50 | 59.00 | 1.50 | 5.60 | 4.60 | 0.20 | 0.80 |
| " | 57 | 62.70 | 60.20 | 2.50 | 6.50 | 4.70 | 0.50 | 1.30 |
| Roma | 8/43 | 15.30 | 14.70 | 0.60 | 28.90 | 20.50 | 6.00 | 2.40 |
| " | 44 | 22.70 | 20.60 | 2.10 | 33.30 | 23.90 | 7.00 | 2.40 |
| " | 45 | 24.70 | 22.60 | 2.10 | 32.70 | 24.10 | 6.40 | 2.20 |
| " | 46 | 37.80 | 36.30 | 1.50 | 23.00 | 17.80 | 3.50 | 1.70 |
| " | 47 | 38.60 | 35.30 | 3.30 | 27.80 | 20.10 | 5.70 | 2.00 |
| " | 48 | 41.20 | 38.70 | 2.50 | 28.80 | 23.50 | 3.50 | 1.80 |
| " | 49 | 37.60 | 35.30 | 2.30 | 25.80 | 17.40 | 6.50 | 1.90 |
| " | 50 | 35.80 | 33.80 | 2.00 | 23.30 | 17.00 | 4.10 | 2.20 |
| " | 51 | 66.80 | 62.40 | 4.40 | 7.20 | 2.70 | 4.50 | 0.00 |
| " | 52 | 42.30 | 40.10 | 2.20 | 9.40 | 6.20 | 1.20 | 2.00 |
| " | 53 | 66.20 | 62.80 | 3.40 | 4.30 | 3.60 | 0.30 | 0.40 |
| " | 54 | 49.00 | 47.20 | 1.80 | 13.40 | 10.30 | 1.20 | 1.90 |

| Sample No. | | Q | Qm | Qp | L | Lv | Ls | Lm |
|---|---|---|---|---|---|---|---|---|
| | | ← Whole-rock percentage → | | | | | | |
| " | 55 | 45.30 | 43.60 | 1.70 | 10.20 | 5.60 | 3.00 | 1.60 |
| " | 56 | 57.20 | 55.60 | 1.60 | 4.50 | 3.40 | 0.70 | 0.40 |
| " | 57 | 41.40 | 40.60 | 0.80 | 9.60 | 5.20 | 3.50 | 0.90 |
| " | 58 | 42.00 | 40.20 | 1.80 | 6.30 | 4.60 | 1.20 | 0.50 |
| " | 59 | 61.40 | 57.60 | 3.80 | 6.10 | 5.20 | 0.40 | 0.50 |
| " | 60 | 53.00 | 51.70 | 1.30 | 7.40 | 5.90 | 0.40 | 1.10 |
| " | 61 | 51.50 | 49.70 | 1.80 | 8.90 | 6.90 | 0.70 | 1.30 |
| " | 63 | 52.20 | 50.70 | 1.50 | 6.50 | 4.90 | 0.70 | 0.90 |
| " | 64 | 47.50 | 46.10 | 1.40 | 7.50 | 6.10 | 0.60 | 0.80 |
| " | 65 | 56.40 | 54.60 | 1.80 | 4.40 | 3.20 | 0.10 | 1.10 |
| Chin. | 4/24 | 64.50 | 63.30 | 1.20 | 11.30 | 6.90 | 2.40 | 2.00 |
| " | 25 | 60.00 | 55.40 | 4.60 | 10.30 | 7.80 | 2.30 | 0.20 |
| " | 27 | 70.70 | 66.20 | 4.50 | 4.40 | 2.50 | 1.40 | 0.50 |
| " | 28 | 44.30 | 42.90 | 1.40 | 13.10 | 8.20 | 2.70 | 2.20 |
| Evergreen Formation | | | | | | | | |
| Mitch. | 2/58 | 79.30 | 77.60 | 1.70 | 1.50 | 1.30 | 0.10 | 0.10 |
| " | 59 | 71.90 | 70.70 | 1.20 | 3.90 | 3.40 | 0.00 | 0.50 |
| Roma | 8/66 | 47.10 | 44.70 | 2.40 | 15.70 | 12.00 | 1.30 | 2.40 |
| " | 67 | 37.70 | 36.80 | 0.90 | 19.40 | 12.70 | 2.60 | 4.10 |
| " | 68 | 57.90 | 57.20 | 0.70 | 13.00 | 12.50 | 0.20 | 0.30 |
| " | 70 | 26.00 | 25.50 | 0.50 | 18.50 | 16.40 | 1.20 | 0.90 |
| Chin. | 4/30 | 34.70 | 34.40 | 0.30 | 9.40 | 8.30 | 0.00 | 1.10 |
| " | 31 | 64.60 | 62.70 | 1.90 | 6.00 | 4.40 | 0.70 | 0.90 |
| " | 32 | 50.20 | 47.20 | 3.00 | 9.90 | 6.90 | 0.70 | 2.30 |
| " | 33 | 59.10 | 56.10 | 3.00 | 9.80 | 6.20 | 2.50 | 1.10 |
| " | 34 | 21.60 | 20.80 | 0.80 | 22.20 | 19.40 | 1.20 | 1.60 |
| " | 35 | 24.00 | 22.70 | 1.30 | 31.50 | 27.80 | 1.10 | 2.60 |
| " | 36 | 34.60 | 32.50 | 2.10 | 33.50 | 30.10 | 2.20 | 1.20 |

| Sample No. | | Q | Qm | Qp | L | Lv | Ls | Lm |
|---|---|---|---|---|---|---|---|---|
| | | ← | | Whole-rock percentage | | | | → |
| " | 37 | 25.50 | 24.80 | 0.70 | 31.50 | 28.60 | 2.00 | 0.90 |
| " | 38 | 20.00 | 19.00 | 1.00 | 27.40 | 23.20 | 2.40 | 1.80 |
| " | 39 | 17.90 | 17.10 | 0.80 | 30.80 | 25.10 | 3.70 | 2.00 |
| <u>Precipice Sandstone</u> | | | | | | | | |
| Mitch. | 2/60 | 76.80 | 74.60 | 2.20 | 2.80 | 0.00 | 2.00 | 0.80 |
| Roma | 8/71 | 49.00 | 47.20 | 1.80 | 12.00 | 0.00 | 11.20 | 0.80 |
| " | 72 | 54.20 | 51.10 | 3.10 | 12.70 | 2.90 | 5.80 | 4.00 |
| Chin. | 4/40 | 74.90 | 72.50 | 2.40 | 4.80 | 4.20 | 0.10 | 0.50 |
| " | 41 | 85.40 | 82.80 | 2.60 | 1.40 | 0.00 | 1.10 | 0.30 |
| " | 42 | 76.00 | 74.70 | 1.30 | 0.10 | 0.00 | 0.10 | 0.00 |
| " | 43 | 87.50 | 85.80 | 1.70 | 0.20 | 0.00 | 0.10 | 0.10 |
| " | 44 | 78.30 | 77.40 | 0.90 | 0.00 | 0.00 | 0.00 | 0.00 |
| " | 45 | 74.80 | 72.90 | 1.90 | 0.40 | 0.00 | 0.20 | 0.20 |

FOOTNOTE TO APPENDIX 1.3

Q = Qm + Qp, sum of mono and polycrystalline quartz.

Qm - Monocrystalline quartz, Qp - Polycrystalline quartz (excluding chert).

L = Total lithics = Lv + Ls + Lm

Lv - Vocanic rock-fragments; Ls - Sedimentary rock-fragments including chert/chalcedony. Lm - Metamorphic rock-fragments.

## APPENDIX 1.4. AMOUNTS OF ALKALI FELDSPAR BASED ON POINT-COUNTING OF STAINED THIN-SECTIONS

Appendix 1.4. Framework grain composition showing the amount of alkai feldspar based on point-counting of 600 grains in each thin-section of a subset of samples stained with sodium cobaltinitrite.

| Sample No. | Stratigraphic Unit | Quartz | K-feldspar | Plagiocalse | Rock-frag. | K-feldspar |
|---|---|---|---|---|---|---|
| | | <———— | (Whole-rock %) | | ————> | (% Total feldspar) |
| Surat 3/5 | Griman Ck. Fm. | 12.00 | 3.00 | 33.50 | 51.50 | 8.20 |
| Surat 3/11 | " | 8.66 | 2.83 | 26.60 | 61.80 | 9.60 |
| Surat 1/5 | Wallumbilla Fm. | 14.66 | 5.16 | 37.00 | 43.20 | 12.25 |
| Surat 3/33 | " | 18.00 | 2.83 | 29.80 | 49.30 | 8.60 |
| Roma 8/3 | Bungil Fm. | 21.30 | 2.16 | 26.80 | 49.70 | 7.50 |
| Surat 3/15 | " | 55.30 | 8.30 | 17.50 | 18.90 | 32.25 |
| Mitch. 2/61 | Mooga Sandstone | 46.80 | 13.50 | 16.16 | 23.50 | 45.50 |
| Roma 8/9 | " | 73.30 | 12.30 | 1.30 | 13.00 | 90.00 |
| Mitch. 2/ 9 | Orallo Fm. | 15.00 | 2.00 | 25.80 | 57.20 | 7.00 |
| Chin. 4/1 | " | 50.30 | 7.30 | 20.00 | 22.30 | 26.80 |
| Mitch. 2/19 | Gubberamunda Sst. | 77.80 | 10.83 | 5.83 | 5.50 | 65.00 |
| " 21 | " | 74.16 | 11.16 | 9.16 | 5.50 | 55.00 |
| Roma 8/24 | " | 60.33 | 10.83 | 13.83 | 15.00 | 44.00 |
| Chin. 4/3 | " | 21.20 | 5.66 | 30.80 | 42.50 | 15.50 |
| Mitch. 2/24 | Westb'ne Fm. | 65.50 | 5.66 | 16.80 | 12.00 | 25.00 |
| Chin. 4/46 | " | 19.00 | 6.16 | 27.00 | 48.00 | 18.60 |
| Roma 8/37 | Walloon Coal M. | 26.00 | 0.60 | 30.60 | 43.00 | 2.00 |
| Chin. 4/23 | " | 20.60 | 1.83 | 12.83 | 64.60 | 12.50 |
| Mitch. 2/35 | Hutton Sandstone | 33.60 | 8.30 | 15.60 | 42.30 | 34.70 |
| " 39 | " | 74.80 | 8.80 | 4.80 | 11.50 | 64.60 |
| Roma 8/46 | " | 46.16 | 6.80 | 11.60 | 35.30 | 37.00 |
| Chin. 4/25 | " | 77.50 | 6.30 | 3.50 | 12.70 | 64.40 |
| Mitch. 2/58 | Evergreen Fm. | 96.16 | 0.30 | 1.50 | 2.00 | 18.00 |
| Roma 8/67 | " | 52.30 | 4.30 | 17.30 | 26.00 | 20.00 |
| Roma 8/72 | Precipice Sst. | 74.50 | 3.80 | 5.60 | 16.00 | 40.30 |
| Chin. 4/43 | " | 96.80 | 0.16 | 0.30 | 2.60 | 33.00 |

## APPENDIX 1.5. PETROGRAPHIC MODAL ANALYSES AND POROSITY-PERMEABILITY DATA

Appendix 1.5. Petrographic modal analyses and porosity-permeability data employed in the thesis. Depth in metres below surface. Epimat.- epimatrix, Protomat. - proto/ortho matrix, s.d. - standard deviation, T.S. Por. - total thin-section porosity, Sec. Por. - secondary dissolution porosity (as opposed to fracture porosity; cf. Appendix 1.9).

| Sample No. | Depth | Quartz | Feldspar | Rock-frag. | Mica | Cement | Epimat. | Protomat. | Gr. size | Sorting | Core por. | Perm. | T.S. Por. | Sec. Por. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (m) | <—— | | (whole-rock %) | | | | ——> | (φ) | (φ s.d.) | (vol. %) | (md) | <— (whole-rock %) | —> |
| Griman Creek Formation | | | | | | | | | | | | | | |
| Surat 3/1 | 16.91 | 4.80 | 20.30 | 35.80 | 3.40 | 5.60 | 0.00 | 10.70 | 2.88 | 0.55 | 27.00 | 35.0 | 6.20 | 3.30 |
| " 2 | 20.26 | 3.90 | 24.40 | 36.00 | 2.90 | 4.10 | 0.00 | 7.50 | 2.83 | 0.50 | 28.00 | 39.0 | 4.10 | 1.50 |
| " 3 | 31.14 | 2.60 | 27.20 | 42.90 | 6.70 | 2.70 | 1.60 | 8.40 | 2.81 | 0.50 | 29.00 | 70.0 | 3.50 | 1.20 |
| " 4 | 47.90 | 2.10 | 29.50 | 35.20 | 5.40 | 10.10 | 0.70 | 11.80 | 2.93 | 0.55 | 27.00 | 0.001 | 2.10 | 1.10 |
| " 5 | 54.00 | 4.70 | 27.20 | 38.30 | 2.00 | 20.00 | 0.00 | 6.50 | 2.47 | 0.60 | 6.00 | 0.001 | 0.00 | 0.00 |
| " 6 | 69.30 | 3.20 | 33.20 | 32.00 | 4.20 | 2.50 | 1.10 | 12.50 | 2.94 | 0.55 | 31.00 | 243.0 | 8.20 | 2.70 |
| " 7 | 99.40 | 4.10 | 29.90 | 33.40 | 5.60 | 2.60 | 0.70 | 12.40 | 2.74 | 0.50 | 31.00 | 143.0 | 7.50 | 2.80 |
| " 9 | 113.20 | 9.10 | 26.60 | 38.10 | 1.80 | 13.60 | 0.20 | 4.80 | 2.57 | 0.65 | 28.00 | 0.6 | 4.00 | 1.20 |
| " 10 | 140.70 | 3.80 | 27.80 | 39.30 | 3.30 | 4.80 | 0.00 | 9.00 | 2.44 | 0.65 | 25.00 | 18.0 | 4.20 | 1.30 |
| " 11 | 147.20 | 4.10 | 20.00 | 50.20 | 3.60 | 10.60 | 0.30 | 2.10 | 1.94 | 1.20 | 28.00 | 93.0 | 5.20 | 0.70 |
| " 12 | 153.90 | 6.30 | 20.80 | 51.70 | 0.50 | 15.50 | 0.00 | 0.00 | 2.05 | 0.55 | 26.00 | 22.0 | 4.50 | 0.60 |
| " 13 | 161.50 | 5.30 | 19.50 | 58.60 | 1.40 | 9.10 | 0.00 | 0.30 | 2.49 | 0.70 | 29.00 | 35.0 | 4.50 | 1.00 |
| " 14 | 164.20 | 5.90 | 23.80 | 39.30 | 4.70 | 5.90 | 0.00 | 7.60 | 2.31 | 0.65 | 30.00 | 640.0 | 11.00 | 5.30 |
| " 15 | 171.80 | 2.40 | 26.40 | 38.80 | 5.70 | 3.70 | 0.30 | 10.50 | 2.47 | 0.55 | 29.00 | 194.0 | 9.40 | 5.10 |
| " 16 | 201.70 | 4.70 | 29.50 | 40.80 | 4.00 | 3.10 | 0.10 | 11.00 | 2.86 | 0.60 | 29.00 | 188.0 | 8.10 | 5.60 |
| " 17 | 213.00 | 6.10 | 31.60 | 41.10 | 1.30 | 6.40 | 0.00 | 0.00 | 2.51 | 0.60 | 30.00 | 166.0 | 7.60 | 2.30 |

| Sample No. | Depth | Quartz | Feldspar | Rock-frag. | Mica | Cement | Epimat. | Protomat. | Gr. size | Sorting | Core por. | Perm. | T.S. Por. | Sec. Por. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (m) | <—— (whole-rock %) | | | | | | ——> | (φ) | (φ s.d.) | (vol. %) | (md) | <— (whole-rock %) | —> |
| Surat 3/18 | 227.80 | 5.80 | 25.10 | 33.30 | 1.30 | 26.70 | 0.00 | 7.40 | 2.84 | 0.60 | 9.00 | 0.001 | 0.00 | 0.00 |
| " 20 | 240.90 | 6.10 | 27.60 | 43.20 | 4.00 | 5.70 | 0.00 | 8.90 | 2.30 | 0.60 | 26.00 | 0.88 | 3.00 | 1.20 |
| " 21 | 263.80 | 7.50 | 40.40 | 17.90 | 2.00 | 0.90 | 0.50 | 6.40 | 2.70 | 0.55 | 27.00 | 299.0 | 11.10 | 3.00 |
| " 22 | 287.50 | 10.50 | 31.20 | 19.40 | 1.20 | 2.30 | 1.80 | 12.00 | 2.79 | 0.55 | 32.00 | 529.0 | 9.80 | 3.70 |
| " 23 | 291.50 | 8.90 | 29.30 | 27.90 | 1.20 | 0.50 | 0.30 | 7.20 | 2.40 | 0.50 | 31.00 | 954.0 | 12.20 | 4.20 |
| " 24 | 295.20 | 12.50 | 43.40 | 18.30 | 0.70 | 4.00 | 0.30 | 2.10 | 2.45 | 0.50 | 31.00 | 1495.0 | 13.60 | 3.20 |
| " 25 | 306.70 | 6.10 | 28.20 | 31.00 | 2.00 | 12.60 | 0.00 | 5.50 | 2.91 | 0.60 | 10.00 | 0.001 | 0.00 | 0.00 |
| " 26 | 313.90 | 7.60 | 34.60 | 23.70 | 1.70 | 0.20 | 2.00 | 13.10 | 2.51 | 0.55 | 33.00 | 642.0 | 11.80 | 3.30 |
| " 27 | 329.00 | 6.30 | 28.80 | 29.40 | 1.00 | 0.00 | 1.80 | 10.80 | 2.70 | 0.50 | 33.00 | 880.0 | 11.30 | 3.20 |
| " 28 | 346.00 | 8.70 | 20.90 | 33.70 | 2.90 | 0.90 | 1.50 | 9.40 | 2.60 | 0.50 | 29.00 | 309.0 | 9.60 | 3.70 |
| <u>Surat Siltstone</u> | | | | | | | | | | | | | | |
| Surat 3/29 | 358.20 | 8.80 | 26.30 | 25.70 | 1.40 | 0.00 | 1.80 | 11.10 | 2.73 | 0.40 | 28.00 | 132.0 | 8.60 | 2.50 |
| " 30 | 402.80 | 15.00 | 18.80 | 11.40 | 1.40 | 4.70 | 0.00 | 15.20 | 2.51 | 0.65 | 16.00 | 0.00 | 0.001 | 0.00 |
| <u>Wallumbilla Formation</u> | | | | | | | | | | | | | | |
| Surat 1/4 | 153.60 | 12.30 | 27.60 | 14.40 | 0.60 | 1.80 | 2.70 | 26.80 | 3.11 | 0.40 | 31.00 | 0.001 | 1.10 | 0.10 |
| " 5 | 160.30 | 7.20 | 30.00 | 25.90 | 1.30 | 0.70 | 3.90 | 21.10 | 2.90 | 0.55 | 31.00 | 95.0 | 3.40 | 0.40 |
| " 8 | 176.90 | 4.10 | 18.10 | 22.30 | 9.00 | 10.30 | 0.00 | 30.10 | 3.29 | 0.80 | 9.00 | 0.001 | 0.00 | 0.00 |

| Sample No. | Depth | Quartz | Feldspar | Rock-frag. | Mica | Cement | Epimat. | Protomat. | Gr. size | Sorting | Core por. | Perm. | T.S. Por. | Sec. Por. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (m) | <— | | | (whole-rock %) | | | —> | (φ) | (φ s.d.) | (vol. %) | (md) | <— (whole-rock %) | —> |
| Surat 1/9 | 181.50 | 6.70 | 28.40 | 31.70 | 2.10 | 0.10 | 3.60 | 16.30 | 2.62 | 0.60 | 30.00 | 82.0 | 2.10 | 0.40 |
| Surat 3/31 | 431.60 | 2.80 | 23.80 | 36.50 | 3.50 | 0.00 | 3.50 | 17.70 | 2.99 | 0.65 | 29.00 | 36.0 | 5.40 | 2.40 |
| " 32 | 436.90 | 4.90 | 21.20 | 28.60 | 4.50 | 17.30 | 1.40 | 17.30 | 3.08 | 0.55 | 17.00 | 0.001 | 0.00 | 0.00 |
| " 33 | 438.02 | 8.30 | 18.30 | 27.50 | 2.20 | 7.70 | 0.00 | 11.40 | 2.35 | 0.80 | 29.40[1] | 24.0 | 8.00 | 4.80 |
| **Bungil Formation** | | | | | | | | | | | | | | |
| Mitch. 2/1 | 52.86 | 38.50 | 12.80 | 9.90 | 0.70 | 0.10 | 0.00 | 21.30 | 2.25 | 0.80 | 28.00 | 94.0 | 2.60 | 0.00 |
| " 3 | 69.63 | 41.90 | 15.70 | 9.20 | 1.90 | 0.80 | 0.40 | 19.20 | 3.04 | 0.55 | 27.00 | 66.0 | 8.00 | 0.10 |
| " 4 | 77.00 | 46.60 | 11.10 | 6.80 | 2.40 | 0.10 | 0.80 | 23.60 | 3.20 | 1.00 | 31.00 | 2456.0 | 6.30 | 0.40 |
| Roma 8/1 | 41.86 | 47.90 | 6.40 | 12.50 | 0.30 | 2.50 | 0.00 | 3.50 | 1.41 | 0.50 | 30.60 | 2800.0 | 13.20 | 4.10 |
| " 2 | 78.50 | 34.40 | 18.10 | 10.00 | 4.30 | 0.00 | 0.00 | 19.40 | 3.46 | 0.50 | 32.40 | 258.0 | 7.30 | 1.20 |
| " 3 | 100.95 | 9.00 | 16.30 | 12.00 | 8.00 | 6.00 | 8.40 | 19.20 | 2.75 | 0.50 | 24.80 | 36.0 | 0.20 | 0.00 |
| " 4 | 113.87 | 31.90 | 23.10 | 10.90 | 1.20 | 0.10 | 1.20 | 22.60 | 3.22 | 0.40 | 34.70 | 104.0 | 5.50 | 1.40 |
| Surat 1/13 | 328.90 | 17.40 | 26.60 | 13.70 | 0.80 | 10.80 | 4.20 | 18.00 | 2.61 | 0.75 | 18.00 | 6.0 | 0.00 | 0.00 |
| " 15 | 342.40 | 20.60 | 21.70 | 15.80 | 2.70 | 12.90 | 2.80 | 14.40 | 2.56 | 0.90 | 15.00 | 0.001 | 0.00 | 0.00 |
| " 16 | 350.46 | 25.50 | 18.30 | 18.90 | 2.90 | 1.50 | 2.60 | 19.00 | 2.60 | 0.75 | N.D.[2] | N.D. | 1.80 | 0.30 |
| " 17 | 350.76 | 27.50 | 20.70 | 22.60 | 3.80 | 1.00 | 0.60 | 11.50 | 2.64 | 0.65 | N.D. | N.D. | 0.50 | 0.10 |
| " 18 | 351.05 | 31.60 | 13.50 | 25.80 | 3.20 | 17.10 | 0.00 | 8.60 | 2.68 | 1.20 | N.D. | N.D. | 0.00 | 0.00 |

| Sample No. | Depth | Quartz | Feldspar | Rock-frag. | Mica | Cement | Epimat. | Protomat. | Gr. size | Sorting | Core por. | Perm. | T.S. Por. | Sec. Por. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (m) | ← (whole-rock %) | | | | | | → | (φ) | (φ s.d.) | (vol. %) | (md) | ← (whole-rock %) | → |
| Mooga Sandstone | | | | | | | | | | | | | | |
| Mitch. 2/61 | 125.64 | 29.90 | 13.70 | 11.10 | 2.80 | 0.10 | 4.10 | 35.60 | 3.09 | 0.75 | 26.20 | 4.90 | 0.50 | 0.00 |
| Roma 8/5 | 135.69 | 50.80 | 17.30 | 2.70 | 2.30 | 0.00 | 3.10 | 17.50 | 3.12 | 0.80 | 29.00 | 46.0 | 6.20 | 0.90 |
| " 7 | 153.34 | 47.50 | 10.90 | 1.80 | 3.30 | 0.00 | 1.40 | 30.00 | 3.51 | 0.45 | 27.60 | 13.0 | 2.00 | 0.00 |
| " 8 | 168.91 | 50.40 | 16.70 | 1.60 | 2.90 | 0.00 | 1.30 | 17.00 | 3.24 | 0.50 | 30.70 | 161.0 | 9.20 | 0.10 |
| " 9 | 182.88 | 42.80 | 7.70 | 10.30 | 13.30 | 0.30 | 5.00 | 17.40 | 1.92 | 1.50 | 18.40 | 0.53 | 0.00 | 0.00 |
| Orallo Formation | | | | | | | | | | | | | | |
| Mitch. 2/6 | 151.18 | 14.70 | 15.70 | 33.20 | 1.90 | 0.00 | 9.20 | 24.30 | 1.89 | 0.48 | 19.00 | 0.32 | 0.20 | 0.00 |
| " 7 | 166.34 | 6.00 | 18.20 | 41.40 | 2.80 | 0.20 | 1.20 | 26.20 | 2.16 | 1.80 | 28.00 | 0.38 | 2.30 | 0.10 |
| " 9 | 180.70 | 13.20 | 24.40 | 41.00 | 1.80 | 0.00 | 1.00 | 11.40 | 1.91 | 0.60 | 27.00 | 311.0 | 5.10 | 0.60 |
| " 10 | 189.52 | 23.30 | 29.40 | 23.50 | 0.80 | 0.00 | 5.00 | 12.00 | 1.80 | 0.70 | 26.00 | 33.0 | 4.80 | 0.20 |
| " 11 | 198.84 | 39.00 | 21.80 | 16.10 | 0.70 | 0.00 | 6.50 | 3.90 | 1.62 | 0.65 | 31.00 | 1296.0 | 12.80 | 3.50 |
| " 12 | 207.39 | 34.20 | 21.70 | 12.10 | 2.20 | 0.00 | 4.50 | 3.70 | 2.43 | 0.60 | 33.00 | 1069.0 | 10.80 | 2.20 |
| " 13 | 215.69 | 43.10 | 18.20 | 13.00 | 0.60 | 0.00 | 1.70 | 2.90 | 1.50 | 0.70 | 33.00 | 3313.0 | 21.10 | 8.80 |
| " 14 | 226.86 | 34.60 | 20.70 | 21.10 | 1.80 | 0.50 | 1.40 | 3.90 | 1.86 | 0.68 | 32.00 | 1983.0 | 15.70 | 4.40 |
| " 15 | 236.40 | 18.70 | 26.40 | 31.80 | 0.70 | 0.20 | 2.60 | 6.40 | 1.98 | 0.65 | 26.00 | 514.0 | 13.30 | 13.30 |
| " 16 | 245.46 | 25.90 | 27.40 | 26.20 | 1.30 | 0.00 | 2.50 | 9.70 | 1.93 | 0.75 | 26.00 | 288.0 | 6.80 | 2.80 |
| " 17 | 253.62 | 29.10 | 18.80 | 25.50 | 1.80 | 0.00 | 2.40 | 10.50 | 1.99 | 0.50 | 31.00 | N.D. | 12.40 | 4.00 |

| Sample No. | Depth | Quartz | Feldspar | Rock-frag. | Mica | Cement | Epimat. | Protomat. | Gr. size | Sorting | Core por. | Perm. | T.S. Por. | Sec. Por. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (m) | <———— | | | (whole-rock %) | | | ————> | ($\phi$) | ($\phi$ s.d.) | (vol. %) | (md) | <— (whole-rock %) | —> |
| Roma 8/10 | 195.52 | 5.80 | 17.40 | 62.00 | 2.40 | 0.00 | 2.40 | 5.90 | 1.87 | 0.70 | 25.10 | 58.0 | 4.10 | 1.50 |
| " 11 | 203.62 | 10.40 | 14.80 | 56.60 | 1.50 | 0.00 | 5.60 | 7.30 | 1.82 | 0.65 | 26.80 | 110.0 | 2.50 | 0.60 |
| " 12 | 222.18 | 10.10 | 32.50 | 38.20 | 0.80 | 7.50 | 1.10 | 5.70 | 1.97 | 0.50 | 27.30 | 120.0 | 2.70 | 1.20 |
| " 13 | 232.10 | 13.00 | 23.60 | 45.00 | 2.10 | 0.40 | 1.60 | 6.80 | 1.72 | 0.48 | 29.10 | 852.0 | 7.10 | 7.10 |
| " 14 | 242.88 | 52.00 | 19.00 | 9.50 | 0.40 | 0.00 | 2.40 | 1.10 | 1.67 | 0.70 | 35.10 | 6324.0 | 14.90 | 5.80 |
| " 15 | 253.22 | 41.40 | 21.90 | 18.80 | 0.30 | 0.00 | 4.30 | 1.10 | 1.25 | 1.80 | 31.30 | 3240.0 | 12.30 | 5.90 |
| " 16 | 263.97 | 22.50 | 14.90 | 33.20 | 1.20 | 0.00 | 0.10 | 20.70 | 1.37 | 1.20 | 25.90 | 1574.0 | 7.20 | 3.50 |
| " 17 | 274.02 | 8.50 | 20.30 | 49.80 | 1.00 | 0.00 | 2.00 | 11.70 | 1.46 | 0.70 | 24.70 | 271.0 | 6.00 | 3.40 |
| " 18 | 284.59 | 16.30 | 25.50 | 29.50 | 2.00 | 0.00 | 4.00 | 13.20 | 1.96 | 0.60 | 25.50 | 282.0 | 7.90 | 3.60 |
| Roma 8/19 | 295.85 | 16.90 | 23.30 | 27.10 | 2.70 | 0.00 | 3.30 | 18.10 | 2.66 | 0.70 | 25.60 | 167.0 | 6.50 | 2.20 |
| " 20 | 306.38 | 14.40 | 28.60 | 30.90 | 2.80 | 0.20 | 3.80 | 12.70 | 2.06 | 0.80 | 26.70 | 424.0 | 6.00 | 2.50 |
| Chin. 4/1 | 39.54 | 40.00 | 24.20 | 18.80 | 0.00 | 0.00 | 2.40 | 1.20 | 1.92 | 0.65 | 29.30 | 1221.0 | 13.00 | 5.00 |
| " 2 | 50.26 | 21.50 | 18.70 | 27.70 | 0.90 | 0.00 | 2.00 | 16.80 | 2.13 | 0.60 | 31.00 | 818.0 | 7.10 | 0.70 |
| Gubberamunda Sandstone | | | | | | | | | | | | | | |
| Mitch. 2/18 | 272.17 | 55.80 | 9.80 | 5.30 | 0.00 | 1.10 | 3.30 | 9.90 | 0.88 | 1.30 | 26.00 | 350.0 | 9.90 | 9.90 |
| " 19 | 283.47 | 51.30 | 14.40 | 6.50 | 0.10 | 1.20 | 6.30 | 4.00 | 1.56 | 0.50 | 33.00 | 2037.0 | 15.20 | 15.20 |
| " 20 | 292.22 | 48.50 | 22.80 | 8.30 | 0.70 | 0.00 | 4.90 | 5.50 | 1.91 | 0.50 | 30.00 | 502.0 | 8.50 | 8.50 |

| Sample No. | Depth (m) | Quartz | Feldspar | Rock-frag. | Mica | Cement | Epimat. | Protomat. | Gr. size (ϕ) | Sorting (ϕ s.d.) | Core por. (vol. %) | Perm. (md) | T.S. Por. | Sec. Por. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ←——— (whole-rock %) | | | | | | ———→ | | | | | ← (whole-rock %) | → |
| Mitch. 2/21 | 299.30 | 58.90 | 10.60 | 6.60 | 0.30 | 0.00 | 5.40 | 4.80 | 1.44 | 1.20 | 28.00 | 1734.0 | 11.90 | 11.90 |
| Roma 8/21 | 324.30 | 33.20 | 18.20 | 13.10 | 2.60 | 0.60 | 3.40 | 19.70 | 1.87 | 0.53 | 31.70 | 623.0 | 7.10 | 0.80 |
| " 22 | 333.44 | 35.10 | 16.80 | 7.70 | 1.20 | 0.20 | 4.00 | 22.60 | 2.47 | 0.48 | 30.70 | 144.0 | 6.80 | 1.50 |
| " 23 | 343.71 | 45.70 | 16.90 | 7.30 | 1.50 | 0.00 | 6.60 | 6.90 | 1.96 | 0.52 | 32.60 | 1011.0 | 12.10 | 2.50 |
| " 24 | 354.21 | 46.10 | 18.80 | 10.50 | 0.50 | 0.10 | 4.60 | 8.70 | 1.72 | 0.50 | 30.30 | 860.0 | 9.20 | 2.70 |
| " 25 | 364.71 | 50.20 | 11.70 | 10.10 | 0.50 | 0.10 | 0.10 | 9.80 | 1.71 | 0.48 | 27.90 | 2427.0 | 14.60 | 3.90 |
| " 26 | 375.57 | 48.30 | 18.10 | 10.00 | 0.70 | 0.00 | 6.20 | 8.10 | 1.87 | 0.53 | 26.60 | 347.0 | 7.60 | 2.20 |
| chin. 4/3 | 65.69 | 21.90 | 22.40 | 32.40 | 0.30 | 0.00 | 0.20 | 11.30 | 1.63 | 0.45 | 26.10 | 527.0 | 9.80 | 9.70 |
| " 5 | 87.43 | 23.80 | 17.20 | 40.80 | 0.00 | 8.40 | 0.00 | 8.80 | 1.40 | 0.65 | 20.30 | 147.0 | 0.40 | 0.00 |
| " 6 | 96.98 | 19.70 | 19.60 | 39.50 | 1.30 | 1.40 | 0.50 | 7.80 | 1.72 | 0.48 | 25.80 | 600.0 | 7.00 | 7.00 |
| " 7 | 105.44 | 19.00 | 26.00 | 34.90 | 0.40 | 0.40 | 1.60 | 9.30 | 1.71 | 0.70 | 26.80 | 1305.0 | 6.40 | 6.40 |
| " 8 | 114.67 | 37.90 | 13.10 | 26.30 | 1.00 | 0.00 | 3.20 | 9.50 | 1.78 | 1.00 | 28.60 | 831.0 | 6.70 | 0.00 |
| " 9 | 125.70 | 30.50 | 17.10 | 28.20 | 0.90 | 0.00 | 3.90 | 9.30 | 1.83 | 0.45 | 27.80 | 723.0 | 7.80 | 0.30 |
| " 10 | 138.80 | 36.10 | 18.80 | 7.40 | 4.20 | 0.30 | 3.70 | 23.70 | 2.13 | 0.65 | 30.80 | 948.0 | 2.40 | 0.10 |
| Westbourne Formation | | | | | | | | | | | | | | |
| Mitch. 2/23 | 324.83 | 58.70 | 9.00 | 9.70 | 0.10 | 0.00 | 1.90 | 2.70 | 1.21 | 0.80 | 30.0 | N.D. | 16.00 | 7.60 |
| " 24 | 365.00 | 48.20 | 19.90 | 8.10 | 0.80 | 0.00 | 8.70 | 2.40 | 2.13 | 0.60 | 30.00 | 2732.0 | 12.20 | 4.30 |
| " 25 | 374.70 | 38.40 | 17.50 | 26.80 | 0.10 | 0.00 | 4.10 | 8.60 | 1.67 | 1.80 | 30.00 | 676.0 | 4.90 | 1.80 |

| Sample No. | | Depth | Quartz | Feldspar | Rock-frag. | Mica | Cement | Epimat. | Protomat. | Gr. size | Sorting | Core por. | Perm. | T.S. Por. | Sec. Por. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (m) | ← | | | (whole-rock %) | | | → | (ϕ) | (ϕ s.d.) | (vol. %) | (md) | ← (whole-rock %) | → |
| Mitch. | 2/26 | 407.39 | 25.80 | 20.20 | 29.90 | 1.30 | 0.00 | 6.20 | 14.50 | 2.21 | 0.48 | 26.00 | 38.0 | 2.70 | 1.20 |
| " | 27 | 417.07 | 27.80 | 19.20 | 26.40 | 1.00 | 0.00 | 5.30 | 14.50 | 2.14 | 0.60 | 28.00 | 123.0 | 2.30 | 1.10 |
| " | 28 | 426.81 | 31.70 | 23.60 | 21.30 | 0.20 | 0.00 | 11.60 | 3.80 | 1.47 | 0.50 | 27.00 | 145.0 | 10.10 | 5.80 |
| " | 29 | 466.64 | 15.40 | 15.80 | 29.10 | 2.40 | 0.50 | 2.20 | 29.40 | 2.81 | 0.50 | 19.00 | 11.0 | 0.00 | 0.00 |
| Roma | 8/28 | 439.80 | 47.10 | 20.20 | 7.80 | 1.00 | 2.80 | 2.20 | 4.10 | 2.36 | 0.45 | 30.20 | 556.0 | 15.10 | 15.10 |
| " | 29 | 451.08 | 33.20 | 13.20 | 16.30 | 3.60 | 0.00 | 2.90 | 31.60 | 3.22 | 0.55 | 27.00 | 19.0 | 2.10 | 0.40 |
| " | 30 | 500.31 | 32.20 | 22.70 | 28.10 | 0.80 | 0.30 | 7.10 | 7.90 | 1.46 | 1.00 | 20.10 | 0.86 | 1.80 | 1.60 |
| Chin. | 4/46 | 194.71 | 13.40 | 23.90 | 31.90 | 0.20 | 0.00 | 2.80 | 24.80 | 1.80 | 0.75 | 18.51 | 0.27 | 0.10 | 0.00 |
| " | 47 | 208.12 | 9.00 | 18.30 | 24.40 | 1.20 | 0.30 | 0.80 | 39.30 | 1.92 | 0.65 | 15.10 | 23.0 | 1.00 | 0.00 |
| " | 48 | 237.26 | 9.80 | 18.70 | 40.30 | 1.30 | 16.70 | 0.00 | 12.80 | 1.83 | 0.90 | 11.40 | 1.70 | 0.00 | 0.00 |
| Springbok Sandstone | | | | | | | | | | | | | | | |
| Mitch. | 2/30 | 507.05 | 8.90 | 12.40 | 31.50 | 1.30 | 0.10 | 0.00 | 41.30 | 2.04 | 0.65 | N.D. | N.D. | 3.60 | 0.00 |
| " | 63 | 477.35 | 13.30 | 28.60 | 21.30 | 1.40 | 0.10 | 4.70 | 25.70 | 2.40 | 0.60 | 22.70 | 3.10 | 1.30 | 1.00 |
| Roma | 8/32 | 533.67 | 11.80 | 35.70 | 23.70 | 0.90 | 0.70 | 4.80 | 21.20 | 2.36 | 0.50 | 17.40 | 5.0 | 0.00 | 0.00 |
| " | 33 | 539.97 | 10.70 | 42.20 | 25.80 | 0.40 | 0.00 | 6.30 | 12.00 | 2.09 | 0.65 | 16.00 | 0.17 | 0.00 | 0.00 |
| Chin. | 4/49 | 258.59 | 8.60 | 34.00 | 32.40 | 0.40 | 0.00 | 2.40 | 19.30 | 2.04 | 0.45 | 20.90 | 0.88 | 0.10 | 0.00 |
| " | 50 | 265.68 | 4.00 | 21.30 | 50.30 | 1.00 | 0.40 | 4.80 | 16.60 | 1.05 | 0.70 | 23.10 | 4.90 | 0.30 | 0.10 |

| Sample No. | | Depth (m) | Quartz | Feldspar | Rock-frag. | Mica | Cement | Epimat. | Protomat. | Gr. size (φ) | Sorting (φ s.d.) | Core por. (vol. %) | Perm. (md) | T.S. Por. | Sec. Por. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ← (whole-rock %) → | | | | | | | | | | | ← (whole-rock %) → | |
| **Walloon Coal Measures** | | | | | | | | | | | | | | | |
| Mitch. | 2/31 | 531.88 | 9.10 | 29.60 | 39.80 | 0.90 | 0.00 | 2.20 | 9.20 | 1.76 | 0.60 | 15.00 | 0.66 | 0.00 | 0.00 |
| " | 62 | 542.15 | 9.50 | 20.70 | 39.70 | 0.00 | 0.00 | 0.10 | 23.70 | 1.99 | 0.65 | 14.80 | 14.0 | 5.60 | 2.10 |
| Roma | 8/34 | 550.11 | 9.60 | 43.60 | 28.10 | 0.20 | 1.10 | 6.70 | 10.00 | 2.40 | 0.80 | 13.20 | 0.11 | 0.00 | 0.00 |
| " | 35 | 561.09 | 18.80 | 9.70 | 31.20 | 1.90 | 0.00 | 0.90 | 36.90 | 2.78 | 0.85 | 10.30 | 0.20 | 0.00 | 0.00 |
| " | 36 | 570.83 | 10.60 | 16.10 | 42.10 | 0.30 | 4.30 | 6.80 | 7.60 | 1.77 | 0.80 | 11.50 | 0.11 | 0.30 | 0.20 |
| " | 37 | 584.26 | 18.10 | 26.20 | 27.90 | 0.70 | 0.00 | 7.90 | 16.90 | 2.17 | 0.48 | 17.60 | 0.32 | 0.00 | 0.00 |
| " | 38 | 593.84 | 24.70 | 13.80 | 20.30 | 2.10 | 0.00 | 1.50 | 35.60 | 2.91 | 0.70 | 17.10 | 0.19 | 0.00 | 0.00 |
| " | 39 | 614.93 | 8.80 | 15.20 | 32.90 | 0.40 | 26.50 | 0.30 | 13.60 | 1.83 | 0.55 | 6.70 | 0.06 | 0.00 | 0.00 |
| " | 40 | 627.70 | 16.20 | 24.90 | 30.50 | 0.80 | 0.00 | 5.90 | 20.80 | 2.20 | 0.95 | 13.10 | 0.19 | 0.10 | 0.00 |
| " | 41 | 640.80 | 15.10 | 13.00 | 34.50 | 0.70 | 6.60 | 1.10 | 27.50 | 1.86 | 0.85 | 12.60 | 0.99 | 0.00 | 0.00 |
| " | 42 | 661.64 | 10.20 | 14.80 | 23.80 | 2.50 | 10.80 | 0.00 | 36.00 | 2.31 | 0.90 | 12.60 | 1.20 | 0.00 | 0.00 |
| Chin. | 4/11 | 513.38 | 24.60 | 26.70 | 18.40 | 0.90 | 0.00 | 0.70 | 27.80 | 2.14 | 0.48 | 14.50 | 22.0 | 0.00 | 0.00 |
| " | 12 | 523.04 | 19.60 | 7.60 | 37.80 | 1.10 | 0.00 | 4.80 | 27.60 | 2.04 | 0.70 | 17.00 | 35.0 | 0.90 | 0.00 |
| " | 13 | 530.99 | 20.70 | 31.60 | 33.00 | 0.70 | 0.00 | 3.40 | 9.40 | 1.92 | 0.65 | 17.00 | 35.0 | 0.90 | 0.40 |
| " | 14 | 540.05 | 20.70 | 37.10 | 28.80 | 1.40 | 0.00 | 2.00 | 8.80 | 1.72 | 0.65 | 17.30 | 19.0 | 0.50 | 0.00 |
| " | 15 | 549.05 | 16.30 | 33.10 | 34.20 | 0.10 | 5.20 | 1.80 | 6.10 | 2.07 | 0.70 | 12.70 | 0.20 | 0.10 | 0.00 |
| " | 16 | 559.96 | 15.40 | 24.00 | 31.30 | 1.20 | 0.10 | 1.00 | 24.50 | 2.91 | 0.70 | 17.90 | 12.0 | 0.00 | 0.00 |
| " | 17 | 571.62 | 16.40 | 17.90 | 34.20 | 1.40 | 0.00 | 1.00 | 27.40 | 2.30 | 0.75 | 15.50 | 13.0 | 0.00 | 0.00 |

| Sample No. | Depth (m) | Quartz | Feldspar | Rock-frag. | Mica | Cement | Epimat. | Protomat. | Gr. size (φ) | Sorting (φ s.d.) | Core por. (vol. %) | Perm. (md) | T.S. Por. | Sec. Por. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ←—— (whole-rock %) | | | | | | ——→ | | | | | ← (whole-rock %) | → |
| Chin. 4/19 | 672.31 | 8.50 | 19.30 | 35.30 | 1.60 | 0.00 | 0.30 | 32.50 | 2.57 | 0.60 | 14.30 | 22.0 | 0.10 | 0.00 |
| " 20 | 681.34 | 22.20 | 28.50 | 37.20 | 0.60 | 0.40 | 4.20 | 6.60 | 1.88 | 0.50 | 17.20 | 0.60 | 0.00 | 0.00 |
| " 21 | 701.81 | 37.60 | 16.40 | 34.80 | 0.60 | 0.00 | 4.20 | 4.70 | 1.47 | 0.50 | 20.80 | 13.00 | 1.40 | 0.00 |
| " 22 | 711.00 | 39.30 | 20.60 | 28.50 | 0.50 | 0.00 | 6.20 | 1.80 | 1.72 | 1.30 | 23.60 | 24.00 | 2.70 | 0.30 |
| " 23 | 727.47 | 11.50 | 15.80 | 47.20 | 1.50 | 0.00 | 1.10 | 20.70 | 2.09 | 0.70 | 15.20 | 8.20 | 0.00 | 0.00 |
| " 51 | 310.63 | 21.90 | 23.80 | 21.50 | 3.70 | 0.20 | 3.60 | 24.30 | 2.47 | 0.55 | 18.30 | 1.50 | 0.30 | 0.10 |
| " 52 | 345.14 | 14.70 | 14.80 | 28.30 | 3.40 | 7.20 | 2.10 | 27.40 | 2.68 | 0.60 | 9.20 | 0.01 | 0.00 | 0.00 |
| " 53 | 434.41 | 11.90 | 17.90 | 33.90 | 1.00 | 3.50 | 1.10 | 30.00 | 2.26 | 0.75 | 20.70 | 1.40 | 0.10 | 0.10 |
| " 54 | 503.19 | 21.80 | 15.20 | 33.70 | 0.50 | 0.50 | 11.10 | 14.60 | 2.08 | 0.75 | 13.30 | 0.07 | 0.00 | 0.00 |
| **Hutton Sandstone** | | | | | | | | | | | | | | |
| Mitch. 2/32 | 580.35 | 22.40 | 18.00 | 25.20 | 3.50 | 0.00 | 0.00 | 29.50 | 2.41 | 0.70 | 21.00 | 25.0 | 0.20 | 0.00 |
| " 33 | 587.70 | 20.20 | 13.10 | 30.30 | 1.40 | 0.00 | 0.00 | 33.70 | 2.03 | 0.55 | 19.00 | 26.0 | 0.30 | 0.00 |
| " 34 | 597.71 | 34.40 | 9.30 | 33.30 | 1.00 | 0.60 | 0.50 | 19.30 | 1.10 | 0.65 | 21.00 | 42.0 | 1.10 | 0.00 |
| " 35 | 608.94 | 23.60 | 18.10 | 27.60 | 3.70 | 0.00 | 3.20 | 22.70 | 2.16 | 0.55 | 22.00 | 56.0 | 0.30 | 0.30 |
| " 36 | 616.11 | 29.90 | 16.10 | 30.90 | 0.70 | 0.00 | 2.70 | 19.10 | 1.71 | 0.55 | 23.00 | 25.0 | 0.30 | 0.10 |
| " 37 | 625.49 | 61.10 | 5.80 | 10.00 | 0.20 | 0.10 | 1.10 | 3.10 | 1.02 | 1.30 | 31.00 | 3815.0 | 18.80 | 4.60 |
| " 38 | 635.54 | 38.10 | 14.80 | 23.40 | 0.70 | 0.00 | 1.50 | 12.80 | 1.58 | 0.60 | 29.00 | 267.0 | 8.40 | 1.80 |
| " 39 | 648.02 | 55.10 | 11.70 | 11.70 | 0.40 | 1.50 | 4.50 | 4.60 | 1.70 | 2.00 | N.D. | N.D. | 10.60 | 2.50 |

| Sample | No. | Depth | Quartz | Feldspar | Rock-frag. | Mica | Cement | Epimat. | Protomat. | Gr. size | Sorting | Core por. | Perm. | T.S. Por. | Sec. Por. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (m) | ←——— (whole-rock %) | | | | | | ———→ | (ϕ) | (ϕ s.d.) | (vol. %) | (md) | ←— (whole-rock %) | —→ |
| Mitch. | 2/40 | 657.57 | 58.30 | 10.90 | 11.40 | 0.20 | 0.10 | 3.10 | 5.10 | 0.66 | 2.50 | 27.00 | 669.0 | 10.80 | 2.70 |
| " | 41 | 668.53 | 51.60 | 11.40 | 9.10 | 1.70 | 5.10 | 6.40 | 8.60 | 2.15 | 0.65 | 25.00 | 89.0 | 5.70 | 0.60 |
| " | 42 | 677.27 | 53.50 | 12.30 | 4.60 | 1.10 | 4.60 | 1.60 | 2.40 | 2.25 | 0.45 | 30.00 | 1876.0 | 19.80 | 5.30 |
| " | 43 | 687.27 | 52.60 | 16.60 | 4.60 | 2.10 | 2.90 | 3.00 | 5.50 | 2.63 | 0.65 | 28.00 | 551.0 | 12.20 | 2.90 |
| " | 44 | 698.63 | 56.30 | 14.20 | 4.00 | 1.30 | 3.90 | 2.40 | 5.60 | 2.13 | 0.65 | 26.00 | 306.0 | 12.00 | 3.00 |
| " | 45 | 707.49 | 56.10 | 12.60 | 3.70 | 0.60 | 2.90 | 3.10 | 3.40 | 2.08 | 0.60 | 24.00 | 747.0 | 17.80 | 5.80 |
| " | 46 | 715.84 | 55.50 | 16.30 | 4.40 | 0.90 | 1.20 | 6.10 | 3.20 | 2.11 | 0.62 | 26.00 | 1018.0 | 12.80 | 6.10 |
| " | 47 | 725.86 | 50.00 | 19.60 | 6.20 | 2.20 | 2.20 | 4.80 | 2.00 | 2.40 | 0.55 | 26.00 | 799.0 | 12.90 | 7.90 |
| " | 49 | 746.09 | 49.10 | 19.80 | 6.30 | 3.90 | 0.80 | 6.90 | 6.90 | 2.69 | 0.60 | 22.00 | 31.0 | 5.80 | 1.40 |
| " | 50 | 755.37 | 51.80 | 19.40 | 7.20 | 1.60 | 0.30 | 6.90 | 8.10 | 2.52 | 0.70 | 22.00 | 66.0 | 4.10 | 0.80 |
| " | 51 | 763.68 | 58.40 | 12.50 | 3.00 | 0.20 | 1.20 | 7.10 | 0.70 | 2.09 | 0.45 | 24.00 | 297.0 | 17.10 | 9.40 |
| " | 52 | 774.16 | 45.80 | 19.10 | 7.30 | 3.50 | 1.10 | 7.70 | 8.30 | 2.50 | 0.62 | 23.00 | 128.0 | 6.50 | 2.40 |
| " | 53 | 783.32 | 55.00 | 19.00 | 6.10 | 2.60 | 0.70 | 4.50 | 5.50 | 2.31 | 0.72 | 20.00 | 65.0 | 6.00 | 2.20 |
| " | 54 | 791.69 | 57.70 | 14.90 | 4.90 | 0.80 | 1.60 | 4.80 | 4.10 | 1.94 | 0.52 | 26.00 | 412.0 | 10.90 | 3.00 |
| " | 55 | 800.52 | 64.30 | 10.70 | 5.00 | 0.60 | 0.70 | 3.50 | 8.10 | 2.16 | 2.00 | 20.00 | 133.0 | 6.60 | 1.00 |
| " | 56 | 809.72 | 60.50 | 14.80 | 5.60 | 1.40 | 1.00 | 9.40 | 2.30 | 2.22 | 0.55 | 24.00 | 466.0 | 4.80 | 0.80 |
| " | 57 | 818.90 | 62.70 | 7.60 | 6.50 | 0.50 | 3.30 | 5.90 | 3.10 | 1.91 | 2.00 | 22.00 | 969.0 | 9.40 | 2.00 |

| Sample | No. | Depth | Quartz | Feldspar | Rock-frag. | Mica | Cement | Epimat. | Protomat. | Gr. size | Sorting | Core por. | Perm. | T.S. Por. | Sec. Por. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (m) | ←——— (whole-rock %) | | | | | | ———→ | (φ) | (φ s.d.) | (vol. %) | (md) | ← (whole-rock %) | → |
| Roma | 8/43 | 683.65 | 15.30 | 14.90 | 28.90 | 5.80 | 0.00 | 3.00 | 28.80 | 2.38 | 0.50 | 15.10 | 8.50 | 0.60 | 0.00 |
| " | 44 | 692.95 | 22.70 | 18.90 | 33.30 | 1.10 | 0.00 | 5.70 | 16.70 | 1.60 | 0.45 | 21.60 | 162.0 | 0.60 | 0.00 |
| " | 45 | 702.64 | 24.70 | 21.10 | 32.70 | 0.50 | 0.00 | 4.10 | 4.60 | 1.98 | 0.50 | 21.20 | 0.94 | 1.00 | 0.10 |
| " | 46 | 713.68 | 37.80 | 16.20 | 23.00 | 0.10 | 0.40 | 7.60 | 4.20 | 1.70 | 0.55 | 26.90 | 677.0 | 12.10 | 6.20 |
| " | 47 | 723.03 | 38.60 | 17.20 | 27.80 | 0.70 | 0.00 | 4.80 | 10.40 | 1.60 | 2.00 | 24.90 | 11.0 | 1.40 | 0.60 |
| " | 48 | 734.55 | 41.20 | 14.10 | 28.80 | 0.40 | 0.00 | 3.60 | 5.40 | 1.43 | 1.40 | 25.50 | 350.0 | 6.60 | 2.60 |
| " | 49 | 747.42 | 37.60 | 13.80 | 25.80 | 3.90 | 0.00 | 3.10 | 13.10 | 2.43 | 1.20 | 20.20 | 1.70 | 2.00 | 0.40 |
| " | 50 | 754.93 | 35.80 | 17.90 | 23.30 | 2.50 | 0.00 | 5.60 | 11.30 | 2.27 | 0.40 | 25.30 | 19.0 | 3.10 | 0.20 |
| " | 51 | 764.10 | 66.80 | 4.30 | 7.20 | 0.00 | 5.50 | 1.10 | 3.10 | 0.79 | 0.90 | 22.90 | 8737.0 | 12.10 | 12.10 |
| " | 52 | 782.78 | 42.30 | 10.30 | 9.40 | 2.60 | 8.20 | 4.20 | 6.30 | 1.92 | 0.85 | 16.60 | 0.19 | 3.30 | 0.70 |
| " | 53 | 791.53 | 66.20 | 7.10 | 4.30 | 0.40 | 3.50 | 3.50 | 2.30 | 1.07 | 1.00 | 21.10 | 2346.0 | 13.10 | 13.10 |
| " | 54 | 802.00 | 49.00 | 12.40 | 13.40 | 1.10 | 1.00 | 4.90 | 6.40 | 1.96 | 0.80 | 23.40 | 77.0 | 11.60 | 11.20 |
| " | 55 | 813.17 | 45.30 | 10.20 | 10.20 | 6.00 | 0.30 | 4.20 | 19.40 | 2.55 | 0.60 | 19.50 | 14.0 | 2.50 | 0.50 |
| " | 56 | 826.02 | 57.20 | 14.60 | 4.50 | 0.70 | 3.20 | 3.10 | 2.60 | 2.17 | 0.60 | 21.90 | 416.0 | 14.90 | 14.90 |
| " | 57 | 845.13 | 41.40 | 11.40 | 9.60 | 5.40 | 0.00 | 4.70 | 24.70 | 2.58 | 0.55 | 20.50 | 2.70 | 1.30 | 0.60 |
| " | 58 | 855.71 | 42.00 | 12.00 | 6.30 | 4.10 | 0.00 | 2.30 | 29.90 | 2.66 | 0.45 | 25.30 | 24.0 | 2.30 | 0.40 |
| " | 59 | 866.91 | 61.40 | 9.50 | 6.10 | 0.60 | 4.80 | 3.80 | 2.60 | 2.10 | 2.50 | 17.80 | 207.0 | 10.60 | 10.60 |
| " | 60 | 876.21 | 53.00 | 16.90 | 7.40 | 0.40 | 4.30 | 2.90 | 3.30 | 2.30 | 0.55 | 23.40 | 375.0 | 11.70 | 11.70 |

| Sample | No. | Depth | Quartz | Feldspar | Rock-frag. | Mica | Cement | Epimat. | Protomat. | Gr. size | Sorting | Core por. | Perm. | T.S. Por. | Sec. Por. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (m) | <— (whole-rock %) | | | | | | —> | (φ) | (φ s.d.) | (vol. %) | (md) | <— (whole-rock %) | —> |
| Roma | 8/61 | 886.05 | 51.50 | 18.30 | 8.90 | 2.60 | 1.60 | 3.40 | 5.80 | 2.39 | 0.60 | 19.90 | 18.0 | 7.30 | 2.50 |
| " | 63 | 906.13 | 52.20 | 17.00 | 6.50 | 1.90 | 3.50 | 2.70 | 8.30 | 2.10 | 0.50 | 21.40 | 25.0 | 6.90 | 2.30 |
| " | 64 | 916.05 | 47.50 | 18.60 | 7.50 | 2.70 | 2.20 | 2.80 | 11.10 | 2.25 | 0.60 | 20.00 | 16.0 | 7.40 | 3.80 |
| " | 65 | 926.03 | 56.40 | 12.80 | 4.40 | 1.00 | 5.10 | 2.80 | 4.90 | 2.12 | 0.48 | 24.40 | 405.0 | 12.60 | 4.90 |
| Chin. | 4/24 | 792.19 | 64.50 | 9.30 | 11.30 | 0.80 | 0.40 | 4.60 | 5.00 | 1.90 | 1.80 | 23.50 | 135.0 | 3.60 | 0.50 |
| " | 25 | 799.31 | 60.00 | 7.50 | 10.30 | 1.40 | 1.90 | 7.20 | 8.40 | 1.73 | 0.95 | 21.20 | 188.0 | 2.70 | 0.30 |
| " | 27 | 826.66 | 70.70 | 4.50 | 4.40 | 0.60 | 0.00 | 2.10 | 3.50 | 1.40 | 1.80 | 25.50 | 2181.0 | 14.00 | 5.60 |
| " | 28 | 866.39 | 44.30 | 11.00 | 13.10 | 2.50 | 0.80 | 4.90 | 16.70 | 2.45 | 0.55 | 20.60 | 28.0 | 2.40 | 0.30 |
| **Evergreen Formation** | | | | | | | | | | | | | | | |
| Mitch. | 2/58 | 844.66 | 79.30 | 1.50 | 1.50 | 0.20 | 3.30 | 11.00 | 0.80 | 1.56 | 0.50 | 17.00 | 105.0 | 2.10 | 0.10 |
| " | 59 | 853.86 | 71.90 | 7.50 | 3.90 | 2.00 | 4.40 | 3.40 | 2.00 | 2.72 | 0.45 | 20.00 | 197.0 | 4.90 | 4.90 |
| Roma | 8/66 | 946.66 | 47.10 | 18.10 | 15.70 | 1.40 | 0.00 | 2.50 | 11.40 | 2.28 | 1.80 | 17.80 | 10.0 | 2.70 | 2.10 |
| " | 67 | 955.29 | 37.70 | 16.40 | 19.40 | 1.80 | 0.00 | 1.70 | 19.10 | 2.35 | 1.75 | 18.60 | 1.80 | 1.90 | 1.90 |
| " | 68 | 979.72 | 57.90 | 5.10 | 13.00 | 2.80 | 4.30 | 1.30 | 8.70 | 3.08 | 0.50 | 24.40 | 6.60 | 6.30 | 6.30 |
| " | 70 | 998.67 | 26.00 | 16.00 | 18.50 | 3.50 | 0.00 | 0.00 | 34.40 | 3.14 | 0.48 | 12.60 | 10.2 | 0.50 | 0.50 |
| Chin | 4/30 | 889.05 | 34.70 | 14.60 | 9.40 | 2.20 | 32.40 | 0.00 | 6.70 | 3.05 | 0.55 | 3.30 | 0.02 | 0.00 | 0.00 |
| " | 31 | 965.36 | 64.60 | 15.80 | 6.00 | 0.90 | 2.90 | 3.00 | 2.10 | 2.28 | 0.95 | 20.30 | 149.0 | 4.00 | 4.00 |
| " | 32 | 973.62 | 50.20 | 18.70 | 9.90 | 3.70 | 2.30 | 5.30 | 5.90 | 2.48 | 0.55 | 21.80 | 14.0 | 2.90 | 2.90 |

| Sample | No. | Depth (m) | Quartz | Feldspar | Rock-frag. | Mica | Cement | Epimat. | Protomat. | Gr. size (ϕ) | Sorting (ϕ s.d.) | Core por. (vol. %) | Perm. (md) | T.S. Por. | Sec. Por. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ← (whole-rock %) | | | | | | → | | | | | ← (whole-rock %) | → |
| Chin. | 4/33 | 983.55 | 59.10 | 13.00 | 9.80 | 1.00 | 6.20 | 1.30 | 9.00 | 1.37 | 2.00 | 13.90 | 0.71 | 0.50 | 0.50 |
| " | 34 | 991.49 | 21.60 | 34.30 | 22.20 | 1.50 | 16.80 | 0.00 | 12.60 | 2.30 | 1.75 | 4.30 | 0.01 | 0.00 | 0.00 |
| " | 35 | 1050.53 | 24.00 | 21.50 | 31.50 | 3.40 | 0.00 | 0.60 | 18.00 | 2.09 | 0.55 | 11.30 | 0.06 | 0.00 | 0.00 |
| " | 36 | 1055.77 | 34.60 | 20.30 | 33.50 | 1.00 | 2.00 | 1.90 | 5.20 | 1.43 | 0.85 | 17.80 | 1.20 | 1.20 | 0.10 |
| " | 37 | 1064.82 | 25.50 | 26.20 | 31.50 | 1.50 | 0.80 | 3.60 | 10.00 | 1.88 | 0.95 | 16.30 | 0.31 | 0.20 | 0.20 |
| " | 38 | 1073.94 | 20.00 | 29.10 | 27.40 | 1.10 | 0.00 | 2.00 | 19.10 | 2.38 | 0.50 | 10.80 | 0.06 | 0.00 | 0.00 |
| " | 39 | 1083.10 | 17.90 | 27.80 | 30.80 | 2.40 | 0.60 | 0.10 | 19.60 | 2.13 | 0.50 | 9.80 | 0.05 | 0.00 | 0.00 |

Precipice Sandstone

| Sample | No. | Depth (m) | Quartz | Feldspar | Rock-frag. | Mica | Cement | Epimat. | Protomat. | Gr. size (ϕ) | Sorting (ϕ s.d.) | Core por. (vol. %) | Perm. (md) | T.S. Por. | Sec. Por. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mitch. | 2/60 | 932.69 | 76.80 | 0.20 | 2.80 | 3.20 | 1.40 | 0.00 | 6.60 | 0.64 | 1.70 | 22.00 | 4501.0 | 8.80 | 2.80 |
| Roma | 8/71 | 1047.66 | 49.00 | 12.50 | 12.00 | 6.10 | 1.30 | 2.00 | 16.30 | 1.37 | 1.70 | 20.40 | 1.40 | 0.20 | 0.00 |
| " | 72 | 1055.69 | 54.20 | 8.30 | 12.70 | 3.40 | 0.30 | 2.70 | 18.60 | 1.93 | 0.60 | 18.60 | 0.68 | 0.10 | 0.00 |
| Chin. | 4/40 | 1182.07 | 74.90 | 3.20 | 4.80 | 0.20 | 3.00 | 5.60 | 3.20 | 2.27 | 0.45 | 22.60 | 234.0 | 5.00 | 5.00 |
| " | 41 | 1190.61 | 85.40 | 0.70 | 1.40 | 0.20 | 0.00 | 1.60 | 3.00 | 1.19 | 1.30 | 22.60 | 1856.0 | 7.50 | 2.40 |
| " | 42 | 1199.81 | 76.00 | 0.90 | 0.10 | 3.40 | 9.20 | 1.30 | 5.30 | 2.35 | 2.00 | 18.00 | 462.0 | 3.00 | 0.10 |
| " | 43 | 1280.64 | 87.50 | 1.00 | 0.20 | 0.600 | 0.20 | 3.50 | 1.70 | 1.80 | 0.90 | 22.80 | 2037.0 | 4.90 | 0.20 |
| " | 44 | 1217.09 | 78.30 | 0.40 | 0.00 | 0.40 | 10.30 | 2.80 | 0.20 | 1.60 | 1.00 | 22.70 | 3197.0 | 7.30 | 7.30 |
| " | 45 | 1225.29 | 74.80 | 0.30 | 0.40 | 0.50 | 3.50 | 2.30 | 4.00 | 1.72 | 1.00 | 23.80 | 4087.0 | 14.10 | 4.60 |

Footnote to Appendix 1.5.

1 Porosity and permeability data measured by the author (as distinct from those by BMR)

2 Not determined.

## APPENDIX 1.6. ELECTRON MICROPROBE ANALYSES OF ZONED AND TWINNED PLAGIOCALSE FELDSPARS

Appendix 1.6. Electron microprobe analyses of zoned and twinned plagioclase feldspars. Multiple analyses on a single sample represent analyses done on different grains within the one thin-section.

Analysis 1. Albite twinned feldspar, GSQ Roma 8/12, Orallo Fm.

```
ANAL. 4426   PT. 1   30-05-1988  18:44:17    8 OXS. CO-ORDS 41951  45828  36228
SiO2       62.75   2.7434
Al2O3      24.39   1.2552
FeO         0.26   0.0095
CaO         6.15   0.2882
Na2O        7.54   0.6392
K2O         0.40   0.0222
          101.49   4.9578
4046  4258  1.052 *   0.0 *  96.8   0.0   3.2 *  30.4  67.3   2.3
```

Analysis 2. GSQ Roma 8/12, Orallo Formation.

```
 ? ALB TWINNED FSPAR
ANAL. 4428   PT. 1   30-05-1988  18:54:02    8 OXS. CO-ORDS 40647  44069  36170
SiO2       61.24   2.6952
Al2O3      25.16   1.3035
FeO         0.23   0.0086
CaO         7.05   0.3323
Na2O        7.02   0.5990
K2O         0.42   0.0238
          101.12   4.9625
4043  4251  1.051 *   0.0 *  97.5   0.0   2.5 *  34.8  62.7   2.5
```

Analysis 3. GSQ Roma 8/12, Orallo·Formation.

```
 ? ZONED PLAG/SKELETAL
ANAL. 4429   PT. 1   30-05-1988  18:59:04    8 OXS. CO-ORDS 45729  44259  36265
SiO2       63.67   2.7970
Al2O3      23.17   1.1986
FeO         0.26   0.0095
CaO         5.06   0.2379
Na2O        7.91   0.6733
K2O         0.80   0.0447
          100.87   4.9610
4041  4258  1.054 *   0.0 *  96.2   0.0   3.8 *  24.9  70.4   4.7
```

Analysis 4. GSQ Roma 8/12, Orallo Formation.

```
 ? ZONED PLAG
ANAL. 4430   PT. 1   30-05-1988  19:05:02    8 OXS. CO-ORDS 52871  44787  36384
SiO2       64.25   2.8351
Al2O3      22.21   1.1541
FeO         0.31   0.0113
CaO         4.56   0.2154
Na2O        7.97   0.6815
K2O         1.04   0.0586
          100.34   4.9561
4043  4273  1.057 *   0.0 *  95.0   0.0   5.0 *  22.5  71.3   6.1
```

Analysis 5. GSQ Roma 8/12, Orallo Formation.

```
? ZONED PLAG
ANAL. 4432   PT. 1   30-05-1988  19:39:17    8 OXS. CO-ORDS 50367  46409  36339
SiO2        60.08   2.6369
Al2O3       26.42   1.3651
FeO          0.23   0.0083
CaO          8.06   0.3790
Na2O         6.60   0.5615
K2O          0.30   0.0169
           101.69   4.9677
4033  4250  1.054 *   0.0 *  97.8   0.0   2.2 *  39.6  58.6   1.8
```

Analysis 6. GSQ Surat 3/14, Bungil Formation.

```
? ST3/14 BUNGIL FM/ZONED PLAG
ANAL. 4199   PT. 1   23-05-1988  15:01:10    12 OXS. CO-ORDS 43195  40634
36438
SiO2        60.97   4.0297
Al2O3       25.20   1.9608
FeO          0.22   0.0119
CaO          6.36   0.4501
Na2O         8.05   1.0316
K2O          0.44   0.0373
           101.24   7.5214
4169  4379  1.050 *   0.0 *  97.4   0.0   2.6 *  29.6  67.9   2.5
```

Analysis 7. GSQ Surat 3/14, Bungil Formation.

```
? ST3/14 BUNGIL FM/ZONED PLAG
ANAL. 4201   PT. 1   23-05-1988  15:12:58    12 OXS. CO-ORDS 43314  47079
36477
SiO2        61.17   4.0172
Al2O3       25.43   1.9664
FeO          0.23   0.0129
CaO          6.72   0.4725
Na2O         8.04   1.0239
K2O          0.38   0.0317
           101.98   7.5245
4147  4372  1.054 *   0.0 *  97.3   0.0   2.7 *  30.9  67.0   2.1
```

Analysis 8. GSQ Surat 3/14, Bungil Formation.

```
? ST3/14 BUNGIL FM/ZONED PLAG - CORE PART
ANAL. 4202   PT. 1   23-05-1988  15:17:28    12 OXS. CO-ORDS 46050  46099
36431
SiO2        58.37   3.8629
Al2O3       27.22   2.1211
FeO          0.35   0.0191
CaO          8.96   0.6353
Na2O         6.59   0.8457
K2O          0.29   0.0242
           101.77   7.5083
4142  4360  1.053 *   0.0 *  97.1   0.0   2.9 *  42.2  56.2   1.6
```

Analysis 9. GSQ Surat 3/14, Bungil Formation.

```
 ? ST3/14 BUNGIL FM/ZONED PLAG - OUTER PORTION
ANAL. 4203   PT. 1   23-05-1988  15:21:56    12 OXS. CO-ORDS 45920  46096
 36436
SiO2        54.00   3.7261
Al2O3       27.43   2.2289
FeO          0.40   0.0233
CaO         10.94   0.8089
Na2O         5.36   0.7167
K2O          0.24   0.0213
            98.38   7.5252
4138  4367  1.055 *   0.0 *  97.2   0.0   2.8 *  52.3  46.3   1.4
```

Analysis 10. GSQ Surat 3/14, Bungil Formation.

```
 ? ST3/14 ZONED PLAG/BUNGIL FM
ANAL. 4206   PT. 1   23-05-1988  15:43:27    12 OXS. CO-ORDS 41082  55890
 36624
SiO2        57.15   3.7984
Al2O3       27.93   2.1853
FeO          0.30   0.0166
CaO         10.03   0.7144
Na2O         5.85   0.7533
K2O          0.34   0.0289
           101.60   7.4968
4112  4340  1.055 *   0.0 *  97.7   0.0   2.3 *  47.7  50.3   1.9
```

Analysis 11. GSQ Surat 3/33, Wallumbilla Formation.

```
 ? ST3/33 WALLUM FM/ZONED PLAG
ANAL. 4189   PT. 1   23-05-1988  12:11:18    12 OXS. CO-ORDS 33505  48833
 36701
SiO2        61.91   4.0359
Al2O3       25.21   1.9351
FeO          0.26   0.0144
CaO          6.83   0.4773
Na2O         8.08   1.0208
K2O          0.49   0.0410
           102.79   7.5245
4068  4369  1.074 *   0.0 *  97.1   0.0   2.9 *  31.0  66.3   2.7
```

Analysis 12. GSQ Surat 3/33, Wallumbilla Formation.

```
 ? ST3/33 ALB TWINNED PLAG
ANAL. 4196   PT. 1   23-05-1988  13:14:36    12 OXS. CO-ORDS 44442  42490
 36338
SiO2        60.42   3.9995
Al2O3       25.31   1.9725
FeO          0.26   0.0142
CaO          7.23   0.5127
Na2O         7.61   0.9771
K2O          0.56   0.0476
           101.39   7.5237
4044  4347  1.075 *   0.0 *  97.3   0.0   2.7 *  33.3  63.6   3.1
```

Analysis 13, GSQ Surat 3/33, Wallumbilla Formation.

```
? ST3/33 WALLUM FM ZONED PLAG
ANAL. 4187   PT. 1   23-05-1988  11:54:42    12 OXS. CO-ORDS 42140  56102
 37053
SiO2        60.17   3.9672
Al2O3       25.75   1.9988
FeO          0.23   0.0129
CaO          7.88   0.5566
Na2O         7.50   0.9582
K2O          0.38   0.0318
           101.91   7.5255
4086  4389  1.074 *   0.0 *  97.7   0.0   2.3 *  36.0  62.0   2.1
```

Analysis 14. GSQ Surat 3/33, Wallumbilla Formation.

```
? ST3/33 ALB TWINNED PLAG
ANAL. 4196   PT. 1   23-05-1988  13:14:36    12 OXS. CO-ORDS 44442  42490
 36338
SiO2        60.42   3.9995
Al2O3       25.31   1.9725
FeO          0.26   0.0142
CaO          7.23   0.5127
Na2O         7.61   0.9771
K2O          0.56   0.0476
           101.39   7 5237
```

Analysis 14. GSQ Surat 3/33, Wallumbilla Formation.

Albite twinned Plagioclase.

```
ANAL. 4192   PT. 1   23-05-1988  12:49:32    12 OXS. CO-ORDS 42168  55989
 37007
SiO2        60.02   3.9658
Al2O3       25.76   2.0044
FeO          0.22   0.0121
CaO          7.48   0.5296
Na2O         7.77   0.9952
K2O          0.46   0.0388
           101.72   7.5460
4049  4351  1.075 *   0.0 *  97.8   0.0   2.2 *  33.9  63.6   2.5
```

Analysis 16. GSQ Surat 3/33, Wallumbilla Formation.

```
? ST3/33 WALLUM FM ZONED PLAG /AGAIN
ANAL. 4191   PT. 1   23-05-1988  12:43:25    12 OXS. CO-ORDS 42168  55989
 37007
SiO2        59.87   3.9650
Al2O3       25.65   1.9999
FeO          0.25   0.0141
CaO          7.53   0.5344
Na2O         7.81   1.0027
K2O          0.41   0.0344
           101.52   7.5506
4049  4351  1.075 *   0.0 *  97.4   0.0   2.6 *  34.0  63.8   2.2
```

## APPENDIX 1.7. ELECTRON MICROPROBE ANALYSES OF UNTWINNED ALTERED FELDSPARS

Appendix 1.7. Electron microprobe analyses of untwinned altered feldspars[1] that were suspected to be alkali feldspars. Multiple analyses on a single sample represent analyses done on different grains within the one thin-section.

Analysis 1. GSQ Mitchell 2/21, Gubberamunda Sandstone.

```
 ? MCL2/21 ALT. KSPAR
ANAL. 176   PT. 1   28-01-1988  11:42:31    8 OXS. CO-ORDS 20318  52418  35526
SiO2       64.64   2.8506
Al203      22.50   1.1695
CaO         2.68   0.1265
Na2O        9.65   0.8249
K2O         0.19   0.0108
           99.66   4.9823
3718  3371 *   0.0 * 100.0   0.0   0.0 *  13.1  85.7   1.1
```

Analysis 2. GSQ Mitchell 2/63, Springbok Sandstone.

```
--->  ? MCL2/63  SBOK SPOTTY FSPAR
ANAL. 459   PT. 1   09-02-1988  17:08:20    6 OXS. CO-ORDS 41074  47455  35764
SiO2       64.61   2.1944
Al203      19.89   0.7963
FeO         0.21   0.0058
MgO         0.00   0.0000
CaO         0.14   0.0050
Na2O       12.14   0.7995
K2O         0.28   0.0120
           97.26   3.8131
4944  4433 *   0.0 *  46.0   0.0  54.0 *   0.6  97.9   1.5
```

Analysis 3. GSQ Mitchell 2/35, Hutton Sandstone.

```
 ? MCL2/35 DIRTY SPOTTY KSPAR
ANAL. 182   PT. 1   28-01-1988  15:13:02    8 OXS. CO-ORDS 32083  44591  35253
SiO2       81.59   3.3520
Al203      13.31   0.6445
FeO         0.30   0.0104
MgO         0.00   0.0000
CaO         0.66   0.0291
Na2O        6.94   0.5526
K2O         0.51   0.0269
          103.32   4.6154
3647  3371 *   0.0 *  73.7   0.0  26.3 *   4.8  90.8   4.4
```

[1]Footnote to Appendix 1.7.

Out of 15 samples only four were found to be K-feldspar (approx. 15% $K_2O$ - orthoclase). The rest of the samples are almost pure albite with the exception of one grain of oligoclase.

Analysis 4. GSQ Roma 8/3, Bungil Formation.

```
 ? ROMA8/3 BUNGIL SPOTTY FSPAR
ANAL. 373   PT. 1   05-02-1988  17:04:49    6 OXS. CO-ORDS 43001  54995  36854
SiO2        65.66   2.2431
Al2O3       19.21   0.7734
FeO          0.00   0.0000
MgO          0.00   0.0000
CaO          0.00   0.0000
Na2O         0.43   0.0282
K2O         15.58   0.6789
           100.87   3.7236
4536  3937 *   0.0 *   0.0    0.0    0.0 *    0.0    4.0  96.0
```

Analysis 5. GSQ Roma 8/5, Mooga Sandstone.

```
 ? ROMA8/5 MOOGA SPOTY FSPAR
ANAL. 469   PT. 1   09-02-1988  19:51:34    6 OXS. CO-ORDS 37982  53860  35981
SiO2        63.62   2.2498
Al2O3       18.09   0.7540
FeO          0.00   0.0000
MgO          0.00   0.0000
CaO          0.06   0.0022
Na2O         0.65   0.0447
K2O         15.28   0.6894
            97.70   3.7401
5124  4474 *   0.0 * 100.0    0.0    0.0 *    0.3    6.1  93.6
```

Analysis 6. GSQ Roma 8/34, Birkhead Formation.

```
 ? ROMA8/34 BIRKHEAD-WCM SPOTTY FSPAR GR. 3
ANAL. 467   PT. 1   09-02-1988  18:56:28    6 OXS. CO-ORDS 60922  53351  34988
SiO2        66.09   2.2102
Al2O3       20.11   0.7926
FeO          0.00   0.0000
MgO          0.00   0.0000
CaO          0.66   0.0237
Na2O        11.24   0.7285
K2O          0.12   0.0051
            98.23   3.7602
5005  4487 *   0.0 * 100.0    0.0    0.0 *    3.1   96.2   0.7
```

Analysis 7. GSQ Roma 8/34, Birkhead Formation.

```
  ? ROMA8/34 BIRKHEAD-WCM SPOTTY FSPAR GR. 2.
ANAL. 466   PT. 1   09-02-1988  18:48:51    6 OXS. CO-ORDS 55824  45000  34682
SiO2       67.91   2.2061
Al2O3      20.99   0.8036
FeO         0.00   0.0000
MgO         0.00   0.0000
CaO         1.03   0.0359
Na2O       10.96   0.6903
K2O         0.07   0.0027
          100.96   3.7385
5021  4532 *   0.0 * 100.0   0.0   0.0 *   4.9  94.7   0.4
```

Analysis 8. GSQ Roma 8/34, Birkhead Formation.

```
  ? ROMA8/34 BIRKHEAD-WCM              SPOTTY FSPAR
ANAL. 461   PT. 1   09-02-1988  17:56:29    6 OXS. CO-ORDS 40276  52234  35229
SiO2       70.62   2.2453
Al2O3      20.22   0.7575
FeO         0.00   0.0000
MgO         0.00   0.0000
CaO         0.36   0.0122
Na2O       11.67   0.7192
K2O         0.07   0.0027
          102.92   3.7368
5111  4582 *   0.0 * 100.0   0.0   0.0 *   1.7  98.0   0.4
```

Analysis 9. GSQ Roma 8/46, Hutton Sandstone.

```
--->  ? ROMA8/46 SPOTTY FSPAR
ANAL. 196   PT. 1   29-01-1988  11:25:09    8 OXS. CO-ORDS 30512  47060  36004
SiO2       68.32   2.9580
Al2O3      20.79   1.0606
FeO         0.00   0.0000
MgO         0.00   0.0000
CaO         0.80   0.0373
Na2O       10.82   0.9082
K2O         0.06   0.0033
          100.80   4.9674
3655  3458 *   0.0 * 100.0   0.0   0.0 *   3.9  95.7   0.4
```

Analysis 10. GSQ Chinchilla 4/54, Walloon Coal Measures,

```
---> ? CHIN4/54 JCM-WCM EQUIV. SPOTTY FSPAR
ANAL. 262   PT. 1   03-02-1988  16:18:10    6 OXS. CO-ORDS 48884  53858  37249
SiO2        69.30   2.2412
Al2O3       20.19   0.7694
FeO          0.00   0.0000
MnO          0.00   0.0000
MgO          0.00   0.0000
CaO          0.28   0.0097
Na2O        11.22   0.7038
K2O          0.08   0.0035
           101.08   3.7276
4174  3747 *   0.0 * 100.0   0.0   0.0 *   1.4  98.2   0.5
```

Analysis 11. GSQ Chinchilla 4/54, Walloon Coal Measures.

```
---> ? CHIN4/54 SPOTTY FSPAR
ANAL. 265   PT. 1   03-02-1988  17:00:49    6 OXS. CO-ORDS 25950  48447  36238
SiO2        70.74   2.2575
Al2O3       20.06   0.7543
FeO          0.00   0.0000
MnO          0.00   0.0000
MgO          0.00   0.0000
CaO          0.05   0.0018
Na2O        11.32   0.7003
K2O          0.08   0.0032
           102.25   3.7170
4131  3744 *   0.0 * 100.0   0.0   0.0 *   0.3  99.3   0.4
```

Analysis 12. GSQ Chinchilla 4/54, Walloon Coal Measures.

```
---> ? CHIN4/54 JCM-WCM SPOTTY FSPAR
ANAL. 267   PT. 1   03-02-1988  17:24:53    6 OXS. CO-ORDS 30751  50263  36560
SiO2        69.66   2.2512
Al2O3       19.90   0.7580
FeO          0.00   0.0000
MnO          0.00   0.0000
MgO          0.00   0.0000
CaO          0.30   0.0104
Na2O        11.11   0.6964
K2O          0.09   0.0039
           101.07   3.7198
4119  3767 *   0.0 * 100.0   0.0   0.0 *   1.5  98.0   0.5
```

Analysis 13. GSQ Chinchilla 4/54, Walloon Coal Measures.

```
---> ? CHIN4/54 SPOTTY FSPAR
ANAL. 266    PT. 1    03-02-1988  17:19:07    6 OXS. CO-ORDS 30625  48240  36338
SiO2        70.08   2.2456
Al2O3       20.33   0.7678
FeO          0.00   0.0000
MnO          0.00   0.0000
MgO          0.00   0.0000
CaO          0.33   0.0112
Na2O        11.07   0.6881
K2O          0.09   0.0035
           101.89   3.7162
4120  3805 *   0.0 * 100.0    0.0    0.0 *   1.6  97.9   0.5
```

Analysis 14. GSQ Chinchilla 4/24, Hutton Sandstone.

```
? CHIN4/24 HOTTON SPOTTY FSPAR
ANAL. 275    PT. 1    03-02-1988  19:57:34    6 OXS. CO-ORDS 44643  54234  36551
SiO2        64.85   2.2489
Al2O3       18.51   0.7563
FeO          0.00   0.0000
MnO          0.00   0.0000
MgO          0.00   0.0000
CaO          0.00   0.0000
Na2O         0.33   0.0222
K2O         16.11   0.7128
            99.79   3.7402
4334  3791 *   0.0 *   0.0    0.0    0.0 *   0.0   3.0  97.0
```

Analysis 15. GSQ Chinchilla 4/24, Hutton Sandstone.

```
---> ? ACHIN4/24 AGAIN/2 SPOTTHUTTON SPOTTY FSPAR
ANAL. 277    PT. 1    03-02-1988  20:12:41    6 OXS. CO-ORDS 36253  55068  36610
SiO2        63.39   2.2496
Al2O3       17.99   0.7522
FeO          0.08   0.0025
MnO          0.00   0.0000
MgO          0.00   0.0000
CaO          0.00   0.0000
Na2O         0.79   0.0547
K2O         15.13   0.6849
            97.38   3.7439
4301  3762 *   0.0 *   0.0    0.0 100.0 *   0.0   7.4  92.6
```

# APPENDIX 1.8.1. DETAILED PETROGRAPHIC MODAL ANALYSES DATA

Appendix 1.8.1. Detailed petrographic modal anlyses (whole-rock percentage) of the Surat Basin sandstones based on thin-section point-counting (1000 points per slide). Qp - polycrystalline quartz including polycrystalline vein quartz (Qvp); Qv - mono- and polycrystalline vein quartz; Fans - albite twinned non-skeletal feldspar; Fas - albite twinned skeletal feldspar; Funs - untwinned non-skeletal feldspar; Fus - untwinned skeletal feldspar; Fo - sum of glomeroporphyritic feldspar (Fg), quartz-feldspar intergrowth (Fi), feldspar replaced by kaolinite/dickite (Eka/Ed/Ekb/Ekcrf), and intragranular pores within skeletal feldspar (2Bdsf); Ka - argillite, and pseudomatrix derived from extraclastic sedimentary rock-fragments (Apms) having diagnostic criteria; Vv - vitric volcanic rock-fragments, including Vvk, Vvu, Vvv, and Vvo; Vo - sum of Vsp, Vg, Vvpq, and pseudomatrix derived from volcanic rock-fragments having diagnostic criteria; Vm/Vl - sum of Vm and Vl; Vf - sum of Vf, Vsi, and Vx. Other symbols as of Appendix 1.1.

| Sample No. | QUARTZ $QV_1$ | $QV_2$ | Qc | Qv | Qp | qc | qcd | FELDSPAR Fans | Fas | Fz | Funs | Fus | Fx | Fp | Fo | VOLC. ROCK-FRAGS. Vv | Vf | Vm/Vl | Achm | Vo | CLASTIC SED. ROCK-FRAGS. Ksq | Kzq | Ksl | Kzl | Ka | METAMORPHIC ROCK-FRAGS. Tp | Ts | Tq | Mkq | Mo | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Griman Creek Formation | | | | | | | | | | | | | | Griman Creek Formation | | | | | | | | | | |
| Surat 3/1 | 0.2 | 0.4 | 3.8 | 0.0 | 0.4 | 0.0 | 0.0 | 3.7 | 0.3 | 0.2 | 15.2 | 0.8 | 0.0 | 0.1 | 0.0 | 25.3 | 2.7 | 1.1 | 1.2 | 3.7 | 0.0 | 0.3 | 0.0 | 0.0 | 0.3 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 2 | 0.0 | 0.2 | 3.5 | 0.0 | 0.1 | 0.0 | 0.0 | 4.3 | 0.3 | 0.2 | 16.9 | 2.4 | 0.1 | 0.1 | 0.1 | 26.8 | 1.1 | 1.7 | 2.5 | 1.8 | 0.1 | 0.6 | 0.0 | 0.1 | 0.0 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 3 | 0.0 | 0.1 | 2.3 | 0.0 | 0.2 | 0.0 | 0.0 | 6.8 | 1.0 | 0.8 | 16.7 | 1.7 | 0.0 | 0.1 | 0.1 | 27.7 | 0.6 | 4.0 | 1.4 | 8.2 | 0.1 | 0.5 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 4 | 0.0 | 0.1 | 2.0 | 0.0 | 0.0 | 0.1 | 0.0 | 3.1 | 0.5 | 0.4 | 24.2 | 1.0 | 0.0 | 0.0 | 0.3 | 24.3 | 3.3 | 2.2 | 1.3 | 2.2 | 0.0 | 0.2 | 0.0 | 0.0 | 0.1 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 5 | 0.1 | 0.1 | 4.5 | 0.0 | 0.0 | 0.0 | 0.0 | 5.4 | 0.0 | 0.7 | 20.0 | 0.0 | 0.0 | 0.2 | 0.9 | 18.3 | 1.6 | 5.4 | 1.4 | 8.7 | 0.2 | 0.8 | 0.0 | 0.6 | 0.0 | 1.2 | 0.0 | 0.0 | 0.0 | 0.1 | 0.3 |
| " 6 | 0.0 | 0.1 | 2.6 | 0.0 | 0.5 | 0.2 | 0.0 | 4.3 | 1.1 | 1.0 | 24.8 | 1.1 | 0.0 | 0.0 | 0.9 | 14.5 | 2.5 | 1.4 | 2.0 | 9.7 | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 7 | 0.1 | 0.1 | 3.8 | 0.0 | 0.1 | 0.1 | 0.0 | 4.0 | 0.1 | 0.5 | 23.5 | 1.2 | 0.0 | 0.1 | 0.5 | 20.1 | 3.5 | 2.1 | 1.9 | 4.8 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 9 | 0.0 | 0.3 | 8.3 | 0.1 | 0.4 | 0.0 | 0.0 | 6.3 | 1.0 | 1.3 | 15.8 | 1.7 | 0.0 | 0.0 | 0.5 | 21.7 | 2.5 | 2.5 | 2.5 | 8.9 | 0.1 | 0.5 | 0.0 | 0.0 | 0.9 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| " 10 | 0.0 | 0.0 | 3.3 | 0.0 | 0.5 | 0.1 | 0.0 | 6.0 | 0.7 | 1.8 | 16.9 | 2.1 | 0.0 | 0.1 | 0.2 | 24.3 | 2.4 | 2.8 | 1.3 | 4.6 | 0.0 | 1.2 | 0.2 | 0.4 | 0.5 | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 11 | 0.1 | 0.4 | 3.2 | 0.0 | 0.4 | 0.3 | 0.0 | 4.9 | 0.5 | 2.2 | 11.5 | 0.7 | 0.0 | 0.0 | 0.2 | 33.4 | 4.4 | 5.1 | 0.8 | 3.1 | 0.0 | 0.9 | 0.0 | 0.8 | 0.2 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 12 | 0.1 | 0.3 | 5.9 | 0.0 | 0.0 | 0.0 | 0.0 | 8.0 | 0.2 | 2.3 | 9.0 | 0.2 | 0.0 | 0.0 | 1.1 | 25.0 | 3.3 | 10.8 | 1.4 | 7.7 | <u>1.2</u>[1] | | <u>0.6</u>[2] | | 0.0 | 1.2 | 0.5 | 0.0 | 0.0 | 0.0 | 0.3 |
| " 13 | 0.0 | 0.2 | 5.1 | 0.0 | 0.0 | 0.1 | 0.1 | 4.4 | 0.6 | 1.9 | 11.7 | 0.0 | 0.0 | 0.2 | 0.7 | 29.9 | 3.3 | 10.5 | 2.9 | 9.4 | <u>0.8</u> | | <u>0.1</u> | | 0.0 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| " 14 | 0.1 | 0.0 | 5.5 | 0.0 | 0.3 | 0.2 | 0.1 | 4.7 | 0.3 | 1.2 | 16.7 | 0.8 | 0.0 | 0.0 | 0.1 | 23.7 | 2.9 | 2.4 | 1.2 | 5.7 | <u>0.6</u> | | <u>0.5</u> | | 0.2 | 1.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 15 | 0.0 | 0.2 | 2.1 | 0.0 | 0.1 | 0.0 | 0.1 | 5.9 | 0.5 | 1.7 | 16.3 | 1.2 | 0.0 | 0.0 | 0.8 | 16.8 | 2.7 | 3.6 | 1.0 | 12.0 | <u>0.3</u> | | <u>0.1</u> | | 0.3 | 1.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 16 | 0.0 | 0.0 | 4.6 | 0.0 | 0.1 | 0.0 | 0.0 | 5.8 | 1.1 | 0.7 | 18.1 | 1.5 | 0.1 | 0.0 | 2.2 | 31.9 | 1.6 | 2.9 | 0.6 | 1.6 | <u>0.2</u> | | <u>0.2</u> | | 0.2 | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 17 | 0.0 | 0.0 | 6.0 | 0.0 | 0.1 | 0.1 | 0.0 | 7.9 | 0.5 | 3.9 | 17.9 | 0.7 | 0.0 | 0.0 | 0.7 | 27.6 | 1.6 | 3.8 | 0.1 | 5.4 | <u>0.6</u> | | <u>0.1</u> | | 0.4 | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 18 | 0.0 | 0.1 | 5.0 | 0.0 | 0.7 | 0.0 | 0.0 | 5.0 | 0.0 | 0.3 | 19.6 | 0.0 | 0.0 | 0.0 | 0.2 | 23.7 | 1.7 | 2.4 | 0.3 | 3.5 | <u>0.3</u> | | <u>0.5</u> | | 0.0 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 20 | 0.3 | 0.0 | 5.5 | 0.0 | 0.3 | 0.3 | 0.0 | 6.6 | 2.5 | 1.0 | 16.6 | 0.3 | 0.0 | 0.1 | 0.5 | 29.7 | 3.3 | 3.7 | 0.3 | 2.9 | <u>0.1</u> | | <u>0.8</u> | | 0.5 | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| " 21 | 0.1 | 0.2 | 6.4 | 0.0 | 0.8 | 0.2 | 0.0 | 6.5 | 0.2 | 1.2 | 29.5 | 2.0 | 0.0 | 0.1 | 0.9 | 11.6 | 2.4 | 0.2 | 0.0 | 2.4 | <u>0.0</u> | | <u>0.2</u> | | 0.0 | 0.8 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| " 22 | 0.2 | 0.1 | 8.5 | 0.0 | 1.7 | 0.1 | 0.1 | 5.1 | 1.6 | 0.6 | 22.3 | 0.5 | 0.0 | 0.0 | 1.1 | 12.5 | 1.6 | 2.3 | 0.3 | 1.8 | <u>0.1</u> | | <u>0.1</u> | | 0.1 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 23 | 0.1 | 0.0 | 8.1 | 0.0 | 0.7 | 0.2 | 0.0 | 5.4 | 0.4 | 1.4 | 20.9 | 0.9 | 0.1 | 0.0 | 0.2 | 17.1 | 3.0 | 4.2 | 0.0 | 2.5 | <u>0.1</u> | | <u>0.2</u> | | 0.0 | 0.4 | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 |
| " 24 | 0.0 | 0.0 | 11.6 | 0.0 | 0.9 | 0.2 | 0.0 | 9.9 | 0.8 | 3.4 | 27.4 | 1.1 | 0.2 | 0.0 | 0.6 | 6.4 | 2.1 | 3.0 | 1.2 | 3.4 | <u>0.1</u> | | <u>0.0</u> | | 0.5 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| " 25 | 0.0 | 0.1 | 5.5 | 0.0 | 0.5 | 0.0 | 0.0 | 6.3 | 0.0 | 0.8 | 20.8 | 0.0 | 0.0 | 0.3 | 0.0 | 20.3 | 1.6 | 3.2 | 2.4 | 2.1 | <u>0.5</u> | | <u>0.0</u> | | 0.4 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 26 | 0.0 | 0.0 | 6.8 | 0.0 | 0.8 | 0.0 | 0.2 | 5.9 | 0.5 | 1.7 | 23.0 | 1.7 | 0.0 | 0.2 | 1.6 | 15.1 | 3.4 | 1.8 | 0.2 | 2.8 | <u>0.2</u> | | <u>0.0</u> | | 0.0 | 0.8 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 |
| " 27 | 0.0 | 0.0 | 5.8 | 0.0 | 0.5 | 0.1 | 0.1 | 5.2 | 0.1 | 0.0 | 21.4 | 0.9 | 0.0 | 0.0 | 1.2 | 20.7 | 2.1 | 2.0 | 0.3 | 2.8 | <u>0.0</u> | | <u>0.3</u> | | 0.0 | 0.7 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 28 | 0.4 | 0.0 | 7.7 | 0.0 | 0.6 | 0.0 | 0.0 | 3.5 | 0.6 | 0.4 | 14.0 | 1.2 | 0.0 | 0.1 | 1.1 | 21.5 | 2.9 | 4.4 | 0.2 | 2.5 | <u>0.2</u> | | <u>1.0</u> | | 0.2 | 0.7 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Average | 0.007 | 0.11 | 5.28 | 0.04 | 0.41 | 0.09 | 0.02 | 5.57 | 0.59 | 1.07 | 18.87 | 0.98 | 0.02 | 0.06 | 0.64 | 21.92 | 2.46 | 3.44 | 1.10 | 4.77 | <u>0.44</u>[3] | | <u>0.27</u>[4] | | 0.18 | 1.10 | 0.04 | 0.01 | 0.00 | 0.00 | 0.04 |

| Sample No. | QUARTZ QV1 | QV2 | Qc | Qv | Qp | qc | qcd | FELDSPAR Fans | Fas | Fz | Funs | Fus | Fx | Fp | Fo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Surat Siltstone** | | | | | | | | | | | | | | | |
| Surat 3/29 | 0.1 | 0.0 | 8.0 | 0.0 | 0.7 | 0.1 | 0.0 | 2.4 | 0.5 | 0.2 | 19.1 | 2.8 | 0.0 | 0.1 | 1.2 |
| " 30 | 0.2 | 0.2 | 13.5 | 0.0 | 1.1 | 0.0 | 0.0 | 0.8 | 0.1 | 0.0 | 17.8 | 0.0 | 0.0 | 0.0 | 0.1 |
| Average | 0.15 | 0.10 | 10.75 | 0.00 | 0.90 | 0.10 | 0.00 | 1.60 | 0.30 | 0.10 | 18.45 | 1.4 | 0.00 | 0.05 | 0.15 |
| **Vallumbilla Formation** | | | | | | | | | | | | | | | |
| Surat 1/4 | 0.1 | 0.0 | 11.9 | 0.0 | 0.3 | 0.1 | 0.0 | 0.7 | 0.0 | 0.1 | 24.4 | 2.2 | 0.0 | 0.0 | 0.2 |
| " 5 | 0.0 | 0.0 | 6.9 | 0.0 | 0.3 | 0.0 | 0.1 | 2.9 | 0.0 | 0.0 | 23.0 | 3.4 | 0.0 | 0.0 | 0.7 |
| " 8 | 0.1 | 0.0 | 3.7 | 0.0 | 0.3 | 0.1 | 0.1 | 2.4 | 0.0 | 0.2 | 15.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 9 | 0.0 | 0.0 | 6.0 | 0.0 | 0.7 | 0.1 | 0.0 | 3.6 | 0.0 | 0.7 | 21.1 | 1.2 | 0.0 | 0.0 | 1.8 |
| Surat 3/31 | 0.0 | 0.0 | 2.8 | 0.0 | 0.0 | 0.0 | 0.0 | 3.8 | 0.1 | 0.1 | 16.3 | 2.6 | 0.0 | 0.0 | 0.9 |
| " 32 | 0.0 | 0.0 | 4.9 | 0.0 | 0.0 | 0.0 | 0.0 | 3.4 | 0.0 | 0.2 | 17.4 | 0.2 | 0.0 | 0.0 | 0.0 |
| " 33 | 0.0 | 0.0 | 7.7 | 0.0 | 0.6 | 0.0 | 0.0 | 1.9 | 0.0 | 0.0 | 13.5 | 1.7 | 0.0 | 0.1 | 1.1 |
| Average | 0.03 | 0.00 | 6.27 | 0.00 | 0.31 | 0.04 | 0.03 | 0.72 | 0.01 | 0.18 | 18.74 | 1.61 | 0.00 | 0.01 | 0.67 |
| **Bungil Formation** | | | | | | | | | | | | | | | |
| Mitch. 2/1 | 0.2 | 0.0 | 36.4 | 0.7 | 1.5 | 0.1 | 0.0 | 0.4 | 0.0 | 0.0 | 11.9 | 0.2 | 0.0 | 0.1 | 0.2 |
| " 3 | 0.0 | 0.0 | 41.4 | 0.0 | 0.5 | 1.0 | 0.1 | 0.2 | 0.0 | 0.0 | 14.9 | 0.1 | 0.0 | 0.0 | 0.5 |
| " 4 | 0.0 | 0.0 | 45.4 | 0.0 | 1.2 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 10.0 | 0.1 | 0.0 | 0.1 | 0.9 |
| Roma 8/1 | 0.2 | 0.0 | 44.6 | 0.5 | 2.6 | 0.3 | 0.1 | 0.5 | 0.2 | 0.1 | 2.6 | 2.4 | 0.0 | 0.3 | 0.3 |
| " 2 | 0.0 | 0.0 | 34.0 | 0.0 | 0.4 | 0.3 | 0.0 | 0.5 | 0.0 | 0.0 | 17.1 | 0.5 | 0.0 | 0.0 | 0.0 |
| " 3 | 0.0 | 0.0 | 8.3 | 0.0 | 0.7 | 0.2 | 0.1 | 2.2 | 0.3 | 0.1 | 11.2 | 2.4 | 0.0 | 0.1 | 0.0 |
| " 4 | 0.0 | 0.0 | 31.8 | 0.0 | 0.1 | 0.5 | 0.0 | 1.3 | 0.3 | 0.0 | 16.4 | 4.7 | 0.0 | 0.0 | 0.4 |
| Surat 1/13 | 1.3 | 0.0 | 14.9 | 0.0 | 1.2 | 0.1 | 0.1 | 1.0 | 0.0 | 0.0 | 22.7 | 1.8 | 0.0 | 0.2 | 0.9 |
| " 15 | 0.6 | 0.0 | 19.2 | 0.2 | 0.6 | 0.0 | 0.1 | 1.0 | 0.0 | 0.0 | 20.4 | 0.1 | 0.1 | 0.0 | 0.1 |
| " 16 | 0.5 | 0.0 | 23.5 | 0.7 | 1.0 | 0.0 | 0.2 | 0.9 | 0.0 | 0.0 | 14.5 | 2.7 | 0.0 | 0.0 | 0.2 |
| " 17 | 0.4 | 0.0 | 25.8 | 0.7 | 0.8 | 0.1 | 0.0 | 0.6 | 0.0 | 0.0 | 15.3 | 4.3 | 0.0 | 0.2 | 0.3 |
| " 18 | 1.5 | 0.0 | 27.5 | 1.1 | 1.5 | 0.3 | 0.1 | 0.5 | 0.0 | 0.0 | 13.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Average | 0.39 | 0.00 | 29.40 | 0.32 | 1.00 | 0.25 | 0.07 | 0.75 | 0.06 | 0.01 | 14.16 | 1.61 | 0.00 | 0.08 | 0.31 |

| Sample No. | VOLC. ROCK-FRAGS. Vv | Vf | Vm/Vl | Achm | Vo | CLASTIC SED. ROCK-FRAGS. Ksq | Kzq | Ksl | Kzl | Ka | METAMORPHIC ROCK-FRAGS. Tp | Ts | Tq | Mkq | Mo | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Surat Siltstone** | | | | | | | | | | | | | | | | |
| Surat 3/29 | 18.2 | 2.4 | 1.9 | 0.0 | 1.1 | | 0.1 | | 1.0 | 0.2 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 30 | 9.0 | 1.3 | 0.3 | 0.0 | 0.4 | | 0.1 | | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Average | 13.60 | 1.85 | 1.10 | 0.00 | 0.75 | | 0.10 | | 0.20 | 0.10 | 0.35 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Vallumbilla Formation** | | | | | | | | | | | | | | | | |
| Surat 1/4 | 9.4 | 2.9 | 1.1 | 0.0 | 0.5 | | 0.1 | | 0.1 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 5 | 17.2 | 2.7 | 2.1 | 0.0 | 1.6 | | 0.1 | | 0.7 | 0.5 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 8 | 15.4 | 1.4 | 3.0 | 0.0 | 1.9 | | 0.0 | | 0.1 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 9 | 21.0 | 3.4 | 2.5 | 0.0 | 1.2 | | 0.7 | | 1.6 | 0.4 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Surat 3/31 | 31.9 | 1.3 | 1.3 | 1.1 | 0.1 | | 0.1 | | 0.3 | 0.1 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 32 | 21.8 | 2.0 | 2.0 | 0.2 | 0.8 | | 0.4 | | 0.4 | 0.8 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 33 | 17.0 | 3.0 | 1.9 | 0.3 | 1.9 | | 0.3 | | 0.9 | 0.6 | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Average | 19.10 | 2.38 | 1.98 | 0.08 | 1.28 | | 0.24 | | 0.58 | 0.34 | 0.61 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Bungil Formation** | | | | | | | | | | | | | | | | |
| Mitch. 2/1 | 5.0 | 1.5 | 0.0 | 0.0 | 1.0 | 0.0 | 1.6 | 0.0 | 0.0 | 0.4 | 0.1 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 |
| " 3 | 6.9 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 4 | 4.9 | 1.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.3 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Roma 8/1 | 5.6 | 1.5 | 1.8 | 0.0 | 0.6 | | 1.9 | | 0.4 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 |
| " 2 | 6.9 | 2.5 | 0.0 | 0.0 | 0.2 | | 0.1 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 3 | 6.5 | 1.4 | 1.8 | 0.0 | 0.3 | | 0.1 | | 1.0 | 0.3 | 0.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| " 4 | 6.1 | 3.3 | 0.1 | 0.0 | 0.2 | | 0.5 | | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Surat 1/13 | 9.3 | 2.1 | 0.5 | 0.8 | 0.4 | | 0.0 | | 0.3 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| " 15 | 9.2 | 2.9 | 1.8 | 0.0 | 1.4 | | 0.1 | | 0.1 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 16 | 13.6 | 3.7 | 0.7 | 0.1 | 0.2 | | 0.1 | | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 17 | 16.8 | 4.2 | 0.4 | 0.0 | 0.9 | | 0.0 | | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 18 | 16.2 | 3.5 | 0.7 | 0.1 | 4.7 | | 0.1 | | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Average | 8.92 | 2.36 | 0.65 | 0.08 | 0.83 | | 0.41 | | 0.21 | 0.09 | 0.07 | 0.00 | 0.03 | 0.01 | 0.00 | 0.08 |

| Sample No. | QUARTZ QV1 | QV2 | Qc | Qv | Qp | qc | qcd | FELDSPAR Fans | Fas | Fz | Fums | Fus | Fx | Fp | Fo | VOLC. ROCK-FRAGS. Vv | Vf | Vm/Vl | Achm | Vo | CLASTIC SED. ROCK-FRAGS. Ksq | Kzq | Ksl | Kzl | Ka | METAMORPHIC ROCK-FRAGS. Tp | Ts | Tq | Mkq | Mo | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Hooga Sandstone** | | | | | | | | | | | | | | | | | | | | | **Hooga Sandstone** | | | | | | | | | | |
| Mitch. 2/61 | 0.0 | 0.0 | 29.2 | 0.0 | 0.7 | 0.1 | 0.0 | 1.1 | 0.0 | 0.0 | 12.3 | 0.2 | 0.0 | 0.0 | 1.2 | 4.6 | 2.5 | 0.0 | 0.4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 3.0 | 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Roma 8/5 | 0.0 | 0.0 | 50.7 | 0.0 | 0.1 | 0.2 | 0.0 | 1.0 | 0.0 | 0.0 | 14.1 | 1.3 | 0.4 | 0.1 | 0.4 | 1.1 | 0.9 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 7 | 0.0 | 0.0 | 47.4 | 0.0 | 0.1 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 9.2 | 0.9 | 0.2 | 0.1 | 0.2 | 0.7 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 8 | 0.0 | 0.0 | 50.3 | 0.0 | 0.1 | 0.2 | 0.0 | 1.1 | 0.0 | 0.0 | 14.3 | 0.3 | 0.6 | 0.1 | 0.3 | 0.6 | 0.5 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 9 | 0.0 | 0.0 | 40.5 | 0.3 | 2.2 | 0.4 | 0.2 | 0.1 | 0.0 | 0.0 | 6.3 | 0.0 | 0.3 | 0.0 | 1.0 | 5.9 | 3.1 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Average | 0.00 | 0.00 | 43.62 | 0.06 | 0.64 | 0.18 | 0.04 | 0.72 | 0.00 | 0.00 | 11.24 | 0.54 | 0.30 | 0.06 | 0.06 | 2.58 | 1.54 | 0.00 | 0.10 | 0.18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.64 | 0.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Orallo Formation** | | | | | | | | | | | | | | | | | | | | | **Orallo Formation** | | | | | | | | | | |
| Mitch. 2/6 | 0.0 | 0.0 | 11.8 | 0.1 | 1.9 | 0.7 | 0.1 | 2.9 | 0.2 | 0.2 | 11.1 | 1.3 | 0.0 | 0.0 | 0.0 | 22.6 | 3.2 | 0.1 | 0.0 | 2.6 | 0.0 | 0.4 | 0.0 | 0.2 | 2.4 | 0.8 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| " 7 | 0.0 | 0.0 | 4.5 | 0.0 | 1.2 | 0.3 | 0.0 | 2.7 | 0.1 | 0.6 | 13.7 | 0.6 | 0.0 | 0.0 | 0.5 | 25.3 | 2.4 | 7.3 | 0.0 | 2.2 | 0.1 | 0.5 | 0.5 | 0.5 | 1.9 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| " 9 | 0.0 | 0.0 | 10.9 | 0.0 | 2.3 | 0.9 | 0.0 | 6.8 | 0.0 | 0.4 | 14.5 | 2.3 | 0.0 | 0.0 | 0.4 | 23.4 | 2.3 | 6.9 | 0.0 | 0.7 | 0.4 | 0.4 | 0.1 | 0.5 | 1.7 | 1.7 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 |
| " 10 | 0.0 | 0.0 | 22.2 | 0.0 | 1.1 | 1.0 | 0.0 | 5.7 | 0.6 | 0.4 | 16.9 | 4.2 | 0.1 | 0.0 | 1.5 | 13.9 | 1.5 | 2.8 | 0.0 | 1.1 | 0.0 | 0.6 | 0.0 | 0.0 | 2.0 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 11 | 0.0 | 0.0 | 37.0 | 0.0 | 2.0 | 0.9 | 0.0 | 1.4 | 0.5 | 0.2 | 10.0 | 7.0 | 0.3 | 0.1 | 2.3 | 7.4 | 1.9 | 2.9 | 0.0 | 1.3 | 0.1 | 0.2 | 0.0 | 0.0 | 1.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 12 | 0.0 | 0.0 | 33.2 | 0.0 | 1.0 | 0.4 | 0.1 | 2.9 | 0.3 | 0.0 | 14.4 | 2.8 | 0.2 | 0.1 | 1.0 | 7.4 | 1.0 | 0.5 | 0.0 | 0.7 | 0.0 | 0.5 | 0.0 | 0.1 | 0.7 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 13 | 0.0 | 0.0 | 38.3 | 2.1 | 3.1 | 0.4 | 0.1 | 2.4 | 0.3 | 0.3 | 10.9 | 2.5 | 0.4 | 0.0 | 1.4 | 8.1 | 0.8 | 1.7 | 0.0 | 0.8 | 0.0 | 0.0 | 0.1 | 0.0 | 0.9 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 14 | 0.0 | 0.0 | 32.5 | 0.0 | 1.9 | 0.0 | 0.1 | 2.5 | 0.6 | 0.9 | 13.6 | 2.3 | 0.1 | 0.3 | 0.4 | 14.4 | 1.5 | 1.4 | 0.0 | 1.3 | 0.2 | 0.3 | 0.2 | 0.1 | 0.4 | 0.8 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 |
| " 15 | 0.0 | 0.0 | 17.9 | 0.0 | 0.8 | 0.3 | 0.0 | 4.4 | 0.7 | 0.5 | 15.8 | 3.3 | 0.0 | 0.3 | 1.4 | 20.6 | 1.7 | 1.7 | 0.0 | 1.2 | 0.1 | 1.8 | 0.4 | 0.7 | 2.1 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 16 | 0.1 | 0.0 | 25.1 | 0.0 | 0.7 | 1.0 | 0.3 | 3.2 | 0.6 | 0.1 | 17.6 | 4.0 | 0.0 | 0.0 | 1.9 | 14.4 | 2.1 | 1.0 | 0.0 | 1.0 | 0.2 | 1.4 | 0.9 | 0.2 | 2.2 | 1.4 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| " 17 | 0.2 | 0.1 | 27.6 | 0.0 | 1.2 | 0.3 | 0.1 | 2.2 | 0.6 | 0.1 | 11.4 | 3.1 | 0.1 | 0.0 | 1.3 | 18.4 | 1.8 | 0.6 | 0.0 | 1.0 | 0.0 | 0.5 | 0.0 | 0.2 | 2.0 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Roma 8/10 | 0.3 | 0.2 | 4.9 | 0.0 | 0.4 | 0.0 | 0.1 | 5.6 | 0.6 | 0.8 | 7.3 | 1.9 | 0.0 | 0.0 | 1.2 | 40.2 | 3.1 | 9.0 | 0.0 | 2.6 | 0.0 | 0.6 | 0.6 | 1.9 | 2.7 | 1.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 |
| " 11 | 0.2 | 0.0 | 7.9 | 0.0 | 2.3 | 0.5 | 0.0 | 2.7 | 0.2 | 0.4 | 6.9 | 0.4 | 0.0 | 0.0 | 0.6 | 41.9 | 3.7 | 5.5 | 0.0 | 0.8 | 0.3 | 1.1 | 0.1 | 0.4 | 1.4 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 12 | 0.2 | 0.0 | 8.9 | 0.0 | 1.0 | 0.1 | 0.0 | 7.1 | 0.7 | 1.3 | 20.4 | 2.2 | 0.0 | 0.0 | 0.8 | 22.1 | 3.1 | 5.8 | 0.0 | 3.0 | 0.5 | 0.3 | 0.4 | 0.5 | 1.4 | 0.9 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| " 13 | 0.1 | 0.0 | 11.9 | 0.2 | 0.8 | 0.0 | 0.0 | 5.7 | 0.4 | 0.7 | 12.7 | 3.4 | 0.0 | 0.0 | 0.7 | 30.9 | 2.0 | 4.6 | 0.0 | 1.5 | 0.1 | 0.2 | 1.8 | 0.4 | 2.2 | 1.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| " 14 | 0.3 | 0.0 | 49.4 | 0.4 | 1.9 | 0.2 | 0.0 | 1.5 | 0.9 | 0.4 | 9.9 | 5.0 | 0.1 | 0.0 | 1.2 | 4.2 | 1.5 | 2.1 | 0.0 | 1.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 15 | 0.3 | 0.0 | 38.4 | 0.9 | 2.0 | 0.5 | 0.0 | 1.1 | 2.3 | 0.1 | 11.4 | 4.6 | 0.0 | 0.0 | 2.4 | 8.5 | 3.1 | 5.0 | 0.0 | 1.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 16 | 0.3 | 0.0 | 19.3 | 1.1 | 2.0 | 0.4 | 0.0 | 3.6 | 0.5 | 1.0 | 8.4 | 0.8 | 0.1 | 0.0 | 0.5 | 21.7 | 2.6 | 3.1 | 0.0 | 3.7 | 0.0 | 0.4 | 0.2 | 0.2 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 17 | 0.2 | 0.0 | 7.3 | 0.3 | 0.9 | 0.2 | 0.0 | 6.1 | 0.3 | 1.3 | 9.1 | 3.1 | 0.1 | 0.0 | 0.3 | 31.6 | 2.8 | 6.2 | 0.0 | 2.7 | 0.4 | 1.1 | 0.4 | 0.8 | 2.1 | 1.4 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| " 18 | 0.0 | 0.0 | 15.8 | 0.0 | 0.5 | 0.1 | 0.0 | 4.7 | 0.5 | 0.6 | 16.4 | 2.4 | 0.0 | 0.0 | 0.9 | 17.9 | 1.6 | 1.8 | 0.0 | 2.9 | 0.3 | 0.6 | 0.0 | 0.6 | 3.2 | 0.4 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |

| Sample No. | ← QUARTZ → | | | | | | | ← FELDSPAR → | | | | | | | | ← VOLC. ROCK-FRAGS. → | | | | | ← CLASTIC SED. ROCK-FRAGS. → | | | | | ← METAMORPHIC ROCK-FRAGS. → | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | QV 1 | QV 2 | Qc | Qv | Qp | qc | qcd | Fans | Fas | Fz | Funs | Fus | Fx | Fp | Fo | Vv | Vf | Va/Vl | Achm | Vo | Ksq | Kmq | Ksl | Kzl | Ka | Tp | Ts | Tq | Mkq | Mo | P |
| Roma 8/19 | 0.0 | 0.0 | 16.4 | 0.0 | 0.5 | 0.1 | 0.1 | 3.1 | 0.1 | 0.0 | 15.8 | 2.8 | 0.0 | 0.0 | 1.5 | 16.5 | 2.9 | 1.0 | 0.0 | 0.7 | 0.1 | 1.8 | 0.3 | 0.4 | 2.2 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 20 | 0.1 | 0.0 | 13.4 | 0.1 | 0.8 | 0.3 | 0.1 | 5.9 | 0.4 | 0.1 | 17.3 | 3.8 | 0.1 | 0.0 | 1.0 | 19.0 | 1.3 | 1.8 | 0.1 | 2.0 | 0.0 | 0.9 | 0.4 | 0.9 | 2.9 | 1.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| Chin. 4/1 | 0.0 | 0.0 | 38.6 | 0.0 | 1.4 | 0.2 | 0.4 | 3.4 | 0.6 | 1.2 | 15.2 | 2.4 | 0.2 | 0.4 | 0.8 | 8.8 | 2.2 | 4.6 | 0.0 | 1.2 | 0.0 | 0.4 | 0.0 | 0.0 | 0.8 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 2 | 0.0 | 0.0 | 20.2 | 0.0 | 1.3 | 0.1 | 0.0 | 2.8 | 0.3 | 0.1 | 11.5 | 2.9 | 0.0 | 0.1 | 1.0 | 18.3 | 1.3 | 1.8 | 0.0 | 2.5 | 0.0 | 0.8 | 0.0 | 0.1 | 2.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Average | 0.09 | 0.01 | 21.39 | 0.21 | 1.37 | 0.37 | 0.06 | 3.76 | 0.51 | 0.49 | 13.00 | 3.03 | 0.07 | 0.05 | 1.04 | 19.06 | 2.14 | 3.30 | 0.00 | 1.65 | 0.12 | 0.62 | 0.26 | 0.36 | 1.65 | 0.74 | 0.00 | 0.04 | 0.00 | 0.02 | 0.00 |

<u>Gubberamunda Sandstone</u>

| Sample No. | QV 1 | QV 2 | Qc | Qv | Qp | qc | qcd | Fans | Fas | Fz | Funs | Fus | Fx | Fp | Fo | Vv | Vf | Va/Vl | Achm | Vo | Ksq | Kmq | Ksl | Kzl | Ka | Tp | Ts | Tq | Mkq | Mo | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mitch. 2/18 | 0.0 | 0.0 | 53.5 | 0.0 | 2.3 | 0.0 | 0.0 | 0.3 | 0.1 | 0.0 | 6.4 | 1.3 | 0.0 | 0.7 | 1.0 | 3.1 | 0.7 | 0.4 | 0.0 | 0.3 | 0.0 | 0.1 | 0.0 | 0.1 | 0.4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 19 | 0.0 | 0.0 | 49.1 | 0.3 | 2.1 | 0.2 | 0.0 | 0.8 | 0.1 | 0.0 | 6.0 | 1.6 | 0.4 | 1.0 | 4.5 | 3.6 | 1.4 | 0.4 | 0.1 | 0.3 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| " 20 | 0.0 | 0.0 | 46.1 | 0.1 | 2.4 | 0.2 | 0.0 | 1.0 | 0.3 | 0.0 | 12.1 | 3.5 | 1.0 | 1.5 | 2.4 | 5.8 | 0.6 | 0.4 | 0.4 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 21 | 0.0 | 0.0 | 55.3 | 0.2 | 3.4 | 0.2 | 0.0 | 1.1 | 0.1 | 0.0 | 3.7 | 1.8 | 0.7 | 1.4 | 1.8 | 4.0 | 0.6 | 1.0 | 0.3 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Roma 8/21 | 0.0 | 0.0 | 31.3 | 0.0 | 1.9 | 0.4 | 0.0 | 1.3 | 0.1 | 0.0 | 9.4 | 3.5 | 1.7 | 0.5 | 1.7 | 7.7 | 1.2 | 1.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.5 | 0.7 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 |
| " 22 | 0.0 | 0.0 | 33.3 | 0.0 | 1.8 | 0.1 | 0.0 | 0.8 | 0.0 | 0.0 | 10.3 | 3.3 | 1.1 | 0.1 | 1.2 | 3.1 | 1.6 | 0.7 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 23 | 0.0 | 0.0 | 43.5 | 0.0 | 2.2 | 0.1 | 0.0 | 0.8 | 0.3 | 0.0 | 9.0 | 2.6 | 0.8 | 0.7 | 2.6 | 3.4 | 1.0 | 1.2 | 0.2 | 0.2 | 0.0 | 0.2 | 0.0 | 0.0 | 0.6 | 0.3 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| " 24 | 0.0 | 0.0 | 44.5 | 0.0 | 1.6 | 0.4 | 0.1 | 0.5 | 0.2 | 0.0 | 11.0 | 3.6 | 1.4 | 0.5 | 1.6 | 5.4 | 1.2 | 0.8 | 0.0 | 0.9 | 0.0 | 0.1 | 0.0 | 0.0 | 1.1 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 25 | 0.0 | 0.0 | 47.8 | 0.1 | 2.3 | 0.1 | 0.0 | 0.5 | 0.1 | 0.0 | 6.3 | 2.5 | 1.0 | 1.2 | 0.7 | 4.7 | 1.6 | 1.1 | 0.3 | 0.6 | 0.0 | 0.1 | 0.0 | 0.0 | 1.2 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 26 | 0.0 | 0.0 | 45.6 | 0.0 | 2.7 | 0.0 | 0.0 | 0.9 | 0.3 | 0.0 | 12.2 | 2.5 | 0.9 | 0.6 | 1.9 | 5.8 | 1.4 | 1.2 | 0.0 | 0.3 | 0.0 | 0.1 | 0.0 | 0.0 | 0.9 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Chin. 4/3 | 0.0 | 0.0 | 20.8 | 0.5 | 0.7 | 0.4 | 0.0 | 3.6 | 0.0 | 3.3 | 13.2 | 1.2 | 0.2 | 0.0 | 0.9 | 20.0 | 2.3 | 4.6 | 0.1 | 1.9 | 0.0 | 0.0 | 0.0 | 0.5 | 2.2 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 5 | 0.0 | 0.0 | 23.2 | 0.0 | 0.6 | 0.6 | 0.0 | 3.4 | 0.0 | 1.0 | 12.4 | 0.2 | 0.2 | 0.0 | 0.0 | 27.0 | 2.6 | 4.6 | 0.4 | 1.4 | 0.0 | 0.0 | 0.2 | 1.2 | 2.6 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 6 | 0.0 | 0.0 | 19.0 | 0.0 | 0.7 | 0.2 | 0.0 | 2.2 | 0.0 | 1.1 | 15.6 | 0.5 | 0.0 | 0.0 | 0.2 | 24.9 | 3.4 | 4.5 | 0.0 | 2.1 | 0.0 | 0.0 | 0.1 | 1.9 | 1.7 | 0.6 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| " 7 | 0.0 | 0.0 | 17.1 | 0.0 | 1.9 | 0.2 | 0.1 | 2.7 | 0.1 | 0.8 | 21.0 | 1.3 | 0.0 | 0.0 | 0.1 | 19.8 | 3.9 | 2.4 | 0.1 | 1.1 | 0.0 | 0.0 | 0.0 | 2.2 | 4.4 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 8 | 0.0 | 0.0 | 36.0 | 0.0 | 1.9 | 0.4 | 0.1 | 0.3 | 0.0 | 0.1 | 10.5 | 1.3 | 0.4 | 0.0 | 0.5 | 16.4 | 2.0 | 1.3 | 0.2 | 1.8 | 0.0 | 0.0 | 0.0 | 0.5 | 3.1 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 9 | 0.0 | 0.0 | 28.5 | 0.0 | 2.0 | 1.0 | 0.0 | 1.9 | 0.1 | 0.3 | 12.1 | 2.2 | 0.2 | 0.1 | 0.2 | 15.6 | 2.6 | 1.7 | 0.1 | 1.3 | 0.0 | 0.0 | 0.3 | 1.6 | 3.0 | 0.8 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 |
| " 10 | 0.0 | 0.0 | 34.7 | 0.0 | 1.4 | 0.3 | 0.1 | 2.7 | 0.0 | 0.0 | 12.9 | 1.5 | 0.8 | 0.6 | 0.3 | 3.6 | 0.3 | 0.3 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.3 | 1.8 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Average | 0.00 | 0.00 | 37.02 | 0.07 | 1.87 | 0.28 | 0.02 | 1.46 | 0.10 | 0.39 | 10.83 | 2.20 | 0.63 | 0.52 | 1.27 | 10.23 | 1.67 | 1.64 | 0.13 | 0.77 | 0.00 | 0.04 | 0.03 | 0.49 | 1.49 | 0.49 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 |

<u>Gubberamunda Sandstone</u>

| Sample No. | QUARTZ | | | | | | | FELDSPAR | | | | | | | | VOLC. ROCK-FRAGS. | | | | | CLASTIC SED. ROCK-FRAGS. | | | | | METAMORPHIC ROCK-FRAGS. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $QV_1$ | $QV_2$ | Qc | Qv | Qp | qc | qcd | Fans | Fas | Fz | Funs | Fus | Fx | Fp | Fo | Vv | Vf | Vm/Vl | Achm | Vo | Ksq | Kzq | Ksl | Kzl | Ka | Tp | Ts | Tq | Mkq | Mo | P |
| **Westbourne Formation** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Mitch. 2/23 | 0.1 | 0.0 | 56.1 | 0.5 | 2.2 | 0.5 | 0.1 | 0.2 | 0.0 | 0.0 | 6.6 | 0.9 | 0.1 | 0.5 | 0.7 | 6.4 | 0.6 | 0.3 | 0.0 | 0.2 | 0.1 | 0.6 | 0.2 | 0.2 | 0.1 | 0.1 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 |
| " 24 | 0.4 | 0.0 | 46.1 | 0.2 | 1.6 | 0.7 | 0.0 | 0.7 | 0.0 | 0.0 | 10.1 | 5.7 | 0.1 | 0.2 | 3.1 | 4.4 | 1.0 | 1.3 | 0.0 | 0.3 | 0.2 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 25 | 2.0 | 0.0 | 34.4 | 0.4 | 1.9 | 1.2 | 0.1 | 0.7 | 0.4 | 0.0 | 7.2 | 6.6 | 0.1 | 0.1 | 2.4 | 10.7 | 2.1 | 3.8 | 0.0 | 2.2 | 0.0 | 0.8 | 0.4 | 0.0 | 4.9 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 26 | 0.0 | 0.0 | 24.7 | 0.0 | 1.1 | 1.4 | 0.0 | 3.0 | 0.4 | 0.0 | 10.5 | 4.2 | 0.0 | 0.0 | 2.1 | 14.3 | 1.5 | 1.9 | 0.0 | 2.1 | 0.0 | 1.5 | 0.0 | 0.1 | 5.2 | 1.7 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 |
| " 27 | 0.1 | 0.0 | 27.7 | 0.0 | 0.9 | 0.6 | 0.1 | 1.3 | 0.3 | 0.0 | 11.0 | 5.0 | 0.1 | 0.3 | 1.2 | 13.5 | 2.5 | 1.0 | 0.0 | 2.1 | 0.1 | 0.6 | 0.1 | 0.2 | 4.4 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 28 | 0.4 | 0.2 | 29.7 | 0.2 | 1.3 | 1.5 | 0.0 | 1.0 | 1.8 | 0.0 | 8.6 | 6.9 | 0.3 | 0.1 | 4.9 | 9.4 | 2.3 | 1.6 | 0.0 | 1.6 | 0.6 | 0.9 | 0.1 | 0.0 | 2.2 | 0.9 | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 |
| " 29 | 0.0 | 0.0 | 14.8 | 0.0 | 0.6 | 0.8 | 0.4 | 1.0 | 0.0 | 0.0 | 14.6 | 0.2 | 0.0 | 0.0 | 0.0 | 15.0 | 2.7 | 0.4 | 0.0 | 0.5 | 0.1 | 3.8 | 0.0 | 0.0 | 4.6 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Roma 8/28 | 0.5 | 0.0 | 44.9 | 0.2 | 1.5 | 0.1 | 0.1 | 1.7 | 0.4 | 0.0 | 13.4 | 1.9 | 1.0 | 0.4 | 1.4 | 5.2 | 0.6 | 0.0 | 0.0 | 0.2 | 0.1 | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 |
| " 29 | 0.1 | 0.0 | 32.8 | 0.0 | 0.3 | 0.0 | 0.1 | 0.6 | 0.0 | 0.0 | 9.3 | 1.0 | 0.4 | 0.8 | 1.1 | 10.4 | 1.2 | 0.0 | 0.0 | 0.2 | 0.0 | 0.7 | 0.0 | 0.0 | 2.7 | 0.7 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 |
| " 30 | 0.6 | 0.0 | 29.7 | 0.7 | 1.0 | 1.6 | 0.1 | 0.4 | 2.2 | 0.0 | 8.6 | 5.4 | 0.2 | 0.2 | 5.7 | 14.4 | 3.9 | 2.6 | 0.0 | 1.8 | 0.1 | 0.5 | 0.1 | 0.1 | 1.4 | 1.2 | 0.0 | 0.0 | 0.2 | 0.1 | 0.9 |
| Chin. 4/46 | 0.6 | 0.2 | 12.1 | 0.2 | 0.5 | 0.6 | 0.0 | 3.6 | 0.4 | 0.5 | 15.5 | 2.2 | 0.1 | 0.0 | 1.6 | 17.2 | 1.4 | 2.5 | 0.0 | 2.1 | 0.0 | 1.6 | 0.8 | 0.5 | 3.6 | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 47 | 0.8 | 0.4 | 7.5 | 0.2 | 0.3 | 0.0 | 0.1 | 4.5 | 0.0 | 0.5 | 12.3 | 0.8 | 0.1 | 0.0 | 0.1 | 17.9 | 1.1 | 1.1 | 0.0 | 0.9 | 0.0 | 0.6 | 0.6 | 0.1 | 1.5 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 48 | 0.4 | 0.0 | 8.5 | 0.4 | 0.5 | 0.2 | 0.0 | 5.1 | 0.0 | 1.2 | 12.2 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.4 | 0.3 | 0.7 | 1.0 | 0.5 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| Average | 0.46 | 0.06 | 28.38 | 0.23 | 1.05 | 0.71 | 0.08 | 1.83 | 0.45 | 0.17 | 10.76 | 3.14 | 0.19 | 0.20 | 1.87 | 10.67 | 1.61 | 1.27 | 0.00 | 1.09 | 0.10 | 0.93 | 0.20 | 0.16 | 2.47 | 0.80 | 0.00 | 0.04 | 0.02 | 0.04 | 0.07 |
| **Springbok Sandstone** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Mitch. 2/30 | 0.0 | 0.0 | 8.2 | 0.0 | 0.7 | 1.0 | 0.0 | 2.5 | 0.0 | 0.3 | 9.4 | 0.1 | 0.1 | 0.0 | 0.0 | 18.5 | 2.0 | 0.8 | 0.4 | 0.9 | 0.4 | 2.4 | 1.4 | 0.3 | 2.8 | 0.5 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| " 63 | 0.0 | 0.0 | 12.7 | 0.0 | 0.6 | 0.0 | 0.0 | 2.0 | 1.6 | 0.0 | 15.5 | 7.1 | 0.0 | 0.0 | 2.4 | 9.2 | 2.4 | 2.4 | 0.8 | 0.4 | 0.0 | 0.0 | 0.1 | 1.1 | 5.4 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Roma 8/32 | 0.0 | 0.0 | 10.9 | 0.0 | 0.9 | 0.2 | 0.1 | 4.5 | 0.3 | 0.0 | 25.0 | 3.4 | 0.3 | 0.1 | 1.9 | 7.6 | 3.2 | 1.5 | 0.4 | 3.9 | 0.0 | 0.0 | 0.5 | 0.8 | 4.7 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 33 | 0.0 | 0.0 | 9.6 | 0.0 | 1.1 | 0.0 | 0.1 | 5.7 | 0.9 | 0.0 | 28.7 | 3.7 | 0.0 | 0.2 | 3.2 | 9.4 | 2.3 | 3.2 | 0.3 | 3.3 | 0.1 | 0.0 | 1.0 | 1.2 | 4.4 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Chin. 4/49 | 0.2 | 0.2 | 7.9 | 0.0 | 0.3 | 0.2 | 0.0 | 6.7 | 0.8 | 6.6 | 13.5 | 4.7 | 0.4 | 0.0 | 1.3 | 15.0 | 1.5 | 8.5 | 0.1 | 0.9 | 0.0 | 0.0 | 0.2 | 1.6 | 4.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 50 | 0.5 | 0.3 | 3.2 | 0.0 | 0.0 | 0.1 | 0.1 | 3.4 | 0.7 | 7.9 | 4.7 | 3.7 | 0.0 | 0.0 | 0.9 | 23.4 | 2.8 | 17.3 | 0.3 | 1.2 | 0.0 | 0.0 | 2.1 | 0.9 | 1.7 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Average | 0.11 | 0.08 | 8.75 | 0.00 | 0.60 | 0.25 | 0.05 | 4.13 | 0.72 | 2.47 | 16.16 | 3.78 | 0.13 | 0.05 | 1.61 | 13.85 | 2.36 | 5.61 | 0.38 | 1.76 | 0.08 | 0.40 | 0.88 | 0.98 | 3.83 | 0.48 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 |
| **Walloon Coal Measures** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Mitch. 2/31 | 0.0 | 0.0 | 8.4 | 0.0 | 0.7 | 0.4 | 0.1 | 1.2 | 0.0 | 0.0 | 14.8 | 9.1 | 0.1 | 0.2 | 4.2 | 20.7 | 3.7 | 1.5 | 0.1 | 2.7 | 0.0 | 4.8 | 1.2 | 1.2 | 3.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 62 | 0.0 | 0.0 | 8.6 | 0.0 | 0.9 | 0.9 | 0.0 | 2.3 | 0.0 | 0.2 | 16.2 | 0.4 | 0.2 | 0.0 | 1.4 | 26.3 | 3.1 | 2.1 | 0.1 | 1.1 | 0.1 | 2.2 | 0.2 | 0.9 | 2.3 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Roma 8/34 | 0.0 | 0.0 | 8.7 | 0.0 | 0.9 | 1.0 | 0.1 | 6.3 | 0.1 | 0.0 | 33.8 | 0.4 | 0.0 | 0.0 | 3.0 | 11.3 | 3.2 | 1.3 | 0.0 | 1.2 | 0.2 | 4.9 | 1.0 | 0.1 | 2.9 | 0.7 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 |

| Sample | No. | QUARTZ | | | | | | | FELDSPAR | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | QV1 | QV2 | Qc | Qv | Qp | qc | qcd | Fans | Fas | Fz | Funs | Fus | Fx | Fp | Fo |
| Roma | 8/35 | 0.0 | 0.0 | 18.3 | 0.0 | 0.5 | 0.5 | 0.2 | 0.8 | 0.0 | 0.0 | 8.4 | 0.0 | 0.0 | 0.0 | 0.5 |
| " | 36 | 0.0 | 0.0 | 10.0 | 0.0 | 0.6 | 1.0 | 0.1 | 2.6 | 0.0 | 0.0 | 7.8 | 2.6 | 0.1 | 0.1 | 2.9 |
| " | 37 | 0.0 | 0.0 | 17.1 | 0.0 | 1.0 | 0.0 | 0.0 | 0.7 | 0.1 | 0.0 | 16.6 | 0.7 | 0.2 | 0.1 | 7.8 |
| " | 38 | 0.0 | 0.0 | 24.0 | 0.0 | 0.7 | 0.2 | 0.0 | 0.8 | 0.0 | 0.0 | 11.1 | 0.3 | 0.0 | 0.0 | 1.6 |
| " | 39 | 0.0 | 0.0 | 8.6 | 0.0 | 0.2 | 0.1 | 0.0 | 2.6 | 0.0 | 0.0 | 12.4 | 0.2 | 0.0 | 0.0 | 0.0 |
| " | 40 | 0.0 | 0.0 | 15.4 | 0.0 | 0.8 | 0.0 | 0.1 | 1.2 | 0.9 | 0.0 | 14.1 | 2.6 | 0.0 | 0.0 | 6.1 |
| " | 41 | 0.0 | 0.0 | 14.3 | 0.0 | 0.8 | 0.3 | 0.0 | 0.9 | 0.0 | 0.0 | 10.3 | 0.0 | 0.0 | 0.0 | 1.8 |
| " | 42 | 0.0 | 0.0 | 10.1 | 0.0 | 0.1 | 0.0 | 0.0 | 1.3 | 0.0 | 0.0 | 13.4 | 0.0 | 0.1 | 0.0 | 0.0 |
| Chin. | 4/11 | 0.3 | 0.0 | 23.8 | 0.0 | 0.5 | 0.0 | 0.0 | 5.6 | 0.0 | 1.4 | 19.4 | 0.0 | 0.1 | 0.0 | 0.2 |
| " | 12 | 0.6 | 0.0 | 18.5 | 0.0 | 0.5 | 0.5 | 0.1 | 1.2 | 0.0 | 0.1 | 6.0 | 0.0 | 0.0 | 0.2 | 0.1 |
| " | 13 | 0.3 | 0.3 | 19.5 | 0.3 | 0.3 | 0.1 | 0.0 | 1.9 | 0.1 | 0.3 | 26.9 | 0.0 | 0.0 | 0.0 | 2.4 |
| " | 14 | 0.3 | 0.0 | 19.6 | 0.3 | 0.5 | 0.2 | 0.0 | 6.3 | 0.3 | 2.5 | 26.5 | 0.0 | 0.0 | 0.0 | 1.5 |
| " | 15 | 0.0 | 0.0 | 15.7 | 0.3 | 0.6 | 1.0 | 0.0 | 3.9 | 0.0 | 0.2 | 25.4 | 2.1 | 0.0 | 0.0 | 1.5 |
| " | 16 | 0.0 | 0.0 | 15.3 | 0.0 | 0.1 | 0.2 | 0.0 | 0.8 | 0.0 | 0.2 | 20.7 | 1.2 | 0.1 | 0.0 | 1.0 |
| " | 17 | 0.0 | 0.0 | 16.2 | 0.0 | 0.2 | 1.5 | 0.2 | 1.6 | 0.0 | 0.0 | 15.2 | 0.5 | 0.0 | 0.0 | 0.6 |
| " | 19 | 0.1 | 0.0 | 7.9 | 0.0 | 0.5 | 0.3 | 0.0 | 3.4 | 0.0 | 0.7 | 14.7 | 0.0 | 0.0 | 0.4 | 0.1 |
| " | 20 | 0.0 | 0.0 | 20.6 | 1.0 | 1.0 | 1.5 | 0.4 | 3.1 | 0.0 | 0.1 | 20.7 | 0.7 | 0.3 | 0.3 | 3.3 |
| " | 21 | 0.0 | 0.0 | 33.3 | 1.3 | 3.7 | 2.3 | 0.1 | 1.4 | 0.0 | 0.0 | 12.6 | 0.8 | 0.1 | 0.0 | 1.5 |
| " | 22 | 0.3 | 0.3 | 33.7 | 3.1 | 4.1 | 0.5 | 0.0 | 0.9 | 0.2 | 0.0 | 14.4 | 2.2 | 0.0 | 0.0 | 2.9 |
| " | 23 | 0.1 | 0.0 | 10.9 | 0.0 | 0.5 | 0.6 | 0.0 | 1.7 | 0.3 | 0.2 | 13.3 | 0.0 | 0.0 | 0.1 | 0.2 |
| " | 51 | 0.1 | 0.0 | 21.0 | 0.0 | 0.8 | 0.3 | 0.3 | 2.6 | 0.1 | 0.1 | 14.6 | 3.9 | 0.0 | 0.1 | 2.4 |
| " | 52 | 0.0 | 0.0 | 14.2 | 0.1 | 0.4 | 0.2 | 0.2 | 0.2 | 0.0 | 0.1 | 11.8 | 0.1 | 0.0 | 0.0 | 2.6 |
| " | 53 | 0.0 | 0.0 | 11.3 | 0.0 | 0.6 | 0.2 | 0.0 | 2.2 | 0.0 | 0.2 | 15.4 | 0.1 | 0.0 | 0.0 | 0.0 |
| " | 54 | 0.0 | 0.0 | 20.7 | 0.0 | 1.1 | 0.4 | 0.0 | 0.8 | 0.0 | 0.0 | 10.7 | 0.3 | 0.0 | 0.0 | 3.4 |
| Average | | 0.08 | 0.02 | 16.51 | 0.24 | 0.84 | 0.53 | 0.07 | 2.16 | 0.08 | 0.23 | 15.82 | 1.04 | 0.05 | 0.05 | 1.96 |

| Sample | No. | VOLC. ROCK-FRAGS. | | | | | CLASTIC SED. ROCK-FRAGS. | | | | | METAMORPHIC ROCK-FRAGS. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Vv | Vf | Vm/Vl | Achm | Vo | Ksq | Kzq | Ksl | Kzl | Ka | Tp | Ts | Tq | Mkq | Mo | P |
| Roma | 8/35 | 13.3 | 2.9 | 0.3 | 0.3 | 0.3 | 0.0 | 3.0 | 0.0 | 0.5 | 8.9 | 0.7 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 |
| " | 36 | 19.5 | 4.4 | 2.3 | 0.1 | 1.8 | 0.5 | 4.4 | 0.7 | 0.2 | 6.1 | 0.5 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 |
| " | 37 | 14.2 | 2.6 | 0.7 | 0.5 | 2.6 | 0.0 | 0.0 | 0.1 | 0.9 | 5.6 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 38 | 6.5 | 2.7 | 0.6 | 0.2 | 0.7 | 0.0 | 0.5 | 0.0 | 0.2 | 8.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 39 | 21.5 | 2.8 | 1.4 | 0.0 | 3.8 | 0.0 | 0.1 | 0.3 | 0.4 | 2.4 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 40 | 14.5 | 2.5 | 1.1 | 0.2 | 1.3 | 0.2 | 0.0 | 0.0 | 1.0 | 9.4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 41 | 17.1 | 2.9 | 1.7 | 0.2 | 2.0 | 0.1 | 0.5 | 0.4 | 2.3 | 6.6 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 42 | 11.0 | 2.0 | 0.7 | 0.1 | 1.8 | 0.0 | 0.0 | 0.0 | 0.3 | 7.8 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Chin. | 4/11 | 10.3 | 1.4 | 0.2 | 0.1 | 0.7 | 0.0 | 0.0 | 0.1 | 2.4 | 3.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 12 | 22.6 | 3.1 | 1.3 | 0.0 | 1.2 | 0.5 | 3.3 | 0.2 | 0.1 | 4.4 | 0.1 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 |
| " | 13 | 20.3 | 1.8 | 1.8 | 0.3 | 1.4 | 0.0 | 1.4 | 0.7 | 0.7 | 4.2 | 0.1 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 |
| " | 14 | 20.8 | 1.1 | 0.9 | 0.1 | 1.5 | 0.0 | 0.6 | 0.7 | 0.3 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 15 | 21.0 | 2.3 | 1.4 | 0.0 | 1.7 | 0.0 | 1.2 | 0.5 | 0.9 | 4.0 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| " | 16 | 21.3 | 0.9 | 2.6 | 0.1 | 0.5 | 0.0 | 0.1 | 0.3 | 0.9 | 4.0 | 0.3 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| " | 17 | 19.3 | 3.9 | 1.7 | 0.1 | 0.6 | 0.0 | 0.6 | 0.1 | 0.3 | 5.3 | 0.5 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| " | 19 | 23.0 | 3.6 | 2.9 | 0.0 | 0.7 | 0.0 | 0.0 | 0.1 | 0.0 | 3.8 | 0.8 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| " | 20 | 14.5 | 5.1 | 5.3 | 0.0 | 1.9 | 0.0 | 0.5 | 0.0 | 0.2 | 2.4 | 4.0 | 0.0 | 0.0 | 0.9 | 0.5 | 0.0 |
| " | 21 | 16.3 | 4.1 | 5.5 | 0.1 | 1.0 | 0.1 | 0.8 | 0.2 | 0.0 | 1.7 | 1.8 | 0.0 | 0.0 | 0.6 | 0.2 | 0.1 |
| " | 22 | 14.0 | 4.0 | 5.6 | 0.0 | 1.8 | 0.1 | 0.1 | 0.1 | 0.1 | 0.5 | 1.4 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 |
| " | 23 | 34.5 | 2.9 | 6.6 | 0.2 | 1.1 | 0.0 | 0.2 | 0.0 | 0.0 | 0.8 | 0.1 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 |
| " | 51 | 15.6 | 3.3 | 0.3 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 52 | 18.2 | 3.4 | 0.4 | 0.1 | 1.2 | 0.0 | 0.1 | 0.0 | 0.1 | 3.9 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 53 | 20.8 | 4.2 | 0.4 | 0.1 | 2.0 | 0.0 | 0.3 | 0.0 | 0.5 | 4.8 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 54 | 14.3 | 6.8 | 1.6 | 0.1 | 2.9 | 0.8 | 0.2 | 0.1 | 1.1 | 5.0 | 0.3 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| Average | | 17.88 | 3.14 | 1.93 | 0.11 | 1.50 | 0.09 | 1.10 | 0.26 | 0.58 | 4.22 | 0.58 | 0.00 | 0.00 | 0.15 | 0.03 | 0.00 |

| Sample No. | QUARTZ | | | | | | | FELDSPAR | | | | | | | | VOLC. ROCK-FRAGS. | | | | | CLASTIC SED. ROCK-FRAGS. | | | | | METAMORPHIC ROCK-FRAGS. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | QV 1 | QV 2 | Qc | Qv | Qp | qc | qcd | Fans | Fas | Fz | Funs | Fus | Fx | Fp | Fo | Vv | Vf | Vm/Vl | Achm | Vo | Ksq | Kzq | Ksl | Kzl | Ka | Tp | Ts | Tq | Mkq | Mo | P |
| **Hutton Sandstone** | | | | | | | | | | | | | | | | | | | | | **Hutton Sandstone** | | | | | | | | | | |
| Mitch. 2/32 | 0.0 | 0.0 | 20.6 | 0.0 | 1.8 | 0.0 | 0.0 | 2.7 | 0.0 | 0.0 | 14.4 | 0.6 | 0.1 | 0.1 | 0.1 | 15.9 | 1.8 | 0.9 | 0.0 | 1.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.7 | 4.5 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 33 | 0.0 | 0.0 | 19.0 | 0.0 | 1.2 | 0.0 | 0.0 | 1.2 | 0.0 | 0.0 | 11.5 | 0.0 | 0.0 | 0.2 | 0.2 | 18.4 | 3.0 | 0.1 | 0.0 | 2.2 | 0.0 | 0.0 | 0.1 | 0.8 | 2.0 | 3.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 34 | 0.0 | 0.0 | 32.1 | 0.0 | 2.3 | 0.7 | 0.0 | 1.2 | 0.0 | 0.0 | 6.6 | 1.0 | 0.0 | 0.1 | 0.4 | 19.8 | 3.3 | 1.4 | 0.0 | 1.9 | 0.0 | 0.0 | 0.9 | 0.6 | 2.6 | 2.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| " 35 | 0.0 | 0.0 | 22.2 | 0.0 | 1.4 | 0.1 | 0.0 | 1.5 | 0.0 | 0.0 | 14.1 | 2.0 | 0.2 | 0.1 | 0.2 | 14.5 | 1.9 | 0.2 | 0.0 | 2.9 | 0.0 | 0.0 | 0.4 | 0.0 | 2.1 | 5.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 36 | 0.0 | 0.0 | 28.4 | 0.0 | 1.5 | 0.1 | 0.0 | 1.9 | 0.0 | 0.0 | 12.5 | 0.8 | 0.0 | 0.0 | 0.9 | 20.2 | 2.4 | 1.3 | 0.0 | 1.3 | 0.0 | 0.0 | 0.5 | 0.0 | 1.8 | 3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 37 | 0.0 | 0.0 | 56.5 | 0.2 | 4.5 | 0.7 | 0.0 | 0.1 | 0.0 | 0.0 | 2.9 | 1.0 | 0.1 | 0.4 | 1.3 | 5.2 | 1.8 | 0.8 | 0.0 | 0.8 | 0.0 | 0.0 | 0.2 | 0.0 | 0.4 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 38 | 0.0 | 0.0 | 36.3 | 0.0 | 1.8 | 0.0 | 0.0 | 2.0 | 0.2 | 0.0 | 10.3 | 1.0 | 0.1 | 0.1 | 1.1 | 13.4 | 2.6 | 1.4 | 0.4 | 2.7 | 0.0 | 0.0 | 0.1 | 0.1 | 0.8 | 1.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 39 | 0.0 | 0.0 | 51.7 | 0.1 | 3.3 | 0.4 | 0.0 | 0.8 | 0.0 | 0.0 | 8.5 | 0.7 | 0.1 | 0.5 | 1.1 | 5.9 | 1.7 | 0.8 | 0.0 | 0.3 | 0.0 | 0.2 | 0.0 | 0.0 | 1.6 | 0.6 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 |
| " 40 | 0.0 | 0.0 | 54.6 | 1.1 | 4.8 | 0.3 | 0.1 | 0.2 | 0.0 | 0.0 | 9.3 | 0.1 | 0.3 | 0.4 | 0.6 | 6.0 | 2.1 | 0.6 | 0.0 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 0.1 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 |
| " 41 | 0.0 | 0.0 | 49.8 | 0.0 | 1.8 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 9.6 | 0.5 | 0.0 | 0.4 | 0.9 | 4.2 | 1.5 | 0.6 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 42 | 0.0 | 0.0 | 52.6 | 0.0 | 0.9 | 0.2 | 0.0 | 0.5 | 0.0 | 0.0 | 8.5 | 1.4 | 0.4 | 1.1 | 0.4 | 1.4 | 1.6 | 0.1 | 0.0 | 0.3 | 0.0 | 0.1 | 0.0 | 0.1 | 0.2 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 43 | 0.0 | 0.0 | 51.1 | 0.0 | 1.5 | 0.2 | 0.0 | 1.3 | 0.2 | 0.0 | 12.8 | 0.4 | 0.3 | 0.3 | 1.3 | 1.8 | 0.9 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 44 | 0.0 | 0.0 | 54.7 | 0.0 | 1.6 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 10.7 | 0.4 | 0.5 | 0.4 | 1.2 | 1.7 | 1.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 | 0.6 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 45 | 0.0 | 0.0 | 53.9 | 0.0 | 2.2 | 0.2 | 0.0 | 1.0 | 0.2 | 0.0 | 9.4 | 0.2 | 0.7 | 0.0 | 1.1 | 1.7 | 0.6 | 0.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.5 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 46 | 0.0 | 0.0 | 53.7 | 0.1 | 1.8 | 0.0 | 0.1 | 0.9 | 0.2 | 0.0 | 12.5 | 0.7 | 0.3 | 0.3 | 1.4 | 2.7 | 0.2 | 0.5 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.5 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 47 | 0.0 | 0.0 | 48.5 | 0.0 | 1.5 | 0.1 | 0.0 | 1.5 | 0.2 | 0.0 | 13.1 | 1.7 | 0.3 | 0.6 | 2.2 | 2.9 | 1.4 | 0.4 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.8 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 49 | 0.0 | 0.0 | 48.6 | 0.0 | 0.5 | 0.0 | 0.0 | 1.5 | 0.0 | 0.0 | 15.3 | 0.8 | 0.0 | 0.6 | 1.6 | 4.6 | 0.5 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 50 | 0.0 | 0.0 | 50.7 | 0.2 | 0.9 | 0.0 | 0.0 | 0.9 | 0.0 | 0.0 | 16.2 | 0.4 | 0.6 | 0.7 | 0.6 | 5.2 | 0.4 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 51 | 0.0 | 0.0 | 56.8 | 0.0 | 1.6 | 0.0 | 0.0 | 0.7 | 0.0 | 0.0 | 9.7 | 0.2 | 0.5 | 0.3 | 1.1 | 1.1 | 0.8 | 0.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.5 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 52 | 0.0 | 0.0 | 44.0 | 0.0 | 1.8 | 0.0 | 0.0 | 1.0 | 0.1 | 0.0 | 15.8 | 0.1 | 0.3 | 0.4 | 1.4 | 2.6 | 1.2 | 0.2 | 0.0 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 53 | 0.0 | 0.0 | 53.0 | 0.0 | 2.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 15.0 | 0.1 | 0.5 | 0.6 | 1.8 | 2.7 | 1.1 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 1.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 54 | 0.0 | 0.0 | 55.3 | 0.1 | 2.3 | 0.1 | 0.0 | 0.3 | 0.2 | 0.0 | 12.1 | 0.3 | 0.1 | 0.4 | 1.5 | 3.4 | 0.5 | 0.3 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 55 | 0.0 | 0.0 | 61.9 | 0.7 | 2.2 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 9.7 | 0.0 | 0.2 | 0.0 | 0.4 | 2.7 | 0.5 | 0.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 56 | 0.0 | 0.0 | 59.0 | 0.0 | 1.5 | 0.1 | 0.0 | 0.6 | 0.0 | 0.0 | 11.5 | 0.1 | 0.4 | 0.2 | 2.0 | 3.7 | 0.3 | 0.3 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 57 | 0.0 | 0.0 | 60.1 | 0.1 | 2.5 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 6.2 | 0.2 | 0.3 | 0.0 | 0.9 | 2.1 | 1.3 | 0.1 | 0.0 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 1.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Roma 8/43 | 0.0 | 0.0 | 14.7 | 0.0 | 0.6 | 0.1 | 0.4 | 2.2 | 0.0 | 0.0 | 12.5 | 0.0 | 0.1 | 0.0 | 0.1 | 14.8 | 1.3 | 1.1 | 0.1 | 3.2 | 0.0 | 0.0 | 0.0 | 1.5 | 4.0 | 2.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 44 | 0.0 | 0.0 | 20.6 | 0.0 | 2.1 | 0.2 | 0.0 | 2.4 | 0.2 | 0.0 | 12.0 | 1.2 | 0.2 | 0.1 | 2.8 | 16.9 | 2.9 | 2.5 | 0.0 | 1.6 | 0.1 | 0.1 | 0.4 | 1.3 | 4.9 | 2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 45 | 0.0 | 0.0 | 22.6 | 0.0 | 2.1 | 0.2 | 0.0 | 0.7 | 0.0 | 0.0 | 16.5 | 1.0 | 0.2 | 0.0 | 2.7 | 15.8 | 4.4 | 2.8 | 0.0 | 1.1 | 0.0 | 0.1 | 0.0 | 2.0 | 4.1 | 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| Sample No. | QUARTZ | | | | | | | FELDSPAR | | | | | | | | VOLC. ROCK-FRAGS. | | | | | CLASTIC SED. ROCK-FRAGS. | | | | | METAMORPHIC ROCK-FRAGS. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | QV 1 | QV 2 | Qc | Qv | Qp | qc | qcd | Fans | Fas | Fz | Funs | Fus | Fx | Fp | Fo | Vv | Vf | Vm/Vl | Achm | Vo | Ksq | Kzq | Ksl | Kzl | Ka | Tp | Ts | Tq | Mxq | Mo | P |
| Roma 8/46 | 0.0 | 0.0 | 36.3 | 0.0 | 1.5 | 0.5 | 0.0 | 1.7 | 0.0 | 0.0 | 9.8 | 2.6 | 0.3 | 0.2 | 1.6 | 8.8 | 4.6 | 3.3 | 0.0 | 1.1 | 0.0 | 0.1 | 0.0 | 0.7 | 2.2 | 1.6 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| " 47 | 0.0 | 0.0 | 35.3 | 0.0 | 3.3 | 1.0 | 0.3 | 1.5 | 0.2 | 0.0 | 13.0 | 0.6 | 0.4 | 0.1 | 1.4 | 9.1 | 3.1 | 6.2 | 0.1 | 1.6 | 0.0 | 0.2 | 0.5 | 0.9 | 2.8 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 48 | 0.0 | 0.0 | 38.7 | 0.0 | 2.5 | 0.8 | 0.0 | 1.9 | 0.0 | 0.0 | 9.2 | 0.6 | 0.2 | 0.3 | 1.9 | 11.3 | 4.8 | 5.6 | 0.0 | 1.8 | 0.0 | 0.7 | 0.0 | 0.1 | 1.9 | 1.6 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 |
| " 49 | 0.0 | 0.0 | 35.0 | 0.3 | 2.3 | 0.1 | 0.2 | 0.5 | 0.0 | 0.0 | 10.7 | 1.0 | 0.1 | 0.0 | 1.5 | 12.4 | 2.3 | 1.7 | 0.0 | 1.0 | 0.0 | 0.1 | 0.0 | 0.9 | 5.2 | 1.8 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| " 50 | 0.0 | 0.0 | 33.8 | 0.0 | 2.0 | 0.3 | 0.1 | 1.9 | 0.0 | 0.0 | 13.9 | 0.7 | 0.2 | 0.1 | 1.1 | 9.1 | 3.6 | 1.8 | 0.0 | 2.5 | 0.0 | 0.1 | 0.1 | 0.6 | 2.9 | 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 51 | 0.0 | 0.0 | 62.3 | 0.2 | 4.4 | 0.5 | 0.1 | 0.3 | 0.0 | 0.0 | 3.1 | 0.1 | 0.2 | 0.0 | 0.6 | 0.9 | 1.5 | 0.2 | 0.0 | 0.1 | 0.0 | 1.3 | 0.0 | 0.2 | 2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 52 | 0.0 | 0.0 | 40.1 | 0.0 | 2.2 | 0.1 | 0.1 | 0.4 | 0.0 | 0.0 | 9.1 | 0.1 | 0.0 | 0.1 | 0.6 | 3.2 | 2.1 | 0.3 | 0.2 | 0.4 | 0.2 | 0.2 | 0.1 | 0.0 | 0.5 | 1.7 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 |
| " 53 | 0.0 | 0.0 | 62.6 | 0.2 | 3.4 | 0.0 | 0.0 | 0.7 | 0.0 | 0.0 | 4.2 | 0.5 | 0.3 | 0.1 | 1.3 | 1.7 | 1.3 | 0.3 | 0.0 | 0.3 | 0.0 | 0.1 | 0.0 | 0.0 | 0.2 | 0.2 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 |
| " 54 | 0.0 | 0.0 | 47.2 | 0.0 | 1.8 | 0.1 | 0.0 | 0.5 | 0.1 | 0.0 | 8.5 | 1.3 | 0.2 | 0.2 | 1.6 | 5.7 | 2.4 | 1.3 | 0.0 | 0.9 | 0.0 | 0.0 | 0.0 | 0.1 | 1.0 | 1.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 55 | 0.0 | 0.0 | 43.6 | 0.0 | 1.7 | 0.1 | 0.1 | 0.8 | 0.0 | 0.0 | 8.9 | 0.1 | 0.1 | 0.1 | 0.2 | 3.8 | 1.3 | 0.5 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 2.5 | 1.5 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| " 56 | 0.0 | 0.0 | 55.6 | 0.0 | 1.6 | 0.1 | 0.0 | 0.6 | 0.1 | 0.0 | 10.3 | 1.0 | 0.9 | 0.0 | 1.7 | 2.3 | 0.6 | 0.3 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 57 | 0.0 | 0.0 | 40.6 | 0.0 | 0.8 | 0.1 | 0.1 | 0.4 | 0.0 | 0.0 | 9.5 | 0.1 | 0.4 | 0.0 | 1.0 | 4.4 | 0.4 | 0.2 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 3.3 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 58 | 0.0 | 0.0 | 40.2 | 0.0 | 1.8 | 0.1 | 0.0 | 1.2 | 0.0 | 0.0 | 10.0 | 0.2 | 0.4 | 0.0 | 0.2 | 2.8 | 1.7 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 0.4 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 59 | 0.0 | 0.0 | 56.6 | 1.3 | 3.8 | 0.1 | 0.0 | 0.3 | 0.0 | 0.0 | 7.3 | 0.9 | 0.3 | 0.0 | 0.7 | 3.4 | 1.3 | 0.2 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 60 | 0.0 | 0.0 | 51.7 | 0.0 | 1.3 | 0.0 | 0.0 | 1.1 | 0.0 | 0.0 | 12.3 | 1.8 | 0.2 | 0.6 | 0.9 | 4.7 | 0.8 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.1 | 0.0 | 0.3 | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 61 | 0.0 | 0.0 | 49.7 | 0.0 | 1.8 | 0.0 | 0.0 | 1.3 | 0.0 | 0.0 | 13.4 | 1.8 | 0.2 | 0.2 | 1.4 | 4.0 | 1.9 | 0.4 | 0.0 | 0.6 | 0.0 | 0.1 | 0.0 | 0.0 | 0.6 | 1.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 63 | 0.0 | 0.0 | 50.7 | 0.0 | 1.5 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 13.5 | 1.3 | 0.8 | 0.5 | 0.4 | 3.2 | 0.9 | 0.2 | 0.0 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 | 0.6 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 64 | 0.0 | 0.0 | 46.1 | 0.0 | 1.4 | 0.0 | 0.0 | 1.4 | 0.0 | 0.0 | 13.8 | 1.0 | 0.9 | 0.3 | 1.2 | 4.5 | 1.1 | 0.4 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 65 | 0.0 | 0.0 | 54.6 | 0.0 | 1.8 | 0.1 | 0.0 | 1.0 | 0.0 | 0.0 | 9.2 | 1.5 | 0.5 | 0.0 | 0.6 | 2.2 | 0.8 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.9 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Chin. 4/24 | 0.0 | 0.3 | 62.4 | 1.3 | 1.2 | 2.0 | 0.1 | 0.1 | 0.0 | 0.0 | 7.8 | 0.4 | 0.2 | 0.3 | 0.6 | 4.9 | 1.4 | 0.2 | 0.0 | 0.4 | 0.0 | 0.2 | 0.0 | 0.0 | 0.1 | 0.5 | 0.0 | 0.1 | 1.2 | 0.2 | 0.0 |
| " 25 | 0.0 | 0.0 | 54.9 | 0.5 | 4.6 | 0.6 | 0.0 | 0.2 | 0.0 | 0.0 | 3.9 | 0.5 | 0.4 | 0.1 | 2.4 | 5.4 | 1.4 | 0.7 | 0.0 | 0.3 | 0.2 | 0.1 | 0.0 | 0.0 | 1.4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 27 | 0.0 | 0.0 | 66.0 | 0.4 | 4.5 | 0.5 | 0.0 | 0.1 | 0.0 | 0.0 | 2.8 | 0.4 | 0.0 | 0.0 | 1.2 | 1.1 | 1.0 | 0.2 | 0.1 | 0.1 | 0.0 | 0.3 | 0.0 | 0.0 | 0.6 | 0.3 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 |
| " 28 | 0.0 | 0.0 | 42.9 | 0.0 | 1.4 | 0.0 | 0.0 | 0.8 | 0.0 | 0.0 | 8.8 | 0.0 | 0.3 | 0.0 | 1.1 | 5.3 | 2.4 | 0.4 | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | 0.2 | 2.4 | 2.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| Average | 0.00 | 0.00 | 45.88 | 0.13 | 2.09 | 2.17 | 0.04 | 0.95 | 0.04 | 0.00 | 10.43 | 0.69 | 0.28 | 0.22 | 1.10 | 6.38 | 1.68 | 0.82 | 0.02 | 0.77 | 0.00 | 0.08 | 0.07 | 0.20 | 1.23 | 1.35 | 0.33 | 0.04 | 0.02 | 0.00 | 0.00 |

**Evergreen Formation** **Evergreen Formation**

| Sample No. | QV 1 | QV 2 | Qc | Qv | Qp | qc | qcd | Fans | Fas | Fz | Funs | Fus | Fx | Fp | Fo | Vv | Vf | Vm/Vl | Achm | Vo | Ksq | Kzq | Ksl | Kzl | Ka | Tp | Ts | Tq | Mxq | Mo | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mitch. 2/58 | 0.0 | 0.0 | 77.2 | 0.6 | 1.7 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.5 | 1.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| " 59 | 0.0 | 0.0 | 70.7 | 0.0 | 1.2 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 6.8 | 0.0 | 0.1 | 0.3 | 0.2 | 2.3 | 1.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Roma 8/66 | 0.0 | 0.0 | 44.2 | 0.7 | 2.4 | 0.3 | 0.0 | 1.4 | 0.0 | 0.0 | 13.6 | 0.7 | 0.0 | 0.0 | 2.4 | 8.6 | 1.9 | 0.8 | 0.0 | 0.7 | 0.0 | 0.1 | 0.0 | 0.0 | 0.9 | 2.3 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |

| Sample No. | QUARTZ | | | | | | | FELDSPAR | | | | | | | | VOLC. ROCK-FRAGS. | | | | | CLASTIC SED. ROCK-FRAGS. | | | | | METAMORPHIC ROCK-FRAGS. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | QV 1 | QV 2 | Qc | Qv | Qp | qc | qcd | Fans | Fas | Fz | Fums | Fus | Fx | Fp | Fo | Vv | Vf | Vm/Vl | Achm | Vo | Ksq | Kzq | Ksl | Kzl | Ka | Tp | Ts | Tq | Mkq | Mo | P |
| Roma 8/67 | 0.0 | 0.0 | 36.8 | 0.0 | 0.9 | 0.4 | 0.0 | 0.7 | 0.0 | 0.0 | 14.1 | 0.5 | 0.1 | 0.1 | 0.9 | 10.4 | 1.5 | 0.2 | 0.0 | 0.6 | 0.1 | 0.3 | 0.1 | 0.2 | 1.5 | 3.6 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 |
| " 68 | 0.0 | 0.0 | 57.2 | 0.0 | 0.7 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 4.4 | 0.0 | 0.0 | 0.0 | 0.7 | 10.4 | 2.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 |
| " 70 | 0.0 | 0.0 | 25.5 | 0.0 | 0.5 | 0.1 | 0.0 | 1.2 | 0.0 | 0.0 | 12.8 | 1.4 | 0.0 | 0.1 | 0.5 | 14.0 | 1.5 | 0.2 | 0.0 | 0.7 | 0.0 | 0.1 | 0.0 | 0.0 | 1.0 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Chin 4/30 | 0.0 | 0.0 | 34.4 | 0.0 | 0.3 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 13.1 | 0.1 | 0.1 | 0.3 | 0.0 | 6.4 | 0.8 | 0.2 | 0.0 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 |
| " 31 | 0.0 | 0.0 | 62.6 | 0.1 | 1.9 | 0.3 | 0.0 | 0.4 | 0.0 | 0.0 | 12.4 | 2.1 | 0.1 | 0.3 | 0.5 | 2.5 | 1.5 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.5 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 |
| " 32 | 0.0 | 0.0 | 47.1 | 0.1 | 3.0 | 0.0 | 0.0 | 1.2 | 0.0 | 0.0 | 14.4 | 2.1 | 0.0 | 0.2 | 0.8 | 6.0 | 0.5 | 0.1 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 | 1.7 | 0.0 | 0.0 | 0.3 | 0.3 | 0.0 |
| " 33 | 0.0 | 0.0 | 55.5 | 1.5 | 3.0 | 0.9 | 0.0 | 0.4 | 0.0 | 0.0 | 10.1 | 0.3 | 0.1 | 0.5 | 1.6 | 4.3 | 0.8 | 0.5 | 0.0 | 0.6 | 0.0 | 0.5 | 0.0 | 0.0 | 1.1 | 0.5 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 |
| " 34 | 0.0 | 0.0 | 20.8 | 0.0 | 0.8 | 0.1 | 0.0 | 2.6 | 0.0 | 0.0 | 31.2 | 0.1 | 0.2 | 0.0 | 0.2 | 13.5 | 1.8 | 2.7 | 0.0 | 1.4 | 0.0 | 0.1 | 0.0 | 0.0 | 1.0 | 1.3 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 |
| " 35 | 0.0 | 0.0 | 22.7 | 0.0 | 1.3 | 0.0 | 0.0 | 1.5 | 0.0 | 0.0 | 19.2 | 0.0 | 0.1 | 0.1 | 0.6 | 20.8 | 1.9 | 2.9 | 0.0 | 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 2.4 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 |
| " 36 | 0.0 | 0.0 | 32.4 | 0.3 | 2.1 | 0.4 | 0.0 | 0.7 | 0.0 | 0.0 | 13.7 | 3.2 | 0.1 | 0.5 | 2.1 | 20.4 | 2.3 | 4.5 | 0.0 | 2.9 | 0.0 | 0.1 | 0.0 | 0.0 | 1.7 | 0.9 | 0.0 | 0.0 | 0.2 | 0.1 | 0.0 |
| " 37 | 0.0 | 0.0 | 24.8 | 0.0 | 0.7 | 0.0 | 0.0 | 1.7 | 0.0 | 0.0 | 18.8 | 3.4 | 0.0 | 0.0 | 2.3 | 20.2 | 2.4 | 4.4 | 0.0 | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 | 0.8 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| " 38 | 0.0 | 0.0 | 19.0 | 0.0 | 1.0 | 0.0 | 0.0 | 2.5 | 0.0 | 0.0 | 24.0 | 0.8 | 0.1 | 0.0 | 1.7 | 17.0 | 1.8 | 3.0 | 0.1 | 1.3 | 0.0 | 0.0 | 0.2 | 0.0 | 2.2 | 1.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 39 | 0.0 | 0.0 | 17.1 | 0.0 | 0.8 | 0.0 | 0.1 | 2.4 | 0.1 | 0.0 | 20.7 | 2.7 | 0.1 | 0.4 | 1.4 | 16.2 | 1.8 | 4.5 | 0.0 | 2.6 | 0.0 | 0.0 | 0.0 | 0.4 | 3.2 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Average | 0.00 | 0.00 | 40.50 | 0.21 | 1.39 | 0.17 | 0.00 | 1.11 | 0.00 | 0.00 | 14.39 | 1.08 | 0.07 | 0.17 | 1.03 | 10.87 | 1.48 | 1.50 | 0.00 | 1.02 | 0.00 | 0.07 | 0.02 | 0.04 | 1.05 | 1.27 | 0.00 | 0.00 | 0.15 | 0.06 | 0.00 |

Precipice Sandstone

Precipice Sandstone

| Sample No. | QV 1 | QV 2 | Qc | Qv | Qp | qc | qcd | Fans | Fas | Fz | Fums | Fus | Fx | Fp | Fo | Vv | Vf | Vm/Vl | Achm | Vo | Ksq | Kzq | Ksl | Kzl | Ka | Tp | Ts | Tq | Mkq | Mo | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mitch. 2/60 | 0.0 | 0.0 | 74.6 | 0.0 | 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| Roma 8/71 | 0.0 | 0.0 | 47.2 | 0.0 | 1.8 | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 9.4 | 0.0 | 0.8 | 1.3 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.9 | 3.4 | 0.0 | 0.0 | 5.3 | 0.3 | 0.1 | 0.0 | 0.4 | 0.0 | 0.0 |
| " 72 | 0.0 | 0.0 | 50.8 | 0.3 | 3.1 | 0.5 | 0.0 | 0.2 | 0.0 | 0.0 | 7.4 | 0.0 | 0.3 | 0.0 | 0.4 | 0.9 | 1.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.9 | 0.0 | 0.0 | 4.4 | 3.1 | 0.7 | 0.0 | 0.0 | 0.2 | 0.0 |
| Chin. 4/40 | 0.0 | 0.0 | 72.3 | 0.2 | 2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.4 | 0.0 | 0.0 | 0.0 | 0.8 | 1.5 | 2.2 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 41 | 0.0 | 0.0 | 81.6 | 1.4 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 0.0 |
| " 42 | 0.0 | 0.0 | 74.1 | 0.8 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 43 | 0.0 | 0.0 | 84.5 | 1.3 | 1.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| " 44 | 0.0 | 0.0 | 76.6 | 0.8 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 45 | 0.0 | 0.0 | 72.9 | 0.0 | 1.9 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| Average | 0.00 | 0.00 | 70.51 | 0.53 | 1.99 | 0.26 | 0.00 | 0.02 | 0.00 | 0.00 | 2.50 | 0.00 | 0.13 | 0.14 | 0.26 | 0.27 | 0.36 | 0.00 | 0.00 | 0.17 | 0.10 | 0.48 | 0.00 | 0.00 | 1.46 | 0.49 | 0.14 | 0.04 | 0.04 | 0.02 | 0.00 |

Footnotes to Appendix 1.8.1.

1 Undifferentiated Kq.

2 Undifferentiated Kl.

3 Mean of Kq including sum of Ksq and Kzq, and undifferentiated Kq.

4 Mean of Kl including sum of Ksl and Kzl, and undifferentiated Kl.

# APPENDIX 1.8.2. MICA AND HEAVY MINERAL CONTENT

Appendix 1.8.2. Detailed mica and heavy mineral content (whole-rock percentage) of the Surat Basin sandstones based on thin-section point-counting (1000 points per slide). Symbols as of Appendix 1.1.

| | <——— MICA | | | ———> | <-HEAVY MINERALS-> | | | MAIN SPECIES OF HT |
|---|---|---|---|---|---|---|---|---|
| Sample No. | Zb | Zw | Zch | Zdi | HP | HT | HO | |
| | | | | | **Griman Creek Formation** | | | |
| Surat 3/1 | 3.0 | 0.2 | 0.2 | 0.0 | 0.0 | 0.2 | 0.0 | |
| " 2 | 2.2 | 0.4 | 0.3 | 0.0 | 0.1 | 0.1 | 0.0 | Zircon |
| " 3 | 5.3 | 1.3 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | Zircon |
| " 4 | 4.4 | 0.7 | 0.3 | 0.0 | 0.3 | 0.2 | 0.0 | Epidote, zircon |
| " 5 | 1.9 | 0.0 | 0.1 | 0.0 | 0.2 | 0.0 | 0.0 | |
| " 6 | 4.0 | 0.1 | 0.1 | 0.0 | 0.4 | 0.6 | 0.4 | Zircon (0.$%), epid. (0.2%) |
| " 7 | 5.5 | 0.1 | 0.0 | 0.0 | 0.5 | 0.8 | 0.8 | Epid. (0.5%), garn. (0.2%), zirc. (0.1%) |
| " 9 | 0.9 | 0.7 | 0.2 | 0.0 | 0.1 | 0.3 | 0.0 | Toumaline (0.2%) |
| " 10 | 2.8 | 0.3 | 0.2 | 0.0 | 0.0 | 0.2 | 0.3 | Epidote (0.2%) |
| " 11 | 3.6 | 0.0 | 0.0 | 0.0 | 0.3 | 0.1 | 0.2 | |
| " 12 | 0.2 | 0.2 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | Tourmaline |
| " 13 | 0.9 | 0.4 | 0.1 | 0.0 | 0.0 | 0.1 | 0.1 | Garnet |
| " 14 | 4.2 | 0.1 | 0.4 | 0.0 | 0.1 | 0.2 | 0.2 | Zircon (0.1%), epidote (0.1%) |
| " 15 | 5.6 | 0.1 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | Epidote (0.2%), tourmaline (0.1%) |
| " 16 | 3.7 | 0.2 | 0.1 | 0.0 | 0.2 | 0.3 | 0.0 | Sphene (0.1%), zircon (0.1%) |
| " 17 | 0.8 | 0.4 | 0.1 | 0.0 | 0.4 | 0.6 | 0.3 | |
| " 18 | 1.3 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.2 | |
| " 20 | 3.9 | 0.1 | 0.0 | 0.0 | 0.2 | 0.1 | 0.2 | Tourmaline |
| " 21 | 1.8 | 0.1 | 0.1 | 0.0 | 0.1 | 0.0 | 0.1 | |
| " 22 | 1.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.3 | 0.6 | Garnet (0.2%), tourmal. (0.1%) |
| " 23 | 1.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 24 | 0.3 | 0.1 | 0.3 | 0.0 | 0.1 | 0.2 | 0.0 | Garnet, tourmaline |
| " 25 | 1.7 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 26 | 1.6 | 0.0 | 0.1 | 0.0 | 0.1 | 0.1 | 0.0 | Epidote |

| Sample No. | ← MICA Zb | Zw | Zch | Zdi → | ←HEAVY MINERALS→ HP | HT | HO | MAIN SPECIES OF HT |
|---|---|---|---|---|---|---|---|---|
| Surat 3/27 | 0.9 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 28 | 2.8 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | Zircon |
| Average | 2.51 | 0.22 | 0.12 | 0.00 | 0.14 | 0.18 | 0.13 | |
| | | | | | Surat Siltstone | | | |
| Surat 3/29 | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | Zircon |
| " 30 | 1.4 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | |
| Average | 1.40 | 0.00 | 0.00 | 0.00 | 0.05 | 0.05 | 0.00 | |
| | | | | | Wallumbilla Formation | | | |
| Surat 1/4 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | Epidote |
| " 5 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.1 | Zircon |
| " 8 | 9.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.2 | |
| " 9 | 2.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | |
| Surat 3/31 | 3.5 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | |
| " 32 | 4.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 33 | 2.2 | 0.0 | 0.0 | 0.0 | 0.2 | 0.1 | 0.0 | Epidote |
| Average | 3.30 | 0.00 | 0.01 | 0.00 | 0.11 | 0.06 | 0.04 | |
| | | | | | Bungil Formation | | | |
| Mitch. 2/1 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 3 | 1.0 | 0.9 | 0.0 | 0.0 | 0.6 | 0.2 | 0.0 | Epidote |
| " 4 | 0.7 | 1.7 | 0.0 | 0.0 | 0.2 | 0.2 | 1.4 | Zirc. (0.2%) |
| Roma 8/1 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 2 | 2.6 | 1.7 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | |
| " 3 | 6.3 | 0.0 | 0.0 | 1.7 | 0.2 | 0.0 | 0.0 | |
| " 4 | 0.9 | 0.3 | 0.0 | 0.0 | 0.0 | 0.3 | 0.1 | Tourmaline (0.2%) |
| Surat 1/13 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |

| Sample No. | MICA Zb | Zw | Zch | Zdi | HEAVY MINERALS HP | HT | HO | MAIN SPECIES OF HT |
|---|---|---|---|---|---|---|---|---|
| Surat 1/15 | 2.7 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | |
| " 16 | 2.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.2 | Zircon, epidote |
| " 17 | 3.7 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | |
| " 18 | 3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | |
| Average | 2.15 | 0.39 | 0.00 | 0.14 | 0.10 | 0.07 | 0.19 | |
| | | | | | Mooga Sandstone | | | |
| Mitch. 2/61 | 0.2 | 0.1 | 0.1 | 2.4 | 0.0 | 0.1 | 0.0 | Epidote |
| Roma 8/5 | 0.0 | 0.2 | 0.3 | 1.8 | 0.0 | 0.1 | 0.0 | Anatase |
| " 7 | 0.0 | 0.3 | 0.2 | 2.8 | 0.0 | 0.1 | 0.1 | Tourmaline |
| " 8 | 0.1 | 0.4 | 0.1 | 2.3 | 0.0 | 0.1 | 0.0 | Tourmaline |
| " 9 | 0.0 | 0.0 | 0.0 | 13.3 | 0.0 | 0.2 | 0.0 | |
| Average | 0.06 | 0.20 | 0.14 | 4.52 | 0.00 | 0.10 | 0.02 | |
| | | | | | Orallo Formation | | | |
| Mitch. 2/6 | 0.5 | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 7 | 0.7 | 2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 9 | 0.0 | 1.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 10 | 0.2 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 11 | 0.3 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | |
| " 12 | 0.7 | 1.5 | 0.0 | 0.0 | 0.1 | 0.2 | 0.2 | Zircon |
| " 13 | 0.1 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | |
| " 14 | 0.4 | 1.4 | 0.0 | 0.0 | 0.2 | 0.1 | 0.2 | Epidote |
| " 15 | 0.3 | 0.4 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | |
| " 16 | 1.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 17 | 1.4 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| Roma 8/10 | 0.8 | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 11 | 1.1 | 0.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | |

| Sample No. | ←— MICA Zb | Zw | Zch | —→ Zdi | ←HEAVY MINERALS→ HP | HT | HO | MAIN SPECIES OF HT |
|---|---|---|---|---|---|---|---|---|
| Roma 8/12 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | Zircon |
| " 13 | 1.3 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 14 | 0.1 | 0.3 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | Epidote |
| " 15 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 16 | 0.1 | 1.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | Zircon |
| " 17 | 0.1 | 0.9 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | Zircon |
| " 18 | 1.1 | 0.9 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | Tourmaline |
| " 19 | 2.0 | 0.5 | 0.2 | 0.0 | 0.0 | 0.2 | 0.1 | Epidote, zircon |
| " 20 | 2.5 | 0.3 | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | |
| Chin. 4/1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.2 | Zircon |
| " 2 | 0.6 | 0.3 | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 | Zircon |
| Average | 0.68 | 0.74 | 0.01 | 0.00 | 0.02 | 0.06 | 0.06 | |

<u>Gubberamunda Sandstone</u>

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Mitch. 2/18 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | Garnet |
| " 19 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 1.0 | 0.0 | Garnet |
| " 20 | 0.0 | 0.0 | 0.0 | 0.7 | 0.0 | 0.2 | 0.0 | Garnet |
| " 21 | 0.1 | 0.0 | 0.1 | 0.1 | 0.0 | 0.3 | 0.0 | Garnet |
| Roma 8/21 | 0.0 | 0.3 | 0.3 | 2.0 | 0.0 | 0.2 | 0.0 | Garnet |
| " 22 | 0.0 | 0.1 | 0.1 | 1.0 | 0.0 | 1.5 | 0.3 | Garnet (1.4%) |
| " 23 | 0.0 | 0.4 | 0.0 | 1.1 | 0.0 | 1.1 | 0.1 | Garnet |
| " 24 | 0.0 | 0.1 | 0.0 | 0.4 | 0.0 | 0.9 | 0.2 | Zircon (0.8%) |
| " 25 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 1.5 | 0.0 | Zircon |
| " 26 | 0.0 | 0.1 | 0.1 | 0.5 | 0.0 | 0.2 | 0.1 | Tourmaline |
| Chin. 4/3 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | |
| " 5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | |
| " 6 | 0.4 | 0.0 | 0.1 | 0.8 | 0.0 | 0.0 | 0.0 | |

| Sample No. | <—— MICA | | ——> | | <-HEAVY MINERALS-> | | | MAIN SPECIES OF HT |
|---|---|---|---|---|---|---|---|---|
| | Zb | Zw | Zch | Zdi | HP | HT | HO | |
| Chin. 4/7 | 0.0 | 0.0 | 0.2 | 0.2 | 0.1 | 0.0 | 0.0 | |
| " 8 | 0.4 | 0.0 | 0.0 | 0.6 | 0.0 | 0. 0 | 0.1 | |
| " 9 | 0.7 | 0.1 | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | Garnet |
| " 10 | 1.6 | 0.3 | 0.0 | 2.3 | 0.0 | 0.3 | 0.0 | Garnet |
| Average | 0.19 | 0.08 | 0.05 | 0.63 | 0.02 | 0.44 | 0.05 | |

<u>Westbourne Formation</u>

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Mitch. 2/23 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.8 | 0.0 | Garnet (0.7%) |
| " 24 | 0.1 | 0.7 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | Sphene, garent |
| " 25 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | |
| " 26 | 1.3 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.2 | |
| " 27 | 0.3 | 0.7 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | Garnet |
| " 28 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 29 | 1.6 | 0.8 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | |
| Roma 8/28 | 0.7 | 0.3 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | Garnet (0.3%) |
| " 29 | 0.6 | 3.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | Garnet (0.3%), zirc. (0.1%) |
| " 30 | 0.1 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| Chin. 4/46 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | |
| " 47 | 1.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | Tourmaline |
| " 48 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| Average | 0.57 | 0.50 | 0.00 | 0.00 | 0.01 | 0.15 | 0.07 | |

<u>Springbok Sandstone</u>

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Mitch. 2/30 | 1.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.1 | 0.1 | Zircon |
| " 63 | 0.5 | 0.1 | 0.0 | 0.8 | 0.1 | 0.0 | 0.0 | |
| Roma 8/32 | 0.0 | 0.1 | 0.6 | 0.2 | 0.0 | 0.2 | 0.0 | Epidote, zircon |
| " 33 | 0.0 | 0.0 | 0.2 | 0.2 | 0.0 | 0.1 | 0.0 | Garnet |

| Sample No. | <—— MICA | | | ——> | <-HEAVY MINERALS-> | | | MAIN SPECIES OF HT |
|---|---|---|---|---|---|---|---|---|
| | Zb | Zw | Zch | Zdi | HP | HT | HO | |
| Chin. 4/49 | 0.0 | 0.2 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | |
| " 50 | 0.0 | 0.1 | 0.0 | 0.9 | 0.0 | 0.0 | 0.0 | |
| Average | 0.25 | 0.08 | 0.18 | 0.38 | 0.01 | 0.06 | 0.01 | |

<u>Walloon Coal Measures</u>

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Mitch. 2/31 | 0.1 | 0.5 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 62 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| Roma 8/34 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | Zircon |
| " 35 | 0.6 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 36 | 0.1 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.1 | |
| " 37 | 0.0 | 0.1 | 0.2 | 0.4 | 0.0 | 0.0 | 0.1 | |
| " 38 | 0.4 | 0.6 | 0.5 | 0.6 | 0.0 | 0.1 | 0.4 | Garnet |
| " 39 | 0.1 | 0.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | |
| " 40 | 0.0 | 0.2 | 0.3 | 0.3 | 0.0 | 0.0 | 0.0 | |
| " 41 | 0.0 | 0.3 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | |
| " 42 | 1.0 | 0.2 | 0.0 | 1.3 | 0.0 | 0.0 | 0.0 | |
| Chin. 4/11 | 0.3 | 0.0 | 0.1 | 0.5 | 0.0 | 0.0 | 0.0 | |
| " 12 | 0.8 | 0.2 | 0.1 | 0.0 | 0.1 | 0.1 | 0.0 | ?Rutile |
| " 13 | 0.6 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | |
| " 14 | 1.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 | Tourmaline |
| " 15 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | |
| " 16 | 1.0 | 0.2 | 0.0 | 0.0 | 0.1 | 0.1 | 0.2 | Epidote |
| " 17 | 1.1 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | |
| " 19 | 0.3 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | |
| " 20 | 0.3 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 21 | 0.1 | 0.5 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | Anatase |
| " 22 | 0.2 | 0.3 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | |

| Sample No. | MICA Zb | Zw | Zch | Zdi | HEAVY MINERALS HP | HT | HO | MAIN SPECIES OF HT |
|---|---|---|---|---|---|---|---|---|
| Chin. 4/23 | 0.3 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | |
| " 51 | 1.7 | 1.9 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | |
| " 52 | 2.1 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | |
| " 53 | 0.7 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | |
| " 54 | 0.4 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| Average | 0.50 | 0.43 | 0.07 | 0.13 | 0.02 | 0.02 | 0.09 | |

Hutton Sandstone

| Sample No. | Zb | Zw | Zch | Zdi | HP | HT | HO | MAIN SPECIES OF HT |
|---|---|---|---|---|---|---|---|---|
| Mitch. 2/32 | 0.1 | 0.5 | 0.6 | 2.3 | 0.0 | 0.0 | 0.0 | |
| " 33 | 0.4 | 0.5 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | |
| " 34 | 0.1 | 0.2 | 0.1 | 0.6 | 0.0 | 0.0 | 0.1 | |
| " 35 | 0.5 | 0.5 | 0.0 | 2.7 | 0.0 | 0.0 | 0.2 | |
| " 36 | 0.0 | 0.0 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | |
| " 37 | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 | |
| " 38 | 0.3 | 0.1 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | |
| " 39 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.1 | |
| " 40 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.1 | |
| " 41 | 0.1 | 0.4 | 0.1 | 1.1 | 0.0 | 0.1 | 0.0 | Garnet |
| " 42 | 0.0 | 0.5 | 0.1 | 0.5 | 0.0 | 0.0 | 0.0 | |
| " 43 | 0.3 | 1.2 | 0.0 | 0.6 | 0.0 | 0.1 | 0.0 | Epidote |
| " 44 | 0.3 | 0.2 | 0.0 | 0.8 | 0.0 | 0.3 | 0.1 | Garnet (0.2%), tourm. (0.1%) |
| " 45 | 0.0 | 0.3 | 0.0 | 0.3 | 0.0 | 0.0 | 0.2 | |
| " 46 | 0.0 | 0.1 | 0.0 | 0.8 | 0.0 | 0.1 | 0.0 | Garnet |
| " 47 | 0.1 | 0.8 | 0.0 | 1.3 | 0.0 | 0.1 | 0.0 | Garnet |
| " 49 | 0.0 | 1.4 | 0.1 | 2.4 | 0.0 | 0.1 | 0.1 | Garnet |
| " 50 | 0.5 | 0.3 | 0.0 | 0.8 | 0.0 | 0.4 | 0.0 | Garnet (0.3%), epid. (0.1%) |
| " 51 | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | 0.2 | 0.0 | Garnet, tourmaline |
| " 52 | 0.2 | 0.9 | 0.1 | 2.3 | 0.0 | 0.2 | 0.0 | Zircon, tourmaline |

| Sample No. | ←— MICA Zb | Zw | Zch | —→ Zdi | ←HEAVY MINERALS→ HP | HT | HO | MAIN SPECIES OF HT |
|---|---|---|---|---|---|---|---|---|
| Mitch. 2/53 | 0.3 | 1.0 | 0.0 | 1.3 | 0.0 | 0.6 | 0.1 | Garnet (0.4%), tourm. (0.2%) |
| " 54 | 0.0 | 0.0 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | |
| " 55 | 0.0 | 0.2 | 0.0 | 0.4 | 0.0 | 0.1 | 0.0 | Garnet |
| " 56 | 0.0 | 0.3 | 0.0 | 1.1 | 0.0 | 0.0 | 0.0 | |
| " 57 | 0.0 | 0.1 | 0.0 | 0.4 | 0.0 | 0.2 | 0.0 | Garnet, anatase |
| Roma 8/43 | 0.5 | 1.0 | 0.0 | 4.3 | 0.0 | 0.1 | 0.0 | Garnet |
| " 44 | 0.1 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | |
| " 45 | 0.1 | 0.1 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | |
| " 46 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 47 | 0.1 | 0.2 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | |
| " 48 | 0.2 | 0.0 | 0.0 | 0.2 | 0.0 | 0.1 | 0.0 | Tourmaline |
| " 49 | 1.1 | 0.6 | 0.0 | 2.2 | 0.0 | 0.0 | 0.0 | |
| " 50 | 0.2 | 0.3 | 0.0 | 2.0 | 0.0 | 0.1 | 0.0 | Anatase |
| " 51 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 52 | 0.1 | 0.0 | 0.0 | 2.5 | 0.0 | 0.0 | 0.0 | |
| " 53 | 0.0 | 0.1 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | |
| " 54 | 0.1 | 0.0 | 0.0 | 1.0 | 0.0 | 0.1 | 0.0 | Epidote |
| " 55 | 0.8 | 0.9 | 0.0 | 4.3 | 0.0 | 0.0 | 0.0 | |
| " 56 | 0.0 | 0.2 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | |
| " 57 | 0.3 | 0.8 | 0.0 | 4.3 | 0.0 | 0.0 | 0.0 | |
| " 58 | 0.3 | 0.9 | 0.0 | 2.9 | 0.0 | 0.2 | 0.0 | Garnet |
| " 59 | 0.0 | 0.2 | 0.0 | 0.4 | 0.0 | 0.4 | 0.0 | Garnet |
| " 60 | 0.0 | 0.1 | 0.0 | 0.3 | 0.0 | 0.1 | 0.0 | ?Anatase |
| " 61 | 0.1 | 0.8 | 0.1 | 1.6 | 0.1 | 0.1 | 0.0 | Tourmaline |
| " 63 | 0.4 | 0.3 | 0.0 | 1.2 | 0.0 | 0.2 | 0.0 | Garnet, epidote |
| " 64 | 0.1 | 0.7 | 0.0 | 1.9 | 0.0 | 0.1 | 0.0 | Garnet |
| " 65 | 0.1 | 0.0 | 0.0 | 0.9 | 0.0 | 0.0 | 0.0 | |

| Sample No. | ← | MICA | | → | ← HEAVY | MINERALS | → | MAIN SPECIES OF HT |
|---|---|---|---|---|---|---|---|---|
| | Zb | Zw | Zch | Zdi | HP | HT | HO | |
| Chin 4/24 | 0.6 | 0.1 | 0.1 | 0.0 | 0.1 | 0.2 | 0.0 | Zircon, epidote |
| " 25 | 0.1 | 0.1 | 0.2 | 1.0 | 0.0 | 0.0 | 0.0 | |
| " 27 | 0.1 | 0.1 | 0.0 | 0.4 | 0.0 | 0.1 | 0.0 | Tourmaline |
| " 28 | 0.1 | 0.3 | 0.0 | 2.1 | 0.0 | 0.3 | 0.0 | Tourmaline |
| Average | 0.17 | 0.34 | 0.03 | 1.15 | 0.00 | 0.09 | 0.02 | |
| | | | | | **Evergreen Formation** | | | |
| Mitch. 2/58 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 59 | 0.3 | 1.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| Roma 8/66 | 0.7 | 0.7 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | Zircon |
| " 67 | 0.9 | 0.9 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | Zircon |
| " 68 | 0.6 | 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | |
| " 70 | 0.7 | 2.5 | 0.3 | 0.0 | 0.0 | 0.3 | 0.0 | Epidote (0.2%), tourm. (0.1%) |
| Chin. 4/30 | 0.7 | 1.4 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 31 | 0.3 | 0.6 | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 | Garnet |
| " 32 | 0.6 | 3.1 | 0.0 | 0.0 | 0.1 | 0.2 | 0.0 | Garnet, epidote |
| " 33 | 0.2 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 34 | 0.7 | 0.8 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | Garnet, epidote |
| " 35 | 2.6 | 0.8 | 0.0 | 0.0 | 0.0 | 0.2 | 0.2 | Sphene, garnet |
| " 36 | 0.2 | 0.8 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | Garnet |
| " 37 | 0.2 | 1.3 | 0.0 | 0.0 | 0.0 | 0.2 | 0.1 | Garnet |
| " 38 | 0.7 | 0.4 | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | Garnet |
| " 39 | 1.0 | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | |
| Average | 0.66 | 1.22 | 0.03 | 0.00 | 0.00 | 0.15 | 0.06 | |

| Sample No. | Zb (MICA) | Zw | Zch | Zdi | HP (HEAVY MINERALS) | HT | HO | MAIN SPECIES OF HT |
|---|---|---|---|---|---|---|---|---|
| | | | | | Precipice sandstone | | | |
| Mitch. 2/60 | 0.0 | 1.2 | 0.0 | 2.0 | 0.0 | 0.2 | 0.0 | Tourmaline |
| Roma 8/71 | 0.0 | 4.4 | 0.0 | 1.7 | 0.0 | 0.0 | 0.0 | |
| " 72 | 0.1 | 1.0 | 0.1 | 2.2 | 0.0 | 0.0 | 0.0 | |
| Chin. 4/40 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| " 41 | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | |
| " 42 | 1.8 | 0.1 | 0.0 | 1.5 | 0.0 | 0.1 | 0.0 | Tourmaline |
| " 43 | 0.0 | 0.4 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | |
| " 44 | 0.1 | 0.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | |
| " 45 | 0.1 | 0.3 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | |
| Average | 0.23 | 0.88 | 0.01 | 0.88 | 0.00 | 0.03 | 0.00 | |

## APPENDIX 1.8.3. TOTAL VOLCANIC COMPONENT

Appendix 1.8.3. Total volcanic component (Lvt; whole-rock percentage) of the Surat Basin sandstones. See Table 2.7 (in the text) for details of calculation.

**Griman Creek Formation**

| Sample No. | Lvt |
|---|---|
| Surat 3/1 | 52.63 |
| " 2 | 54.37 |
| " 3 | 68.31 |
| " 4 | 59.69 |
| " 5 | 60.72 |
| " 6 | 59.98 |
| " 7 | 59.04 |
| " 9 | 58.83 |
| " 10 | 59.46 |
| " 11 | 65.54 |
| " 12 | 68.29 |
| " 13 | 74.38 |
| " 14 | 57.48 |
| " 15 | 59.96 |
| " 16 | 64.67 |
| " 17 | 67.72 |
| " 18 | 55.02 |
| " 20 | 65.86 |
| " 21 | 52.46 |
| " 22 | 47.39 |
| " 23 | 53.30 |
| " 24 | 55.68 |
| " 25 | 55.72 |
| " 26 | 52.68 |
| " 27 | 53.76 |
| " 28 | 50.14 |

**Surat Siltstone**

| | |
|---|---|
| Surat 3/29 | 45.07 |
| " 30 | 28.41 |

**Wallumbilla Formation**

| Sample No. | Lvt |
|---|---|
| Surat 1/4 | 36.94 |
| " 5 | 47.83 |
| " 8 | 38.35 |
| " 9 | 53.01 |
| Surat 3/31 | 55.18 |
| " 32 | 46.06 |
| " 33 | 39.14 |

**Bungil Formation**

| | |
|---|---|
| Mitch. 2/1 | 17.78 |
| " 3 | 20.12 |
| " 4 | 14.72 |
| Roma 8/1 | 12.62 |
| " 2 | 23.78 |
| " 3 | 21.56 |
| " 4 | 24.74 |
| Surat 1/13 | 34.28 |
| " 15 | 33.30 |
| " 16 | 31.46 |
| " 17 | 35.78 |
| " 18 | 37.60 |

**Mooga Sandstone**

| | |
|---|---|
| Mitch. 2/61 | 7.70 |
| Roma 8/5 | 2.20 |
| " 7 | 1.40 |
| " 8 | 1.20 |
| " 9 | 9.50 |

**Orallo Formation**

| | |
|---|---|
| Mitch. 2/6 | 41.01 |
| " 7 | 52.38 |
| " 9 | 52.86 |
| " 10 | 41.27 |

**Orallo Formation (contd.)**

| | |
|---|---|
| Mitch. 2/11 | 25.80 |
| " 12 | 25.58 |
| " 13 | 24.60 |
| " 14 | 34.22 |
| " 15 | 45.07 |
| " 16 | 38.68 |
| " 17 | 35.54 |
| Roma 8/10 | 69.45 |
| " 11 | 61.62 |
| " 12 | 60.89 |
| " 13 | 57.02 |
| " 14 | 21.21 |
| " 15 | 33.05 |
| " 16 | 43.88 |
| " 17 | 59.00 |
| " 18 | 44.35 |
| " 19 | 38.66 |
| " 20 | 45.88 |
| Chin. 4/1 | 35.28 |
| " 2 | 37.47 |

**Gubberamunda Sandstone**

| | |
|---|---|
| Mitch. 2/18 | 4.50 |
| " 19 | 5.80 |
| " 20 | 7.50 |
| " 21 | 6.10 |
| Roma 8/21 | 10.30 |
| " 22 | 5.80 |
| " 23 | 6.00 |
| " 24 | 8.30 |
| " 25 | 8.30 |
| " 26 | 8.70 |
| Chin 4/3 | 32.20 |
| " 5 | 37.00 |
| " 6 | 36.00 |
| " 7 | 28.10 |
| " 8 | 21.80 |
| " 9 | 21.60 |
| " 10 | 4.30 |

**Westbourne Formation**

| | |
|---|---|
| Mitch. 2/23 | 13.49 |
| " 24 | 19.41 |
| " 25 | 29.38 |
| " 26 | 33.03 |
| " 27 | 30.31 |
| " 28 | 28.83 |
| " 29 | 30.98 |
| Roma 8/28 | 20.14 |
| " 29 | 20.37 |
| " 30 | 37.05 |
| Chin. 4/46 | 41.83 |
| " 47 | 36.87 |
| " 48 | 53.29 |

**Springbok Sandstone**

| | |
|---|---|
| Mitch. 2/30 | 32.43 |
| " 63 | 31.96 |
| Roma 8/32 | 42.38 |
| " 33 | 49.98 |
| Chin. 4/49 | 52.04 |
| " 50 | 62.16 |

**Walloon Coal Measures**

| | |
|---|---|
| Mitch. 2/31 | 47.57 |
| " 62 | 51.56 |
| Roma 8/34 | 57.62 |
| " 35 | 26.17 |
| " 36 | 40.65 |
| " 37 | 44.09 |
| " 38 | 23.31 |
| " 39 | 43.63 |
| " 40 | 40.48 |
| " 41 | 36.05 |
| " 42 | 29.36 |
| Chin. 4/11 | 38.22 |
| " 12 | 35.77 |
| " 13 | 55.74 |
| " 14 | 59.84 |
| " 15 | 55.51 |

Walloon Coal Measures (contd.)

| | |
|---|---|
| Chin. 4/16 | 46.58 |
| " 17 | 41.89 |
| " 19 | 48.16 |
| " 20 | 52.32 |
| " 21 | 41.51 |
| " 22 | 43.18 |
| " 23 | 60.15 |
| " 51 | 38.91 |
| " 52 | 36.99 |
| " 53 | 44.22 |
| " 54 | 41.61 |

Hutton Sandstone

| | |
|---|---|
| Mitch. 2/32 | 19.60 |
| " 33 | 23.70 |
| " 34 | 26.40 |
| " 35 | 19.50 |
| " 36 | 25.20 |
| " 37 | 8.60 |
| " 38 | 20.50 |
| " 39 | 8.70 |
| " 40 | 9.90 |
| " 41 | 7.00 |
| " 42 | 3.40 |
| " 43 | 3.00 |
| " 44 | 3.00 |
| " 45 | 2.60 |
| " 46 | 3.60 |
| " 47 | 5.10 |
| " 49 | 5.20 |
| " 50 | 5.80 |
| " 51 | 2.20 |
| " 52 | 4.60 |
| " 53 | 4.10 |
| " 54 | 4.30 |
| " 55 | 3.50 |
| " 56 | 4.60 |
| " 57 | 4.70 |

Hutton Sandstone (contd.)

| | |
|---|---|
| Roma 8/43 | 20.50 |
| " 44 | 23.90 |
| " 45 | 24.10 |
| " 46 | 17.80 |
| " 47 | 20.10 |
| " 48 | 23.50 |
| " 49 | 17.40 |
| " 50 | 17.00 |
| " 51 | 2.70 |
| " 52 | 6.20 |
| " 53 | 3.60 |
| " 54 | 10.30 |
| " 55 | 5.60 |
| " 56 | 3.40 |
| " 57 | 5.20 |
| " 58 | 4.60 |
| " 59 | 5.20 |
| " 60 | 5.90 |
| " 61 | 6.90 |
| " 63 | 4.90 |
| " 64 | 6.10 |
| " 65 | 3.20 |
| Chin. 4/24 | 6.90 |
| " 25 | 7.80 |
| " 27 | 2.50 |
| " 28 | 8.20 |

Evergreen Formation

| | |
|---|---|
| Mitch. 2/58 | 1.30 |
| " 59 | 3.40 |
| Roma 8/66 | 12.00 |
| " 67 | 12.70 |
| " 68 | 12.50 |
| " 70 | 16.40 |
| Chin. 4/30 | 8.30 |
| " 31 | 4.40 |
| " 32 | 6.90 |
| " 33 | 6.20 |
| " 34 | 19.40 |

| Evergreen Formation (contd.) | |
|---|---|
| Chin. 4/35 | 27.80 |
| " 36 | 30.10 |
| " 37 | 28.60 |
| " 38 | 23.20 |
| " 39 | 25.10 |
| Precipice Sandstone | |
| Mitch. 2/60 | 0.00 |
| Roma 8/71 | 0.00 |
| " 72 | 2.90 |
| Chin. 4/40 | 4.20 |
| " 41 | 0.00 |
| " 42 | 0.00 |
| " 43 | 0.00 |
| " 44 | 0.00 |
| " 45 | 0.00 |

# APPENDIX 1.9. DETAILED THIN-SECTION POROSITY CATEGORIES

Appendix 1.9. Detailed thin-section porosity categories of the Surat Basin sandstones based on point-counting. T.S. Por. - Total thin-section porosity. 2Bdo - Intragranular secondary porosity within grains other than skeletal feldspar (i.e., 2Bdsf). Other symbols as of Appendix 1.1.

| Sample No. | Depth (m) | T.S. Por. | Primary Por. 1A | Secondary Porosity 2Agd | 2Acd/2Amd | 2Bdo | 2Bdsf | 2Bf | Other | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | (whole-rock %) | | | | | | | | |
| Griman Creek Formation | | | | | | | | | | |
| Surat 3/1 | 16.91 | 6.2 | 2.9 | 2.0 | 0.0 | 1.0 | 0.3 | 0.0 | 0.0 | 3.3 |
| " 2 | 20.26 | 4.1 | 2.6 | 0.7 | 0.0 | 0.2 | 0.6 | 0.0 | 0.0 | 1.5 |
| " 3 | 31.14 | 3.5 | 2.3 | 0.7 | 0.0 | 0.1 | 0.4 | 0.0 | 0.0 | 1.2 |
| " 4 | 47.90 | 2.1 | 1.0 | 0.8 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 1.1 |
| " 5 | 54.00 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 6 | 69.30 | 8.2 | 5.5 | 1.7 | 0.0 | 0.3 | 0.7 | 0.0 | 0.0 | 2.7 |
| " 7 | 99.40 | 7.5 | 4.7 | 2.2 | 0.0 | 0.5 | 0.1 | 0.0 | 0.0 | 2.8 |
| " 9 | 113.20 | 4.0 | 2.8 | 0.9 | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 1.2 |
| " 10 | 140.70 | 4.2 | 2.8 | 1.1 | 0.0 | 0.0 | 0.2 | 0.0 | 3bo (0.1%) | 1.4 |
| " 11 | 147.20 | 5.2 | 4.3 | 0.6 | 0.0 | 0.0 | 0.1 | 0.0 | 3bo (0.2%) | 0.9 |
| " 12 | 153.90 | 4.5 | 3.9 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.0 | 1.6 |
| " 13 | 161.50 | 4.5 | 3.5 | 0.8 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 1.0 |
| " 14 | 164.20 | 11.0 | 5.7 | 3.8 | 0.0 | 1.0 | 0.5 | 0.0 | 0.0 | 5.3 |

| Sample No. | Depth (m) | T.S. Por. | Primary Por. 1A | Secondary Porosity 2Agd | 2Acd/2Amd | 2Bdo | 2Bdsf | 2Bf | Other | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | (whole-rock %) | | | | | | | | |
| Surat 1/15 | 171.80 | 9.4 | 4.3 | 4.0 | 0.0 | 0.5 | 0.6 | 0.0 | 0.0 | 5.1 |
| " 16 | 201.70 | 8.1 | 2.5 | 4.2 | 0.0 | 0.3 | 1.1 | 0.0 | 0.0 | 5.6 |
| Surat 3/17 | 213.00 | 7.6 | 5.3 | 1.8 | 0.0 | 0.4 | 0.1 | 0.0 | 0.0 | 2.3 |
| " 18 | 227.80 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 20 | 240.90 | 3.0 | 1.8 | 0.9 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 1.2 |
| " 21 | 263.80 | 11.1 | 8.1 | 2.6 | 0.0 | 0.1 | 0.3 | 0.0 | 0.0 | 3.0 |
| " 22 | 287.50 | 9.8 | 6.1 | 3.3 | 0.0 | 0.1 | 0.3 | 0.0 | 0.0 | 3.7 |
| " 23 | 291.50 | 12.2 | 8.0 | 3.8 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 4.2 |
| " 24 | 295.20 | 13.6 | 10.4 | 2.2 | 0.0 | 0.6 | 0.5 | 0.0 | 0.0 | 3.2 |
| " 25 | 306.70 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 26 | 313.90 | 11.8 | 8.5 | 2.3 | 0.0 | 0.7 | 0.3 | 0.0 | 0.0 | 3.3 |
| " 27 | 329.00 | 11.3 | 8.1 | 2.2 | 0.0 | 0.6 | 0.4 | 0.0 | 0.0 | 3.2 |
| " 28 | 346.00 | 9.6 | 5.9 | 2.9 | 0.0 | 0.4 | 0.4 | 0.0 | 0.0 | 3.7 |
| Surat Siltstone | | | | | | | | | | |
| Surat 3/29 | 358.20 | 8.6 | 6.1 | 1.4 | 0.0 | 0.5 | 0.6 | 0.0 | 0.0 | 2.5 |
| " 30 | 402.80 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| Sample | No. | Depth (m) | T.S. Por. | Primary Por. 1A | Secondary Porosity 2Agd | 2Acd/2Amd | 2Bdo | 2Bdsf | 2Bf | Other | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (whole-rock %) | | | | | | | | |
| **Wallumbilla Formation** | | | | | | | | | | | |
| Surat | 1/4 | 153.60 | 1.1 | 1.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| " | 5 | 160.30 | 3.4 | 3.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 |
| " | 8 | 176.90 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 9 | 181.50 | 2.1 | 1.7 | 0.2 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.4 |
| Surat | 3/31 | 431.60 | 5.4 | 3.0 | 1.3 | 0.0 | 0.5 | 0.6 | 0.0 | 0.0 | 2.4 |
| " | 32 | 436.90 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 33 | 438.02 | 8.0 | 3.2 | 3.4 | 0.0 | 0.6 | 0.8 | 0.0 | 0.0 | 4.8 |
| **Bungil Formation** | | | | | | | | | | | |
| Mitch. | 2/1 | 52.86 | 2.6 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 3 | 69.63 | 8.0 | 7.9 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| " | 4 | 77.00 | 6.3 | 5.9 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 |
| Roma | 8/1 | 41.86 | 13.2 | 9.1 | 3.6 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 4.1 |
| " | 2 | 78.50 | 7.3 | 6.1 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.2 |
| " | 3 | 100.95 | 0.2 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 4 | 113.87 | 5.5 | 4.1 | 0.6 | 0.3 | 0.2 | 0.3 | 0.0 | 0.0 | 1.4 |
| Surat | 1/13 | 328.90 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| Sample | No. | Depth (m) | T.S. Por. | Primary Por. 1A | Secondary Porosity 2Agd | 2Acd/2Amd | 2Bdo | 2Bdsf | 2Bf | Other | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (whole-rock %) | | | | | | | | |
| Surat | 1/15 | 342.40 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 16 | 350.46 | 1.8 | 1.5 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| " | 17 | 350.76 | 0.5 | 0.4 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| " | 18 | 351.05 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| <u>Mooga Sandstone</u> | | | | | | | | | | | |
| Mitch. | 2/61 | 125.64 | 0.5 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Roma | 8/5 | 135.69 | 6.2 | 5.3 | 0.6 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.9 |
| " | 7 | 153.34 | 2.0 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 8 | 168.91 | 9.2 | 9.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| " | 9 | 182.88 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| <u>Orallo Formation</u> | | | | | | | | | | | |
| Mitch. | 2/6 | 151.18 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 3bo (0.1%) | 0.2 |
| " | 7 | 166.34 | 2.3 | 1.5 | 0.0 | 0.0 | 0.1 | 0.0 | 0.7 | 0.0 | 0.8 |
| " | 9 | 180.70 | 5.1 | 4.5 | 0.3 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.6 |
| " | 10 | 189.52 | 4.8 | 4.6 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.2 |
| " | 11 | 198.84 | 12.8 | 9.3 | 2.0 | 0.0 | 0.4 | 1.1 | 0.0 | 0.0 | 3.5 |
| " | 12 | 207.39 | 10.8 | 8.6 | 1.9 | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 2.2 |

| Sample | No. | Depth (m) | T.S. Por. | Primary Por. 1A | Secondary Porosity 2Agd | 2Acd/2Amd | 2Bdo | 2Bdsf | 2Bf | Other | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (whole-rock %) | | | | | | | | |
| Mitch. | 2/13 | 215.69 | 21.1 | 12.2 | 7.8 | 0.2 | 0.1 | 0.7 | 0.1 | 0.0 | 8.9 |
| " | 14 | 226.86 | 15.7 | 11.3 | 8.0 | 0.0 | 0.4 | 0.4 | 0.0 | 0.0 | 4.4 |
| " | 15 | 236.40 | 13.3 | 0.0 | 3.2 | 8.6 | 0.6 | 0.9 | 0.0 | 0.0 | 13.3 |
| " | 16 | 245.46 | 6.8 | 4.0 | 1.2 | 0.1 | 0.2 | 1.3 | 0.0 | 0.0 | 2.8 |
| " | 17 | 253.62 | 12.4 | 8.3 | 2.9 | 0.0 | 0.2 | 0.9 | 0.1 | 0.0 | 4.1 |
| Roma | 8/10 | 195.52 | 4.1 | 2.6 | 0.1 | 0.0 | 0.5 | 0.9 | 0.0 | 0.0 | 1.5 |
| " | 11 | 203.62 | 2.5 | 1.9 | 0.0 | 0.0 | 0.3 | 0.3 | 0.0 | 0.0 | 0.6 |
| " | 12 | 222.18 | 2.7 | 1.5 | 0.3 | 0.0 | 0.5 | 0.4 | 0.0 | 0.0 | 1.2 |
| " | 13 | 232.10 | 7.1 | 0.0 | 1.5 | 5.2 | 0.3 | 0.1 | 0.0 | 0.0 | 7.1 |
| " | 14 | 242.88 | 14.9 | 9.1 | 5.4 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 5.8 |
| " | 15 | 253.22 | 12.3 | 6.4 | 5.2 | 0.0 | 0.5 | 0.2 | 0.0 | 0.0 | 5.9 |
| " | 16 | 263.97 | 7.2 | 3.6 | 1.0 | 1.3 | 1.1 | 0.1 | 0.0 | 2Br (0.1%) | 3.6 |
| " | 17 | 274.02 | 6.0 | 2.4 | 2.7 | 0.4 | 0.2 | 0.1 | 0.1 | 2Br (0.1%) | 3.6 |
| " | 18 | 284.59 | 7.9 | 4.2 | 2.8 | 0.3 | 0.2 | 0.3 | 0.1 | 0.0 | 3.7 |
| Roma | 8/19 | 295.85 | 6.5 | 4.3 | 1.4 | 0.4 | 0.1 | 0.3 | 0.0 | 0.0 | 2.2 |
| " | 20 | 306.38 | 6.0 | 3.5 | 1.4 | 0.5 | 0.4 | 0.2 | 0.0 | 0.0 | 2.5 |
| Chin. | 4/1 | 39.54 | 13.0 | 8.0 | 4.6 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 5.0 |
| " | 2 | 50.26 | 7.1 | 6.4 | 0.1 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.7 |

| Sample No. | Depth (m) | T.S. Por. | Primary Por. | ← Secondary Porosity → | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1A | 2Agd | 2Acd/2Amd | 2Bdo | 2Bdsf | 2Bf | Other | Total |
| | | ← (whole-rock %) → | | | | | | | | |
| <u>Gubberamunda Sandstone</u> | | | | | | | | | | |
| Mitch. 2/18 | 272.17 | 9.9 | 0.0 | 3.1 | 6.7 | 0.0 | 0.1 | 0.0 | 0.0 | 9.9 |
| " 19 | 283.47 | 15.2 | 0.0 | 2.9 | 11.1 | 0.0 | 1.2 | 0.0 | 0.0 | 15.2 |
| " 20 | 292.22 | 8.5 | 0.0 | 1.8 | 5.6 | 0.0 | 1.1 | 0.0 | 0.0 | 8.5 |
| Mitch. 2/21 | 299.30 | 11.9 | 0.0 | 3.0 | 8.8 | 0.0 | 0.1 | 0.0 | 0.0 | 11.9 |
| Roma 8/21 | 324.30 | 7.1 | 6.3 | 0.5 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.8 |
| " 22 | 333.44 | 6.8 | 5.3 | 1.2 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 1.5 |
| " 23 | 343.71 | 12.1 | 9.6 | 1.8 | 0.0 | 0.0 | 0.7 | 0.0 | 0.0 | 2.5 |
| " 24 | 354.21 | 9.2 | 6.5 | 2.3 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 2.7 |
| " 25 | 364.71 | 14.6 | 10.7 | 3.3 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 3.9 |
| " 26 | 375.57 | 7.6 | 5.4 | 1.7 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 2.2 |
| Chin. 4/3 | 65.69 | 9.8 | 0.0 | 0.4 | 8.6 | 0.1 | 0.6 | 0.1 | 0.0 | 9.8 |
| " 5 | 87.43 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 6 | 96.98 | 7.0 | 0.0 | 0.1 | 6.9 | 0.0 | 0.0 | 0.0 | 0.0 | 7.0 |
| " 7 | 105.44 | 6.4 | 0.0 | 0.1 | 6.3 | 0.0 | 0.0 | 0.0 | 0.0 | 6.4 |
| " 8 | 114.67 | 6.7 | 6.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " 9 | 125.70 | 7.8 | 7.5 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| " 10 | 138.80 | 2.4 | 2.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |

| Sample | No. | Depth (m) | T.S. Por. | Primary Por. 1A | Secondary Porosity 2Agd | 2Acd/2Amd | 2Bdo | 2Bdsf | 2Bf | Other | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (whole-rock %) | | | | | | | | |
| Westbourne Formation | | | | | | | | | | | |
| Mitch. | 2/23 | 324.83 | 16.0 | 8.4 | 7.4 | 0.0 | 0.2 | 0.2 | 0.0 | 0.0 | 7.6 |
| " | 24 | 365.00 | 12.2 | 7.9 | 2.9 | 0.0 | 0.3 | 1.1 | 0.0 | 0.0 | 4.3 |
| " | 25 | 374.70 | 4.9 | 3.1 | 0.2 | 0.0 | 0.0 | 1.6 | 0.0 | 0.0 | 1.8 |
| Mitch. | 2/26 | 407.39 | 2.7 | 1.5 | 0.3 | 0.0 | 0.1 | 0.8 | 0.0 | 0.0 | 1.2 |
| " | 27 | 417.07 | 2.3 | 1.2 | 0.1 | 0.0 | 0.2 | 0.8 | 0.0 | 0.0 | 1.1 |
| " | 28 | 426.81 | 10.1 | 4.3 | 3.4 | 0.0 | 0.0 | 2.4 | 0.0 | 0.0 | 5.8 |
| " | 29 | 466.64 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Roma | 8/28 | 439.80 | 15.1 | 0.0 | 9.8 | 4.1 | 0.2 | 1.0 | 0.0 | 0.0 | 15.1 |
| " | 29 | 451.08 | 2.1 | 1.7 | 0.1 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.4 |
| " | 30 | 500.31 | 1.8 | 0.2 | 0.2 | 0.0 | 0.1 | 1.3 | 0.0 | 0.0 | 1.6 |
| Chin. | 4/46 | 194.71 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 47 | 208.12 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3bp (0.9%), 2Br (0.1) | 1.0 |
| " | 48 | 237.26 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Springbok Sandstone | | | | | | | | | | | |
| Mitch. | 2/30 | 507.05 | 3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2Bs (0.1%), 3bp (0.8%), 3bo (2.7%) | 3.6 |
| " | 63 | 477.35 | 1.3 | 0.3 | 0.3 | 0.0 | 0.0 | 0.7 | 0.0 | 0.0 | 1.0 |

| Sample | No. | Depth (m) | T.S. Por. | Primary Por. 1A | Secondary Porosity 2Agd | 2Acd/2Amd | 2Bdo | 2Bdsf | 2Bf | Other | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (whole-rock %) | | | | | | | | |
| Roma | 8/32 | 533.67 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 33 | 539.97 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Chin. | 4/49 | 258.59 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3bp (0.1%) | 0.1 |
| " | 50 | 265.68 | 0.3 | 0.2 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 |
| <u>Walloon Coal Measures</u> | | | | | | | | | | | |
| Mitch. | 2/31 | 531.88 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 62 | 542.15 | 5.6 | 1.5 | 1.8 | 0.2 | 0.1 | 0.0 | 0.0 | 3bp (1.5%), 3bo (0.5%) | 4.1 |
| Roma | 8/34 | 550.11 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 35 | 561.09 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 36 | 570.83 | 0.3 | 0.1 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| " | 37 | 584.26 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 38 | 593.84 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 39 | 614.93 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 40 | 627.70 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 41 | 640.80 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 42 | 661.64 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Chin. | 4/11 | 513.38 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 12 | 523.04 | 0.9 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3bp (0.4%), 3bo (0.4%) | 0.8 |

| Sample | No. | Depth (m) | T.S. Por. | Primary Por. 1A | Secondary Porosity 2Agd | 2Acd/2Amd | 2Bdo | 2Bdsf | 2Bf | Other | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (whole-rock %) | | | | | | | | |
| Chin. | 4/13 | 530.99 | 0.9 | 0.5 | 0.0 | 0.1 | 0.2 | 0.1 | 0.0 | 0.0 | 0.4 |
| " | 14 | 540.05 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3bp (0.2%), 3bo (0.3%) | 0.5 |
| " | 15 | 549.05 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3bp (0.1%) | 0.1 |
| " | 16 | 559.96 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 17 | 571.62 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Chin. | 4/19 | 672.31 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3bp (0.1%) | 0.1 |
| " | 20 | 681.34 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 21 | 701.81 | 1.4 | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 22 | 711.00 | 2.7 | 2.4 | 0.0 | 0.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.3 |
| " | 23 | 727.47 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 51 | 310.63 | 0.3 | 0.2 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 |
| " | 52 | 345.14 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 53 | 434.41 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| " | 54 | 503.19 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Hutton Sandstone** | | | | | | | | | | | |
| Mitch. | 2/32 | 580.35 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.2 |
| " | 33 | 587.70 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.3 |

| Sample No. | Depth (m) | T.S. Por. | Primary Por. 1A | ← Secondary Porosity 2Agd | 2Acd/2Amd | 2Bdo | 2Bdsf | 2Bf | Other | Total → |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ← (whole-rock %) → | | | | | | | | |
| Mitch. 2/34 | 597.71 | 1.1 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 0.0 | 0.8 |
| " 35 | 608.94 | 0.3 | 0.0 | 0.0 | 0.0 | 0.2 | 0.1 | 0.0 | 0.0 | 0.3 |
| " 36 | 616.11 | 0.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.2 |
| " 37 | 625.49 | 18.8 | 14.2 | 4.0 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 4.6 |
| " 38 | 635.54 | 8.4 | 6.6 | 1.5 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 1.8 |
| " 39 | 648.02 | 10.6 | 8.1 | 2.2 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 2.5 |
| Mitch. 2/40 | 657.57 | 10.8 | 8.1 | 2.5 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 2.7 |
| " 41 | 668.53 | 5.7 | 5.1 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 |
| " 42 | 677.27 | 19.8 | 14.5 | 5.1 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 5.3 |
| " 43 | 687.27 | 12.2 | 9.3 | 0.0 | 2.5 | 0.0 | 0.4 | 0.0 | 0.0 | 2.9 |
| " 44 | 698.63 | 12.0 | 9.0 | 2.7 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 3.0 |
| " 45 | 707.49 | 17.8 | 12.0 | 3.0 | 2.3 | 0.0 | 0.5 | 0.0 | 0.0 | 5.8 |
| " 46 | 715.84 | 12.8 | 6.7 | 2.6 | 2.7 | 0.0 | 0.8 | 0.0 | 0.0 | 6.1 |
| " 47 | 725.86 | 12.9 | 5.0 | 3.4 | 3.8 | 0.0 | 0.7 | 0.0 | 0.0 | 7.9 |
| " 49 | 746.09 | 5.8 | 4.4 | 0.5 | 0.5 | 0.0 | 0.4 | 0.0 | 0.0 | 1.4 |
| " 50 | 755.37 | 4.1 | 3.3 | 0.3 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 |
| " 51 | 763.68 | 17.1 | 7.7 | 3.2 | 5.9 | 0.0 | 0.3 | 0.0 | 0.0 | 9.4 |
| " 52 | 774.16 | 6.5 | 4.1 | 1.2 | 1.1 | 0.1 | 0.0 | 0.0 | 0.0 | 2.4 |

| Sample | No. | Depth (m) | T.S. Por. | Primary Por. 1A | Secondary Porosity 2Agd | 2Acd/2Amd | 2Bdo | 2Bdsf | 2Bf | Other | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (whole-rock %) | | | | | | | | |
| Mitch. | 2/53 | 783.32 | 6.0 | 3.8 | 0.6 | 1.1 | 0.0 | 0.5 | 0.0 | 0.0 | 2.2 |
| " | 54 | 791.69 | 10.9 | 7.9 | 2.4 | 0.3 | 0.1 | 0.2 | 0.0 | 0.0 | 3.0 |
| " | 55 | 800.52 | 6.6 | 5.6 | 0.6 | 0.0 | 0.3 | 0.1 | 0.0 | 0.0 | 1.0 |
| " | 56 | 809.72 | 4.8 | 4.0 | 0.5 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.8 |
| " | 57 | 818.90 | 9.4 | 7.4 | 1.9 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 2.0 |
| Roma | 8/43 | 683.65 | 0.6 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.4 |
| " | 44 | 692.95 | 0.6 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.2 |
| " | 45 | 702.64 | 1.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.2 |
| " | 46 | 713.68 | 12.1 | 5.9 | 4.1 | 0.0 | 0.7 | 1.4 | 0.0 | 0.0 | 6.2 |
| " | 47 | 723.03 | 1.4 | 0.8 | 0.3 | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 0.6 |
| " | 48 | 734.55 | 6.6 | 3.9 | 1.8 | 0.0 | 0.0 | 0.8 | 0.1 | 0.0 | 2.7 |
| " | 49 | 747.42 | 2.0 | 1.6 | 0.3 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.4 |
| " | 50 | 754.93 | 3.1 | 2.9 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.2 |
| " | 51 | 764.10 | 12.1 | 0.0 | 6.1 | 5.9 | 0.0 | 0.1 | 0.0 | 0.0 | 12.1 |
| " | 52 | 782.78 | 3.3 | 2.6 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 |
| " | 53 | 791.53 | 13.1 | 0.0 | 5.4 | 7.0 | 0.4 | 0.3 | 0.0 | 0.0 | 13.1 |
| " | 54 | 802.00 | 11.6 | 0.4 | 2.3 | 8.2 | 0.1 | 0.6 | 0.0 | 0.0 | 11.2 |
| " | 55 | 813.17 | 2.5 | 2.0 | 0.4 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.5 |

| Sample | No. | Depth (m) | T.S. Por. | Primary Por. 1A | Secondary Porosity 2Agd | 2Acd/2Amd | 2Bdo | 2Bdsf | 2Bf | Other | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (whole-rock %) | | | | | | | | |
| Roma | 8/56 | 826.02 | 14.9 | 0.0 | 3.9 | 9.9 | 0.0 | 1.1 | 0.0 | 0.0 | 14.9 |
| " | 57 | 845.13 | 1.3 | 0.7 | 0.5 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.6 |
| " | 58 | 855.71 | 2.3 | 1.9 | 0.2 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.4 |
| " | 59 | 866.91 | 10.6 | 0.0 | 3.0 | 6.9 | 0.0 | 0.7 | 0.0 | 0.0 | 10.6 |
| " | 60 | 876.21 | 11.7 | 0.0 | 2.1 | 9.3 | 0.0 | 0.3 | 0.0 | 0.0 | 11.7 |
| Roma | 8/61 | 886.05 | 7.3 | 4.8 | 2.3 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 2.5 |
| " | 63 | 906.13 | 6.9 | 4.6 | 2.1 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 2.3 |
| " | 64 | 916.05 | 7.4 | 3.6 | 3.0 | 0.0 | 0.0 | 0.8 | 0.0 | 0.0 | 3.8 |
| " | 65 | 926.03 | 12.6 | 7.7 | 4.6 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 4.9 |
| Chin. | 4/24 | 792.19 | 3.6 | 3.1 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 |
| " | 25 | 799.31 | 2.7 | 2.4 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| " | 27 | 826.66 | 14.0 | 8.4 | 5.5 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 5.6 |
| " | 28 | 866.39 | 2.4 | 2.1 | 0.2 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.3 |
| <u>Evergreen Formation</u> | | | | | | | | | | | |
| Mitch. | 2/58 | 844.66 | 2.1 | 2.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| " | 59 | 853.86 | 4.9 | 0.0 | 0.6 | 4.3 | 0.0 | 0.0 | 0.0 | 0.0 | 4.9 |
| Roma | 8/66 | 946.66 | 2.7 | 0.6 | 1.7 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 2.1 |
| " | 67 | 955.29 | 1.9 | 0.0 | 1.4 | 0.3 | 0.0 | 0.2 | 0.0 | 0.0 | 1.9 |

| Sample | No. | Depth (m) | T.S. Por. | Primary Por. 1A | Secondary Porosity 2Agd | 2Acd/2Amd | 2Bdo | 2Bdsf | 2Bf | Other | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (whole-rock %) | | | | | | | | |
| Roma | 8/68 | 979.72 | 6.3 | 0.0 | 2.0 | 4.0 | 0.0 | 0.3 | 0.0 | 0.0 | 6.3 |
| " | 70 | 998.67 | 0.5 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 |
| Chin | 4/30 | 889.05 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 31 | 965.36 | 4.0 | 0.0 | 0.6 | 3.3 | 0.0 | 0.1 | 0.0 | 0.0 | 4.0 |
| " | 32 | 973.62 | 2.9 | 0.0 | 0.6 | 2.2 | 0.0 | 0.1 | 0.0 | 0.0 | 2.9 |
| Chin. | 4/33 | 983.55 | 0.5 | 0.0 | 0.2 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.5 |
| " | 34 | 991.49 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 35 | 1050.53 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 36 | 1055.77 | 1.2 | 1.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| " | 37 | 1064.82 | 0.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.2 |
| " | 38 | 1073.94 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 39 | 1083.10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Precipice Sandstone | | | | | | | | | | | |
| Mitch. | 2/60 | 932.69 | 8.8 | 6.0 | 2.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.8 |
| Roma | 8/71 | 1047.66 | 0.2 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 72 | 1055.69 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Chin. | 4/40 | 1182.07 | 5.0 | 0.0 | 1.6 | 3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 5.0 |
| " | 41 | 1190.61 | 7.5 | 5.1 | 2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.4 |

| Sample | No. | Depth (m) | T.S. Por. | Primary Por. 1A | ← Secondary Porosity 2Agd | 2Acd/2Amd | 2Bdo | 2Bdsf | 2Bf | Other | Total → |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ← (whole-rock %) | | | | | | | | → |
| Chin. | 4/42 | 1199.81 | 3.0 | 2.9 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| " | 43 | 1280.64 | 4.9 | 4.7 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| " | 44 | 1217.09 | 7.3 | 6.5 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.3 |
| " | 45 | 1225.29 | 14.1 | 9.5 | 4.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.6 |

APPENDIX 1.10.1. PETROGRAPHIC MODAL ANALYSES OF THE SURAT BASIN SANDSTONES RECALCULATED TO QFR AND LvLsLm COMPONENTS.

Appendix 1.10.1. Petrographic modal analyses of the Surat Basin sandstones recalculated to QFR and LvLsLm components.

| Sample No. | Q | F | R | Lv | Ls | Lm |
|---|---|---|---|---|---|---|
| | | | Griman Creek Formation | | | |
| Surat 3/1 | 7.9 | 33.3 | 58.8 | 95.0 | 1.7 | 3.3 |
| " 2 | 6.1 | 37.9 | 56.0 | 94.2 | 2.2 | 3.6 |
| " 3 | 3.6 | 37.4 | 59.0 | 97.6 | 1.4 | 1.0 |
| " 4 | 3.1 | 44.2 | 52.7 | 94.6 | 1.1 | 4.3 |
| " 5 | 6.7 | 38.7 | 54.6 | 92.4 | 4.2 | 3.4 |
| " 6 | 4.7 | 48.5 | 46.8 | 94.1 | 1.2 | 4.7 |
| " 7 | 6.1 | 44.3 | 49.6 | 97.0 | 0.9 | 2.1 |
| " 9 | 12.3 | 36.1 | 51.6 | 92.1 | 3.9 | 4.0 |
| " 10 | 5.4 | 39.2 | 55.4 | 90.0 | 6.4 | 3.6 |
| " 11 | 5.5 | 26.9 | 67.6 | 93.2 | 4.4 | 2.4 |
| " 12 | 8.0 | 26.4 | 65.6 | 93.2 | 3.5 | 3.3 |
| " 13 | 6.3 | 23.4 | 70.3 | 95.6 | 1.9 | 2.5 |
| " 14 | 8.5 | 34.5 | 57.0 | 91.3 | 4.1 | 4.6 |
| " 15 | 3.5 | 39.1 | 57.4 | 93.0 | 2.1 | 4.9 |
| " 16 | 6.3 | 39.3 | 54.4 | 94.6 | 1.5 | 3.9 |
| " 17 | 7.7 | 40.1 | 52.2 | 93.7 | 2.9 | 3.4 |
| " 18 | 9.0 | 39.1 | 51.9 | 94.9 | 2.4 | 2.7 |
| " 20 | 7.9 | 35.9 | 56.2 | 92.4 | 3.9 | 3.7 |
| " 21 | 11.4 | 61.4 | 27.2 | 92.7 | 2.3 | 5.0 |
| " 22 | 17.2 | 51.1 | 31.7 | 95.4 | 2.6 | 2.0 |
| " 23 | 13.5 | 44.3 | 42.2 | 96.1 | 1.8 | 2.1 |
| " 24 | 16.8 | 58.5 | 24.7 | 88.0 | 9.3 | 2.7 |
| " 25 | 9.3 | 43.2 | 47.5 | 95.5 | 2.9 | 1.6 |
| " 26 | 11.5 | 52.5 | 36.0 | 93.7 | 1.7 | 4.6 |
| " 27 | 9.8 | 44.6 | 45.6 | 94.9 | 1.7 | 3.4 |
| " 28 | 13.8 | 33.0 | 53.2 | 93.5 | 4.1 | 2.4 |

| Sample No. | Q | F | R | Lv | Ls | Lm |
|---|---|---|---|---|---|---|
| | | | Surat Siltstone | | | |
| Surat 3/29 | 14.5 | 43.2 | 42.3 | 91.8 | 5.5 | 2.7 |
| " 30 | 33.2 | 41.6 | 25.2 | 96.5 | 3.5 | 0.0 |
| | | | Wallumbilla Formation | | | |
| Surat 1/4 | 22.7 | 50.8 | 26.5 | 96.5 | 2.1 | 1.4 |
| " 5 | 11.4 | 47.5 | 41.1 | 91.1 | 5.4 | 3.5 |
| " 8 | 9.2 | 40.7 | 50.1 | 97.3 | 1.4 | 1.3 |
| " 9 | 10.0 | 42.5 | 47.5 | 88.7 | 8.8 | 2.5 |
| Surat 3/31 | 4.4 | 37.7 | 57.9 | 97.8 | 1.4 | 0.8 |
| " 32 | 9.0 | 38.7 | 52.3 | 93.7 | 5.6 | 0.7 |
| " 33 | 15.4 | 33.8 | 50.8 | 87.6 | 6.6 | 5.8 |
| | | | Bungil Formation | | | |
| Mitch. 2/1 | 62.9 | 20.9 | 16.2 | 75.8 | 21.2 | 3.0 |
| " 3 | 62.7 | 23.5 | 13.8 | 82.6 | 16.3 | 1.1 |
| " 4 | 72.2 | 17.2 | 10.6 | 88.2 | 8.8 | 3.0 |
| Roma 8/1 | 71.7 | 9.6 | 18.7 | 76.0 | 21.6 | 2.4 |
| " 2 | 55.0 | 29.0 | 16.0 | 96.0 | 4.0 | 0.0 |
| " 3 | 24.1 | 43.7 | 32.2 | 83.3 | 14.2 | 2.5 |
| " 4 | 48.4 | 35.1 | 16.5 | 89.0 | 11.0 | 0.0 |
| Surat 1/13 | 30.2 | 46.1 | 23.7 | 95.6 | 3.7 | 0.7 |
| " 15 | 35.5 | 37.3 | 27.2 | 96.8 | 1.9 | 1.3 |
| " 16 | 40.7 | 29.2 | 30.1 | 96.8 | 3.2 | 0.0 |
| " 17 | 38.9 | 29.2 | 31.9 | 98.7 | 1.3 | 0.0 |
| " 18 | 44.6 | 19.0 | 36.4 | 97.7 | 2.3 | 0.0 |

| Sample No. | | Q | F | R | Lv | Ls | Lm |
|---|---|---|---|---|---|---|---|
| | | | | **Mooga Sandstone** | | | |
| Mitch. | 2/61 | 54.7 | 25.0 | 20.3 | 69.4 | 27.9 | 2.7 |
| Roma | 8/5 | 71.8 | 24.4 | 3.8 | 81.5 | 11.1 | 7.4 |
| " | 7 | 78.9 | 18.1 | 3.0 | 77.8 | 0.0 | 22.2 |
| " | 8 | 73.4 | 24.3 | 2.3 | 75.0 | 12.5 | 12.5 |
| " | 9 | 70.4 | 12.7 | 16.9 | 92.2 | 6.8 | 1.0 |
| | | | | **Orallo Formation** | | | |
| Mitch. | 2/6 | 23.1 | 24.7 | 52.2 | 85.8 | 11.5 | 2.7 |
| " | 7 | 9.2 | 27.7 | 63.1 | 89.8 | 9.7 | 0.5 |
| " | 9 | 16.8 | 31.0 | 52.2 | 81.2 | 14.2 | 4.6 |
| " | 10 | 30.6 | 38.6 | 30.8 | 82.1 | 15.3 | 2.6 |
| " | 11 | 50.7 | 28.3 | 21.0 | 83.8 | 13.7 | 2.5 |
| " | 12 | 50.3 | 31.9 | 17.8 | 79.3 | 14.9 | 5.8 |
| " | 13 | 58.0 | 24.5 | 17.5 | 87.7 | 11.5 | 0.8 |
| " | 14 | 45.3 | 27.1 | 27.6 | 88.1 | 6.2 | 5.7 |
| " | 15 | 24.3 | 34.3 | 41.4 | 79.2 | 17.0 | 3.8 |
| " | 16 | 32.6 | 34.5 | 32.9 | 70.6 | 23.7 | 5.7 |
| " | 17 | 39.6 | 25.6 | 34.8 | 85.5 | 12.2 | 2.3 |
| Roma | 8/10 | 6.8 | 20.4 | 72.8 | 88.6 | 9.5 | 1.9 |
| " | 11 | 12.7 | 18.1 | 69.2 | 91.7 | 6.7 | 1.6 |
| " | 12 | 12.5 | 40.2 | 47.3 | 89.0 | 8.4 | 2.6 |
| " | 13 | 15.9 | 28.9 | 55.2 | 86.7 | 10.4 | 2.9 |
| " | 14 | 64.6 | 23.6 | 11.8 | 93.7 | 5.3 | 1.0 |
| " | 15 | 50.4 | 26.7 | 22.9 | 94.7 | 4.8 | 0.5 |
| " | 16 | 31.9 | 21.1 | 47.0 | 93.7 | 6.3 | 0.0 |
| " | 17 | 10.8 | 25.8 | 63.4 | 86.9 | 10.1 | 3.0 |
| " | 18 | 22.9 | 35.7 | 41.4 | 82.0 | 16.3 | 1.7 |

| Sample No. | | Q | F | R | Lv | Ls | Lm |
|---|---|---|---|---|---|---|---|
| Roma | 8/19 | 25.1 | 34.6 | 40.3 | 77.9 | 17.7 | 4.4 |
| " | 20 | 19.5 | 38.7 | 41.8 | 78.3 | 17.8 | 3.9 |
| Chin. | 4/1 | 48.2 | 29.2 | 22.6 | 89.4 | 9.6 | 1.0 |
| " | 2 | 31.7 | 27.5 | 40.8 | 86.3 | 10.8 | 2.9 |

<u>Gubberamunda Sandstone</u>

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Mitch. | 2/18 | 78.7 | 13.8 | 7.5 | 84.9 | 11.3 | 3.8 |
| " | 19 | 71.1 | 19.9 | 9.0 | 89.2 | 6.2 | 4.6 |
| " | 20 | 60.9 | 28.7 | 10.4 | 90.4 | 4.8 | 4.8 |
| " | 21 | 77.4 | 13.9 | 8.7 | 92.4 | 4.6 | 3.0 |
| Roma | 8/21 | 51.5 | 28.2 | 20.3 | 78.6 | 14.5 | 6.9 |
| " | 22 | 58.9 | 28.2 | 12.9 | 75.3 | 7.8 | 16.9 |
| " | 23 | 65.4 | 24.2 | 10.4 | 82.2 | 12.3 | 5.5 |
| " | 24 | 61.2 | 24.9 | 13.9 | 79.0 | 16.2 | 4.8 |
| " | 25 | 69.7 | 16.3 | 14.0 | 82.2 | 13.9 | 3.9 |
| " | 26 | 63.2 | 23.7 | 13.1 | 87.0 | 10.0 | 3.0 |
| Chin. | 4/3 | 28.6 | 29.2 | 42.2 | 89.2 | 9.6 | 1.2 |
| " | 5 | 29.1 | 21.0 | 49.9 | 88.2 | 11.3 | 0.5 |
| " | 6 | 25.0 | 24.9 | 50.1 | 88.3 | 9.9 | 1.8 |
| " | 7 | 23.8 | 32.5 | 43.7 | 78.2 | 19.8 | 2.0 |
| " | 8 | 49.0 | 17.0 | 34.0 | 82.5 | 15.6 | 1.9 |
| " | 9 | 40.2 | 22.6 | 37.2 | 75.5 | 20.9 | 3.6 |
| " | 10 | 57.9 | 30.2 | 11.9 | 58.1 | 33.8 | 8.1 |

<u>Westbourne Formation</u>

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Mitch. | 2/23 | 75.8 | 11.6 | 12.6 | 77.3 | 18.6 | 4.1 |
| " | 24 | 63.3 | 26.1 | 10.6 | 86.4 | 12.4 | 1.2 |
| " | 25 | 46.4 | 21.2 | 32.4 | 70.2 | 27.6 | 2.2 |

| Sample No. | | Q | F | R | Lv | Ls | Lm |
|---|---|---|---|---|---|---|---|
| Mitch. | 2/26 | 34.0 | 26.6 | 39.4 | 66.2 | 27.4 | 6.4 |
| " | 27 | 37.9 | 26.1 | 36.0 | 72.4 | 23.1 | 4.5 |
| " | 28 | 41.2 | 30.7 | 28.1 | 69.9 | 24.9 | 5.2 |
| " | 29 | 25.5 | 26.2 | 48.3 | 63.9 | 33.3 | 2.8 |
| Roma | 8/28 | 62.7 | 26.9 | 10.4 | 76.9 | 15.4 | 7.7 |
| " | 29 | 53.0 | 21.0 | 26.0 | 72.4 | 21.5 | 6.1 |
| " | 30 | 38.8 | 27.3 | 33.9 | 80.8 | 13.9 | 5.3 |
| Chin. | 4/46 | 19.4 | 34.5 | 46.1 | 72.7 | 22.3 | 5.0 |
| " | 47 | 17.4 | 35.4 | 47.2 | 86.1 | 11.9 | 2.0 |
| " | 48 | 14.2 | 27.2 | 58.6 | 91.8 | 6.7 | 1.5 |
| | | | | Springbok Sandstone | | | |
| Mitch. | 2/30 | 16.9 | 23.5 | 59.6 | 71.7 | 26.4 | 1.9 |
| " | 63 | 21.0 | 45.3 | 33.7 | 67.6 | 31.0 | 1.4 |
| Roma | 8/32 | 16.6 | 50.1 | 33.3 | 70.0 | 26.6 | 3.4 |
| " | 33 | 13.6 | 53.6 | 32.8 | 71.7 | 26.4 | 1.9 |
| Chin. | 4/49 | 11.5 | 45.3 | 43.2 | 80.3 | 18.5 | 1.2 |
| " | 50 | 5.3 | 28.2 | 66.5 | 89.5 | 9.7 | 0.8 |
| | | | | Walloon Coal Measures | | | |
| Mitch. | 2/31 | 11.6 | 37.7 | 50.7 | 72.1 | 26.9 | 1.0 |
| " | 62 | 13.6 | 29.6 | 56.8 | 82.4 | 16.6 | 1.0 |
| Roma | 8/34 | 11.8 | 53.6 | 34.6 | 60.5 | 36.3 | 3.2 |
| " | 35 | 31.5 | 16.2 | 52.3 | 54.8 | 42.0 | 3.2 |
| " | 36 | 15.4 | 23.4 | 61.2 | 66.7 | 30.9 | 2.4 |
| " | 37 | 25.1 | 36.3 | 38.6 | 73.8 | 23.7 | 2.5 |
| " | 38 | 42.0 | 23.5 | 34.5 | 52.7 | 43.8 | 3.5 |
| " | 39 | 15.5 | 26.7 | 57.8 | 89.7 | 10.0 | 0.3 |

| Sample No. | | Q | F | R | Lv | Ls | Lm |
|---|---|---|---|---|---|---|---|
| Roma | 8/40 | 22.6 | 34.8 | 42.6 | 64.3 | 35.1 | 0.6 |
| " | 41 | 24.1 | 20.8 | 55.1 | 69.3 | 29.6 | 1.1 |
| " | 42 | 20.9 | 30.3 | 48.8 | 65.6 | 34.0 | 0.4 |
| Chin | 4/11 | 35.3 | 28.3 | 26.4 | 69.0 | 30.4 | 0.6 |
| " | 12 | 30.2 | 11.7 | 58.1 | 74.6 | 24.1 | 1.3 |
| " | 13 | 24.3 | 37.0 | 38.7 | 77.6 | 21.5 | 0.9 |
| " | 14 | 23.9 | 42.8 | 33.3 | 84.7 | 15.3 | 0.0 |
| " | 15 | 19.5 | 39.6 | 40.9 | 77.2 | 22.2 | 0.6 |
| " | 16 | 21.8 | 33.9 | 44.3 | 81.1 | 17.6 | 1.3 |
| " | 17 | 24.0 | 26.1 | 49.9 | 74.8 | 23.4 | 1.8 |
| " | 19 | 13.5 | 30.6 | 55.9 | 85.6 | 11.9 | 2.5 |
| " | 20 | 25.3 | 32.4 | 42.3 | 72.0 | 13.5 | 14.5 |
| " | 21 | 42.3 | 18.5 | 39.2 | 77.6 | 14.9 | 7.5 |
| " | 22 | 44.5 | 23.3 | 32.2 | 89.1 | 4.9 | 6.0 |
| " | 23 | 15.4 | 21.2 | 63.4 | 96.0 | 3.4 | 0.6 |
| Chin. | 4/51 | 32.6 | 35.4 | 32.0 | 93.9 | 5.6 | 0.5 |
| " | 52 | 25.4 | 25.6 | 49.0 | 82.3 | 15.9 | 1.8 |
| " | 53 | 18.7 | 28.1 | 53.2 | 81.1 | 17.1 | 1.8 |
| " | 54 | 30.8 | 21.5 | 47.7 | 76.3 | 22.5 | 1.2 |

<u>Hutton Sandstone</u>

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Mitch. | 2/32 | 34.2 | 27.4 | 38.4 | 77.8 | 3.6 | 18.6 |
| " | 33 | 31.8 | 20.6 | 47.6 | 78.2 | 9.6 | 12.2 |
| " | 34 | 44.7 | 12.1 | 43.2 | 79.3 | 14.4 | 6.3 |
| " | 35 | 34.1 | 26.1 | 39.8 | 70.7 | 9.4 | 19.9 |
| " | 36 | 38.9 | 20.9 | 40.2 | 81.5 | 7.8 | 10.7 |
| " | 37 | 79.5 | 7.5 | 13.0 | 86.0 | 13.0 | 1.0 |
| " | 38 | 49.9 | 19.4 | 30.7 | 87.6 | 4.3 | 8.1 |

| Sample No. | | Q | F | R | Lv | Ls | Lm |
|---|---|---|---|---|---|---|---|
| Mitch. | 2/39 | 70.2 | 14.9 | 14.9 | 74.4 | 18.8 | 6.8 |
| " | 40 | 72.3 | 13.5 | 14.2 | 86.9 | 10.5 | 2.6 |
| " | 41 | 71.6 | 15.8 | 12.6 | 76.9 | 7.7 | 15.4 |
| " | 42 | 76.0 | 17.5 | 6.5 | 73.9 | 13.0 | 13.1 |
| " | 43 | 71.3 | 22.5 | 6.2 | 65.2 | 17.4 | 17.4 |
| " | 44 | 75.6 | 19.1 | 5.3 | 75.0 | 7.5 | 17.5 |
| " | 45 | 77.5 | 17.4 | 5.1 | 70.3 | 13.5 | 16.2 |
| " | 46 | 72.8 | 21.4 | 5.8 | 81.8 | 4.6 | 13.6 |
| " | 47 | 66.0 | 25.8 | 8.2 | 82.3 | 3.2 | 14.5 |
| " | 49 | 65.3 | 26.3 | 8.4 | 82.5 | 0.0 | 17.5 |
| " | 50 | 66.1 | 24.7 | 9.2 | 80.6 | 1.4 | 18.0 |
| " | 51 | 79.0 | 16.9 | 4.1 | 73.3 | 6.7 | 20.0 |
| " | 52 | 63.4 | 26.5 | 10.1 | 63.0 | 2.7 | 34.3 |
| " | 53 | 68.7 | 23.7 | 7.6 | 67.2 | 9.8 | 23.0 |
| " | 54 | 74.5 | 19.2 | 6.3 | 87.8 | 2.0 | 10.2 |
| " | 55 | 80.4 | 13.4 | 6.2 | 70.0 | 0.0 | 30.0 |
| " | 56 | 74.8 | 18.3 | 6.9 | 82.1 | 3.6 | 14.3 |
| " | 57 | 81.6 | 9.9 | 8.5 | 72.3 | 7.7 | 20.0 |
| Roma | 8/43 | 25.9 | 15.2 | 48.9 | 70.9 | 20.8 | 8.3 |
| " | 44 | 30.3 | 25.2 | 44.5 | 71.8 | 21.0 | 7.2 |
| " | 45 | 31.5 | 26.9 | 41.6 | 73.7 | 19.6 | 6.7 |
| " | 46 | 49.1 | 21.0 | 29.9 | 77.4 | 15.2 | 7.4 |
| " | 47 | 46.2 | 20.6 | 33.2 | 72.3 | 20.5 | 7.2 |
| " | 48 | 49.0 | 16.8 | 34.2 | 81.6 | 12.2 | 6.2 |
| " | 49 | 48.7 | 17.9 | 33.4 | 67.4 | 25.2 | 7.4 |
| " | 50 | 46.5 | 23.2 | 30.3 | 73.0 | 17.6 | 9.4 |
| " | 51 | 85.3 | 5.5 | 9.2 | 37.5 | 62.5 | 0.0 |
| " | 52 | 68.2 | 16.6 | 15.2 | 65.9 | 12.8 | 21.3 |

| Sample No. | | Q | F | R | Lv | Ls | Lm |
|---|---|---|---|---|---|---|---|
| Roma | 8/53 | 85.3 | 9.1 | 5.6 | 83.7 | 7.0 | 9.3 |
| " | 54 | 65.5 | 16.6 | 17.9 | 76.9 | 8.9 | 14.2 |
| " | 55 | 69.0 | 15.5 | 15.5 | 54.9 | 29.4 | 15.7 |
| " | 56 | 75.0 | 19.1 | 5.9 | 75.6 | 15.5 | 8.9 |
| " | 57 | 66.3 | 18.3 | 15.4 | 54.2 | 36.4 | 9.4 |
| " | 58 | 69.7 | 19.9 | 10.4 | 73.0 | 19.1 | 7.9 |
| " | 59 | 79.8 | 12.3 | 7.9 | 85,2 | 6.6 | 8.2 |
| " | 60 | 68.6 | 21.8 | 9.6 | 79.7 | 5.4 | 14.9 |
| " | 61 | 65.4 | 23.3 | 11.3 | 77.5 | 7.9 | 14.6 |
| " | 63 | 69.0 | 22.4 | 8.6 | 75.4 | 10.8 | 13.8 |
| " | 64 | 64.5 | 25.3 | 10.2 | 81.3 | 8.0 | 10.7 |
| " | 65 | 76.6 | 17.4 | 6.0 | 72.7 | 2.3 | 25.0 |
| Chin. | 4/24 | 75.8 | 10.9 | 13.3 | 61.1 | 21.2 | 17.7 |
| " | 25 | 77.1 | 9.7 | 13.2 | 75.7 | 22.3 | 2.0 |
| " | 27 | 88.8 | 5.7 | 5.5 | 56.8 | 31.8 | 11.4 |
| " | 28 | 64.8 | 16.1 | 19.1 | 62.6 | 20.6 | 16.8 |

<u>Evergreen Formation</u>

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Mitch. | 2/58 | 96.4 | 1.8 | 1.8 | 86.7 | 6.6 | 6.7 |
| " | 59 | 86.3 | 9.0 | 4.7 | 87.2 | 0.0 | 12.8 |
| Roma | 8/66 | 58.2 | 22.4 | 19.4 | 76.4 | 8.3 | 15.3 |
| " | 67 | 51.3 | 22.3 | 26.4 | 65.5 | 13.4 | 21.1 |
| " | 68 | 76.2 | 6.7 | 17.1 | 96.2 | 1.5 | 2.3 |
| " | 70 | 43.0 | 26.4 | 30.6 | 88.6 | 6.5 | 4.9 |
| Chin. | 4/30 | 59.1 | 24.9 | 16.0 | 88.3 | 0.0 | 11.7 |
| " | 31 | 74.8 | 18.3 | 6.9 | 73.3 | 11.7 | 15.0 |
| " | 32 | 63.7 | 23.7 | 12.6 | 69.7 | 7.1 | 23.2 |
| " | 33 | 72.1 | 15.9 | 12.0 | 63.3 | 25.5 | 11.2 |

| Sample No. | | Q | F | R | Lv | Ls | Lm |
|---|---|---|---|---|---|---|---|
| Chin. | 4/34 | 27.7 | 43.9 | 28.4 | 87.4 | 5.4 | 7.2 |
| " | 35 | 31.2 | 27.9 | 40.9 | 88.3 | 3.5 | 8.2 |
| " | 36 | 39.1 | 23.0 | 37.9 | 89.8 | 6.6 | 3.6 |
| " | 37 | 30.6 | 31.5 | 37.9 | 90.8 | 6.3 | 2.9 |
| " | 38 | 26.2 | 38.0 | 35.8 | 84.7 | 8.7 | 6.6 |
| " | 39 | 23.4 | 36.3 | 40.3 | 81.5 | 12.0 | 6.5 |

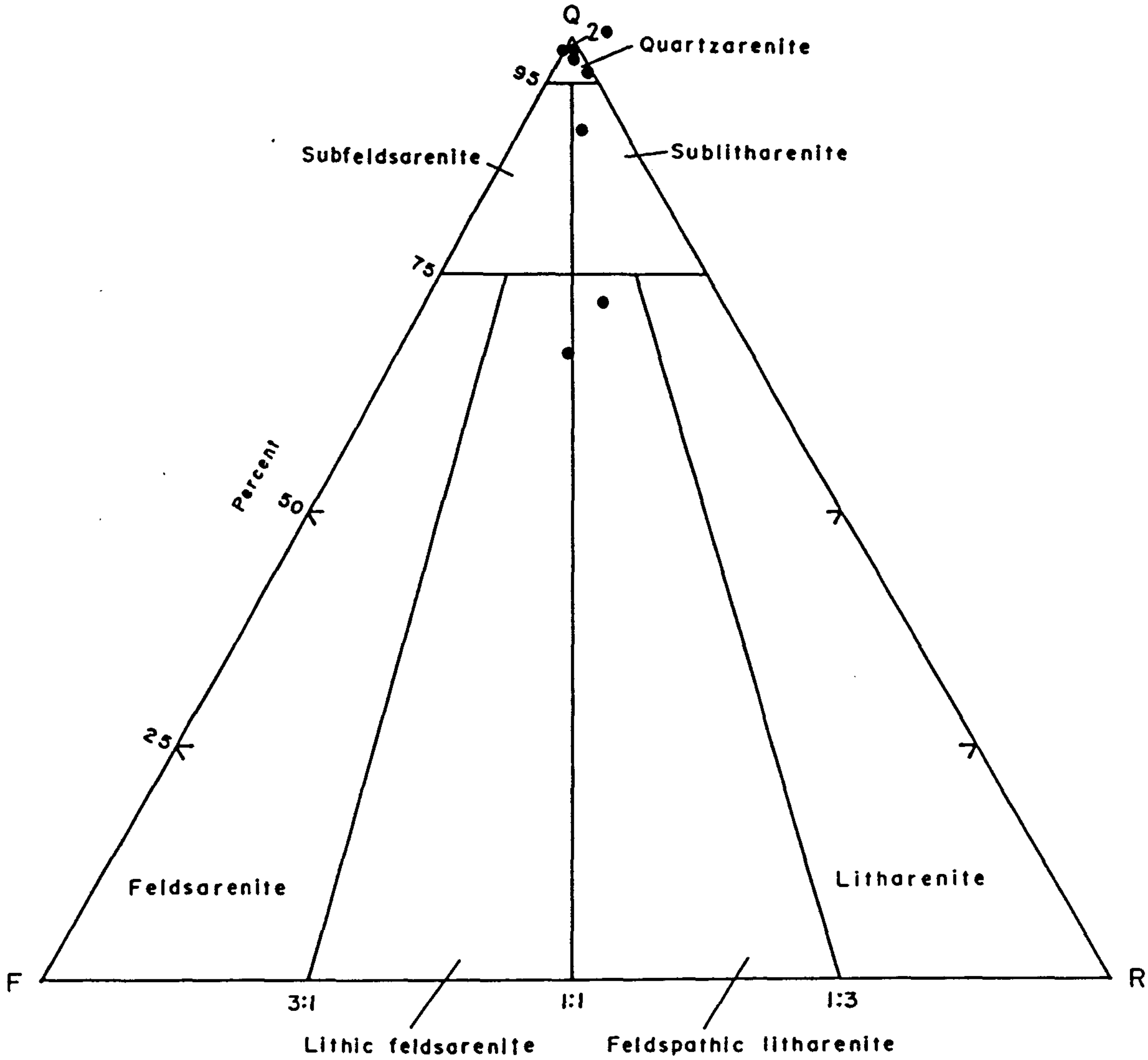
Precipice Sandstone

| Sample No. | | Q | F | R | Lv | Ls | Lm |
|---|---|---|---|---|---|---|---|
| Mitch. | 2/60 | 96.2 | 0.3 | 3.5 | 0.0 | 71.4 | 28.6 |
| Roma | 8/71 | 66.7 | 17.0 | 16.3 | 0.0 | 93.3 | 6.7 |
| " | 72 | 72.1 | 11.0 | 16.9 | 22.8 | 45.7 | 31.5 |
| Chin. | 4/40 | 90.3 | 3.9 | 5.8 | 87.5 | 2.1 | 10.4 |
| " | 41 | 97.6 | 0.8 | 1.6 | 0.0 | 78.6 | 21.4 |
| " | 42 | 98.7 | 1.2 | 0.1 | 0.0 | 100.0 | 0.0 |
| " | 43 | 98.7 | 1.1 | 0.2 | 0.0 | 50.0 | 50.0 |
| " | 44 | 99.5 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| " | 45 | 99.1 | 0.4 | 0.5 | 0.0 | 50.0 | 50.0 |

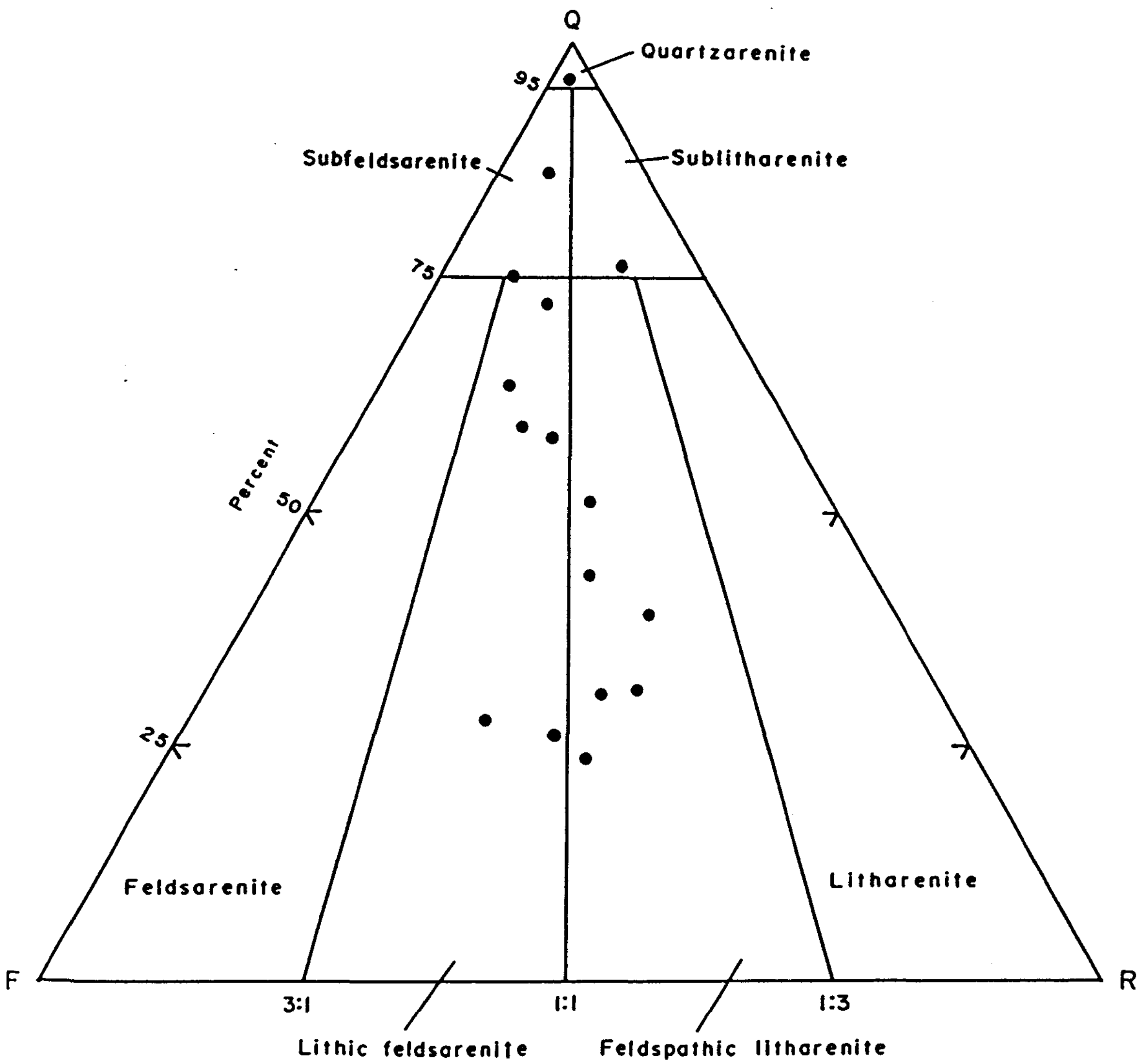
APPENDIX 1.10.2. QFR TRIANGULAR PLOTS OF SANDSTONES IN DIFFERENT FORMATIONS IN THE SURAT BASIN.

Appendix 1.10.2. QFR triangular plots of sandstones in different formations in the Surat Basin. n - number of samples.

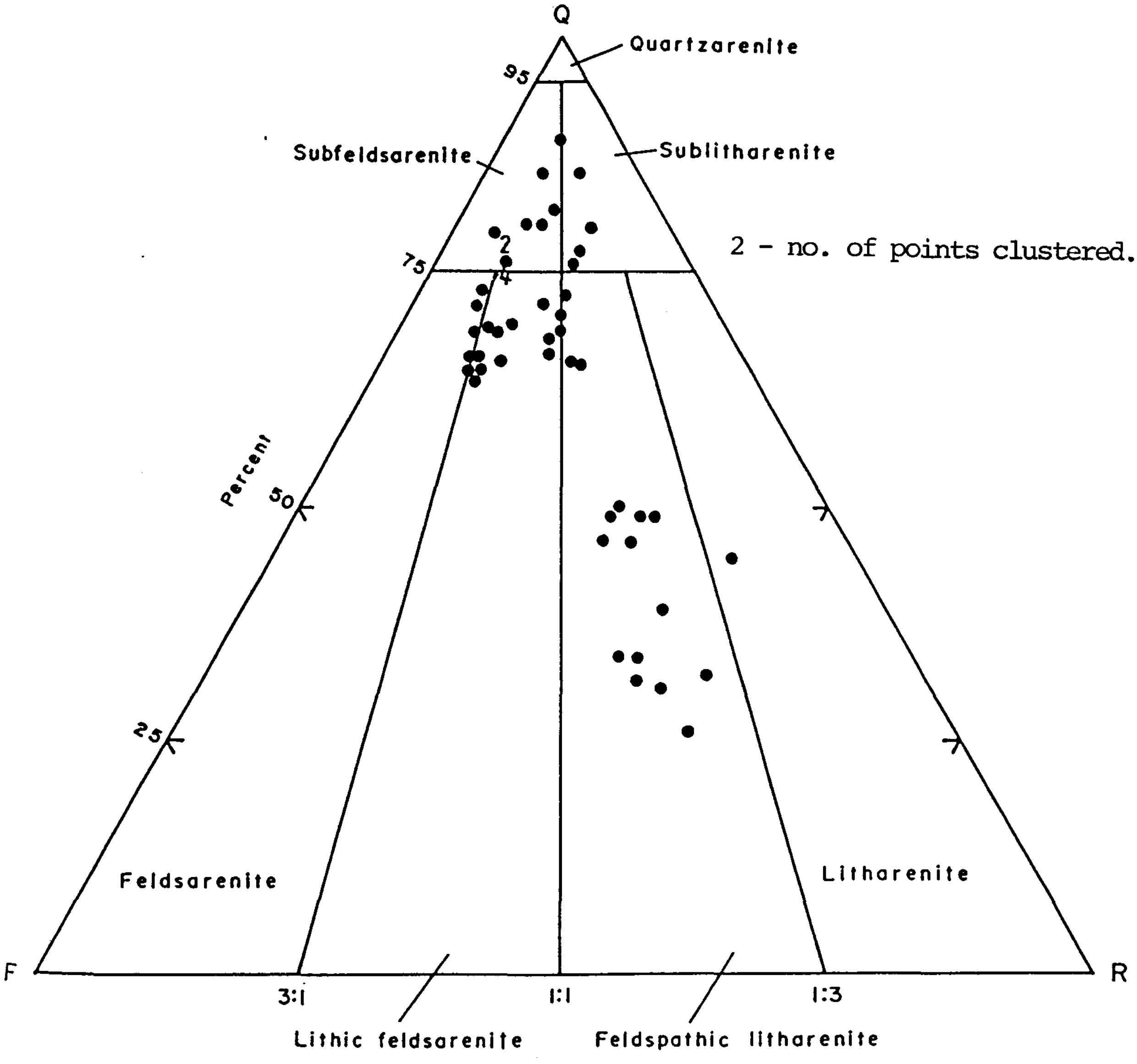
Precipice Sandstone, n = 9.



Evergreen Formation, n = 16.

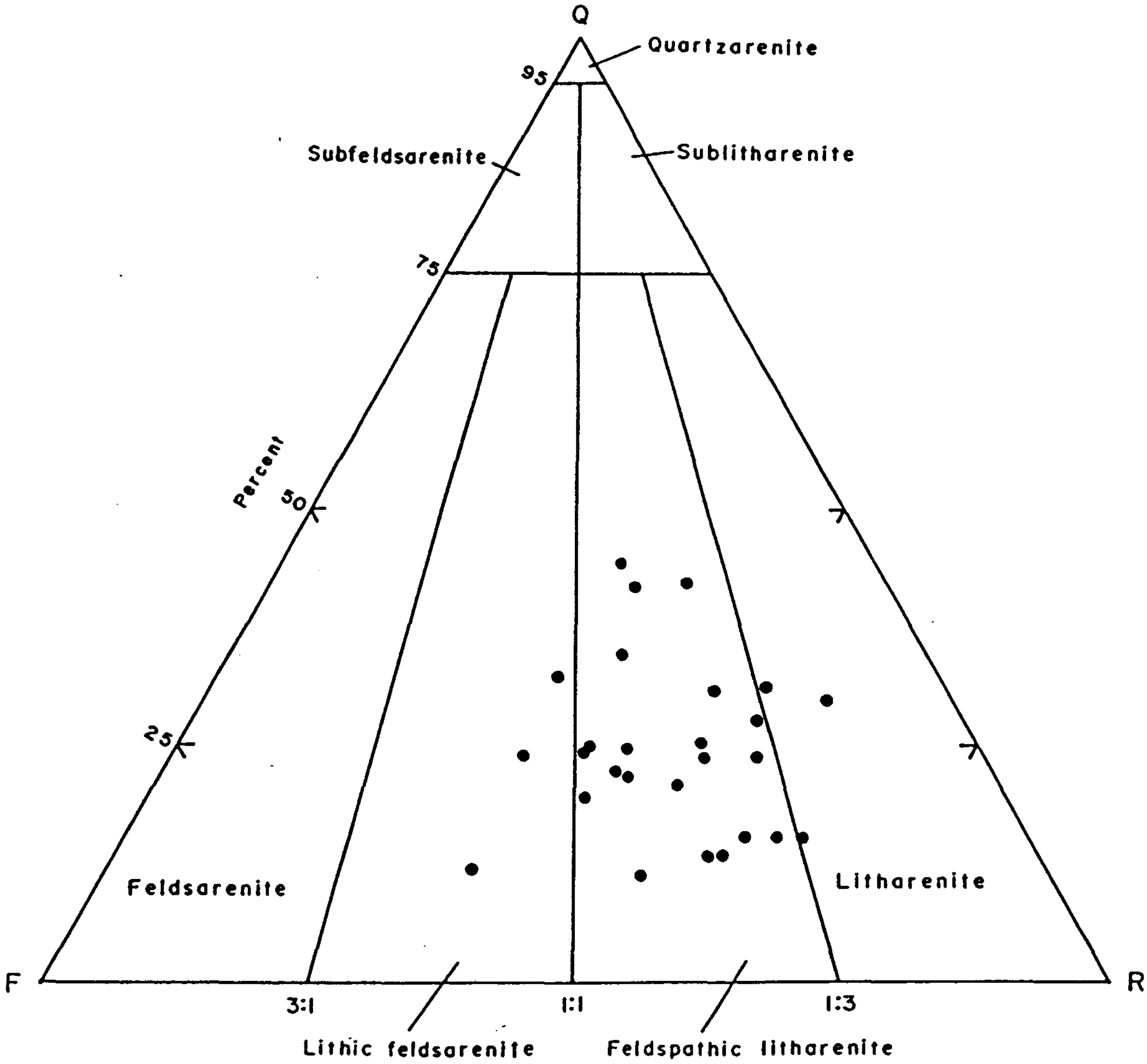


Hutton Sandstone, n = 51.

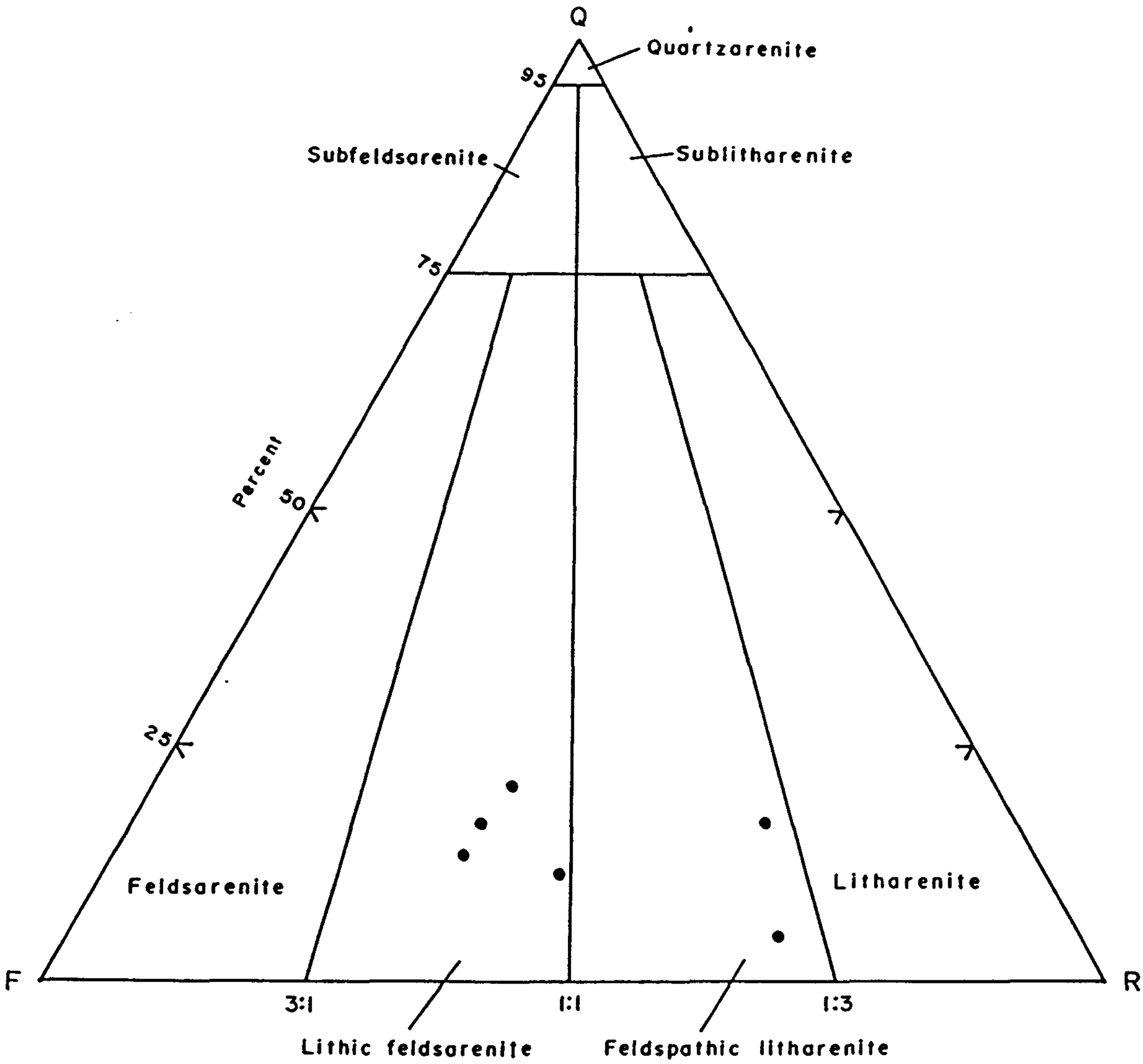



2 - no. of points clustered.

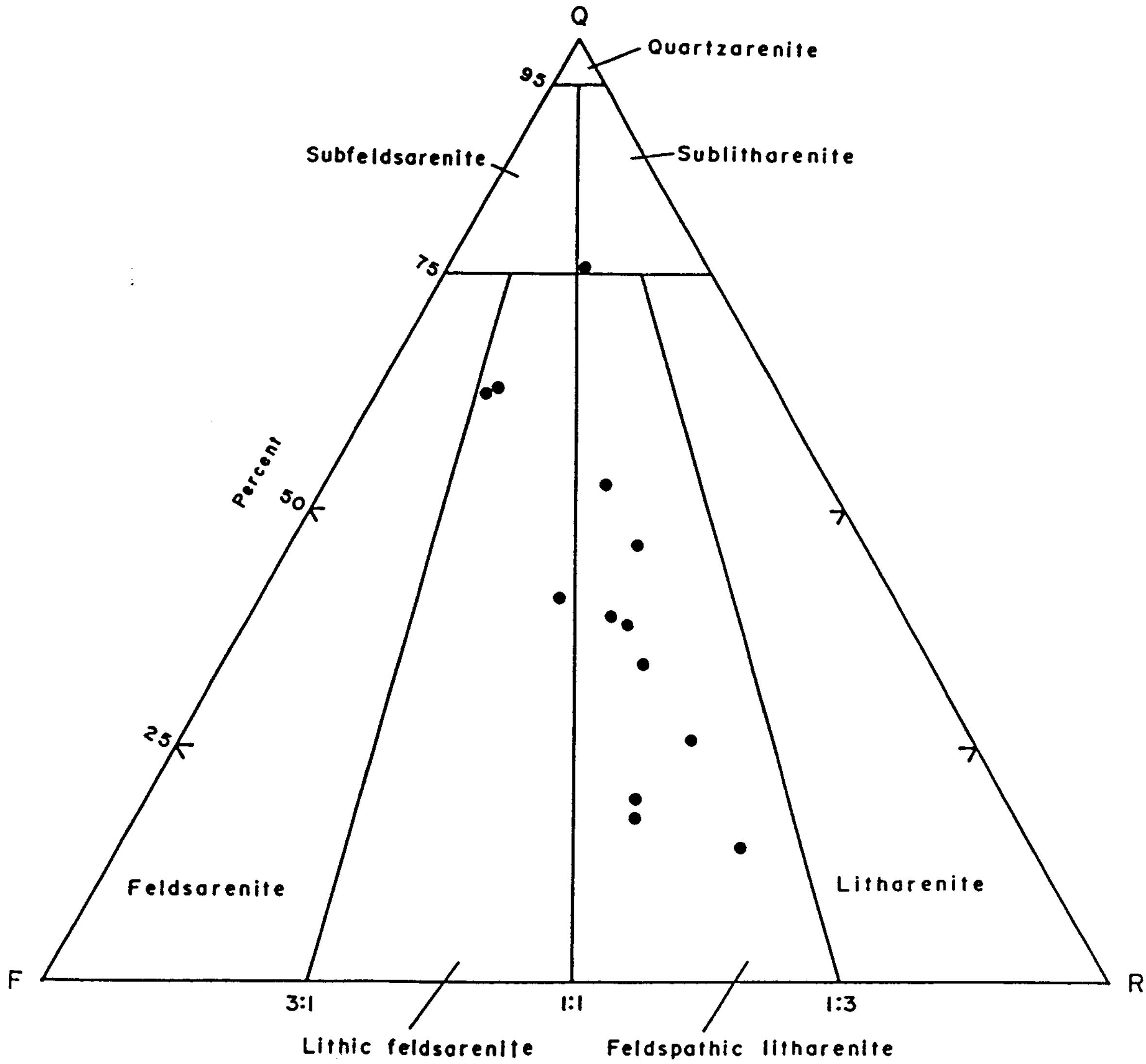
Walloon Coal Measures, n = 27.



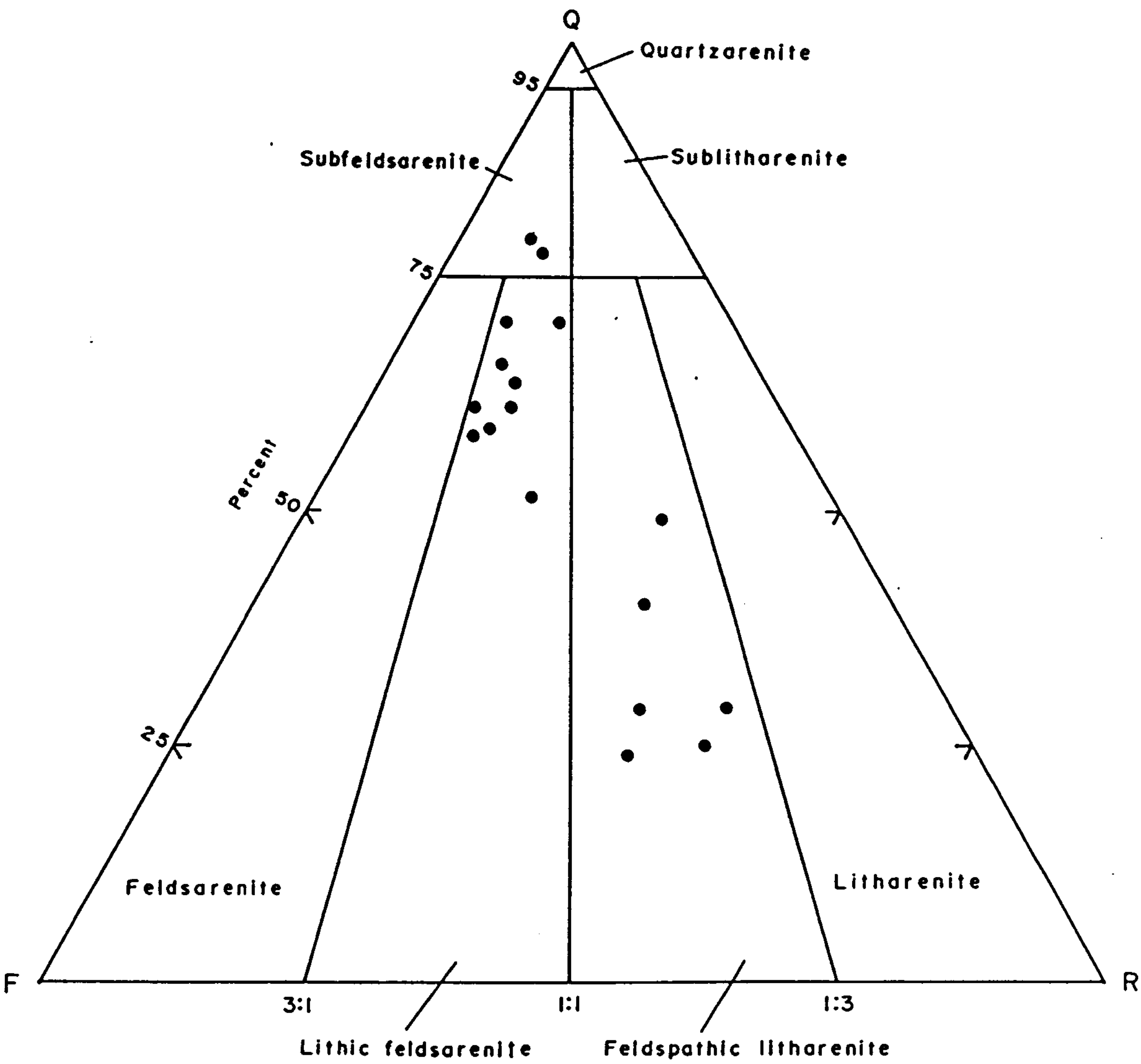
Springbok Sandstone, n = 6.



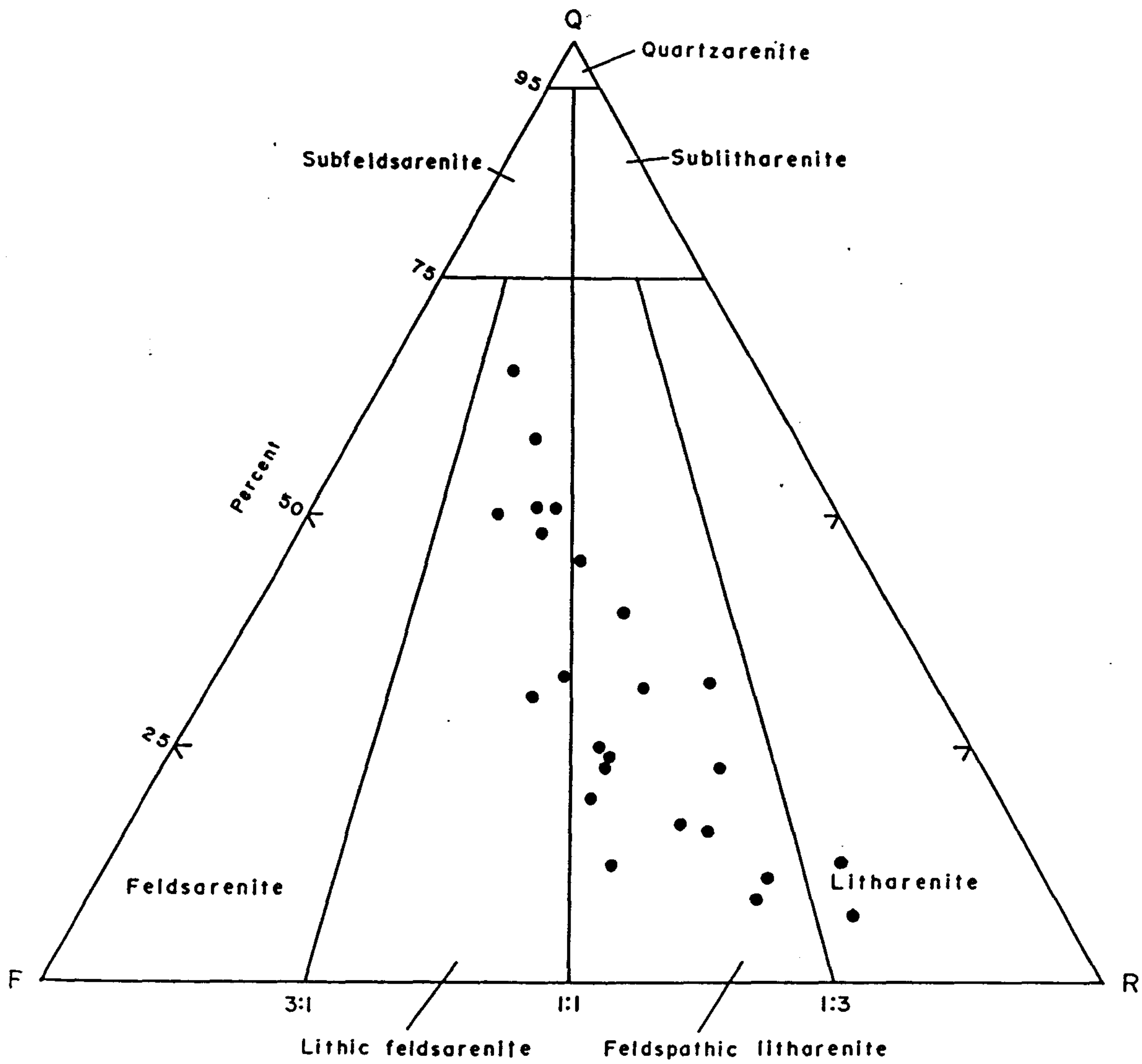
Westbourne Formation, n = 13.



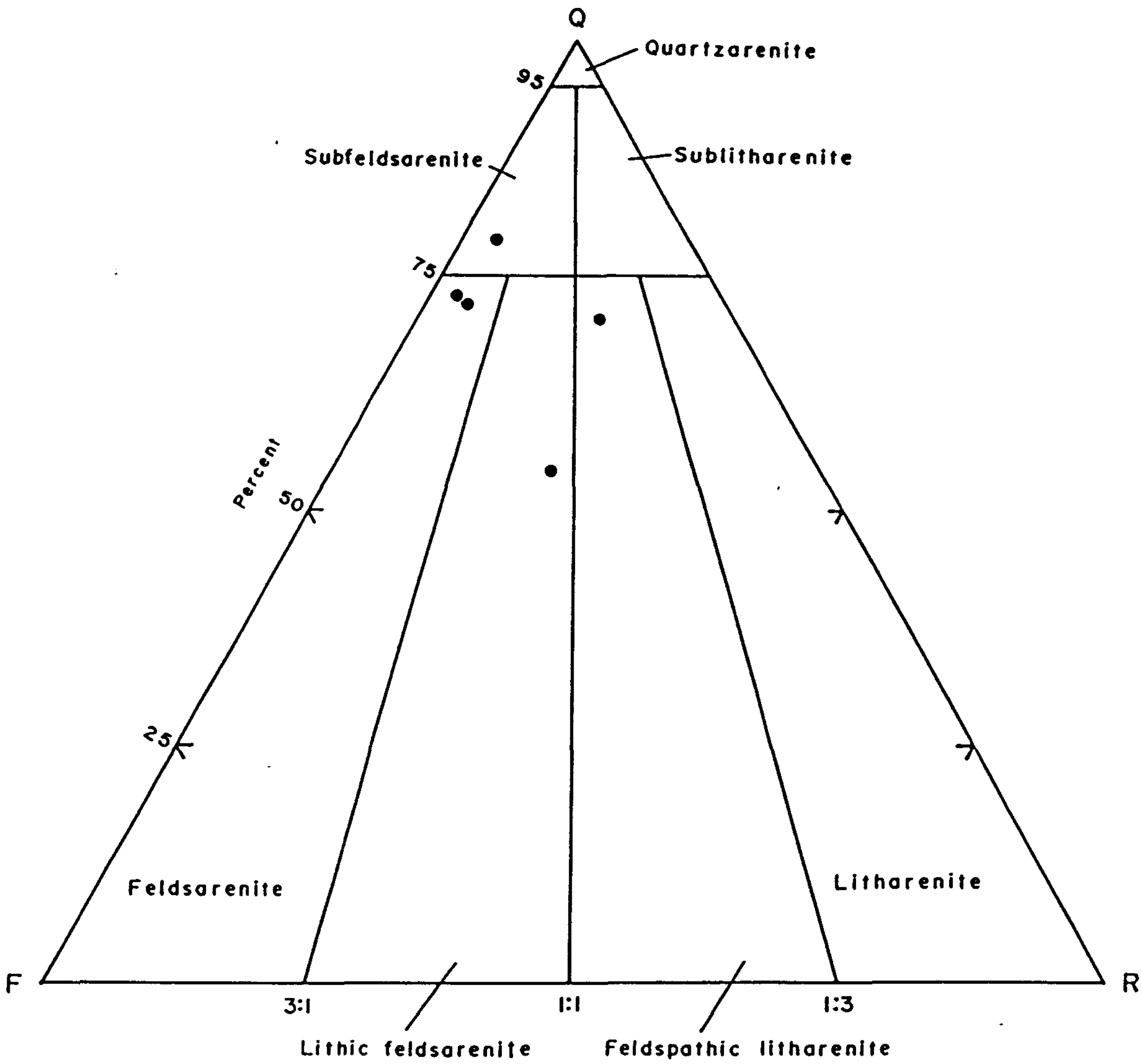
Gubberamunda Sandstone, n = 17.



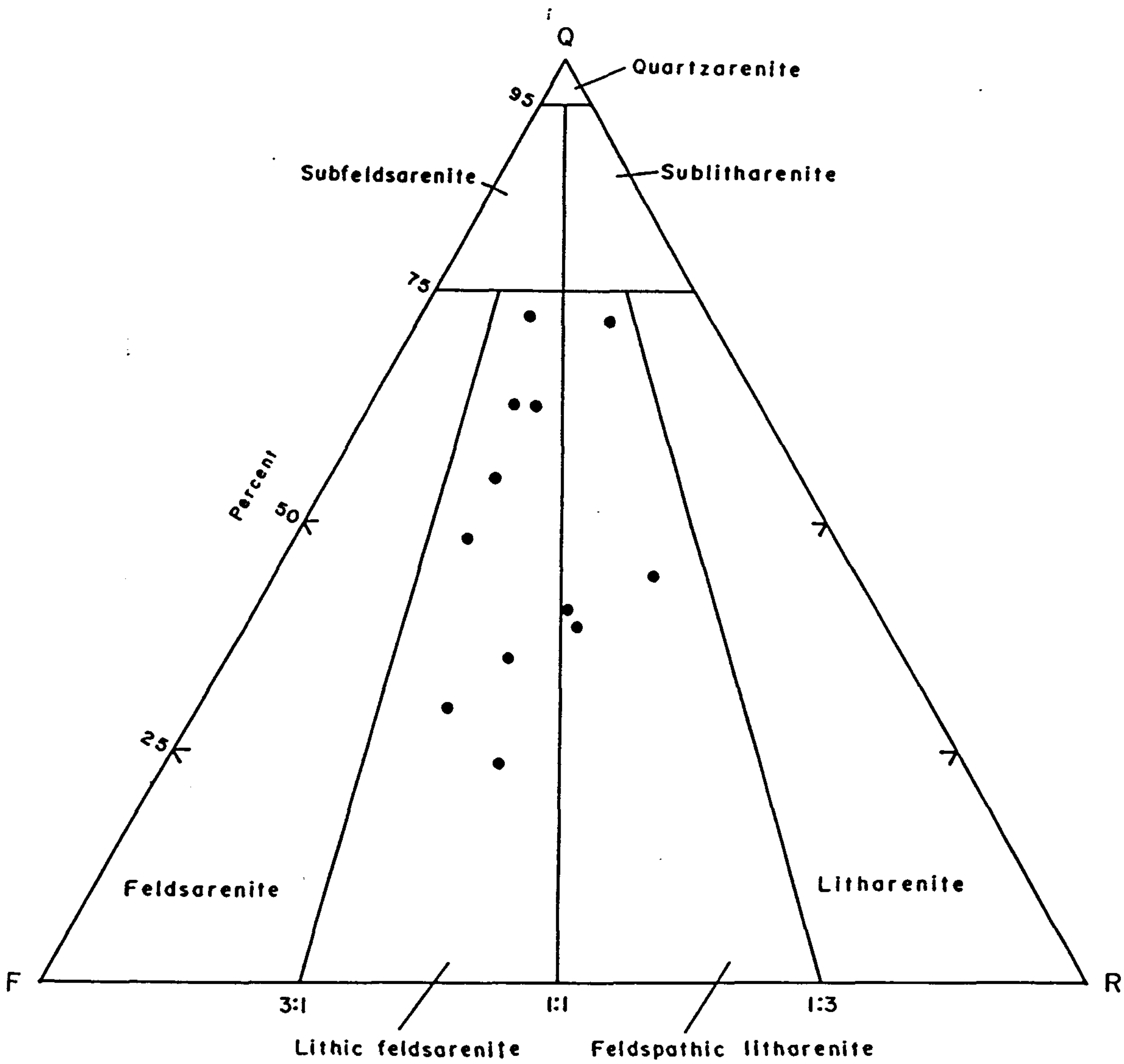
Orallo Formation, n = 24.



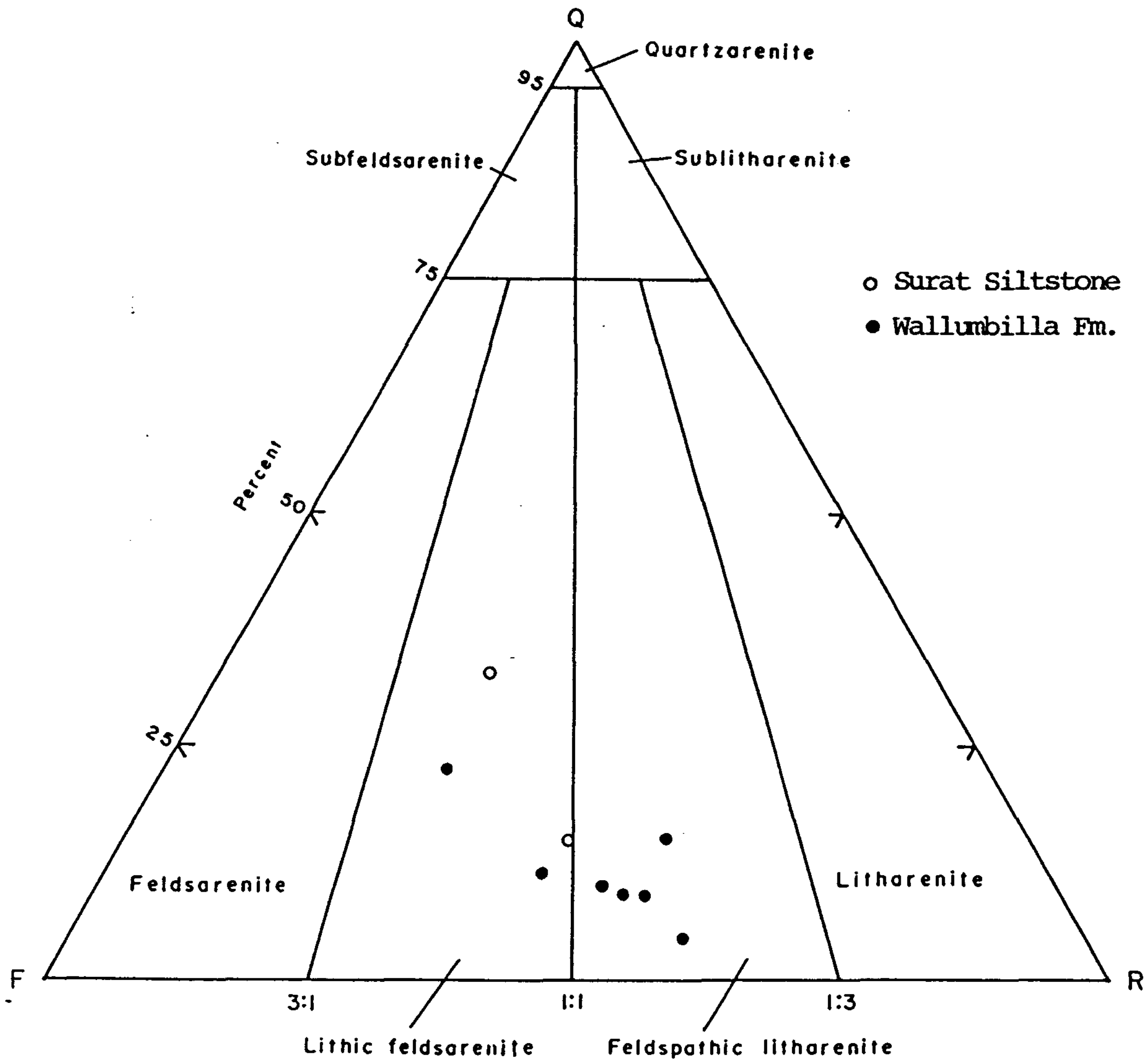
Mooga Sandstone, n = 5.



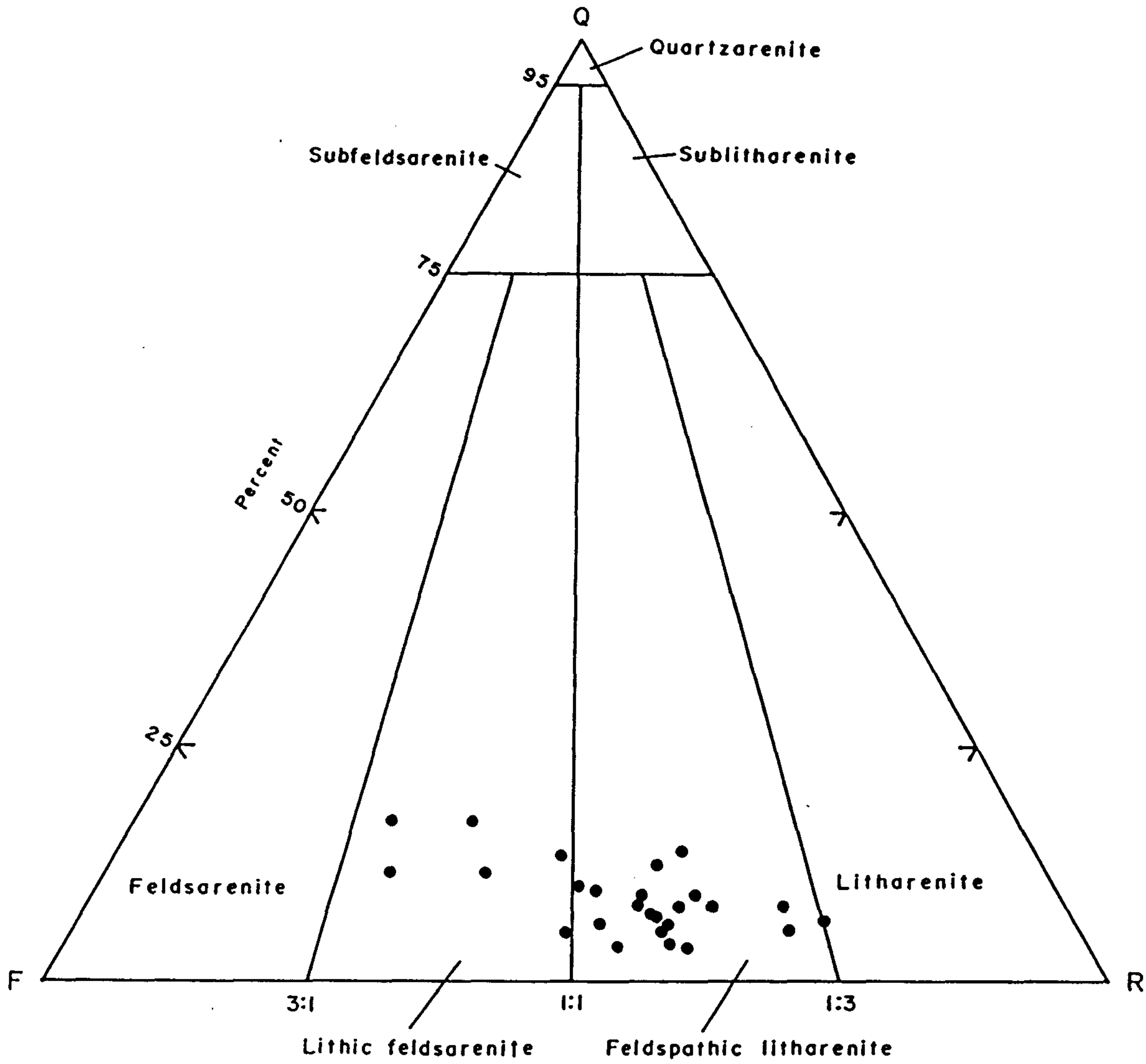
Bungil Formation, n = 12.



Surat Siltstone (n = 2), and Wallumbilla Formation (n = 7).



Griman Creek Formation, n = 26.



## APPENDIX 1.11. METHODOLOGY

Appendix 1.11. Methodology adopted in the Report.

## METHODODLOGY

Data used in this report derive principally from porosity-permeability measurements and point-counting of 215 thin-sections made from core materials from a west-east transect of five fully-cored Geological Survey of Queensland (GSQ) stratigraphic test wells (Figure 1.1., Table 1.1). Sample distribution within these wells covers a depth range of 17 to 1225 m. Samples are commonly taken at intervals not more than 10 m except where units are thin in which case the minimum sampling interval is 1 m (cf. Noon and Coote, 1983). Sample selections were biased towards the sandstone-rich (coarser grain-size) parts of the formations. Thin-sections were cut normal to bedding and the slabbed cores from which the thin-sections were cut were impregnated with blue epoxy resin to distinguish natural porosity from artificial holes caused by grain-plucking during slide making. All thin-sections were stained for carbonates using alizarin red-S and potassium ferricyanide. An additional subset of 26 thin-sections (in addition to the 215) were made and stained for K-feldspar using sodium cobaltinitrite solution (Friedman, 1971). Consistently 1000 points were counted in each thin-section which included detailed petrographic grain-type and porosity categories as shown in Appendix 1.1. Only 600 grains (= points) were counted in samples stained for K-feldspar. Grid-spacing in each case of point-counting was adjusted to account for the grainsize so as not to count the same grain more than once (Textoris, 1971). Point-counting results are unbiased regardless of the grid-spacing, but the standard deviation of the unbiased procedure is minimised with the spacing suggested (cf. Textoris, ibid.).

Average grainsize was determined by measurement of the long-axis dimension of 10 grains in the dominant size mode in each thin-section. Sorting was estimated using the visual sorting images of Pettijohn et al (1972; fig. A-1). Routine porosity and permeability measurements were made (following standard techniques) by Bureau of Mineral Resources (BMR) personnel on most of the samples studied in this report (Appendix 1.5). But some additional measurements were made by the author (Appendix 1.5) at the BMR petrophysical laboratory, Canberra, on the same equipment to check the reproducibility of existing data and to extend the data-base. Porosity was measured using helium as the saturating medium and permeability with dry nitrogen as the flowing medium. Permeability refers to horizontal permeability throughout this report unless otherwise stated.

Since the purpose of the point-counting was to document the detrital mineralogy as well as porosity and diagenetic alterations, a detailed manual tally of altered and psudomorphously replaced and leached minerals were maintained throughout the point-counting. This allowed reconstruction of the detrital mineralogy at the time of deposition by looking through the 'veil of diagenetic alterations' while at the same time documenting both the quantitative extent and qualitative/genetic characteristics of diagenetic alterations (e.g., in terms of growth of cement, alteration of framework-grains, etc.) and porosity. Thus intragranular porosity within skeletal feldspar (2Bdsf; cf. Appendices 1.1. and 1.9.) was counted as pores for the purpose of documentation of porosity but was included with feldspar for petrologic classification and provenance studies. Likewise, cement and epimatrix (e.g., kaolinite) replacing detrital grains were allocated to the detrital grain category where identification permitted.

With respect to porosity classification, fracture porosity was excluded from secondary dissolution porosity and unless otherwise stated secondary porosity refers to dissolution porosity throughout this report.

Fracture porosity is shown along with other porosity types in Appendix 1.9 and is included in the total secondary porosity.

With regard to size classification of porosity, microporosity is arbitrarily defined here as having pore diameters < 20 um (which is different from the definition used by Pittman (1979) based on examination of many mercury injection capillary pressure curves). The 20 um cut-off figure that is adopted here is arbitary and does not imply that blue epoxy can not get into pores smaller than 20 um. This figure is taken because in a 30 um-thick thin-section, the minimum visual limit is roughly 20 um under high magnification. This thin-section pore size of less than 20 um for defining the microporosity category is quite satisfactory for comparative purposes (E. D. Pittman; written comm., 1987).

Fifty eight rough-cut samples (with artificially broken surfaces) from the remnants of core materials after thin-section preparation were coated with gold and various aspects of texture, diagenetic minerals, and pore geometry were examined using a JEOL JSM 840 scanning electron microscope (SEM). About 500 SEM photomicrographs were taken. Some detrital and authigenic minerals were also subjected to energy dispersive X-ray (EDX) analyses with an EDX facility attached to a scanning electron microscope.

Identification of certain diagenetic and detrital minerals was facilitated by electron microprobing performed on 17 polished thin-sections.

Orientated X-ray diffraction (XRD) samples of the clay fraction (<2 um) from 11 samples were prepared and analyzed following procedures described by Drever (1973), Brindley and Brown (1980) and Carroll (1970). The specimens were crushed and agitated in water suspension in a sonic bath before separation of the into < 2 um fraction by centrifuging (cf. Carroll, 1970). Orientated clay mounts were prepared using the modified filter-membrane peel technique of Drever (1973). In a few samples containig swelling clays (especially montmorillonite) the technique was unsatisfactory and the 'smear on glass' technique (Gibbs, 1965) was used. Three slides were made from each sample. After air drying one was treated with ethylene glycol, one was heated in a muffle furnace at 500 °C for an hour and the third was kept untreated by glycol/heat. The samples were then separately subjected to x-ray diffraction.

Statistical analyses of petrologic and petrophysical data were performed using the SPSSX software (SPSS Inc., 1983) on the Macquarie University VAX mainframe computer system.

## References

Brindley, G. W., and Brown, G., 1980, Crystal structures of clay minerals and their X-ray identification. Mineral. Soc. Monogr. 5, 495 p.

Carroll, D., 1970, Clay minerals - a guide to their X-ray identification. Geol. Soc. of Amer. Sp. Paper 126.

Drever, J. I., 1973, The preparation of oriented clay mineral specimens for X-ray diffraction analysis by a filter-membrane peel technique. Amer. Mineral., v. 58, pp. 553-554.

Friedman, G. M., 1971, Staining. In Carver, R. E. (ed.) Procedures in sedimentary petrology. Wiley-Intersc., New York, pp. 511-530.

Gibbs, R. J., 1965, Error due to segregation in quatitative clay mineral x-ray diffraction mounting techniques. Amer. Mineral., v. 50, pp. 741-751.

Noon, T. A., and Coote, S. M., 1983, Review of departmental stratigraphic drilling in Queensland. Qld. Govt. Min. Jour., v. 84/985, pp. 417-453.

Pettijohn, F. J., Potter, P. E., and Siever, R., 1972, Sand and sandstone. Springer-Verlag, New York. 618 p.

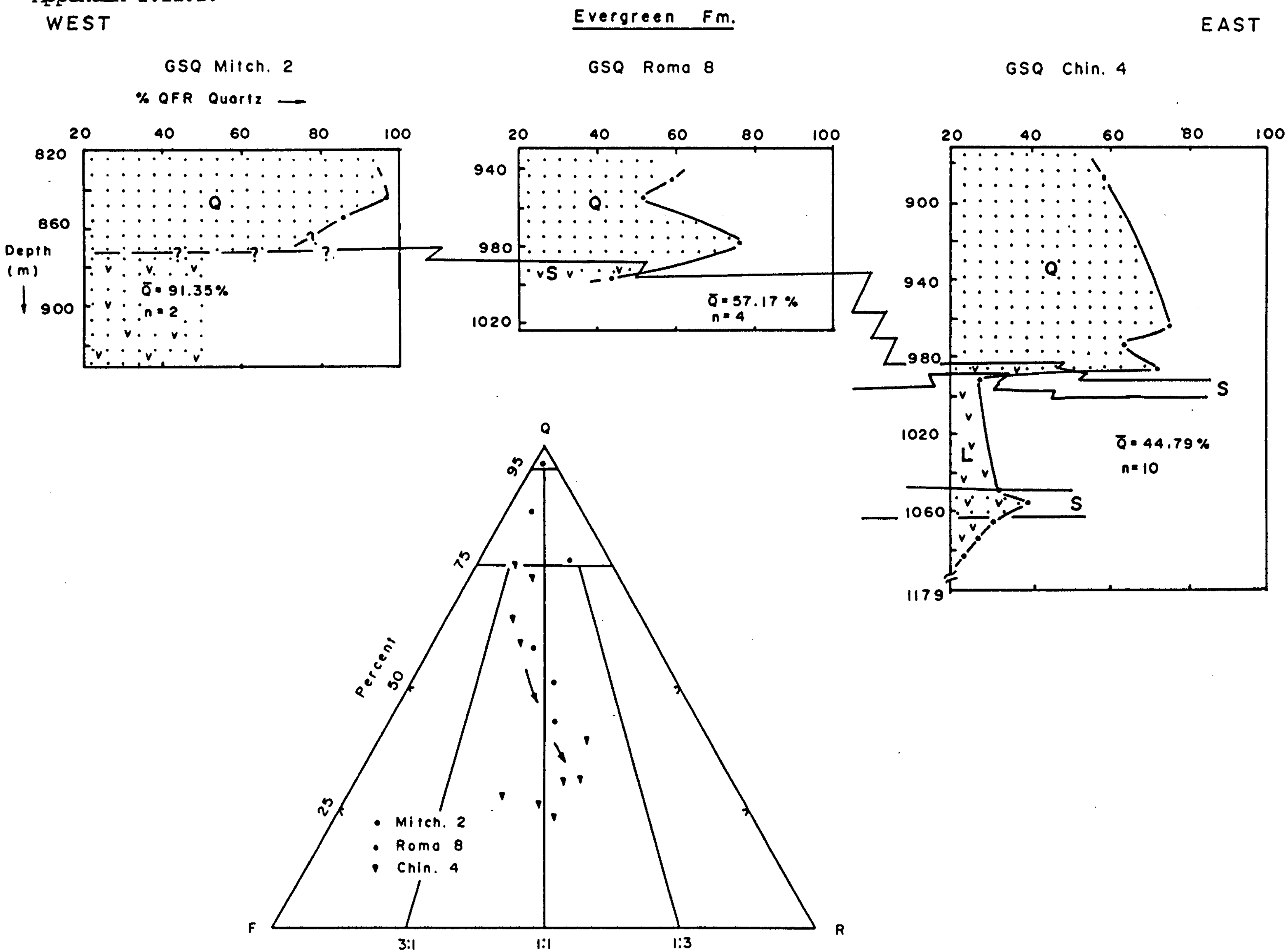
SPSS Inc., 1983, SPSSX user guide. McGraw Hill, New York, 806 p.

Textoris, D. A., 1971, Grain-size measurement in thin-section. In Carver, R. E., (ed.) Procedures in sedimentary petrology. Wiley Intersc., New York, pp. 95-107.

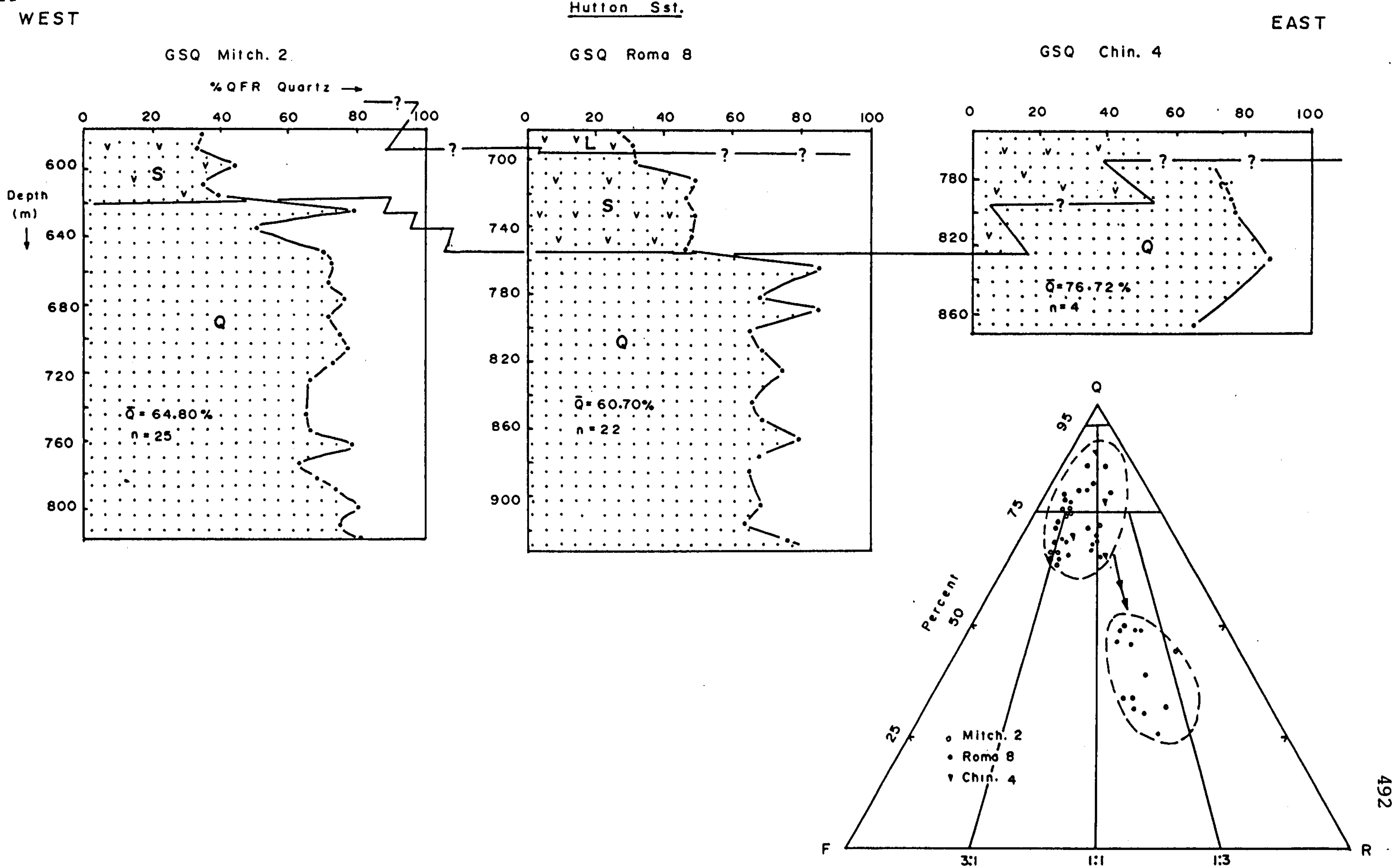
APPENDIX 1.12. UPSEQUENCE AND LATERAL PETROGRAPHIC TRENDS IN SOME SURAT BASIN SANDSTONES.

Appendix 1.12. Upsequence and lateral petrographic trends in some Surat Basin sandstones. $\bar{Q}$ - mean detrital quartz content (on a QFR basis); n - number of samples. Q - quartzose petrofacies; S - sublabile/intermediate petrofacies; L - labile petrofacies. Arrows on QFR triangular plots indicate first-order trends of eastward increase in lithic content, except in the Hutton Sandstone where it indicates upsequence increase in rock-fragments. In the plots of detrital quartz content against depth, formation tops are taken as datum lines. All formation boundaries are from Coote (1986).

Appendix 1.12.1.

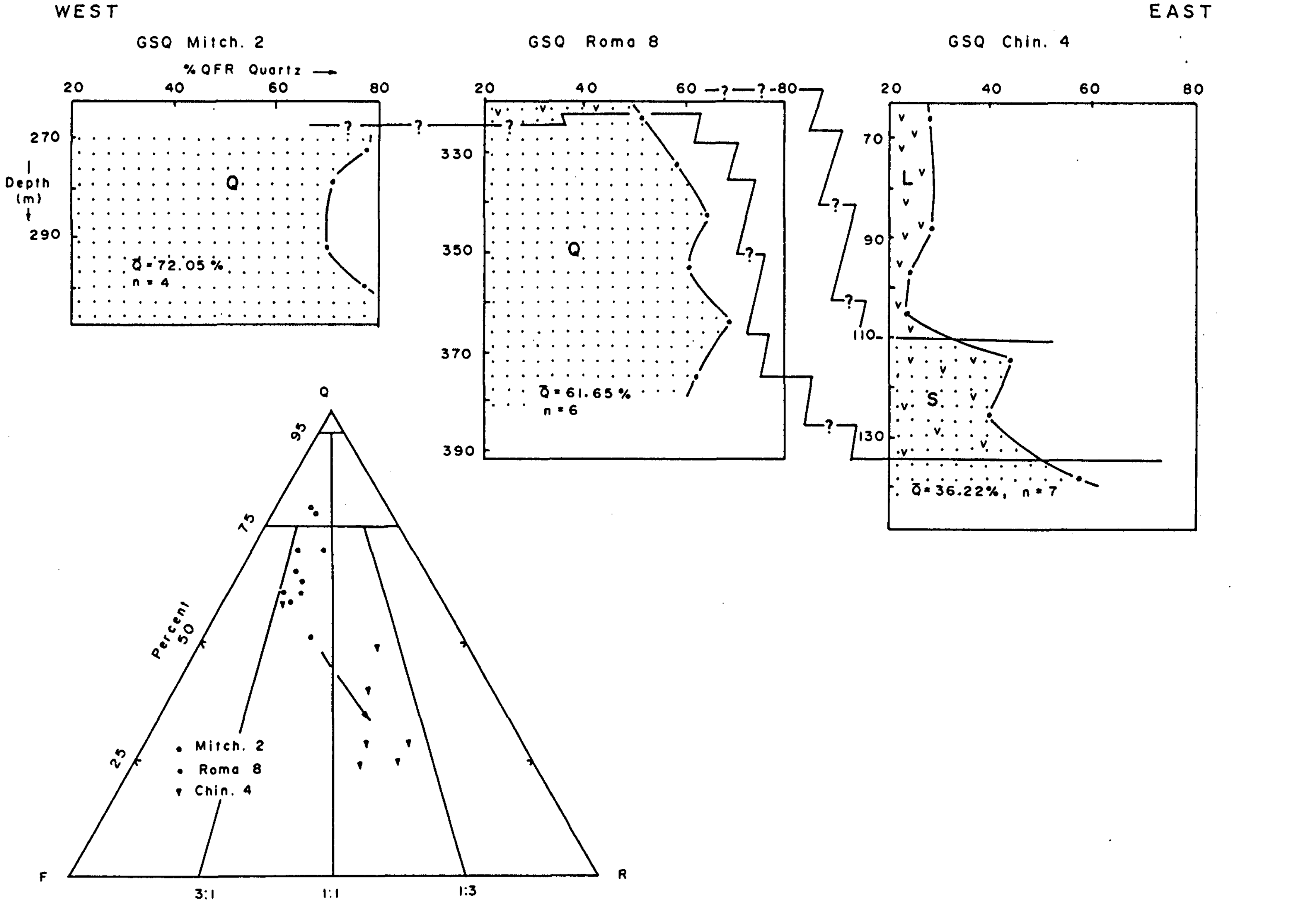


Appendix 1.12.2.

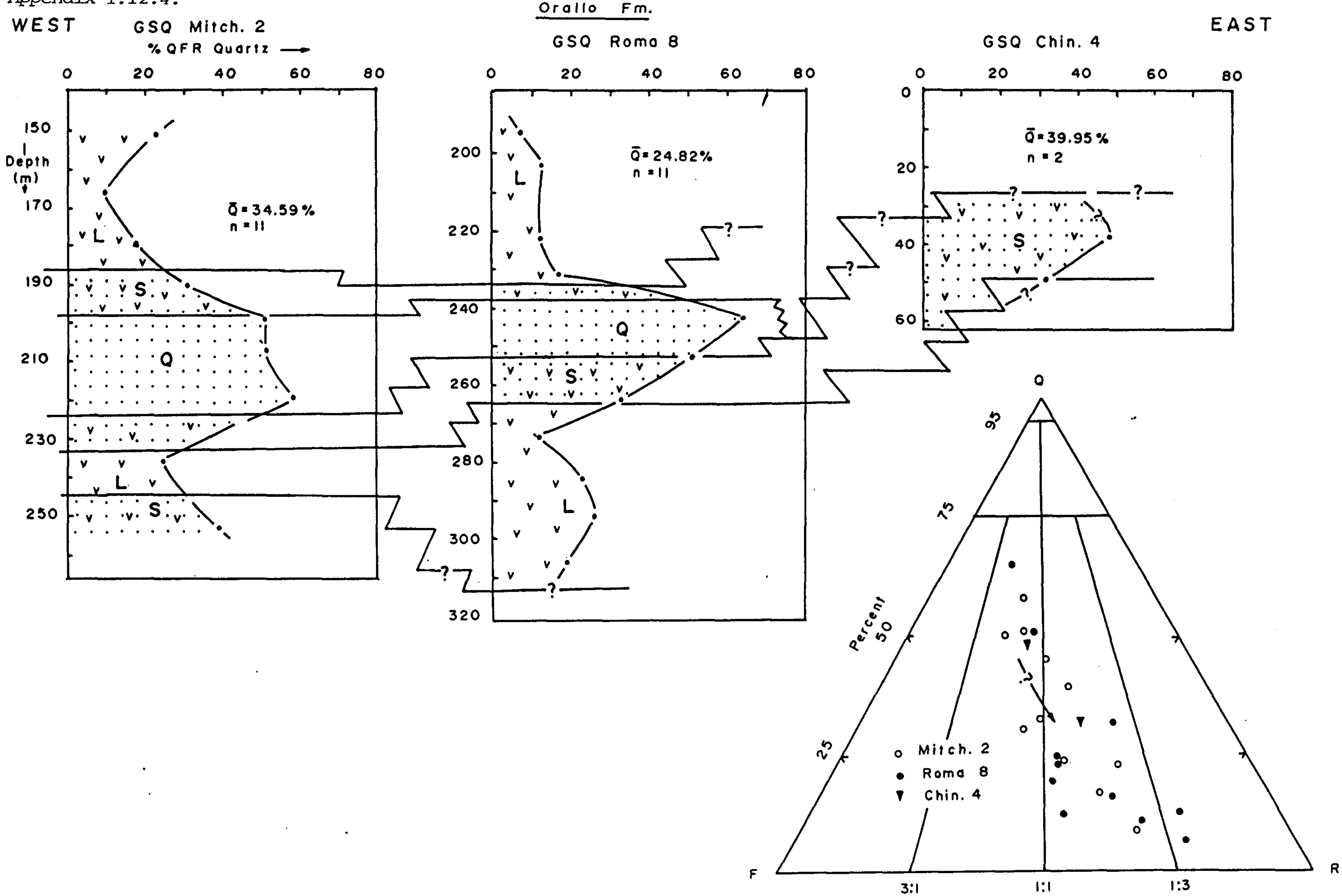


Appendix 1.12.3.

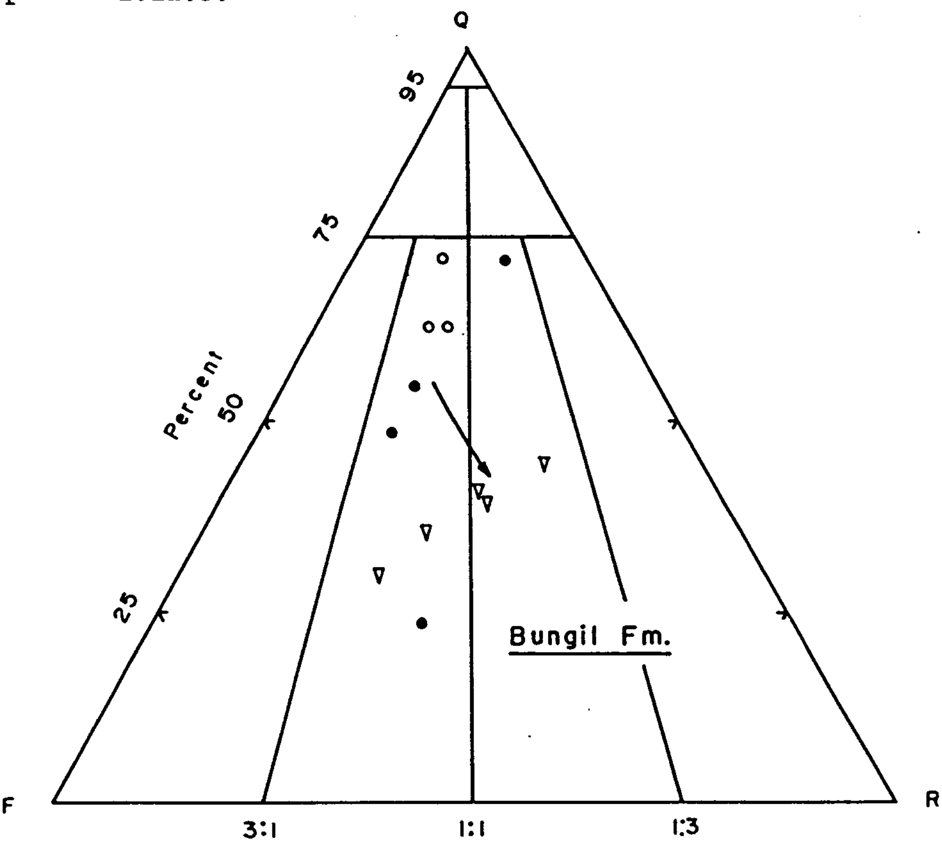
Gubberamunda Sst.

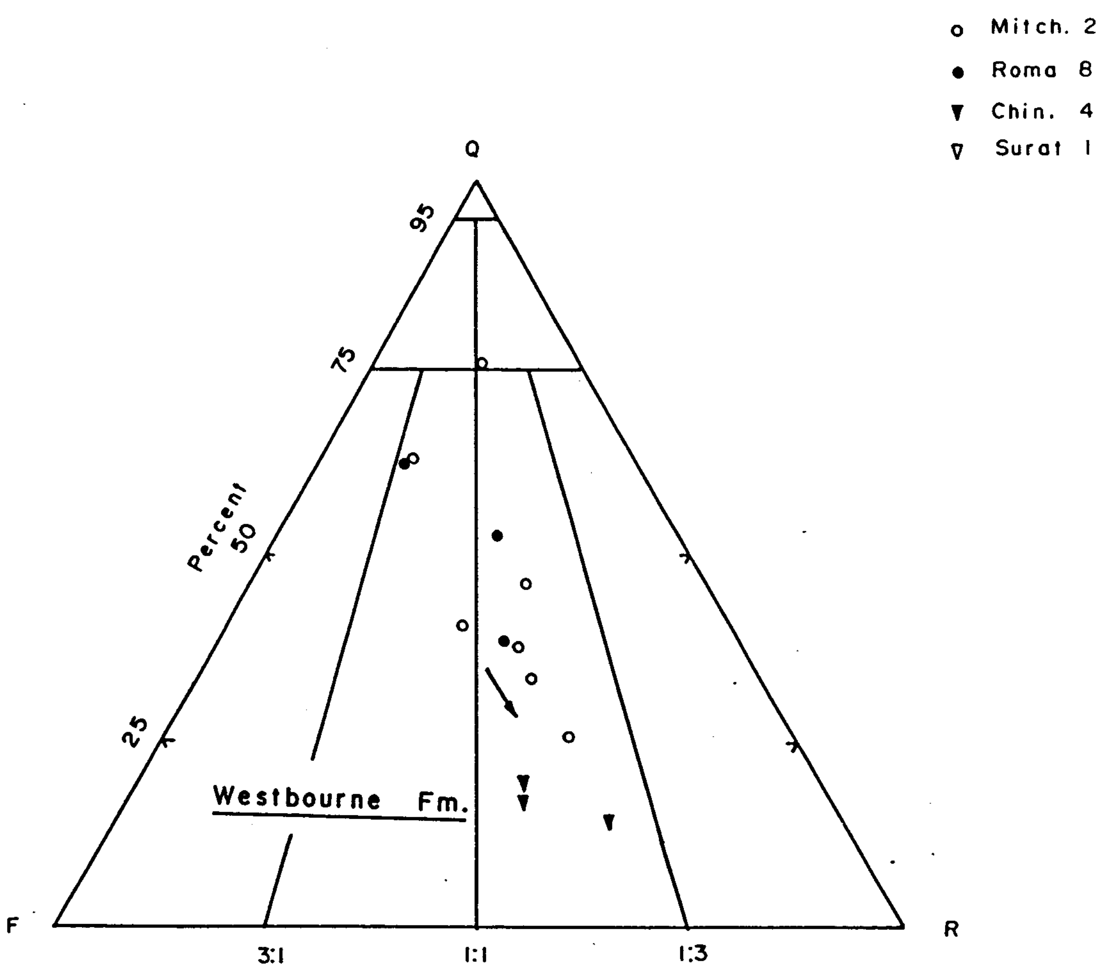


*Appendix 1.12.4.*



Appendix 1.12.5.



Reference cited in Appendix 1.12.

Coote, S. M., 1986, Departmental stratigraphic drilling in Queensland, 1983 to 1986. Qld. Govt. Min. Jour., v. 87/1017, pp. 306-326.

## APPENDIX 1.14. RECONNAISSANCE PALAEOCURRENT DATA FROM SURFACE OUTCROPS

Appendix 1.14. Reconnaissance palaeocurrent data from surface outcrops of some Surat Basin formations. N - sample size; L - resultant vector length; $\theta$ - mean direction; $\sigma$ - circular standard deviation.

| Formation | Locality | Current indicator [1] | N | L (percent) | $\theta$ (degrees) | [2] | $\sigma$ (degrees) | Notes |
|---|---|---|---|---|---|---|---|---|
| Doncaster Mbr. of Wallumbilla Fm. | Roma 1: 250 000 GR. 6682, 0576 | XBDA | 1 | —— | 300 | | —— | |
| Kingul Mbr. of Bungil Fm. | Roma 1: 250 000 Gr. 6645, 0745 | " | 28 | 66.8 | 229 | | 21.1 | bracketed with the next 4 rows |
| Nullawurt Mbr. of Bungil Fm. | Roma 1: 250 000 GR. 6640, 0709 | " | 4 | 60.6 | 250 | | 66.6 | |
| " " | Roma 1: 250 000 GR. 6635, 0724 | " | 2 | 76.0 | 213 | 211 [2] | —— | pooled mean for Kingul to Minmi rows |
| " " | Roma 1: 250 000 GR. 6645, 0745 | RP(FS) | numerous (highly-polarized) | —— | 225 | | —— | |
| Minmi Mbr. of Bungil Fm. | Roma 1: 250 000 GR. 6806, 0661 | XBDA | 1 | —— | 138 | | —— | |
| Mooga Sandstone | Roma 1: 250 000 GR. 6601, 0827 | " | 30 | 63.7 | 006 | | 23.9 | bracketed with the next row |
| " " | " | XBTA | 5 | 92.9 | 118 | 112 | 19.8 | pooled mean for both Mooga rows |
| Orallo Formation | Roma 1: 250 000 GR. 6577, 0850 | XBDA | 24 | 86.9 | 112 | | 12.2 | bracketed with the next 3 rows |
| " " | " | XBTA | 6 | 93.4 | 065 | | 17.6 | |
| " " | Roma 1: 250 000 GR. 6772, 0800 | XBDA | 8 | 90.7 | 110 | 118 | 18.1 | pooled mean for all 4 Orallo rows |
| " " | " | XBTA | 6 | 98.5 | 161 | | 7.9 | |
| Gubberamunda Sandstone | Roma 1: 250 000 GR. 6717, 0950 | XBDA | 41 | 88.4 | 111 | | 6.9 | bracketed with the next row |
| " " | Roma 1: 250 000 GR. 6742, 0919 | " | 15 | 79.0 | 109 | 110 | 21.3 | pooled mean for both Gubberamunda rows |
| Westbourne Formation | Roma 1: 250 000 GR. 6712, 0962 | " | 30 | 71.2 | 134 | | 19.1 | |
| Eurombah Fm./Walloon Coal Meas. | Roma 1: 250 000 GR. 6836, 1178 | " | 15 | 95.6 | 064 | | 8.7 | bracketed with the next row |
| " " | " | XBTA | 15 | 75.6 | 045 | 56 | 22.9 | pooled mean for both Eurombah rows |
| Hutton Sandstone | Taroom 1: 250 000 GR. 6665, 1509 | XBDA | numerous | —— | northeast | | —— | |
| Evergreen Formation | Taroom 1:250 000 GR. 6815, 1755 | XLTA | numerous (hightly-polarized) | —— | 332 | | —— | |

Footnote to Table 1.14.

1 XBDA - cossbed dip-azimuth; XBTA - crossbed trough-axdis; XLTA - ripple trough-axis; RP(FS) - ripple pavement (form-sets).

2 Average vector-mean azimuth for the whole formation based on pooled sample-vector-means of: (1) different current indicators at one or more than one locality; and (2) the same current indicator at more than one locality.

# APPENDIX 2.1. ELECTRON MICROPROBE ANALYSES OF COCKSCOMB SKELETAL FELDSPARS

Appendix 2.1. Electron microprobe analyses of Skeletal feldspars. Multiple analyses on a single sample represent analyses done on different grains within the one thin-section.

Analysis 1. GSQ Mitchell 2/63, Skeletal feldspar, Springbok Sst.

```
---> ? MCL2/63 SBOK SKEL. FSPAR GR. NO.4
ANAL. 379    PT. 1    05-02-1988  18:43:16    6 OXS. CO-ORDS 48650  57066  36225
SiO2         69.13   2.2535
Al2O3        19.61   0.7535
FeO           0.00   0.0000
MgO           0.00   0.0000
CaO           0.00   0.0000
Na2O         11.45   0.7237
K2O           0.04   0.0017
            100.24   3.7324
4401  3905 *   0.0 *   0.0    0.0    0.0 *   0.0  99.8   0.2
```

Analysis 2. GSQ Mitchell 2/63, Skeletal feldspar, Springbok Sst.

```
---> ? Mcl 2/63, S'bok Sst., Skeletal feldspar.
ANAL. 375    PT. 1    05-02-1988  18:18:06    6 OXS. CO-ORDS 49754  57756  36155
SiO2         69.18   2.2404
Al2O3        20.20   0.7711
FeO           0.00   0.0000
MgO           0.00   0.0000
CaO           0.00   0.0000
Na2O         11.54   0.7248
K2O           0.00   0.0000
            100.93   3.7363
4484  3958 *   0.0 *   0.0    0.0    0.0 *   0.0 100.0   0.0
```

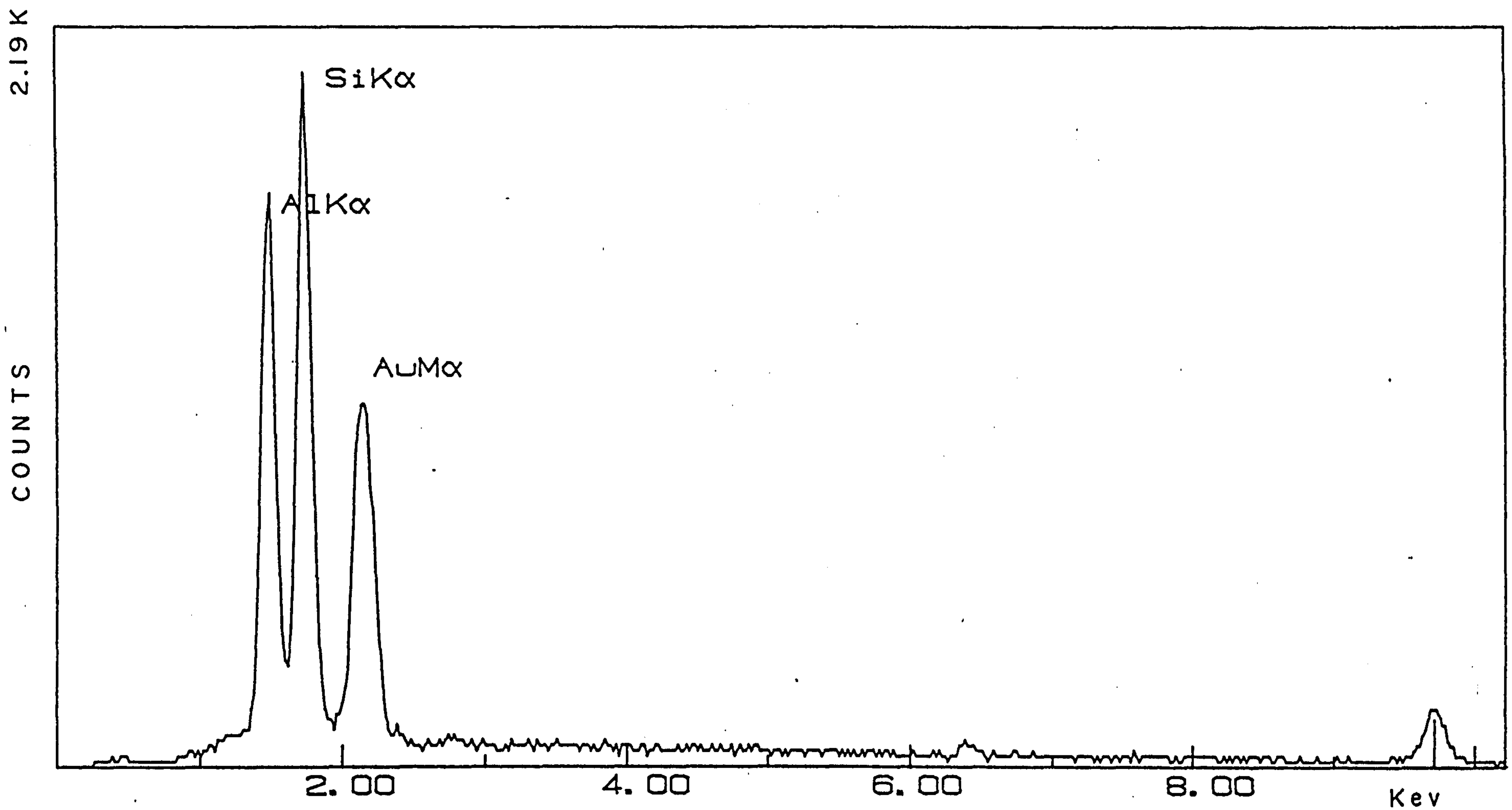
Analysis 3. GSQ Roma 8/46, Skeletal feldspar, Hutton Sst.

```
---> ? ROMA8/46 SKEL. FSPAR
ANAL. 193    PT. 1    29-01-1988  11:02:07    8 OXS. CO-ORDS 56821  47838  3745
SiO2         69.81   3.0249
Al2O3        19.26   0.9837
FeO           0.00   0.0000
MgO           0.00   0.0000
CaO           0.00   0.0000
Na2O         11.30   0.9490
K2O           0.00   0.0000
            100.37   4.9576
3658  3458 *   0.0 *   0.0    0.0    0.0 *   0.0 100.0   0.0
```

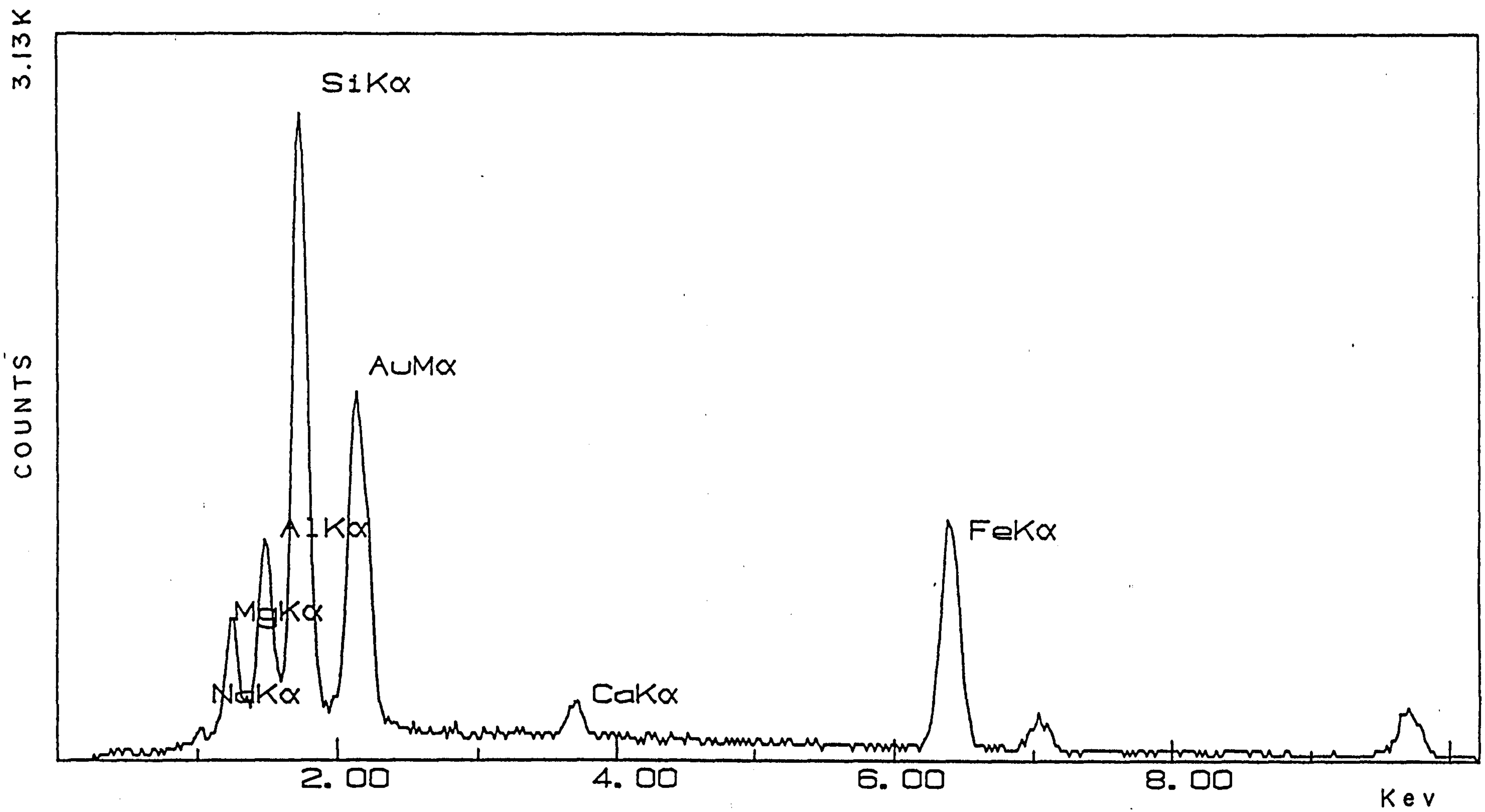
Analysis 4. GSQ Chnichilla 4/24, Skeletal feldspar, Hutton Sst.

```
---> ? CHIN4/24 HUTTON SKEL. FSPAR
ANAL. 276   PT. 1   03-02-1988  20:06:28   6 OXS. CO-ORDS 35714  55057  36602
SiO2        68.16   2.2425
Al2O3       19.52   0.7567
FeO          0.00   0.0000
MnO          0.00   0.0000
MgO          0.00   0.0000
CaO          0.00   0.0000
Na2O        11.89   0.7583
K2O          0.04   0.0015
            99.60   3.7590
4313  3836 *   0.0 *   0.0    0.0    0.0 *   0.0  99.8   0.2
```

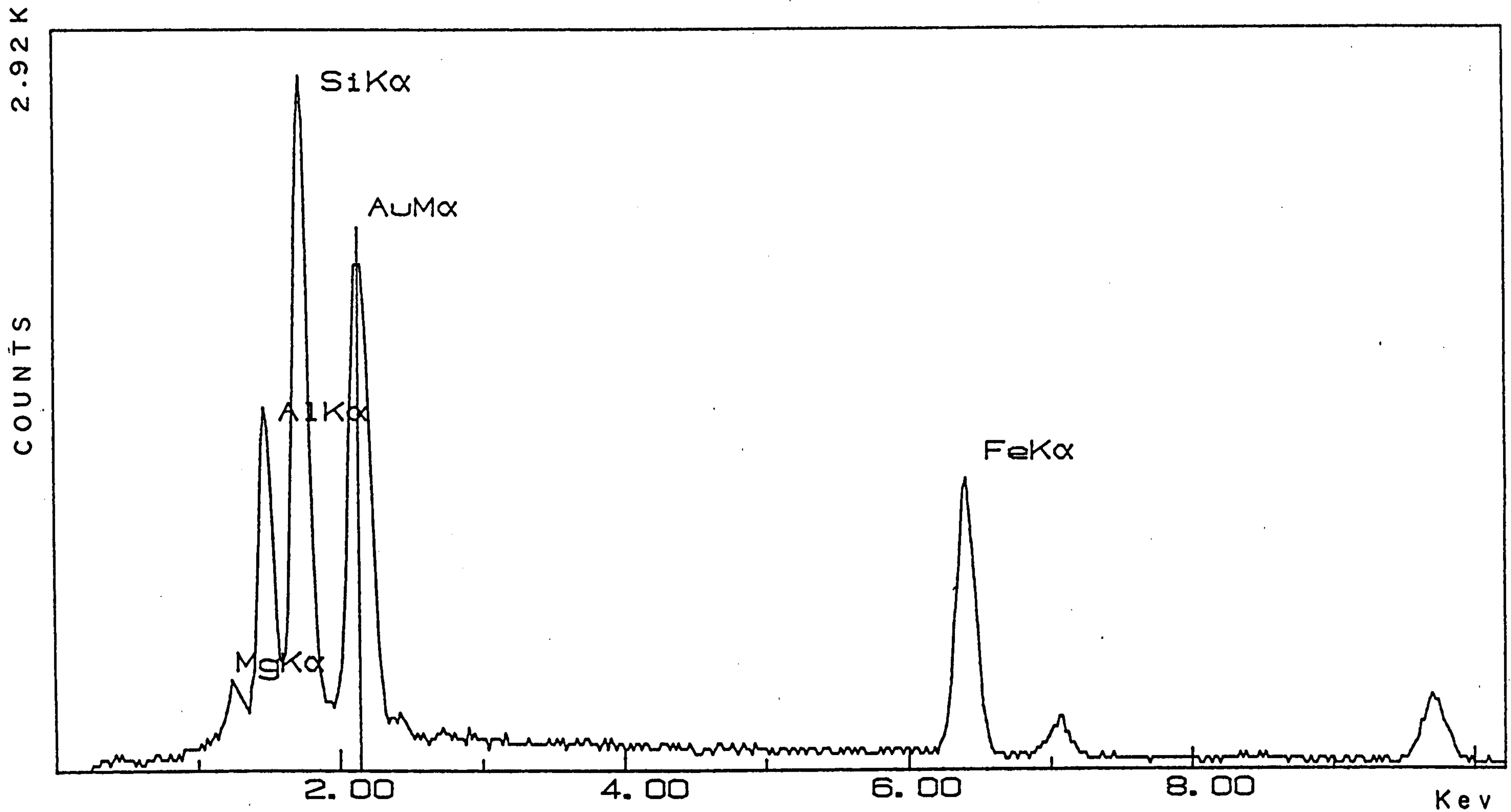
## APPENDIX 2.2. ENERGY DISPERSIVE X-RAY (EDX) DIFFRACTOGRAMS OF SOME AUTHIGENIC MINERAL SPECIES



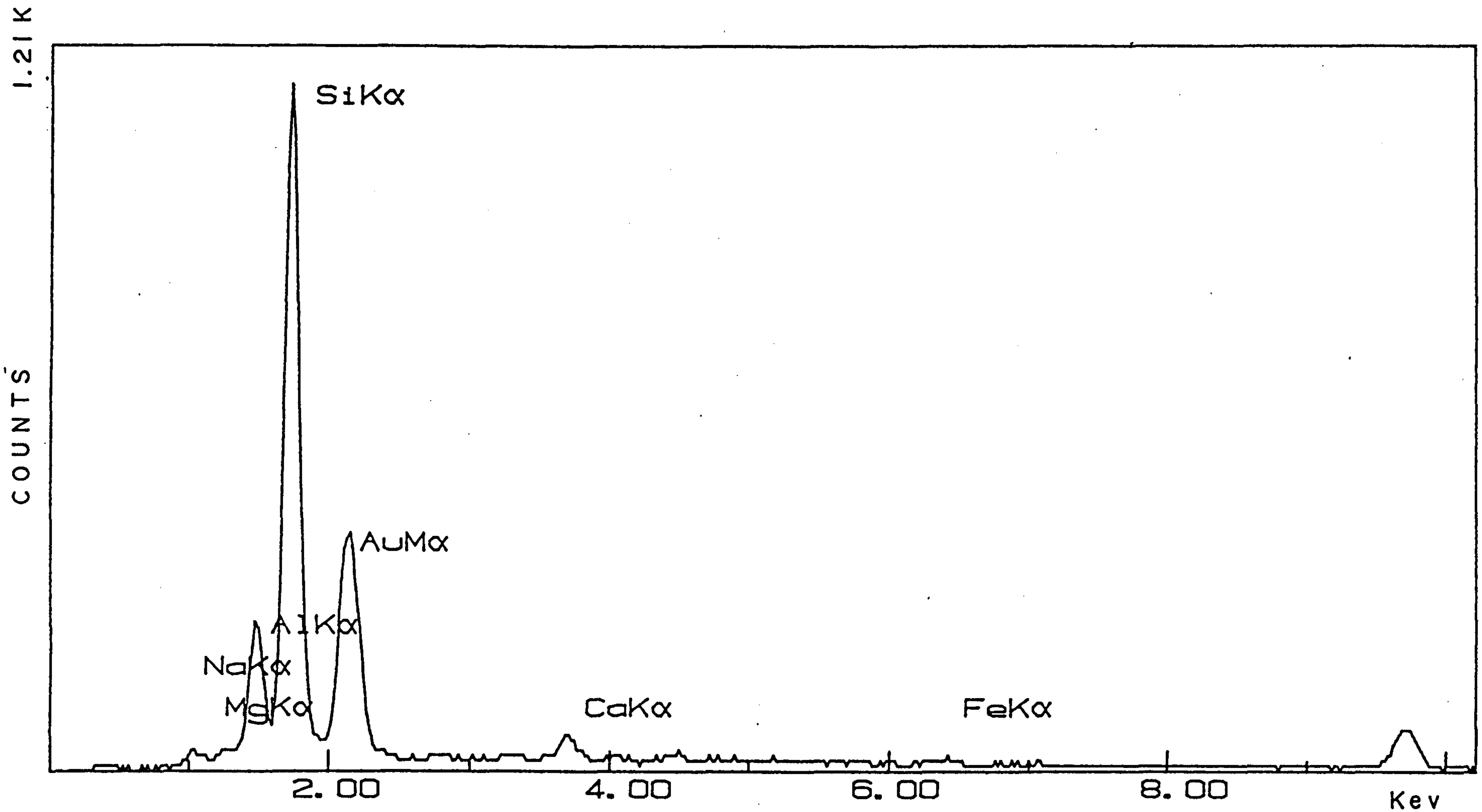

Appendix 2.2.1. EDX diffractogram of authigenic pore filling coarse-grained kaolinite. Gubberamunda Sandstone, depth - 324 m, GSQ Roma 8/21.



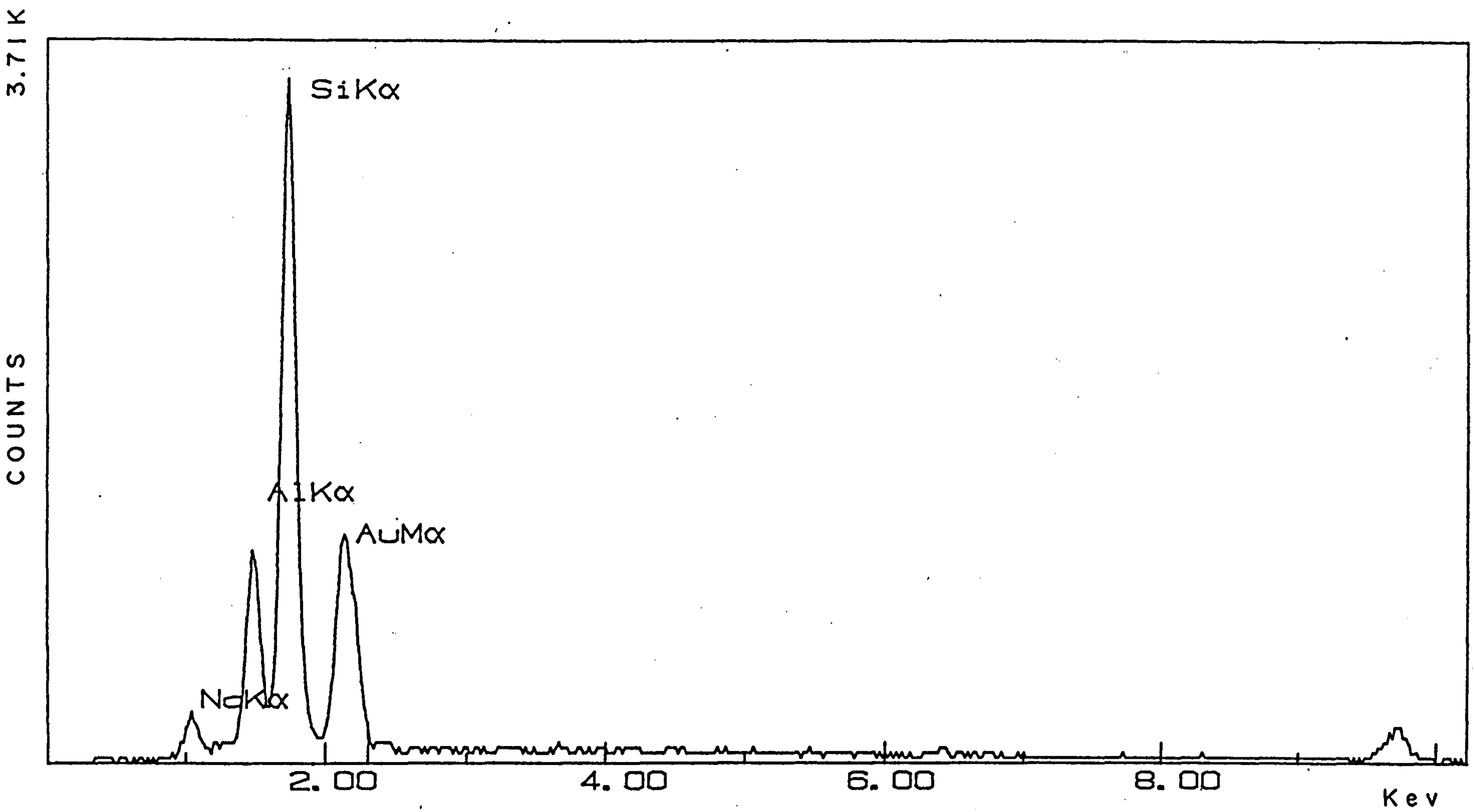

Appendix 2.2.2. EDX diffractogram of authigenic pore-lining smectite (nontronite). Griman Creek Formation, depth - 147 m, GSQ Surat 3/11. Note the distinctive Fe peak.




Appendix 2.2.3. EDX diffractogram of grain-coating authigenic chlorite. Hutton Sandstone, depth - 783 m, GSQ Roma 8/52.




Appendix 2.2.4. EDX diffractogram of pore-filling authigenic heulandite. Griman Creek Formation, depth - 295 m, GSQ Surat 3/24.

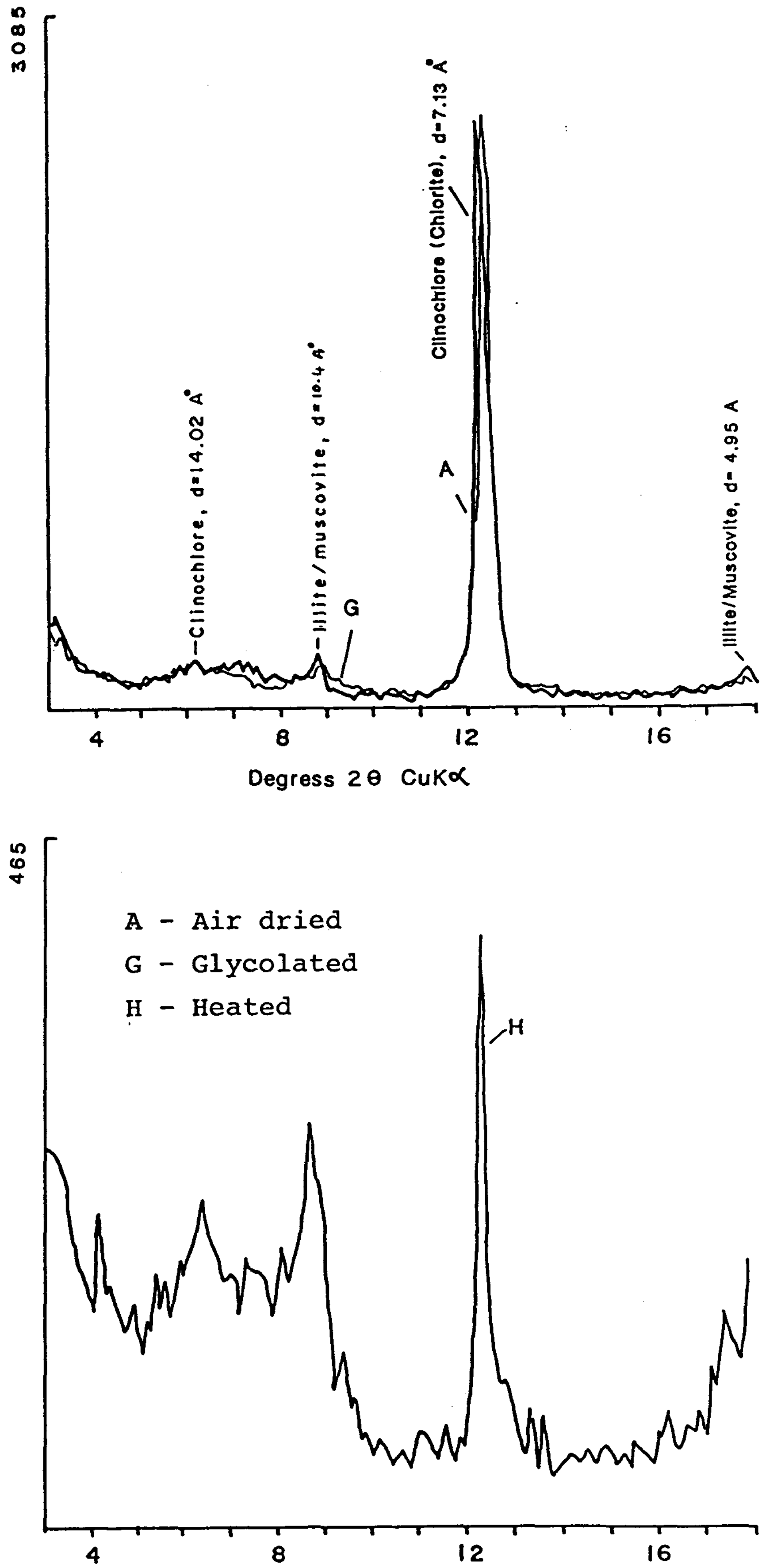



Appendix 2.2.5. EDX diffractogram of authigenic cockscomb skeletal feldspar. Gubberamunda Sandstone, depth - 324 m, GSQ Roma 8/21. Note the pure albitic composition and absence of any Ca and K peaks.

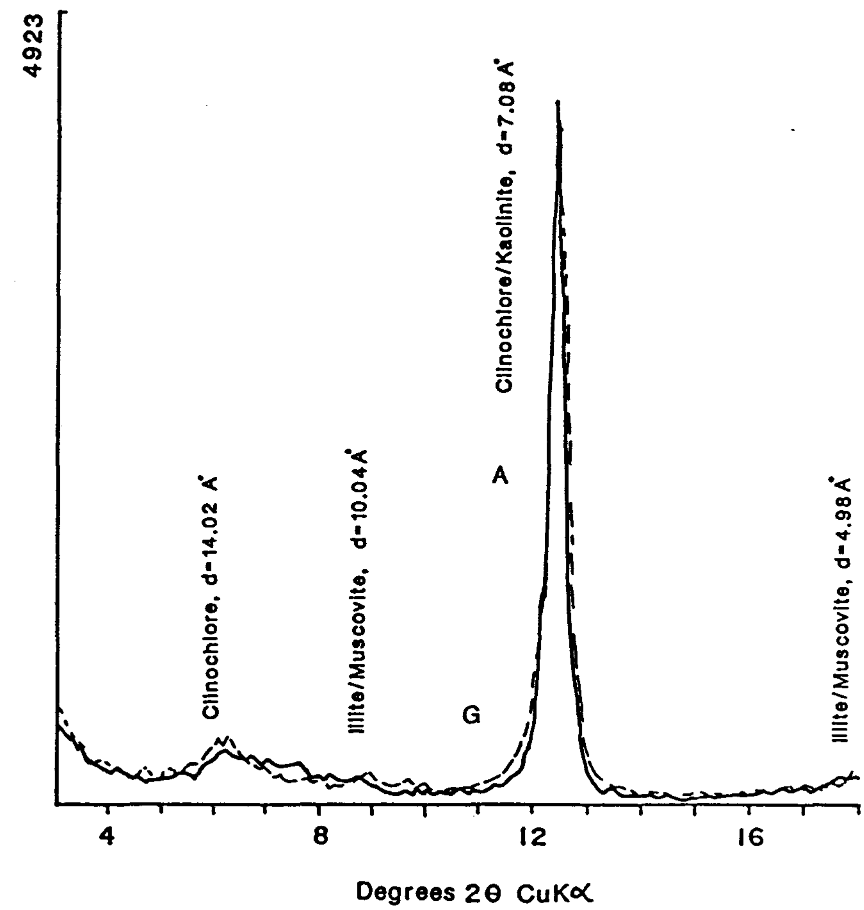
## APPENDIX 2.3.

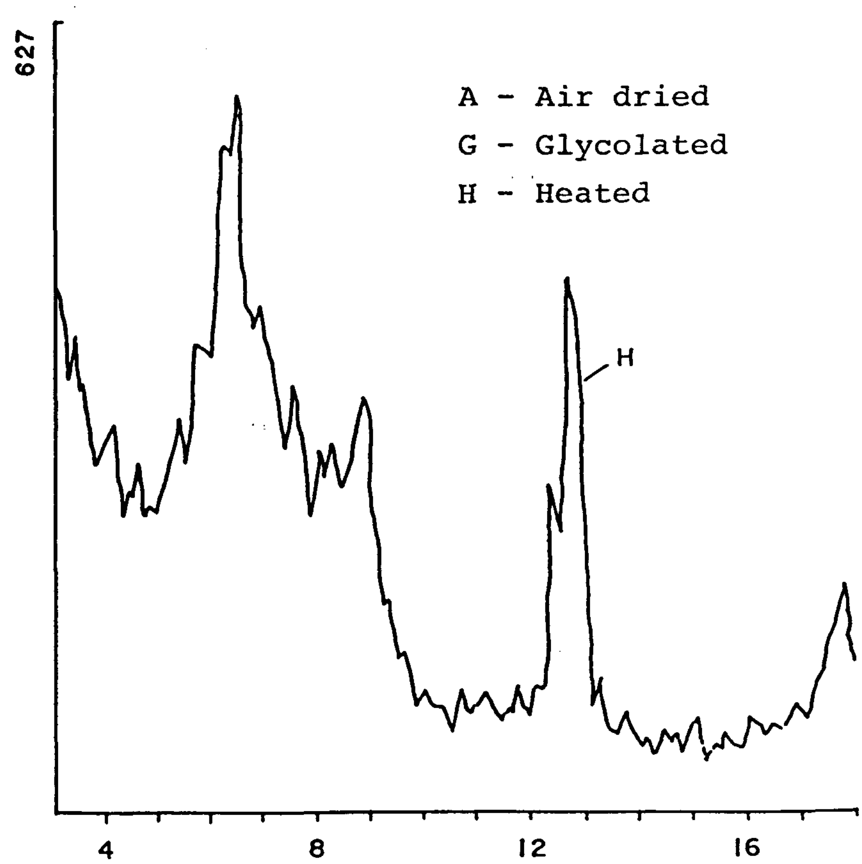
## X-RAY DIFFRACTOGRAMS OF SELECTED SAMPLES
(less than 2 um fractions)

Appendix 2.3.1. X-ray diffractogram of Hutton Sandstone, depth-726 m, GSQ Mitchell 2/47.

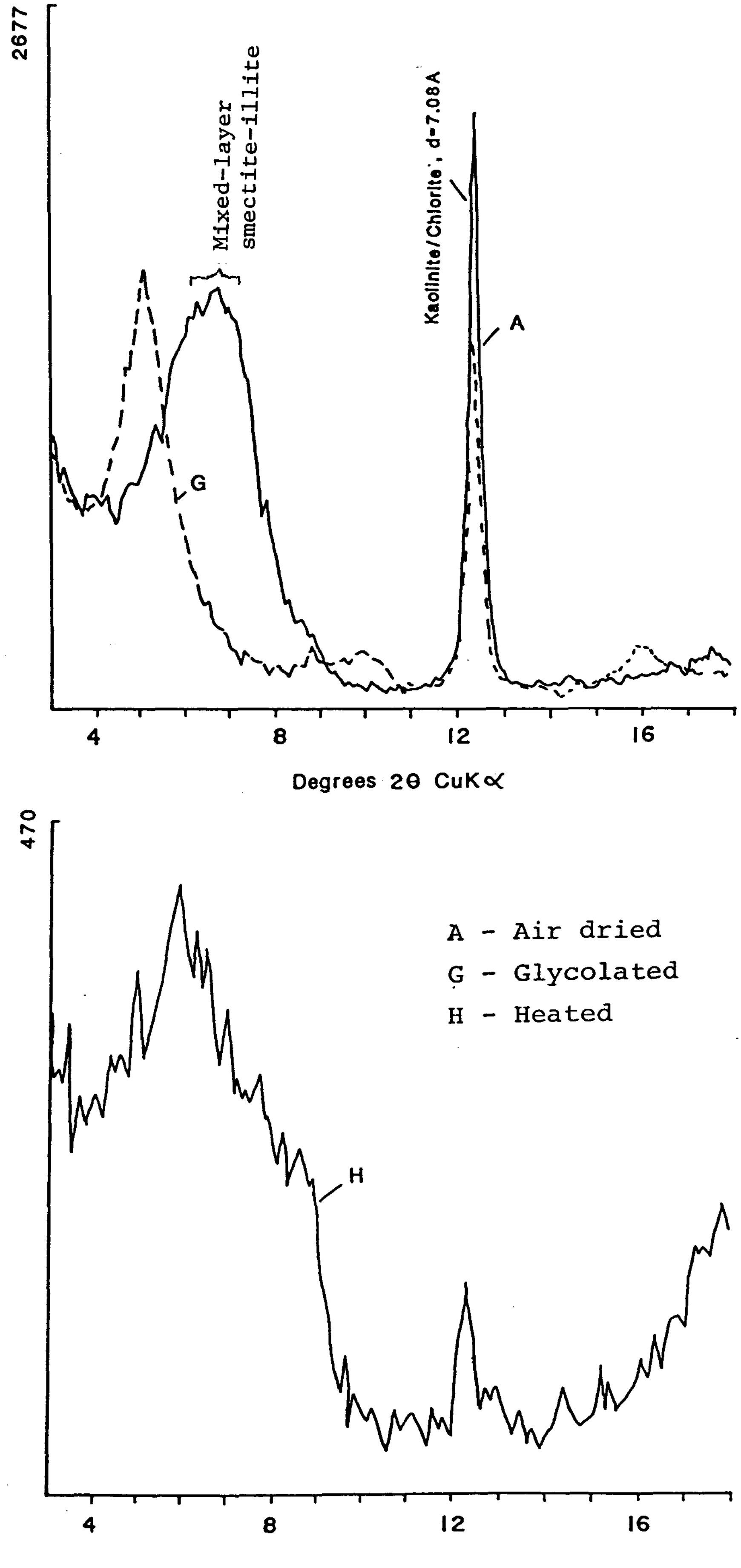


Appendix 2.3.2. X-ray diffractogram of Hutton Sst., depth - 783 m, GSQ Roma 8/52.

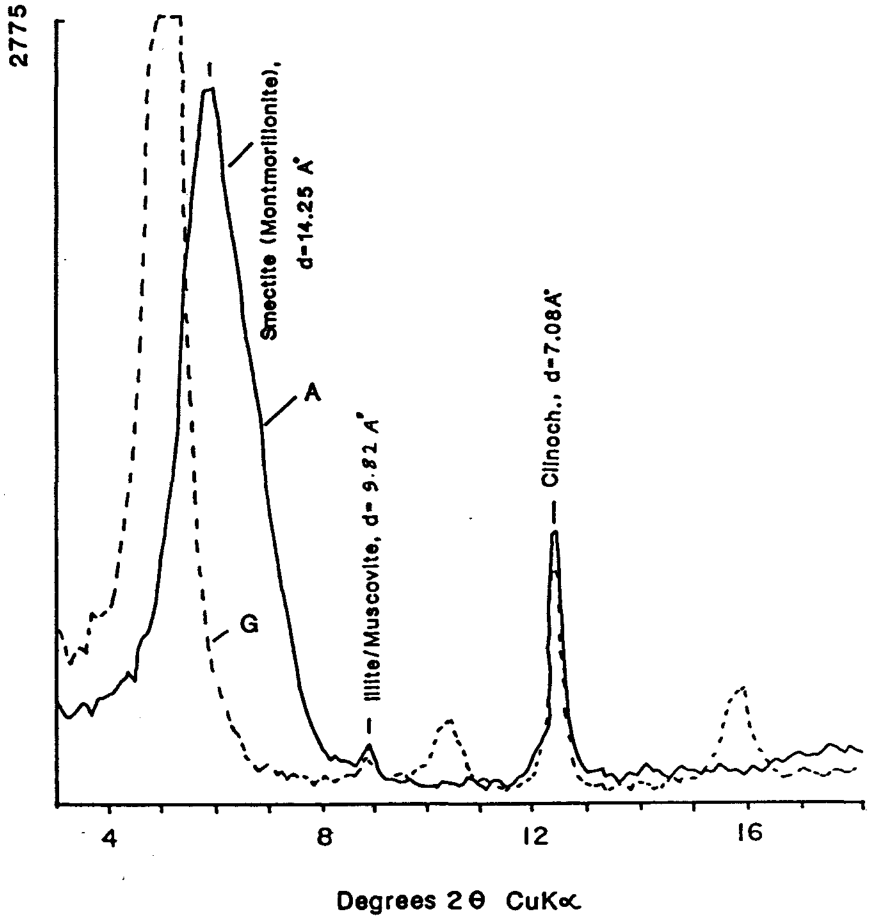


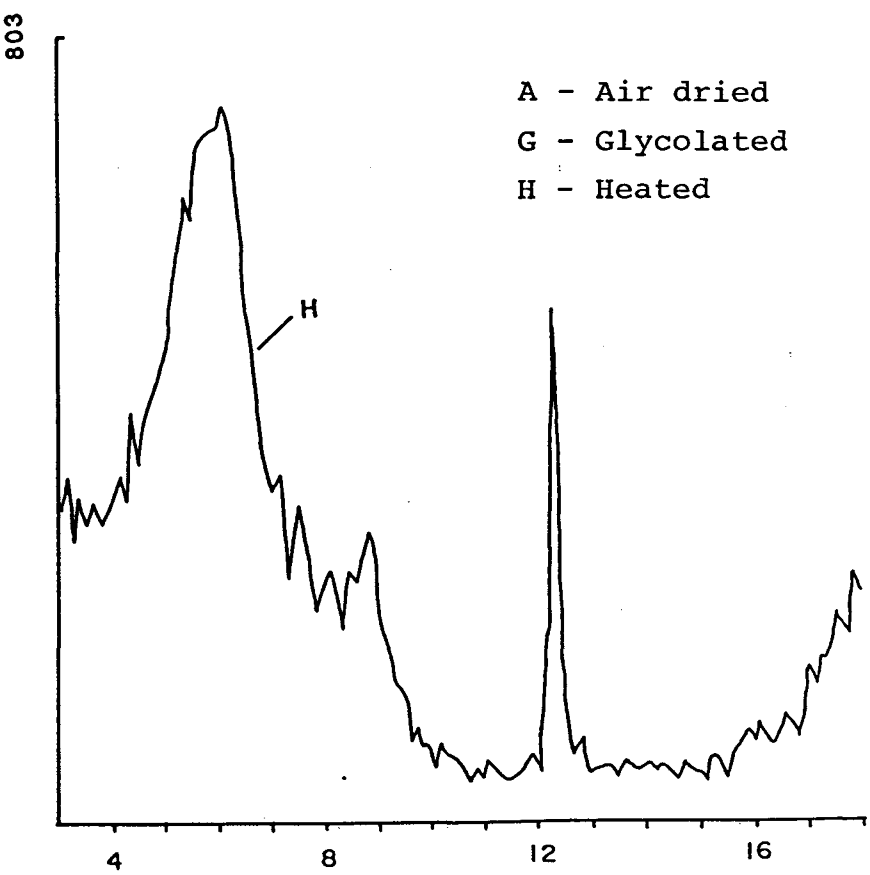



Appendix 2.3.3. X-ray diffractogram of Evergreen Fm., depth - 1065 m, GSQ Chinchilla 4/37.

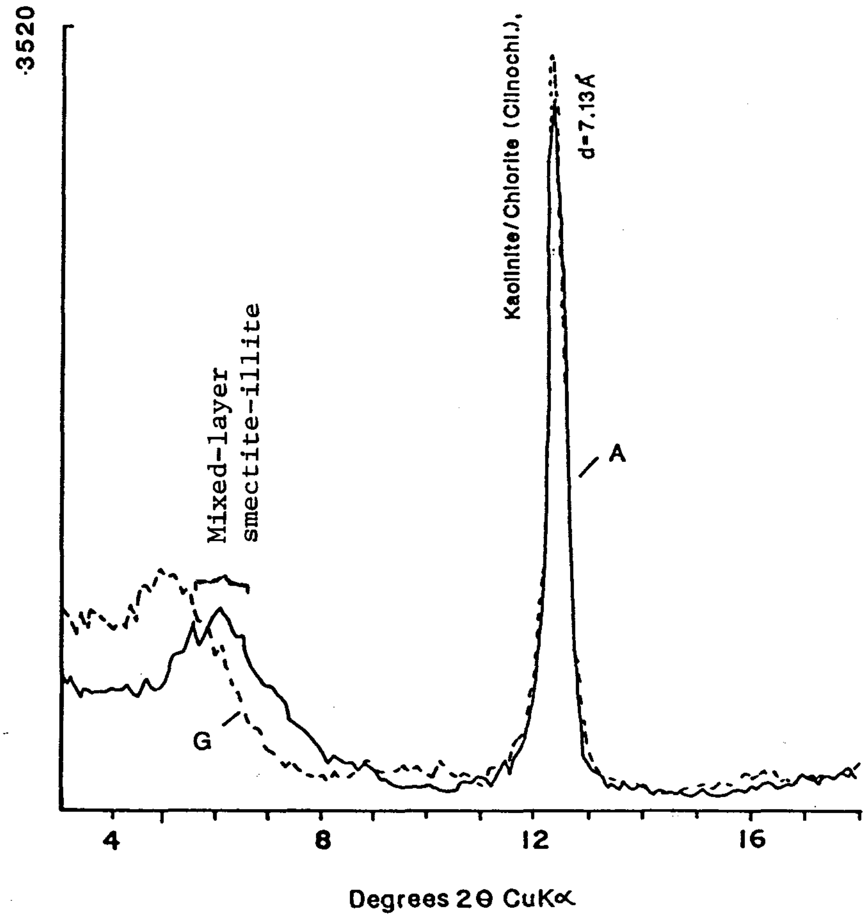


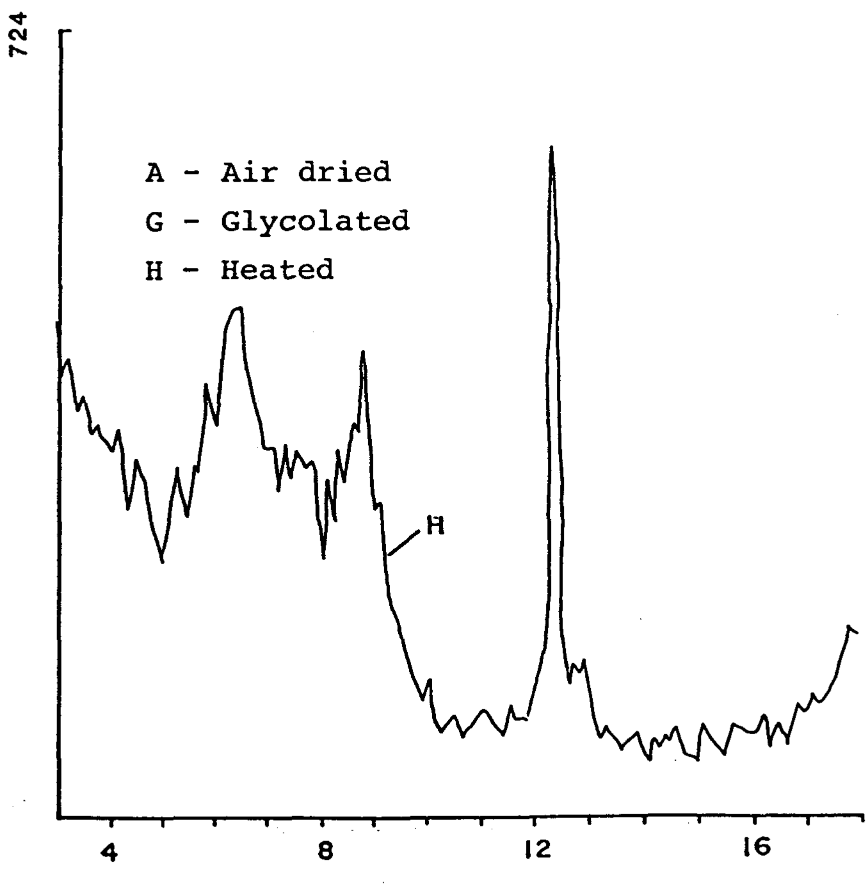
Appendix 2.3.4. X-ray diffractogram of Walloon Coal Measures, depth - 681 m, GSQ Chinchilla 4/20.



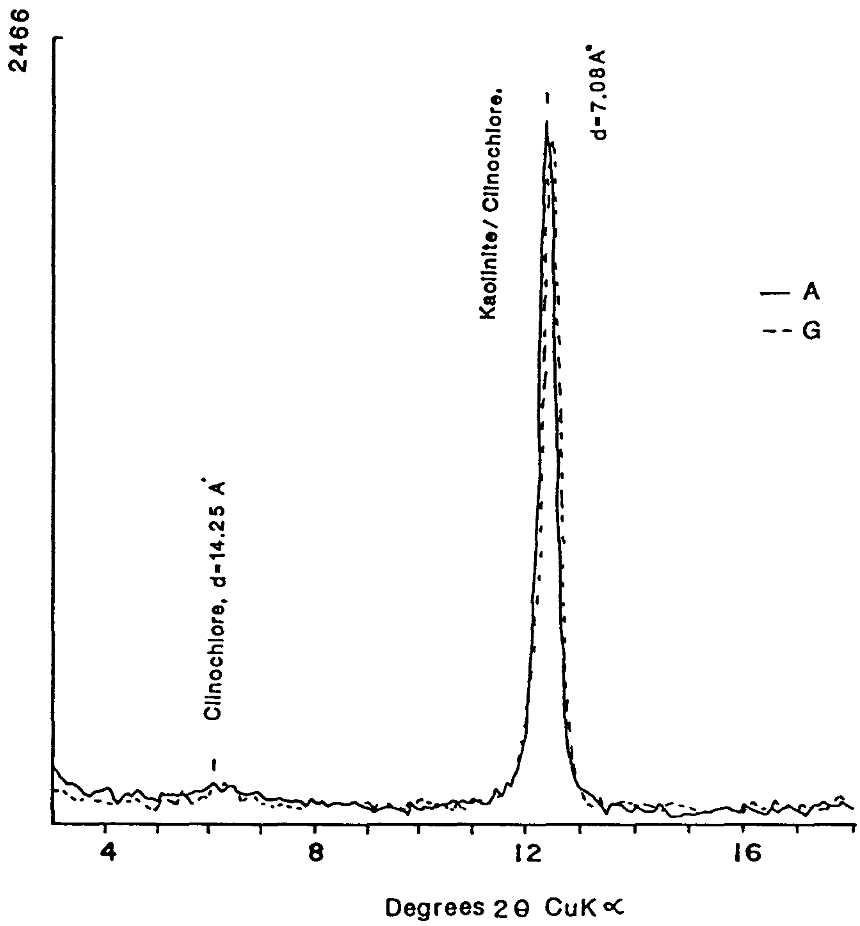



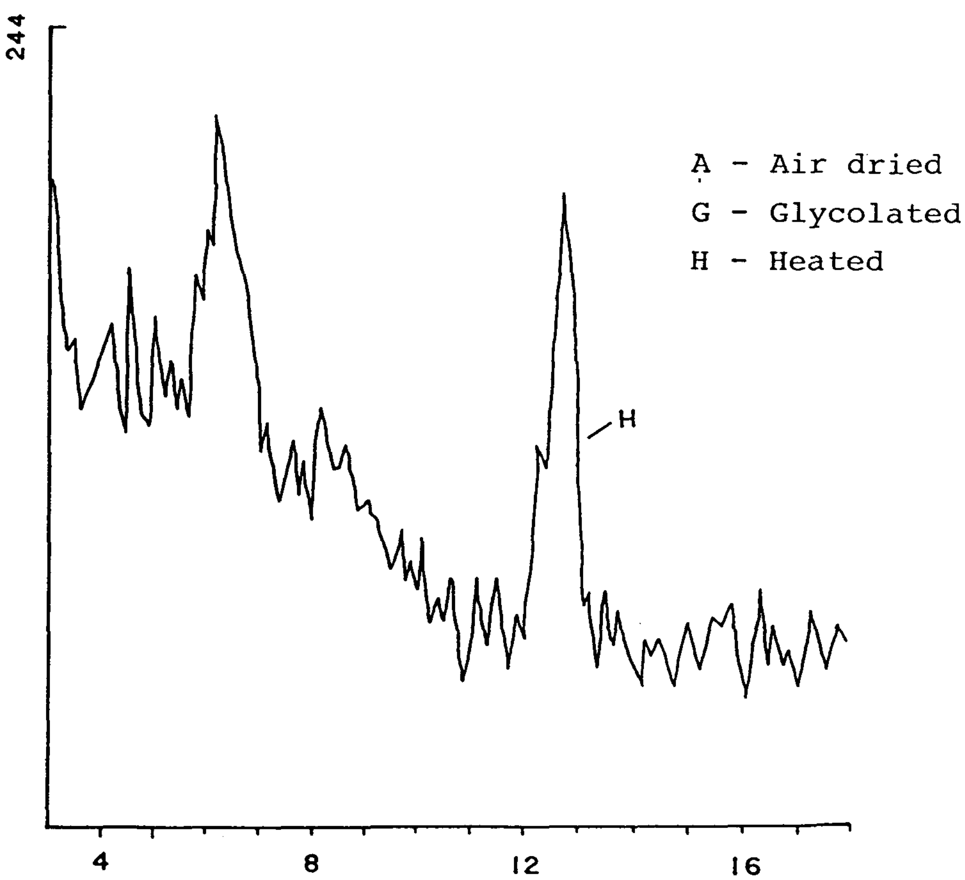
Appendix 2.3.5. X-ray diffractogram of Gubberamunda Sandstone, depth - 324 m, GSQ Roma 8/21.



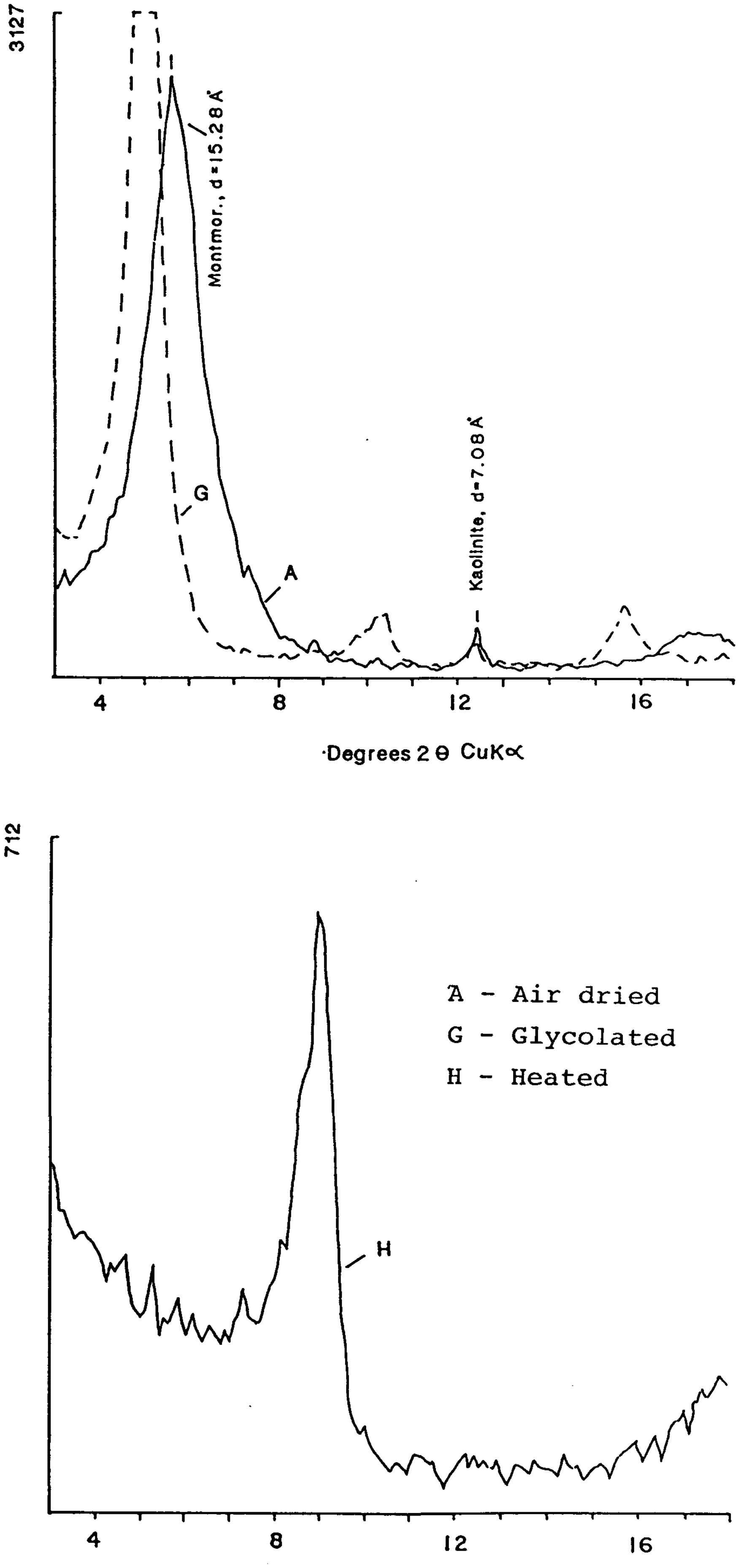



Appendix 2.3.6. X-ray diffractogram of Gubberamunda Sandstone, depth - 365 m, GSQ Roma 8/25.

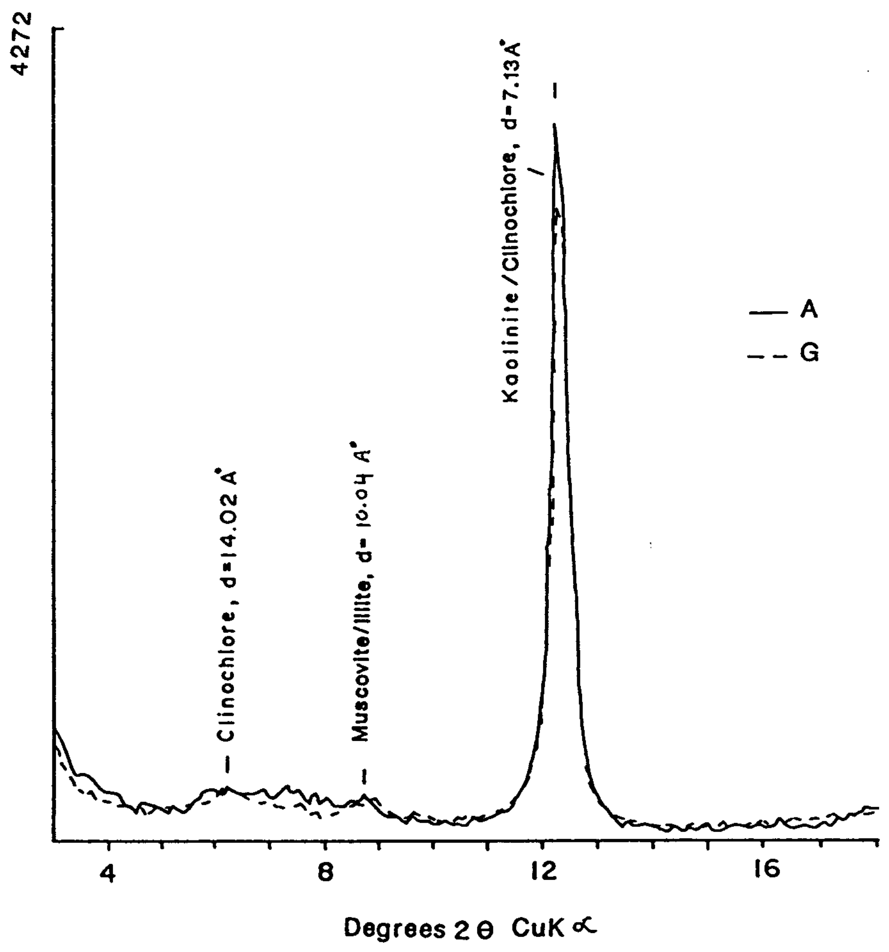


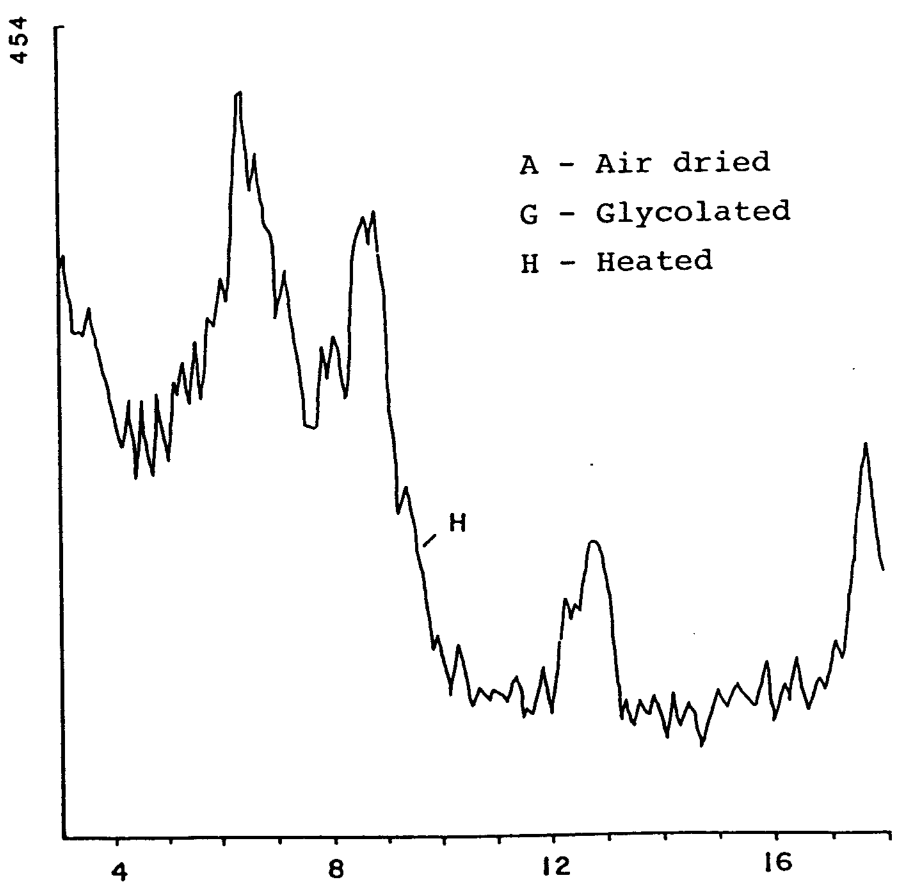



Appendix 2.3.7. X-ray diffractogram of Gubberamunda Sst., depth - 66m, GSQ Chinchilla 4/3.

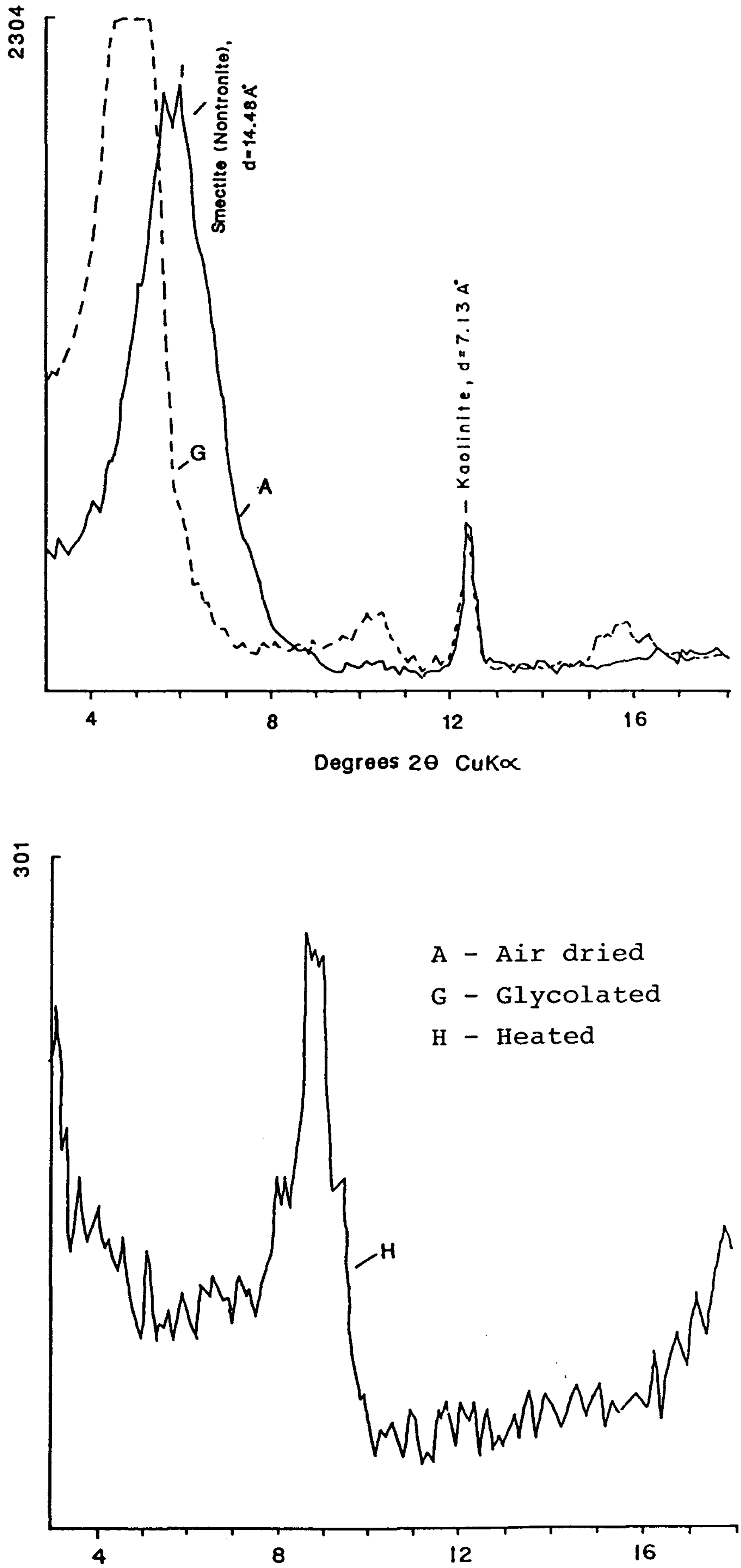


Appendix 2.3.8. X-ray diffractogram of Mooga Sandstone, depth - 136 m, GSQ Roma 8/5.

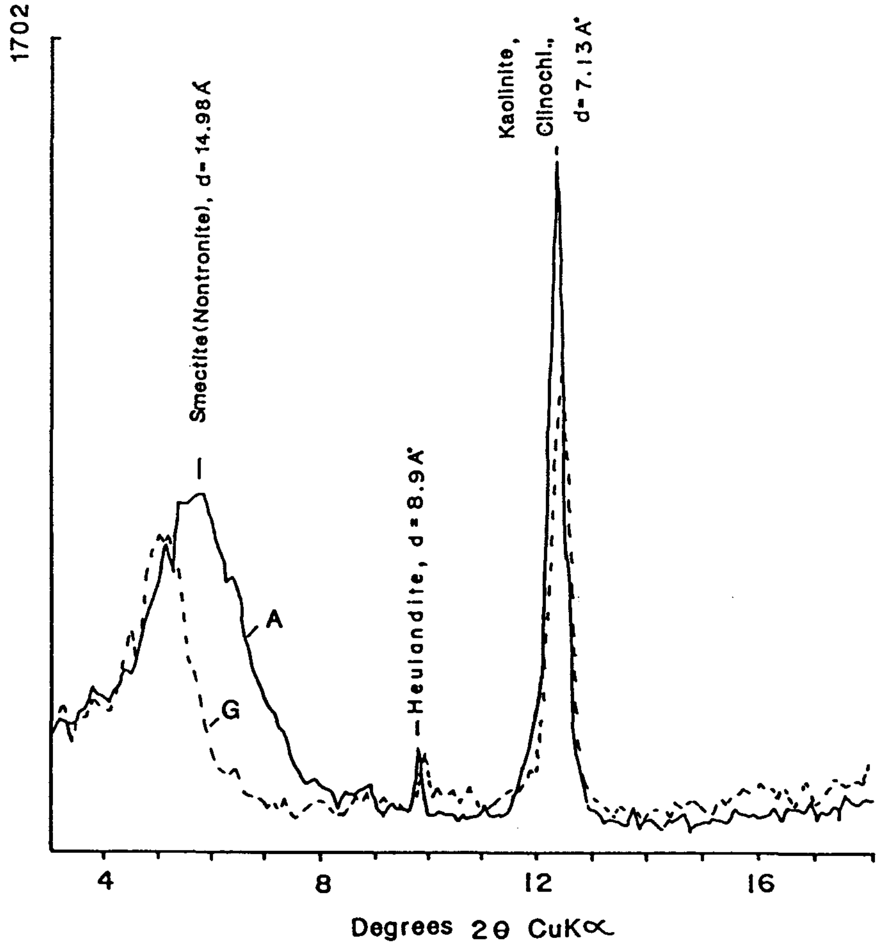


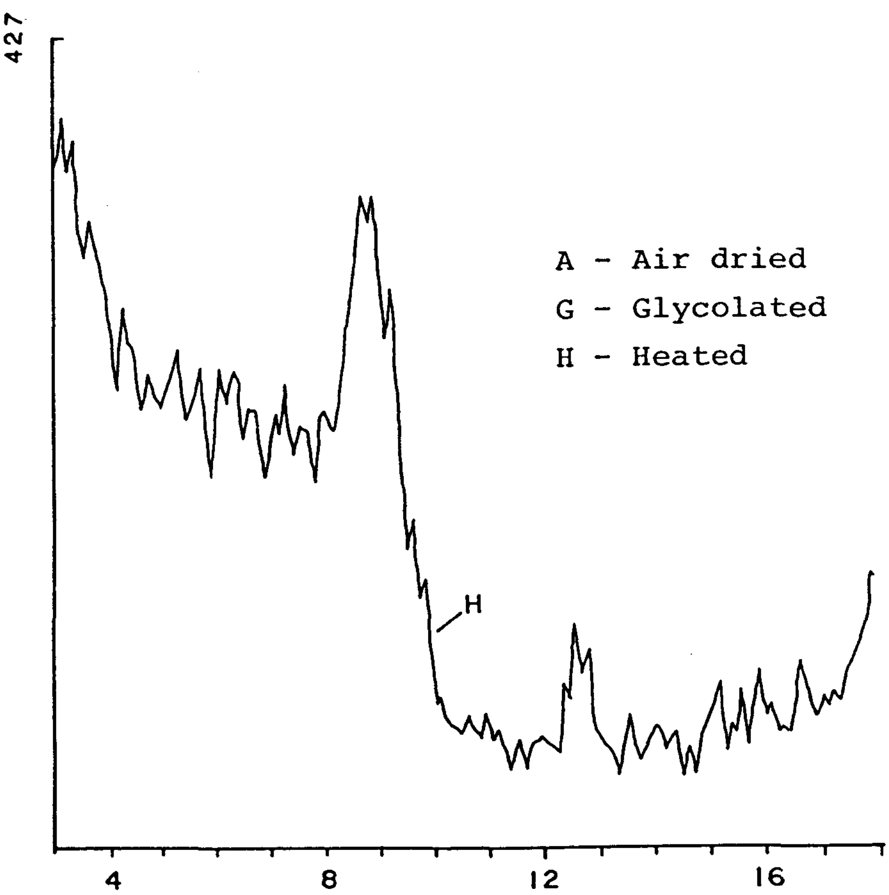



Appendix 2.3.9. X-ray diffractogram of Wallumbilla Formation, depth - 438 m, GSQ Surat 3/33.



Appendix 2.3.10. X-ray diffractogram of Griman Creek Formation, depth - 295 m, GSQ Surat 3/24.




A - Air dried

G - Glycolated

H - Heated

## APPENDIX 2.4. ELECTRON MICROPROBE ANALYSES OF AUTHIGENIC ZEOLITES

Appendix 2.4. Electron microprobe analyses of authigenic zeolites. Multiple analyses on a single sample represent analyses done on different grains within the one thin-section.

Analysis 1. GSQ Surat 3/10, Griman Creek Formation.

```
---> ? SURAT3/10
ANAL. 205    PT. 1    29-01-1988  15:06:04     8 OXS. CO-ORDS 42452  51375  35388
SiO2         49.26    2.5470
Al2O3        23.60    1.4377
FeO           0.32    0.0140
MgO           0.05    0.0040
CaO           8.48    0.4699
Na2O          4.94    0.4956
K2O           0.42    0.0275
             87.08    4.9955
3756   3275 *  22.2 *  96.3   0.8    2.9 *  47.3  49.9   2.8
```

Analysis 2. GSQ Surat 3/10, Griman Creek Formation.

```
---> ? SURAT3/10
ANAL. 206    PT. 1    29-01-1988  15:17:37     8 OXS. CO-ORDS 43076  57386  36499
SiO2         65.77    3.2213
Al2O3        14.82    0.8557
FeO           0.16    0.0064
MgO           0.77    0.0562
CaO           3.11    0.1632
Na2O          0.60    0.0570
K2O           0.62    0.0390
             85.85    4.3987
3757   3012 *  89.8 *  72.3  24.9    2.8 *  63.0  22.0  15.0
```

Analysis 3. GSQ Surat 3/14, Griman Creek Formation.

```
---> ? SURAT3/14
ANAL. 203   PT. 1   29-01-1988  14:14:43    8 OXS. CO-ORDS 50791  44048  34234
SiO2        60.85   3.1320
Al2O3       15.90   0.9645
FeO          0.10   0.0042
MgO          0.83   0.0638
CaO          3.32   0.1833
Na2O         0.45   0.0446
K2O          0.47   0.0309
            81.92   4.4233
3688   2716 *  93.8 *  72.9  25.4   1.7 *  70.8  17.2  11.9
```

Analysis 4. GSQ Surat 3/14, Griman Creek Formation.

```
---> ? SURAT3/14
ANAL. 202   PT. 1   29-01-1988  13:59:50    8 OXS. CO-ORDS 37015  45907  34696
SiO2        67.03   3.1616
Al2O3       16.72   0.9294
FeO          0.14   0.0055
MgO          1.01   0.0713
CaO          3.44   0.1739
Na2O         0.36   0.0330
K2O          0.51   0.0308
            89.22   4.4055
3697   2802 *  92.8 *  69.4  28.4   2.2 *  73.2  13.9  13.0
```

Analysis 5. GSQ Surat 3/14, Griman Creek Formation.

```
---> ? SURAT3/14
ANAL. 199   PT. 1   29-01-1988  13:11:53    8 OXS. CO-ORDS 42554  51217  35018
SiO2        62.28   3.1290
Al2O3       16.03   0.9490
FeO          0.25   0.0105
MgO          0.80   0.0597
CaO          3.57   0.1921
Na2O         0.85   0.0826
K2O          0.46   0.0295
            84.24   4.4524
3711   2988 *  85.1 *  73.2  22.8   4.0 *  63.2  27.1   9.7
```

Analysis 6. GSQ Surat 3/14, Griman Creek Formation.

```
---> ? SURAT3/14
ANAL. 197   PT. 1    29-01-1988  12:35:14    8 OXS. CO-ORDS 50438  50205  34866
SiO2        60.88   3.1536
Al2O3       15.14   0.9241
FeO          0.15   0.0064
MgO          0.91   0.0706
CaO          3.00   0.1667
Na2O         0.91   0.0915
K2O          0.52   0.0342
            81.51   4.4470
3718   3236 *  91.6 *  68.4  29.0   2.6 * 57.0  31.3  11.7
```

Analysis 7. GSQ Surat 3/33, Wallumbilla Formation.

```
---> ? SURAT3/33
ANAL. 210   PT. 1    29-01-1988  17:50:50    8 OXS. CO-ORDS 43300  47897  36135
SiO2        57.29   3.0903
Al2O3       15.59   0.9907
FeO          0.00   0.0000
MgO          1.61   0.1298
CaO          2.84   0.1643
Na2O         0.32   0.0339
K2O          0.64   0.0442
            78.30   4.4532
3739   3294 * 100.0 *  55.9  44.1   0.0 * 67.8  14.0  18.2
```

Analysis 8. GSQ Surat 3/33, Wallumbilla Formation.

```
---> ? SURAT3/33
ANAL. 241   PT. 1    29-01-1988  18:00:06    8 OXS. CO-ORDS 46951  46881  36094
SiO2        63.48   3.1335
Al2O3       15.97   0.9293
FeO          0.14   0.0057
MgO          1.85   0.1363
CaO          2.68   0.1418
Na2O         0.77   0.0737
K2O          0.58   0.0363
            85.47   4.4567
3733   3428 *  96.0 *  50.0  48.0   2.0 * 56.3  29.3  14.4
```

Analysis 9. GSQ Surat 3/33, Wallumbilla Formation.

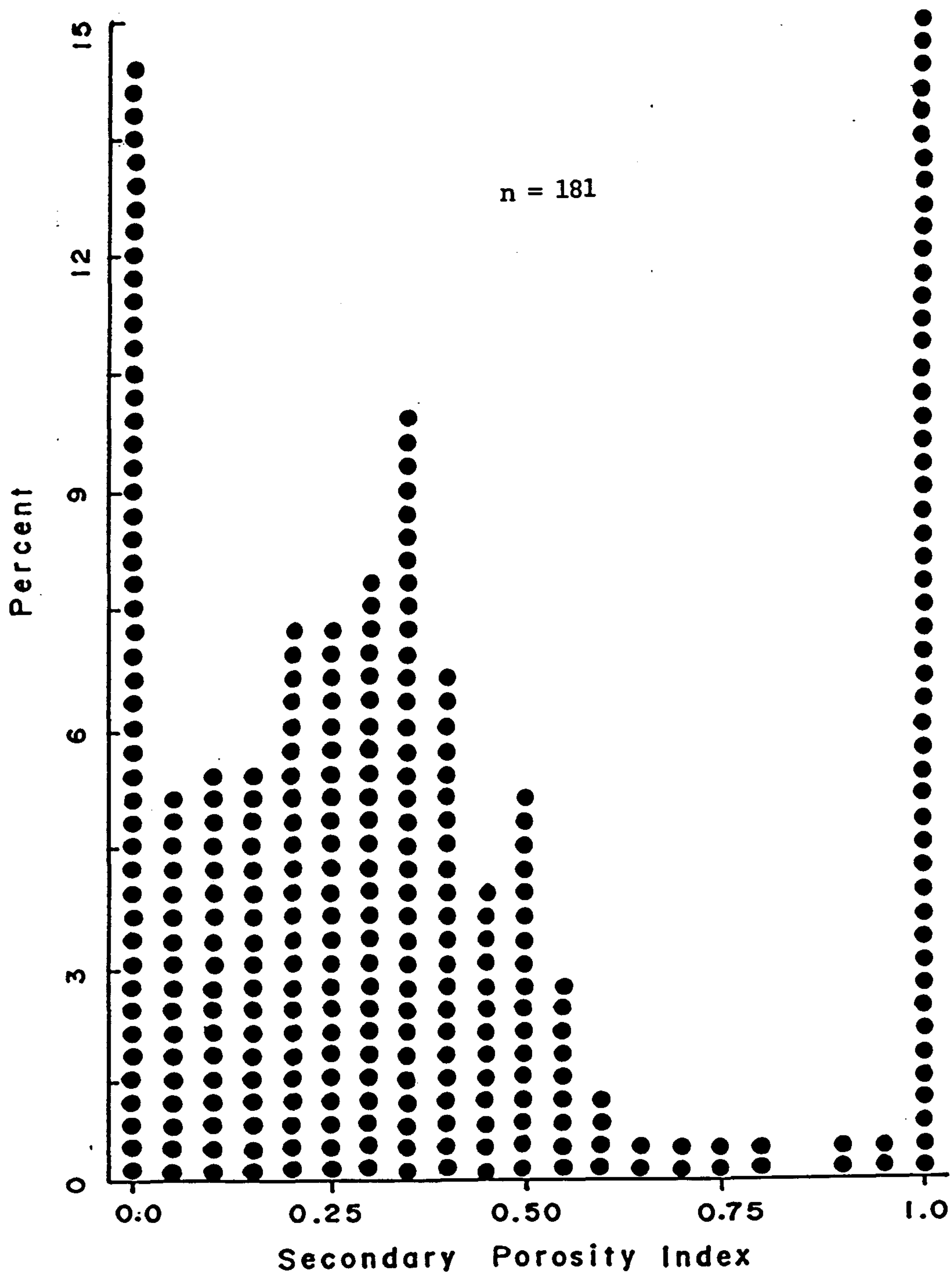
```
---> ? SURAT3/33
ANAL. 208    PT. 1   29-01-1988  17:25:33    8 OXS. CO-ORDS 45351  38081  36425
SiO2        65.72   3.1638
Al2O3       15.92   0.9034
FeO          0.18   0.0074
MgO          1.94   0.1395
CaO          2.61   0.1344
Na2O         0.41   0.0384
K2O          0.54   0.0332
            87.34   4.4202
3747  2996 *  94.9 *  47.8  49.6   2.6 *  65.2  18.6  16.1
```

Analysis 10. GSQ Surat 3/33, Wallumbilla Formation.

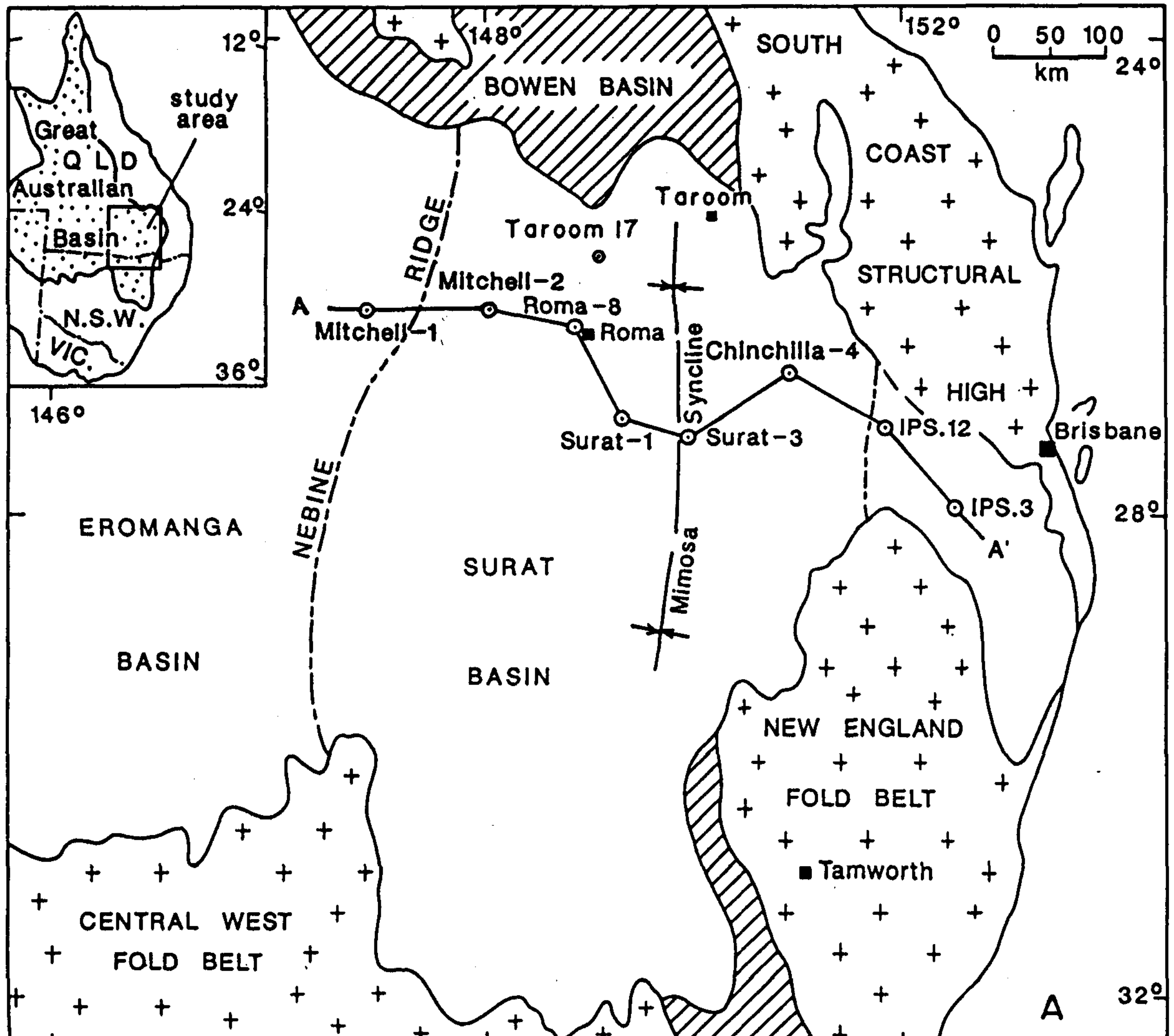
```
---> ? SURAT3/33
ANAL. 209    PT. 1   29-01-1988  17:36:36    8 OXS. CO-ORDS 42630  45686  36330
SiO2        60.36   3.1346
Al2O3       15.27   0.9344
FeO          0.19   0.0081
MgO          1.84   0.1425
CaO          2.57   0.1429
Na2O         0.42   0.0419
K2O          0.44   0.0293
            81.08   4.4337
3741  3362 *  94.6 *  48.7  48.5   2.8 *  66.7  19.6  13.7
```

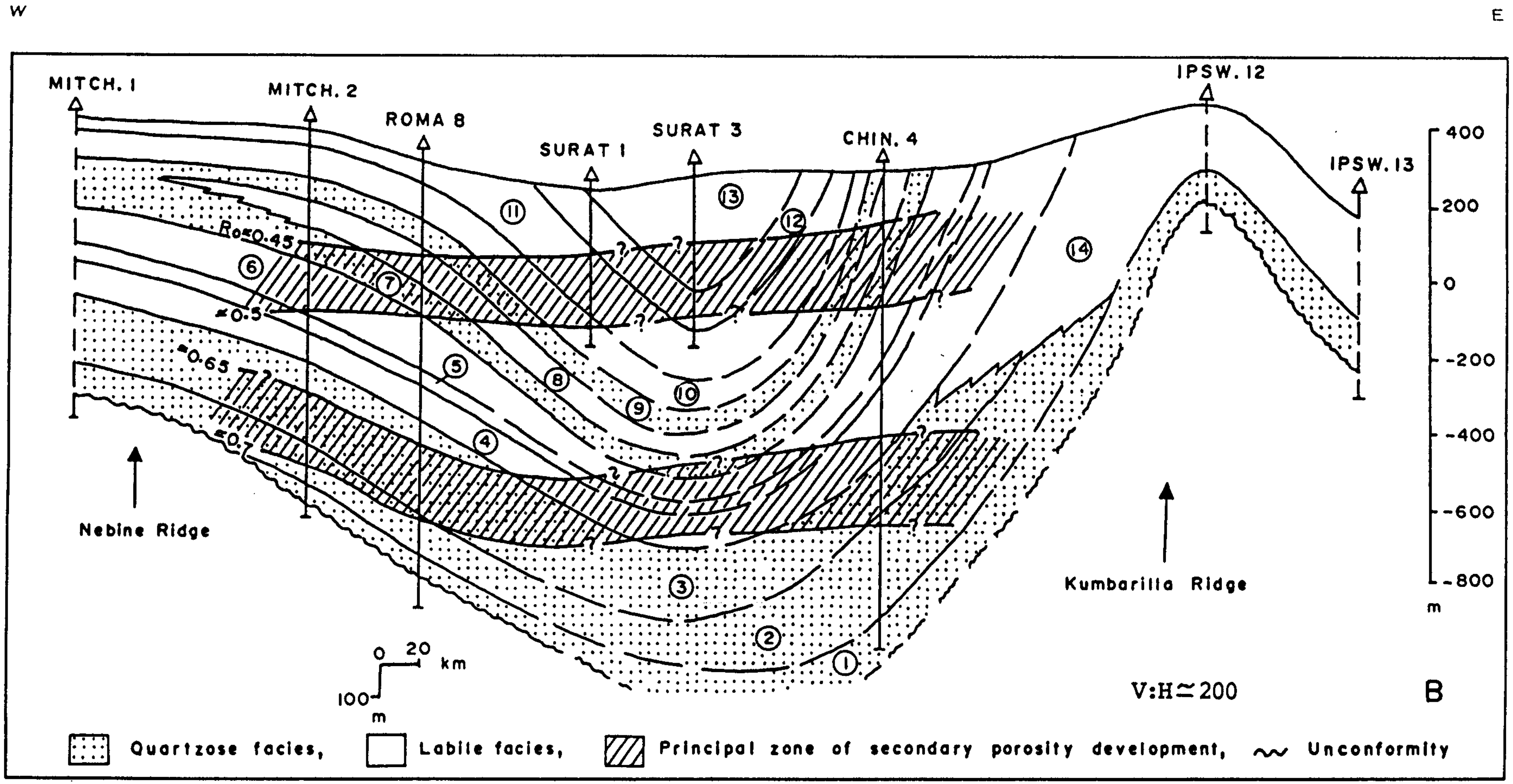
APPENDIX 2.5.1. HISTOGRAM OF SECONDARY POROSITY INDEX (SPI) DISTRIBUTION

Appendix 2.5.1. Histogram of Secondary Porosity Index (SPI) distribution in the Surat Basin succession. All formations having more than zero thin-section porosity (n = 181) have been plotted. As can be seen from the histogram, 14.4% of all cases have 100% secondary porosity (SPI = 1), and 13.3% of all cases have 0% secondary porosity. All porosity in the latter 13.3% cases are primary in origin.



APPENDIX 2.5.2. A WEST-EAST CROSS-SECTION OF THE SURAT BASIN SHOWING THE PRINCIPAL ZONES OF SECONDARY POROSITY DEVELOPMENT


12°
24°
36°
146°
study area
Great
Q L D
Australian
Basin
N.S.W.
VIC.
148°
152°
0 50 100
km
24°
28°
32°
BOWEN BASIN
SOUTH
COAST
STRUCTURAL
HIGH
Taroom
Taroom 17
RIDGE
NEBINE
Mitchell-2
A
Mitchell-1
Roma-8
Roma
Syncline
Mimosa
Chinchilla-4
IPS.12
Brisbane
Surat-1
Surat-3
IPS.3
A'
EROMANGA
BASIN
SURAT
BASIN
NEW ENGLAND
FOLD BELT
Tamworth
CENTRAL WEST
FOLD BELT
A




Appendix 2.5.2. A west-east cross-section (B) of the Surat Basin (section AA' in A) showing the major petrofacies and the stratigraphically discordant principal zones of secondary porosity development. The depth ranges bounding these zones are calculated using the regression equations of the vitrinite reflectance (Ro) - depth relationships separately in each of wells GSQ Mitchell 2, GSQ Roma 8, and GSQ Chinchilla 4 (cf. Appendices 2.8.2 - 2.8.4). No vitrinite reflectance data is available for GSQ Surat 1 and Surat 3 nor for other GSQ wells in their vicinity. The depth ranges in GSQ Surat 1 and Surat 3 were calculated using the average basin-wide Ro - depth relationship derived from four wells (e.g., GSQ Mitchell 2, GSQ Roma 8, GSQ Chinchilla 4, and GSQ Taroom 17 taken together; cf. Appendix 2.8.1). Therefore the Ro-defined zones depicted here are relatively unconstrained in this central part of the basin. Dashed vertical lines represent wells not sampled in this study. Circled numbers indicate formations: 1 - Precipice Sandstone; 2 - Evergreen Formation; 3 - Hutton Sandstone; 4 - Walloon Coal Measures; 5 - Springbok Sandstone; 6 - Westbourne Formation; 7 - Gubberamunda Sandstone; 8 - Orallo Formation; 9 - Mooga Sandstone; 10 - Bungil Formation; 11 - Wallumbilla Formaton; 12 - Surat Siltstone; 13 - Griman Creek Formation, 14 - Marburg Fm.

# APPENDIX 2.6. ELECTRON MICROPROBE ANALYSES OF AUTHIGENIC KAOLINITE

Appendix 2.6. Electron microprobe analyses of authigenic kaolinite. Multiple analyses on a singlè sample represent analyses done on different grains within the one thin-section.

Analysis 1. GSQ Mitchell 2/57, Hutton Sandstone.

```
 ? AGAIN/2 , coarse-gr. fan-shaped kaolinite.
ANAL. 191   PT. 1   28-01-1988  18:09:37    8 OXS. CO-ORDS 47084  40131  35458
SiO2        44.47   2.2722
Al2O3       36.89   2.2209
FeO          2.03   0.0868
MgO          0.29   0.0218
CaO          0.00   0.0000
Na2O         0.06   0.0059
K2O          0.38   0.0250
            84.12   4.6325
3679  3286 *  20.1 *   0.0  20.1  79.9 *   0.0  19.2  80.8
```

Analysis 2. GSQ Mitchell 2/57, Hutton Sandstone.

```
? MCL2/57 KAOL. FAN WORK
ANAL. 190   PT. 1   28-01-1988  18:04:54    8 OXS. CO-ORDS 46995  39941  35550
SiO2        44.34   2.2975
Al2O3       35.78   2.1846
FeO          2.18   0.0946
MgO          0.30   0.0228
CaO          0.08   0.0044
Na2O         0.05   0.0048
K2O          0.10   0.0069
            82.83   4.6157
3681  3338 *  19.4 *   3.6  18.7  77.7 *  27.2  30.0  42.8
```

Analysis 3. GSQ Roma 8/3, Bungil Formation.

```
---> ? AGAIN/3 , fine-gr. kaolinite.
ANAL. 361   PT. 1   05-02-1988  14:26:26    6 OXS. CO-ORDS 40154  49445  36373
SiO2        44.53   1.7452
Al2O3       35.87   1.6565
FeO          0.26   0.0085
MgO          0.11   0.0066
CaO          0.15   0.0065
Na2O         0.04   0.0032
K2O          0.06   0.0029
            81.03   3.4293
4487  3974 *  43.5 *  30.0  30.5  39.5 *  51.4  25.7  22.9
```

Analysis 4. GSQ Roma 8/3, Bungil Formation.

```
---> ? ROMA8/3 BUNGIL PORE-FILL fine-gr. kaolinite.
ANAL. 358    PT. 1    05-02-1988  14:09:03    6 OXS. CO-ORDS 45017  50213  36205
SiO2        44.72   1.7585
Al2O3       35.45   1.6428
FeO          0.24   0.0078
MgO          0.09   0.0050
CaO          0.08   0.0033
Na2O         0.03   0.0024
K2O          0.05   0.0025
            80.65   3.4223
4514  4058 *  39.1 *  20.7  31.0  48.3 *  40.5  28.7  30.8
```

Analysis 5. GSQ Roma 8/34, Birkhead Formation.

```
 ? ROMA8/34 BIRKHEAD-WCM KAOL. CL. F-GR.
ANAL. 460    PT. 1    09-02-1988  17:50:04    6 OXS. CO-ORDS 40327  52070  35346
SiO2        45.74   1.7109
Al2O3       38.82   1.7111
FeO          0.09   0.0030
MgO          0.06   0.0034
CaO          0.09   0.0037
Na2O         0.00   0.0000
K2O          0.05   0.0023
            84.86   3.4344
5126  4298 *  53.6 *  36.8  33.9  29.4 *  61.4   0.0  38.6
```

Analysis 6. GSQ Roma 8/46, Hutton Sandstone.

```
---> ? ROMA8/46 KAOL. CL. F-GR.
ANAL. 195    PT. 1    29-01-1988  11:17:14    8 OXS. CO-ORDS 36140  52426  3668
SiO2        40.41   2.3074
Al2O3       33.45   2.2507
FeO          0.00   0.0000
MgO          0.05   0.0042
CaO          0.00   0.0000
Na2O         0.08   0.0092
K2O          0.00   0.0000
            74.00   4.5715
3658  3520 * 100.0 *   0.0 100.0   0.0 *   0.0 100.0   0.0
```

Analysis 7. GSQ Roma 8/46, Hutton Sandstone.

```
---> ? ROMA8/46 KAOL. CL. F-GR.
ANAL. 194   PT. 1   29-01-1988  11:09:03    8 OXS. CO-ORDS 45899  52665  3720
SiO2        43.03   2.3028
Al2O3       35.83   2.2594
FeO          0.00   0.0000
MgO          0.00   0.0000
CaO          0.00   0.0000
Na2O         0.10   0.0099
K2O          0.00   0.0000
            78.95   4.5721
3660  3497 *   0.0 *   0.0    0.0    0.0 *   0.0 100.0   0.0
```

Analysis 8. GSQ Chinchilla 4/53, Walloon Coal Measures.

```
? AGAIN/2, fine-gr. kaolinite.
ANAL. 338   PT. 1   04-02-1988  22:56:55    6 OXS. CO-ORDS 45819  48943  36310
SiO2        49.77   1.8575
TiO2         0.00   0.0000
Al2O3       33.45   1.4713
Cr2O3        0.00   0.0000
FeO          0.55   0.0170
MnO          0.00   0.0000
MgO          0.89   0.0497
CaO          0.21   0.0083
Na2O         0.00   0.0000
K2O          0.11   0.0054
            84.98   3.4093
4633  4146 *  74.5 *  11.1   66.2   22.7 *  60.8   0.0  39.2
```

Analysis 9. GSQ Chinchilla 4/54, Walloon Coal Measures.

```
---> ? CHIN4/54 FINE-GR. DIRTY KAOLIN
ANAL. 272   PT. 1   03-02-1988  18:12:49    6 OXS. CO-ORDS 40166  46696  36586
SiO2        47.87   1.7569
Al2O3       38.13   1.6489
FeO          0.10   0.0031
MnO          0.00   0.0000
MgO          0.09   0.0051
CaO          0.09   0.0036
Na2O         0.00   0.0000
K2O          0.04   0.0019
            86.32   3.4194
4106  3611 *  62.5 *  30.3   43.6   26.1 *  65.1   0.0  34.9
```

Analysis 10. GSQ Chinchilla 4/54, Walloon Coal Measures.

```
---> ? CHIN4/54 WCJCM-WCM KAOL. C-GR BOOKLETS.
ANAL. 271    PT. 1    03-02-1988  18:05:39    6 OXS. CO-ORDS 34462  39482  35945
SiO2        48.43   1.7414
Al2O3       39.43   1.6707
FeO          0.13   0.0040
MnO          0.00   0.0000
MgO          0.05   0.0026
CaO          0.09   0.0034
Na2O         0.00   0.0000
K2O          0.04   0.0019
            88.18   3.4240
4116  3594 *  39.7 *  34.2  26.1  39.7 *  64.4   0.0  35.6
```

Analysis 11. GSQ Chinchilla 4/54, Walloon Coal Measures.

```
---> ? CHIN4/54 JCM-WCM KAOL. CL. F-GR.
ANAL. 270    PT. 1    03-02-1988  17:55:32    6 OXS. CO-ORDS 33275  42222  36024
SiO2        48.03   1.7548
Al2O3       38.51   1.6581
FeO          0.00   0.0000
MnO          0.00   0.0000
MgO          0.05   0.0030
CaO          0.00   0.0000
Na2O         0.00   0.0000
K2O          0.00   0.0000
            86.59   3.4159
4116  3650 * 100.0 *   0.0 100.0   0.0 *   0.0   0.0   0.0
```

Analysis 12. GSQ Chinchilla 4/41, Precipice Sandstone.

```
---> ? AGAIN/2, coarse-gr. kaolinite.
ANAL. 354    PT. 1    05-02-1988  12:05:21    6 OXS. CO-ORDS 40550  51876  36306
SiO2        47.64   1.7514
Al2O3       38.43   1.6646
FeO          0.00   0.0000
MgO          0.00   0.0000
CaO          0.00   0.0000
Na2O         0.00   0.0000
K2O          0.00   0.0000
            86.07   3.4160
4692  4251 *   0.0 *   0.0   0.0   0.0 *   0.0   0.0   0.0
```

Analysis 13. GSQ Chinchilla 4/41, Precipice Sandstone.

```
---> ? AGAIN/2 , coarse-gr.kaolinite.
ANAL. 347   PT. 1   05-02-1988  11:24:57    6 OXS. CO-ORDS 55711  57006  36588
SiO2        46.34   1.7777
Al2O3       36.05   1.6295
FeO          0.00   0.0000
MgO          0.00   0.0000
CaO          0.00   0.0000
Na2O         0.00   0.0000
K2O          0.00   0.0000
            82.39   3.4073
4747  4244 *  0.0 *  0.0    0.0    0.0 *   0.0    0.0    0.0
```

Analysis 14. GSQ Chinchilla 4/40, Precipice Sandstone.

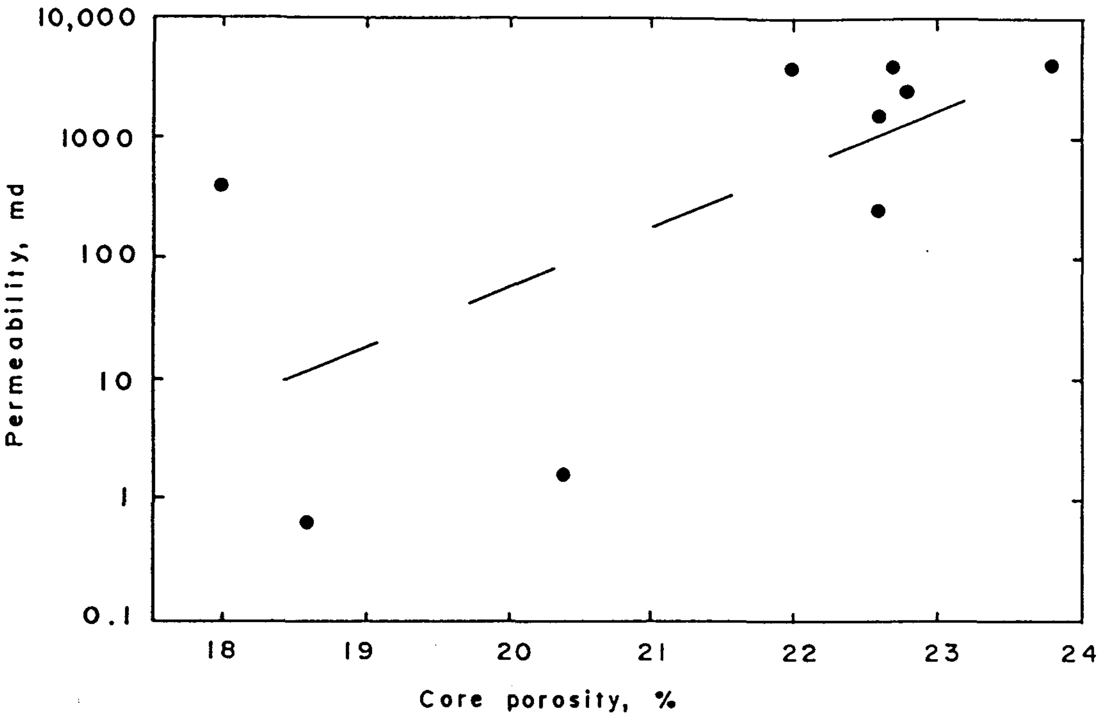
```
 ? CHIN4/40 PREC MUSCOV. ALTERED TO KAOL.
ANAL. 327   PT. 1   04-02-1988  19:58:00    6 OXS. CO-ORDS 49551  39287  35965
SiO2        46.60   1.7345
TiO2         0.00   0.0000
Al2O3       38.23   1.6768
Cr2O3        0.00   0.0000
FeO          0.07   0.0023
MnO          0.00   0.0000
MgO          0.04   0.0024
CaO          0.00   0.0000
Na2O         0.07   0.0051
K2O          0.35   0.0168
            85.37   3.4378
4583  4016 * 50.9 *  0.0   50.9   49.1 *   0.0   23.3   76.7
```

Analysis 15. GSQ Chinchilla 4/40, Precipice Sandstone.

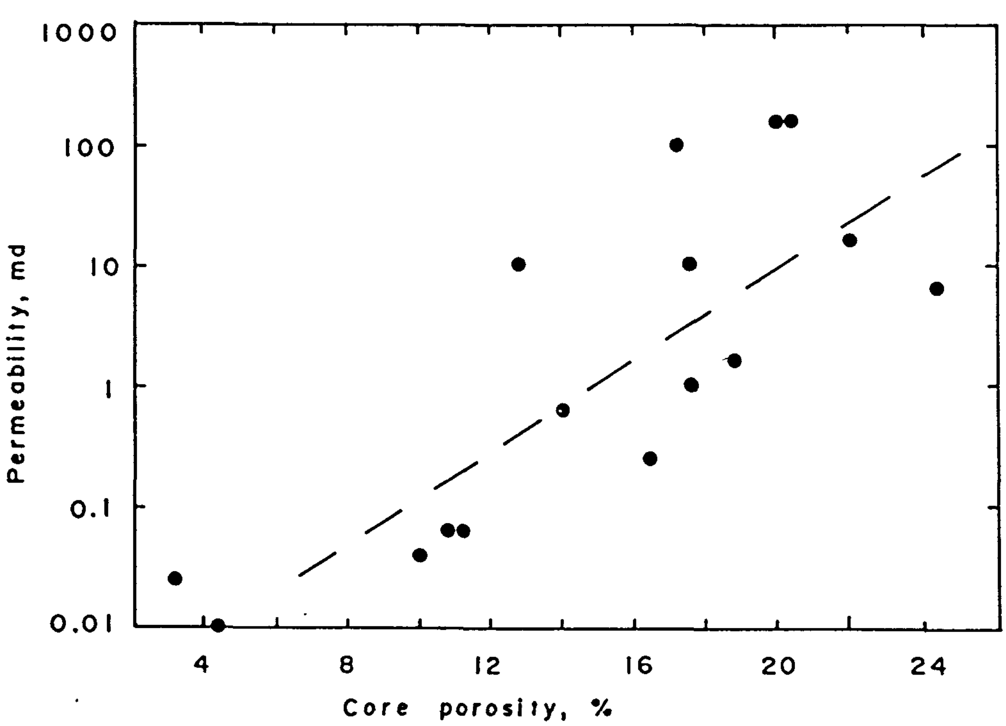
```
 ? CHIN4/40 PREC. PORE-FILL KAOL. EKA.
ANAL. 328   PT. 1   04-02-1988  20:10:49    6 OXS. CO-ORDS 45703  44455  36172
SiO2        45.87   1.7248
TiO2         0.00   0.0000
Al2O3       38.37   1.7001
Cr2O3        0.00   0.0000
FeO          0.00   0.0000
MnO          0.00   0.0000
MgO          0.00   0.0000
CaO          0.00   0.0000
Na2O         0.00   0.0000
K2O          0.00   0.0000
            84.23   3.4249
4575  4101 *  0.0 *  0.0    0.0    0.0 *   0.0    0.0    0.0
```

# APPENDIX 2.7.

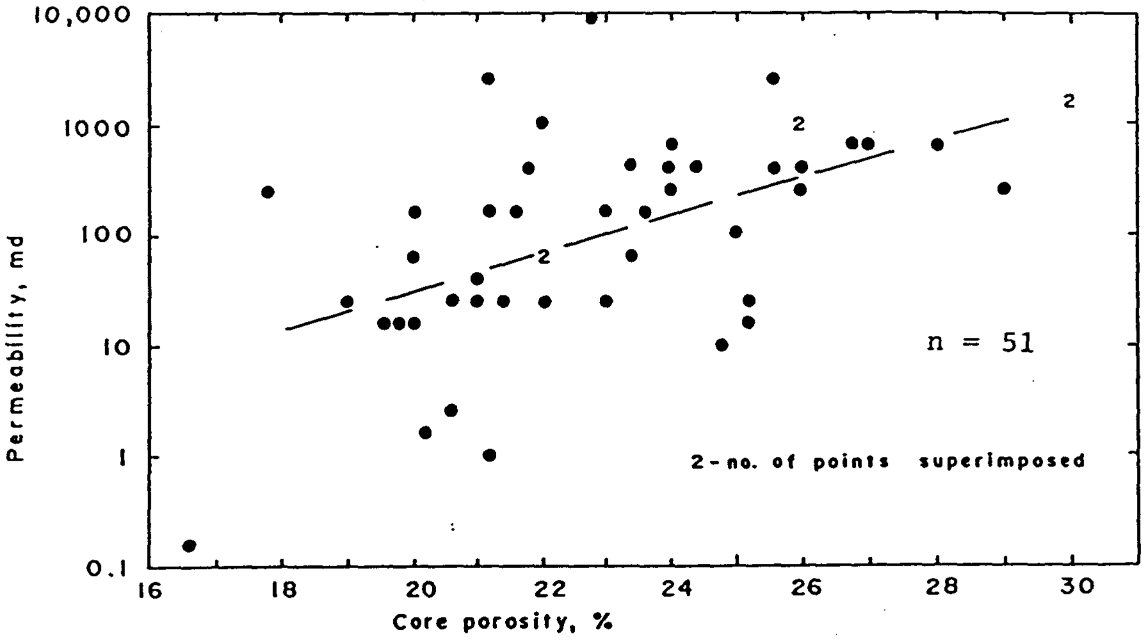
## CORE POROSITY - PERMEABILITY RELATIONSHIPS OF DIFFERENT STRATIGRAPHIC UNITS



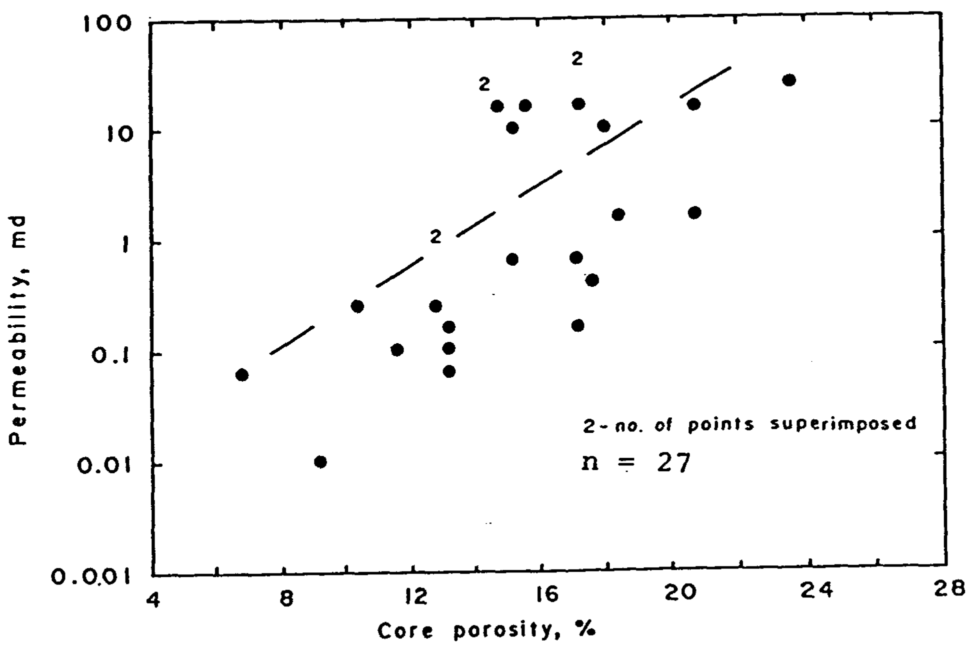

Appendix 2.7.1. Porosity - permeability relationship of the Precipice Sst. with computed regression line. n=9, r=0.66, $r^2$=0.43, Std. err. est.=1.18, intercept (A)=-7.84, slope (B)= 0.48, sig.=0.053.



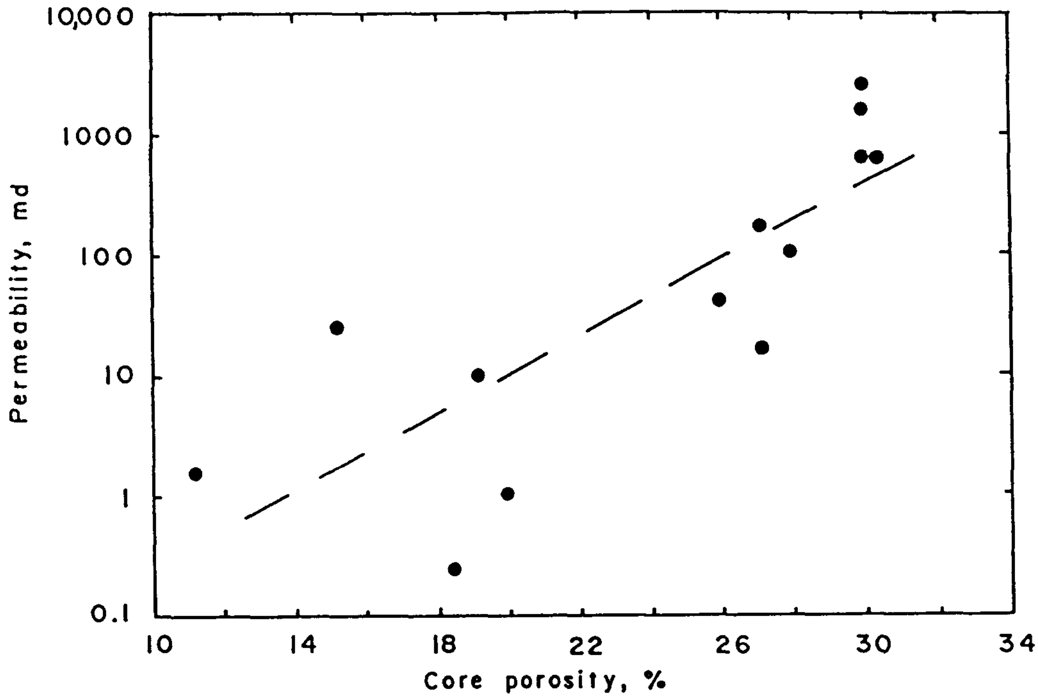

Appendix 2.7.2. Porosity - permeability relationship of the Evergreen Fm. with computed regression line. n=16, r=0.80, $r^2$=0.64, std. err. est.=0.86, A=-2.65, B=0.187, sig.=0.000.



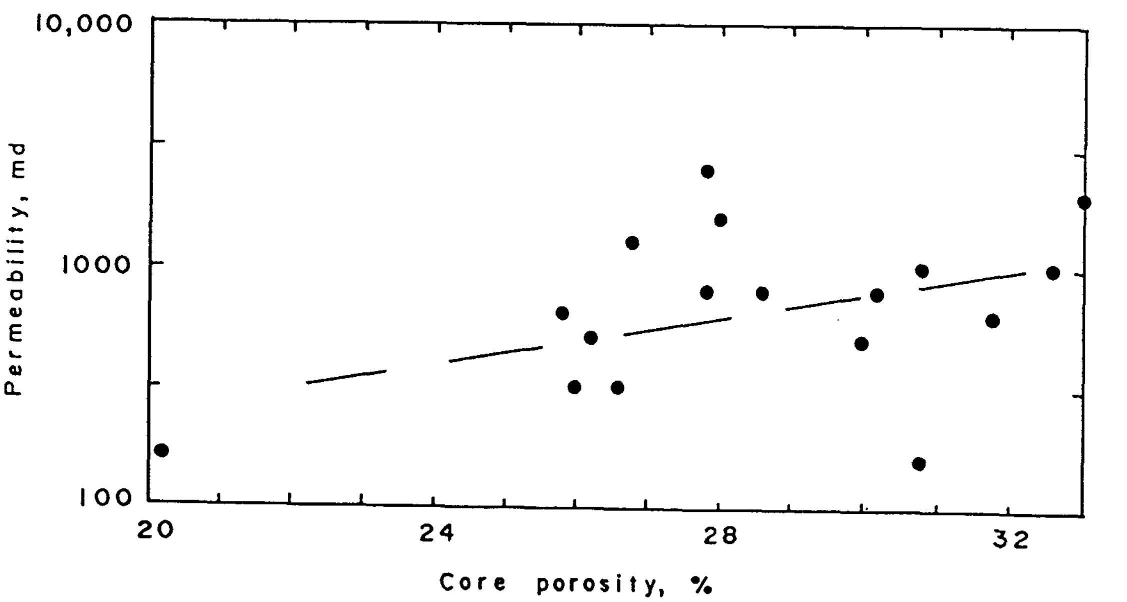

Appendix 2.7.3. Porosity - permeability relationship of the Hutton Sst. with computed regression line. r=0.62, $r^2$= 0.39, std. err. est.=0.75, A=-2.06, B=0.17, sig. 0.000.



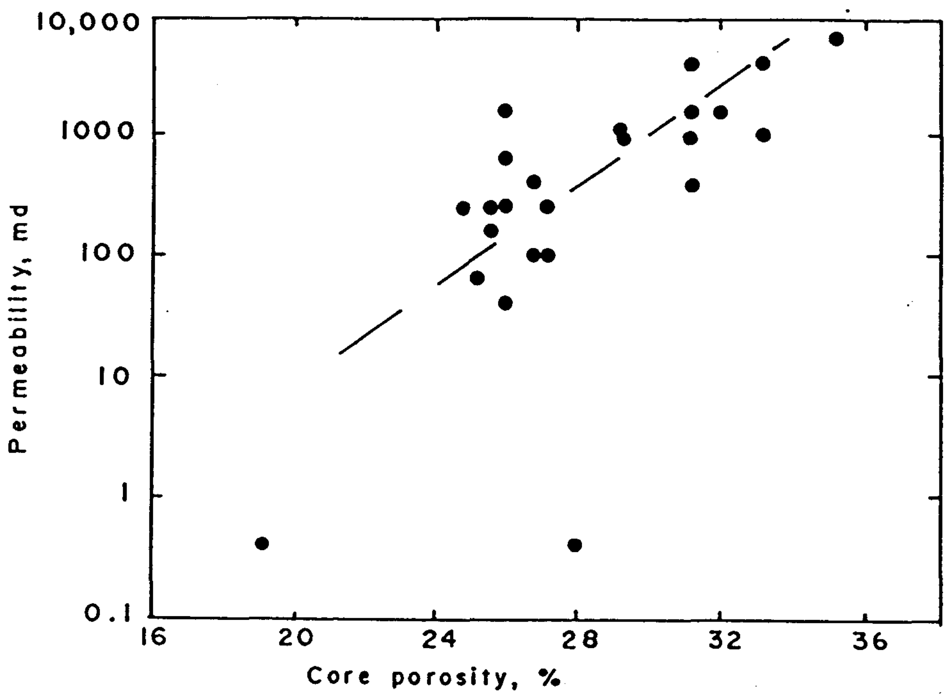

Appendix 2.7.4. Porosity - permeability relationship of the Walloon Coal Measures with computed regression line. r=0.62, $r^2$=0.38, std. err. est.=0.83, A=-2.50, B=0.17, sig.=0.0002.



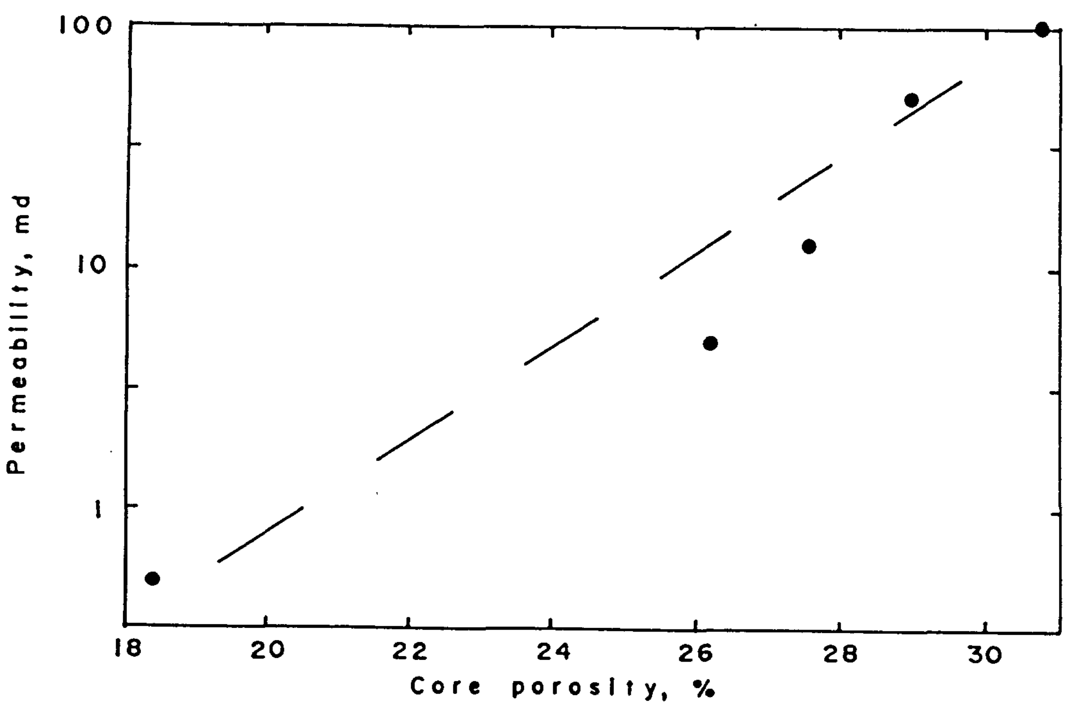

Appendix 2.7.5. Porosity - permeability relationship of the Westbourne Formation with computed regression line. n=13, r=0.80, $r^2$=0.65, std. err. est.=0.78, A=-2.17, B=0.16, sig.=0.0009.



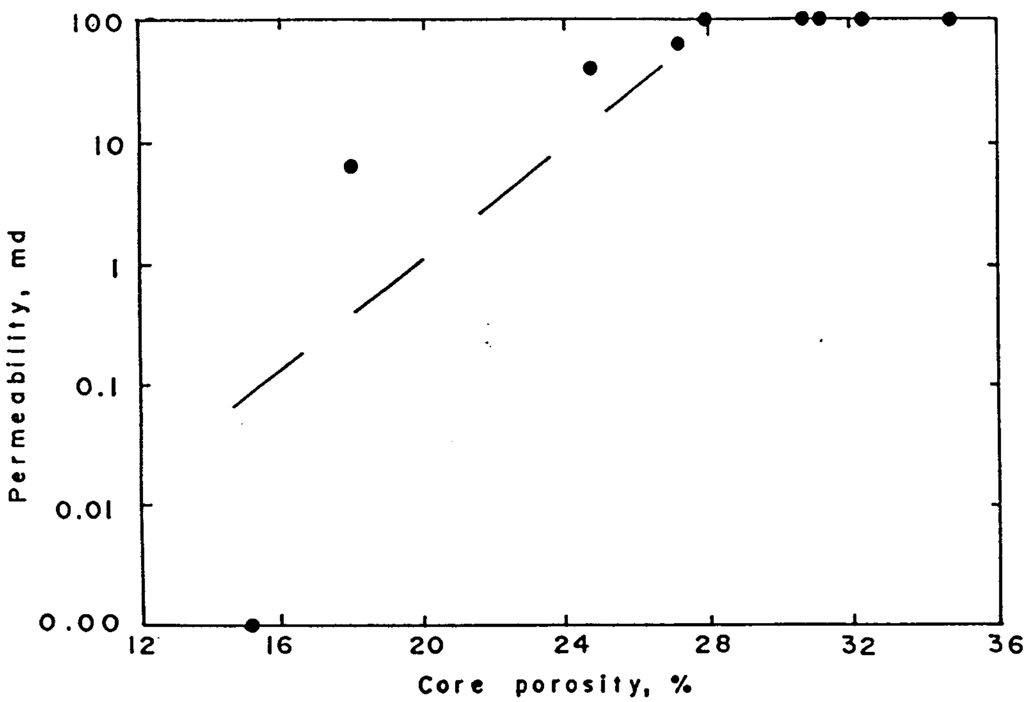

Appendix 2.7.6. Porosity - permeability relationship of the Gubberamunda Sst. with computed regression line. n=17, r=0.44, $r^2$=0.19, Std. err. est.=0.32, A=1.44, B=0.048, sig.=0.0776.



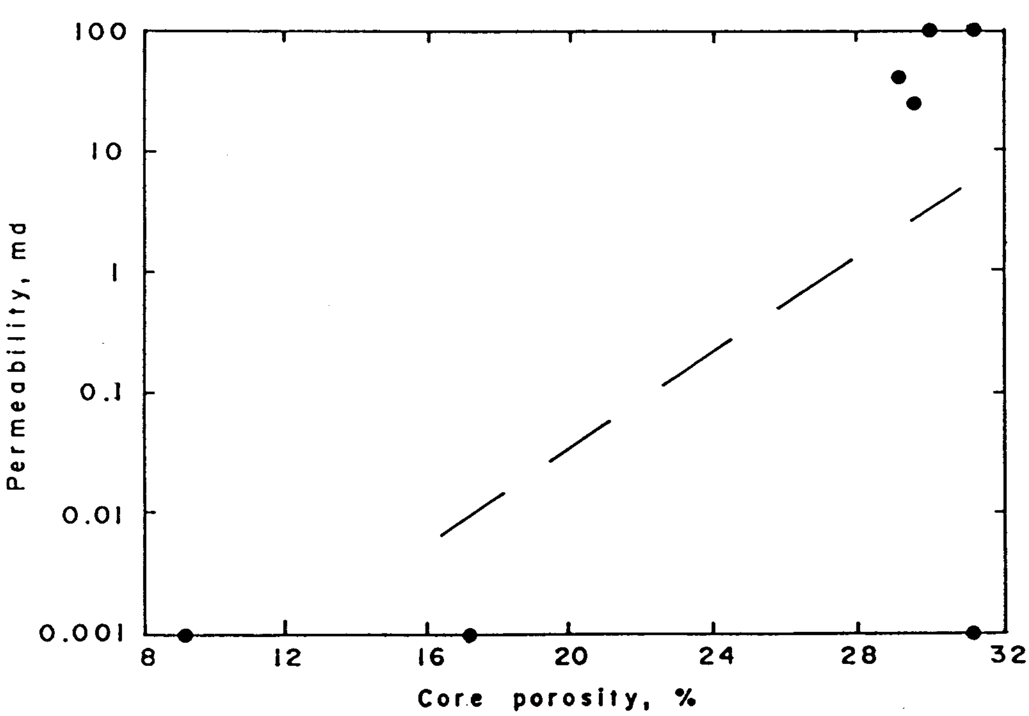

Appendix 2.7.7. Porosity - permeability relationship of the Orallo Formation with computed regression line. n=24, r=0.69, $r^2$=0.47, std. err. est.=0.785, A=-3.31, B=0.20, sig.=0.0002.



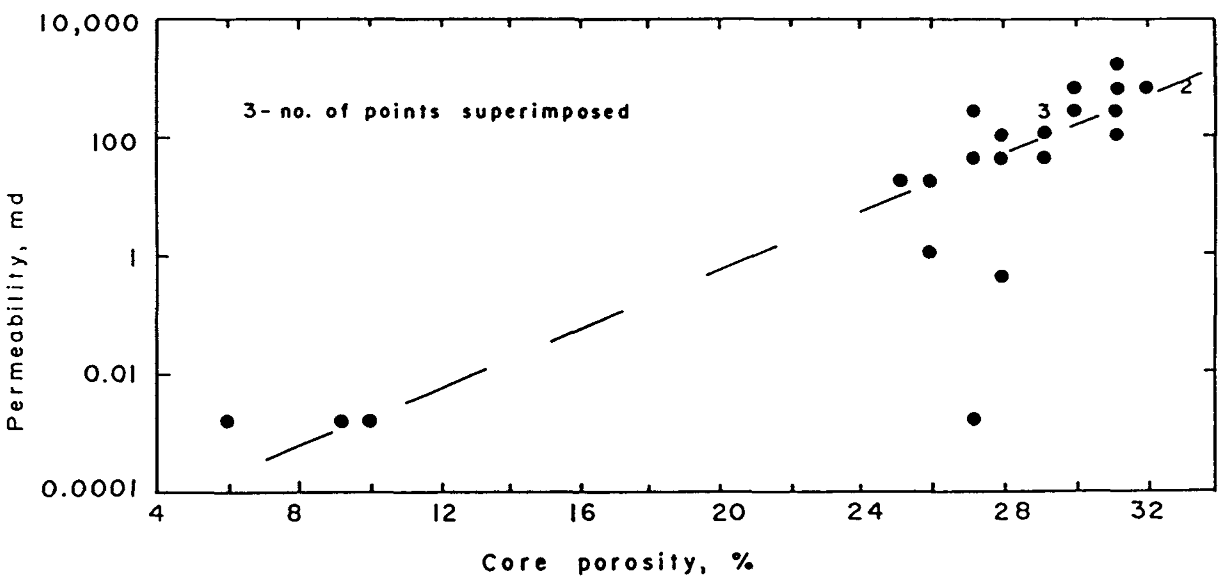

Appendix 2.7.8. Core porosity - permeability relationship of the Mooga Sandstone with computed regression line. n=5, r=0.96, $r^2$=0.92, std. err. est.=0.31, A=-3.95, B=0.19, sig. 0.0101.




Appendix 2.7.9. Core porsoity - permeability relationship of the Bungil Formation with computed regression line. n=9, r=0.94, $r^2$=0.88, Std. err. est.=0.69, A=-2.67, B=0.17, sig.=0.0002.

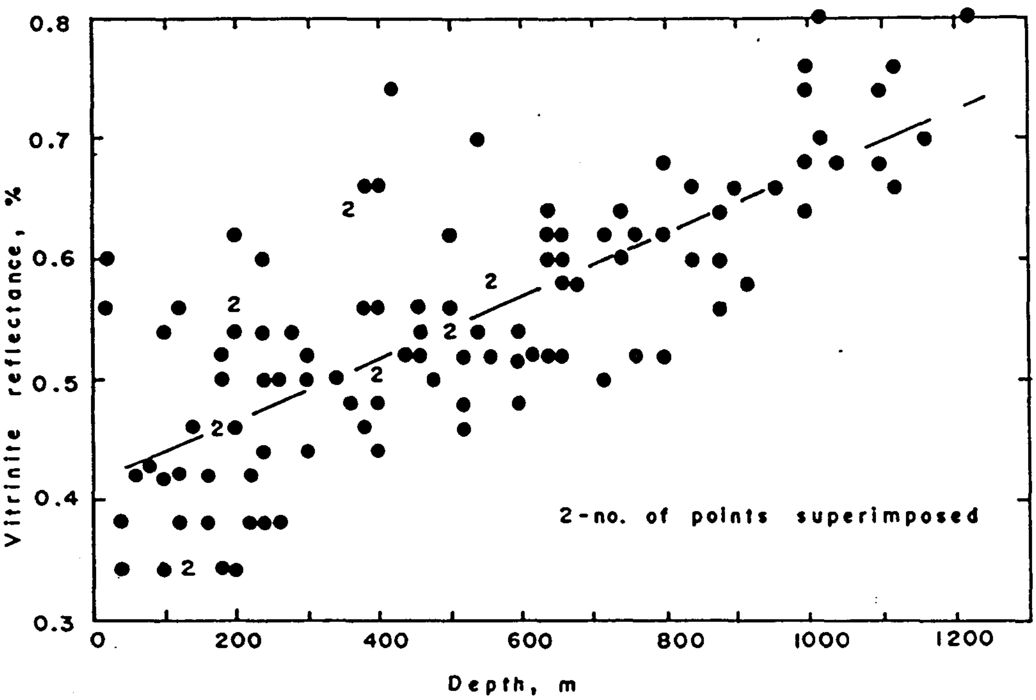



Appendix 2.7.10. Porosity - permeability relationship of the Wallumbilla Formation with computed regression line. n=7, r=0.67, $r^2$=0.45, std. err. est.=2.05, A= -5.22, B=0.19, sig.=0.099.

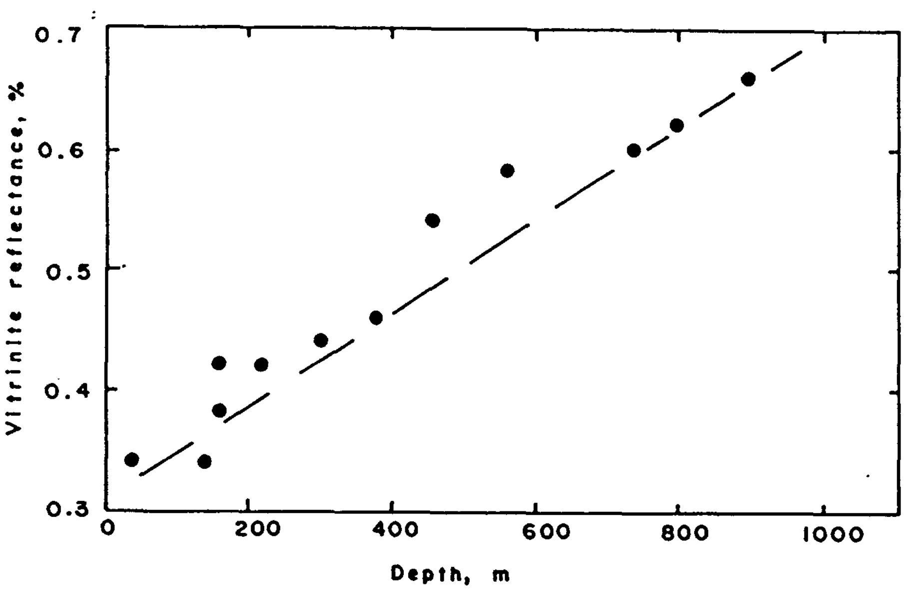



Appendix 2.7.11. Porosity - permeability relationship of the Griman Creek Formation with computed regression line. n=26, r=0.85, $r^2$=0.72, std. err. est.=1.08, A=-5.20, B=0.24, sig.=0.000.

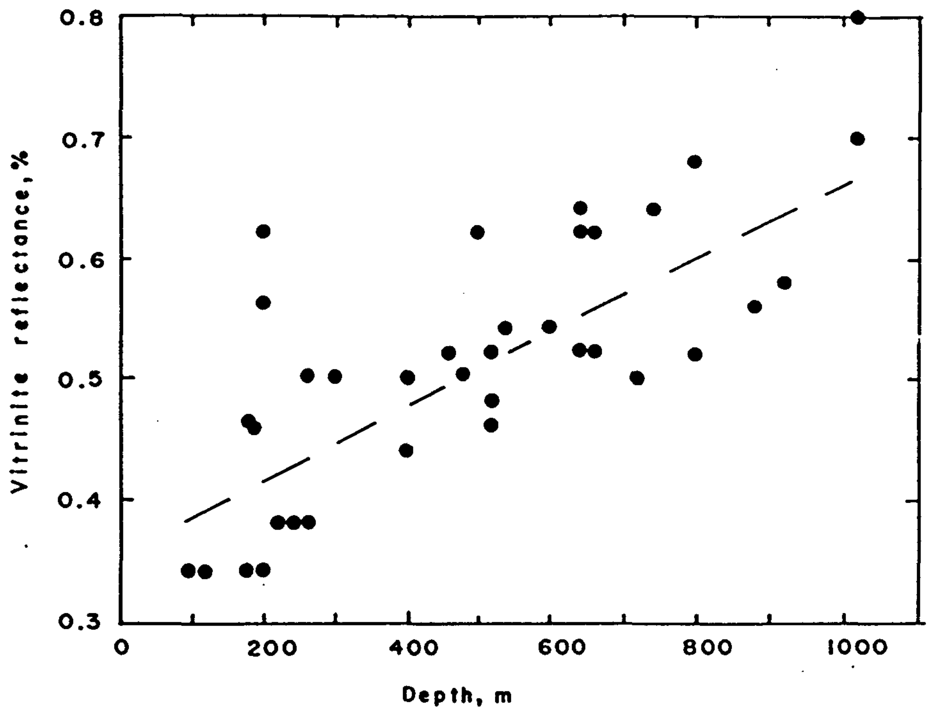
# APPENDIX 2.8. VITRINITE REFLECTANCE - DEPTH RELATIONSHIPS



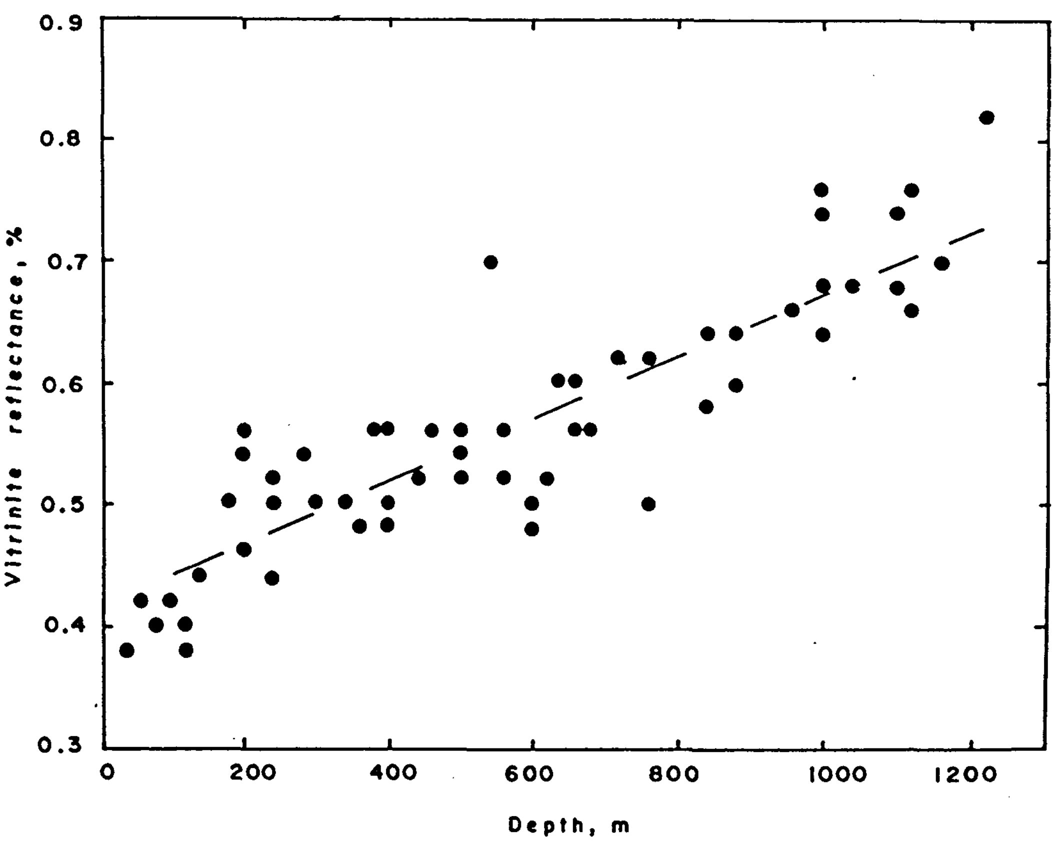

Appendix 2.8.1. Vitrinite reflectance (Ro) - depth relationship[1] of the Surat Basin succession (all formations) based on data from GSQ Mitchell 2, Roma 8, Chin. 4 and Taroom 17 taken together. The regression line is computed (as opposed to eye-balled). n=115, r=0.74, $r^2$=0.55, std. err. est.= 0.07, intercept (A)=0.41, slope (B)=0.00025, sig.=0.0000.



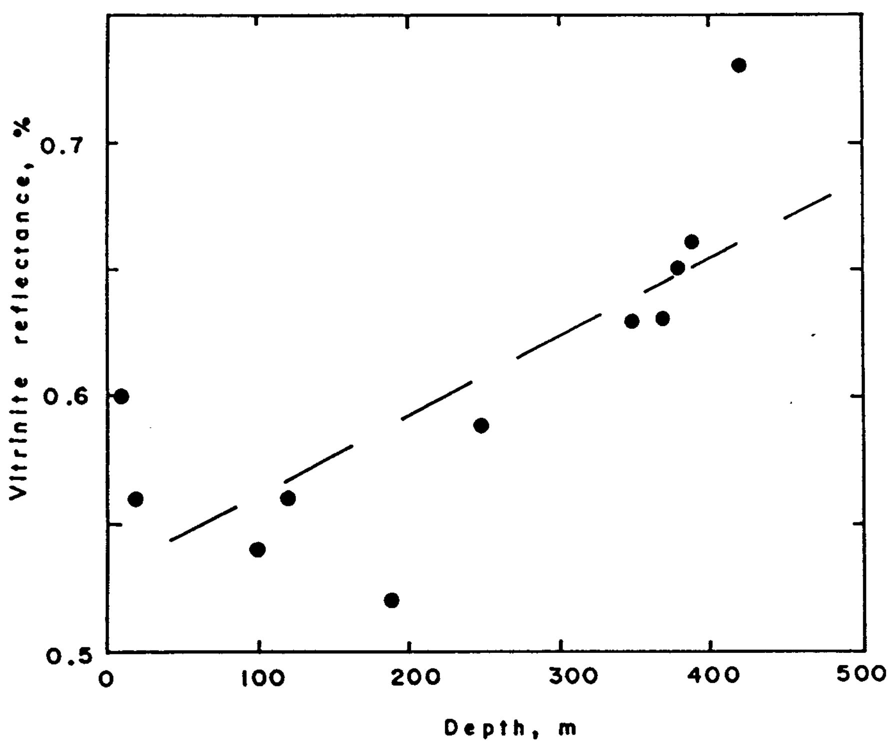

Appendix 2.8.2. Plot of Ro against depth. GSQ Mitchell 2. The regression line is computed. n=12, r=0.97, $r^2$=0.96, std. err. est.=0.023, A=0.32, B=0.00038, sig.=0.0000.




Appendix 2.8.3. Plot of Ro against depth with computed regression line. GSQ Roma 8. n=36, r=0.76, $r^2$=0.57, std.err. est.=0.071, A=0.36, B=0.00031, sig.=0.0000.




Appendix 2.8.4. Plot of Ro against depth with computed regression line. GSQ Chinchilla 4. n=56, r=0.88, $r^2$=0.78, std. err. est.=0.047, A=0.41, B=0.00026, sig.=0.0000.




Appendix 2.8.5. Ro - depth relationship in GSQ Taroom 17 with computed regression line. n=11, r=0.77, r2=0.59, std. err. est.=0.041, A=0.53, B=0.0003, sig.=0.0054.

1. Reflectance data from Coote (1986); cf. Appendix 2.8.6.

Appendix 2.8.6. Vitrinite reflectance (Ro) data from GSQ stratigraphic wells. From Coote (1986).

| Depth (m) | Ro (%) |
|---|---|
| **GSQ Mitchell 2** | |
| 46.92 | 0.35 |
| 140.34 | 0.34 |
| 153.72 | 0.39 |
| 169.36 | 0.41 |
| 228.31 | 0.41 |
| 301.45 | 0.43 |
| 375.98 | 0.46 |
| 450.32 | 0.53 |
| 556.22 | 0.58 |
| 737.35 | 0.59 |
| 800.72 | 0.62 |
| 891.07 | 0.66 |
| **GSQ Roma 8** | |
| 107.12 | 0.34 |
| 116.84 | 0.33 |
| 174.17 | 0.35 |
| 174.33 | 0.46 |
| 184.68 | 0.45 |
| 193.14 | 0.55 |
| 205.82 | 0.61 |
| 205.96 | 0.35 |
| 215.08 | 0.37 |
| 240.44 | 0.38 |
| 263.90 | 0.38 |
| 268.98 | 0.49 |
| 301.63 | 0.49 |
| 403.29 | 0.43 |
| 403.37 | 0.50 |
| 458.20 | 0.51 |
| 479.87 | 0.49 |
| 495.06 | 0.61 |
| 510.23 | 0.48 |
| 529.47 | 0.45 |
| 529.51 | 0.52 |
| 548.51 | 0.53 |
| 604.78 | 0.54 |
| 633.63 | 0.63 |
| 635.07 | 0.51 |
| 648.23 | 0.61 |
| 664.61 | 0.62 |
| 664.72 | 0.51 |
| 726.27 | 0.49 |
| 738.25 | 0.64 |
| 795.71 | 0.67 |
| 795.85 | 0.51 |

| Depth (m) | Ro (%) |
|---|---|
| **GSQ Roma 8 (contd.)** | |
| 883.36 | 0.56 |
| 926.54 | 0.57 |
| 1012.10 | 0.69 |
| 1012.11 | 0.80 |
| **GSQ Chinchill 4** | |
| 41.16 | 0.39 |
| 52.94 | 0.42 |
| 74.20 | 0.41 |
| 101.87 | 0.42 |
| 116.00 | 0.41 |
| 129.02 | 0.39 |
| 147.06 | 0.45 |
| 186.30 | 0.50 |
| 192.35 | 0.54 |
| 198.00 | 0.46 |
| 198.57 | 0.56 |
| 243.00 | 0.44 |
| 243.83 | 0.53 |
| 243.88 | 0.49 |
| 275.69 | 0.54 |
| 309.40 | 0.51 |
| 348.37 | 0.50 |
| 357.42 | 0.48 |
| 372.00 | 0.56 |
| 391.28 | 0.56 |
| 400.14 | 0.50 |
| 405.00 | 0.47 |
| 449.25 | 0.52 |
| 452.00 | 0.55 |
| 493.50 | 0.53 |
| 505.39 | 0.54 |
| 505.56 | 0.56 |
| 547.18 | 0.69 |
| 564.78 | 0.52 |
| 565.05 | 0.57 |
| 590.00 | 0.47 |
| 595.96 | 0.51 |
| 627.83 | 0.52 |
| 638.00 | 0.60 |
| 661.00 | 0.57 |
| 661.68 | 0.60 |
| 682.37 | 0.57 |
| 722.94 | 0.61 |
| 766.76 | 0.61 |
| 768.40 | 0.51 |
| 835.76 | 0.65 |
| 847.00 | 0.59 |

| Depth (m) | Ro (%) |
|---|---|
| **GSQ Chinchilla 4 (contd.)** | |
| 874.17 | 0.63 |
| 874.25 | 0.60 |
| 954.78 | 0.66 |
| 991.93 | 0.67 |
| 992.00 | 0.63 |
| 992.66 | 0.74 |
| 992.67 | 0.75 |
| 1049.00 | 0.68 |
| 1093.83 | 0.74 |
| 1107.27 | 0.67 |
| 1123.46 | 0.76 |
| 1124.00 | 0.66 |
| 1159.00 | 0.69 |
| 1213.00 | 0.82 |
| **GSQ Taroom 17** | |
| 11.08 | 0.60 |
| 24.61 | 0.56 |
| 99.93 | 0.54 |
| 116.19 | 0.56 |
| 185.48 | 0.52 |
| 245.93 | 0.59 |
| 287.54 | 0.86 [1] |
| 288.87 | 0.75 |
| 317.78 | 0.90 |
| 352.65 | 0.63 |
| 368.00 | 0.63 |
| 378.43 | 0.65 |
| 392.71 | 0.66 |
| 422.61 | 0.73 |

Reference cited in Appendix 2.8.

Coote, S. M., 1986, Departmental stratigraphic drilling in Queensland, 1983 to 1986. Queensland Govt. Min. Jour., v. 87, no. 1017, pp. 306-326.

Footnote to Appendix 2.8.6.

1. These anomalous values of Ro probably represent recycled/reworked vitrinites and were not taken into Ro - depth plots.

# APPENDIX 3.1. GLOSSARY OF TEXT MNEMONICS AND MATHEMATICAL SYMBOLS USED IN CHAPTER 4

Appendix 3.1. Glossary of text mnemonics and mathematical symbols used in Chapter 4.

CEC - Cation-exchange capacity.

DST - Drill-stem test(ing).

d - Sample depth below surface, m.

FWL - Free-water level.

OWC - Oil/water contact.

MPI - Microporosity index.

$M_z$ - Mean grain-size.

PTS - Pore-throat sorting.

SP - Spontaneous potential.

**Mathematical Symbols**

$\gamma$ - Interfacial tension.

$\sigma$ - grain-size sorting, phi units.

$\rho_o$ - Density of oil.

$\rho_w$ - Density of water.

F - Formation resistivity factor.

$F^*$ -Formation resistivity factor for very small $R_w$ approximating F of a clean formation with the same porosity.

g - Acceleration due to gravity.

K - Permeability.

$K_{ro}$- Relative permeability to oil.

$K_{rw}$- Relative permeability to water.

m - Cementation exponent.

n - Saturation exponent.

$\phi$ - porosity, %.

$R_w$- Resistivity of formation water.

$R_o$- Resistivity of formation 100% saturated with water.

$R_t$- Resistivity of the undisturbed formation.

$R_{xo}$- Resistivity of the zone flushed by drilling mud-filtrate.

$r_p$- Radius of pore.

$r_t$- Radius of pore-throat.

S - Specific surface area.

$S_o$- Oil saturation.

$S_w$- Water saturation.

$S_{wi}$- Irreducible water saturation.

$Z_o$- Height of the oil-column above FWL.

## APPENDIX 4.1. CORRELATION MATRIX AND RELEVANT MULTIPLE REGRESSION STATISTICS FOR DIFFERENT FORMAIONS AND SUBSET OF SAMPLES.

Appendix 4.1. Correlation matrix and relevant multiple regression statistics for different formations and subset of samples.

## Evergreen Formation, n = 16

**** MULTIPLE REGRESSION ****

Correlation, 1-tailed Sig:

| | COREPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | DEPTH | AGE |
|---|---|---|---|---|---|---|---|---|
| COREPOR | 1.000 | .625 | -.607 | .458 | -.045 | -.070 | -.178 | .412 |
| | .999 | .005 | .006 | .037 | .434 | .399 | .255 | .056 |
| QUARTZ | .625 | 1.000 | -.043 | .659 | -.106 | -.003 | -.766 | .046 |
| | .005 | .999 | .437 | .003 | .348 | .496 | .000 | .432 |
| CEMENT | -.607 | -.043 | 1.000 | -.247 | .299 | .037 | -.388 | -.698 |
| | .006 | .437 | .999 | .179 | .131 | .446 | .069 | .001 |
| EPIMAT | .458 | .659 | -.247 | 1.000 | -.373 | -.193 | -.488 | .186 |
| | .037 | .003 | .179 | .999 | .077 | .237 | .027 | .245 |
| MEANSIZE | -.045 | -.106 | .299 | -.373 | 1.000 | -.373 | -.224 | .063 |
| | .434 | .348 | .131 | .077 | .999 | .077 | .203 | .409 |
| SORTING | -.070 | -.003 | .037 | -.193 | -.373 | 1.000 | -.007 | -.210 |
| | .399 | .496 | .446 | .237 | .077 | .999 | .490 | .217 |
| DEPTH | -.178 | -.766 | -.388 | -.488 | -.224 | -.007 | 1.000 | .076 |
| | .255 | .000 | .069 | .027 | .203 | .490 | .999 | .390 |
| AGE | .412 | .046 | -.698 | .186 | .063 | -.210 | .076 | 1.000 |
| | .056 | .432 | .001 | .245 | .409 | .217 | .390 | .999 |

Variable(s) Entered on Step Number 2.. CEMENT

| | | |
|---|---|---|
| Multiple R | .85267 |
| R Square | .72705 |
| Adjusted R Square | .68506 |
| Standard Error | 3.36324 |

Analysis of Variance

| | DF | Sum of Squares | Mean Square |
|---|---|---|---|
| Regression | 2 | 391.69218 | 195.84609 |
| Residual | 13 | 147.04782 | 11.31137 |

F = 17.31409 Signif F = .0002

------------------ Variables in the Equation ------------------

| Variable | B | SE B | Beta | Correl | Part Cor | Partial | T | Sig T |
|---|---|---|---|---|---|---|---|---|
| QUARTZ | .181304 | .043848 | .599700 | .624768 | .599142 | .753701 | 4.135 | .0012 |
| CEMENT | -.410813 | .102584 | -.580815 | -.606697 | -.580274 | -.743168 | -4.005 | .0015 |
| (Constant) | 9.335444 | 2.101042 | | | | | 4.443 | .0007 |

Hutton Sandstone, n = 51.

* * * * MULTIPLE REGRESSION * * * *

Correlation, 1-tailed Sig:

| | COREPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | DEPTH | AGE |
|---|---|---|---|---|---|---|---|---|
| COREPOR | 1.000 | .304 | -.069 | -.006 | -.282 | .082 | -.302 | -.062 |
| | 999 | .015 | .316 | .483 | .022 | .284 | .016 | .332 |
| QUARTZ | .304 | 1.000 | .427 | .184 | -.206 | .408 | .477 | .550 |
| | .015 | .999 | .001 | .098 | .073 | .001 | .000 | .000 |
| CEMENT | -.069 | .427 | 1.000 | -.063 | -.021 | -.020 | .319 | .341 |
| | .316 | .001 | .999 | .330 | .441 | .446 | .011 | .007 |
| EPIMAT | -.006 | .184 | -.063 | 1.000 | .264 | -.047 | .264 | .322 |
| | .483 | 098 | .330 | .999 | .030 | .371 | .030 | .011 |
| MEANSIZE | -.282 | -.206 | -.021 | .264 | 1.000 | -.442 | .305 | .414 |
| | .022 | .073 | .441 | .030 | .999 | .001 | .015 | .001 |
| SORTING | .082 | .408 | -.020 | -.047 | -.442 | 1.000 | .017 | -.055 |
| | .284 | .001 | .446 | .371 | .001 | .999 | .453 | .351 |
| DEPTH | -.302 | .477 | .319 | .264 | .305 | .017 | 1.000 | .695 |
| | .016 | .000 | .011 | .030 | .015 | .453 | .999 | .000 |
| AGE | -.062 | .550 | .341 | .322 | .414 | -.055 | .695 | 1.000 |
| | 332 | .000 | .007 | .011 | .001 | .351 | .000 | .999 |

Variable(s) Entered on Step Number 2.. DEPTH

| | |
|---|---|
| Multiple R | .59208 |
| R Square | .35056 |
| Adjusted R Square | .32350 |
| Standard Error | 2.77280 |

Analysis of Variance

| | DF | Sum of Squares | Mean Square |
|---|---|---|---|
| Regression | 2 | 199.20238 | 99.60119 |
| Residual | 48 | 369.04507 | 7.68844 |

F = 12.95467 Signif F = .0000

------------------ Variables in the Equation ------------------

| Variable | B | SE B | Beta | Correl | Part Cor | Partial | T | Sig T |
|---|---|---|---|---|---|---|---|---|
| QUARTZ | .145566 | .033229 | .579927 | .303746 | .509550 | .534422 | 4.381 | .0001 |
| DEPTH | -.021732 | .004974 | -.578421 | -.301520 | -.508227 | -.533429 | -4.369 | .0001 |
| (Constant) | 32.511171 | 3.316963 | | | | | 9.801 | .0000 |

Walloon Coal Measures, n = 27.

* * * * MULTIPLE REGRESSION * * * *

Correlation, 1-tailed Sig:

| | COREPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | DEPTH | AGE |
|---|---|---|---|---|---|---|---|---|
| COREPOR | 1.000 | .623 | -.601 | .180 | -.181 | .117 | .113 | .137 |
| | .999 | .000 | .000 | .184 | .182 | .281 | .286 | .248 |
| QUARTZ | .623 | 1.000 | -.357 | .325 | -.246 | .157 | .159 | .074 |
| | .000 | .999 | .034 | .049 | .108 | .217 | .215 | .358 |
| CEMENT | -.601 | -.357 | 1.000 | -.275 | -.125 | -.047 | .033 | .011 |
| | .000 | .034 | .999 | .082 | .268 | .408 | .436 | .479 |
| EPIMAT | .180 | .325 | -.275 | 1.000 | -.257 | .177 | -.032 | -.161 |
| | .184 | .049 | .082 | .999 | .098 | .189 | .437 | .211 |
| MEANSIZE | -.181 | -.246 | -.125 | -.257 | 1.000 | .003 | -.335 | -.411 |
| | .182 | .108 | .268 | .098 | .999 | .493 | .044 | .017 |
| SORTING | .117 | .157 | -.047 | .177 | .003 | 1.000 | .285 | .231 |
| | .281 | .217 | .408 | .189 | .493 | .999 | .075 | .124 |
| DEPTH | .113 | .159 | .033 | -.032 | -.335 | .285 | 1.000 | .918 |
| | .286 | .215 | .436 | .437 | .044 | .075 | .999 | .000 |
| AGE | .137 | .074 | .011 | -.161 | -.411 | .231 | .918 | 1.000 |
| | .248 | .358 | .479 | .211 | .017 | .124 | .000 | .999 |

Variable(s) Entered on Step Number 2.. CEMENT

| | |
|---|---|
| Multiple R | .74343 |
| R Square | .55269 |
| Adjusted R Square | .51541 |
| Standard Error | 2.56350 |

Analysis of Variance

| | DF | Sum of Squares | Mean Square |
|---|---|---|---|
| Regression | 2 | 194.87121 | 97.43560 |
| Residual | 24 | 157.71620 | 6.57151 |

F = 14.82698 Signif F = .0001

------------------------------ Variables in the Equation ------------------------------

| Variable | B | SE B | Beta | Correl | Part Cor | Partial | T | Sig T |
|---|---|---|---|---|---|---|---|---|
| QUARTZ | .218924 | .068339 | .468189 | .623132 | .437343 | .547286 | 3.203 | .0038 |
| CEMENT | -.286296 | .096398 | -.434054 | -.601182 | -.405457 | -.518410 | -2.970 | .0067 |
| (Constant) | 12.010516 | 1.393092 | | | | | 8.621 | .0000 |

Gubberamunda Sandstone, n = 17.

* * * * M U L T I P L E   R E G R E S S I O N * * * *

Correlation, 1-tailed Sig:

| | COREPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | DEPTH | AGE |
|---|---|---|---|---|---|---|---|---|
| COREPOR | 1.000 | .399 | -.658 | .669 | .500 | -.226 | .527 | .430 |
| | .999 | .056 | .002 | .002 | .020 | .191 | .015 | .043 |
| QUARTZ | .399 | 1.000 | -.319 | .650 | -.236 | .402 | .765 | .666 |
| | .056 | .999 | .106 | .002 | .181 | .055 | .000 | .002 |
| CEMENT | -.658 | -.319 | 1.000 | -.420 | -.346 | .033 | -.351 | -.398 |
| | .002 | .106 | .999 | .047 | .087 | .450 | .084 | .057 |
| EPIMAT | .669 | .650 | -.420 | 1.000 | .216 | .082 | .604 | .622 |
| | .002 | .002 | .047 | .999 | .203 | .377 | .005 | .004 |
| MEANSIZE | .500 | -.236 | -.346 | .216 | 1.000 | -.616 | .149 | .198 |
| | .020 | .181 | .087 | .203 | .999 | .004 | .284 | .223 |
| SORTING | -.226 | .402 | .033 | .082 | -.616 | 1.000 | -.049 | .152 |
| | .191 | .055 | .450 | .377 | .004 | .999 | .425 | .281 |
| DEPTH | .527 | .765 | -.351 | .604 | .149 | -.049 | 1.000 | .507 |
| | .015 | .000 | .084 | .005 | .284 | .425 | .999 | .019 |
| AGE | .430 | .666 | -.398 | .622 | .198 | .152 | .507 | 1.000 |
| | .043 | .002 | .057 | .004 | .223 | .281 | .019 | .999 |

| | |
|---|---|
| Multiple R | .78756 |
| R Square | .62025 |
| Adjusted R Square | .56600 |
| Standard Error | 2.06323 |

Analysis of Variance

| | DF | Sum of Squares | Mean Square |
|---|---|---|---|
| Regression | 2 | 97.34097 | 48.67049 |
| Residual | 14 | 59.59667 | 4.25691 |

F = 11.43330 Signif F = .0011

------------------ Variables in the Equation ------------------

| Variable | B | SE B | Beta | Correl | Part Cor | Partial | T | Sig T |
|---|---|---|---|---|---|---|---|---|
| EPIMAT | .670214 | .255327 | .476324 | .668740 | .432315 | .574308 | 2.625 | .0200 |
| CEMENT | -.714160 | .282753 | -.458326 | -.658298 | -.415980 | -.559491 | -2.526 | .0242 |
| (Constant) | 26.708825 | 1.107661 | | | | | 24.113 | .0000 |

Orallo Formation, n = 24.

* * * * M U L T I P L E   R E G R E S S I O N * * * *

Correlation, 1-tailed Sig:

| | COREPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | DEPTH | AGE |
|---|---|---|---|---|---|---|---|---|
| COREPOR | 1.000 | .738 | -.038 | -.317 | -.104 | .099 | -.086 | .197 |
| | .999 | .000 | .430 | .065 | .314 | .322 | .345 | .178 |
| QUARTZ | .738 | 1.000 | -.221 | .062 | -.286 | .051 | -.096 | .272 |
| | .000 | .999 | .150 | .387 | .088 | .406 | .327 | .099 |
| CEMENT | -.038 | -.221 | 1.000 | -.227 | .072 | -.154 | .039 | -.193 |
| | .430 | .150 | .999 | .143 | .370 | .237 | .429 | .183 |
| EPIMAT | -.317 | .062 | -.227 | 1.000 | .064 | -.165 | -.069 | -.194 |
| | .065 | .387 | .143 | .999 | .382 | .220 | .375 | .182 |
| MEANSIZE | -.104 | -.286 | .072 | .064 | 1.000 | -.276 | -.106 | .176 |
| | .314 | .088 | .370 | .382 | .999 | .096 | .310 | .206 |
| SORTING | .099 | .051 | -.154 | -.165 | -.276 | 1.000 | .092 | -.097 |
| | .322 | .406 | .237 | .220 | .096 | .999 | .334 | .325 |
| DEPTH | -.086 | -.096 | .039 | -.069 | -.106 | .092 | 1.000 | .485 |
| | .345 | .327 | .429 | .375 | .310 | .334 | .999 | .008 |
| AGE | .197 | .272 | -.193 | -.194 | .176 | -.097 | .485 | 1.000 |
| | .178 | .099 | .183 | .182 | .206 | .325 | .008 | .999 |

Variable(s) Entered on Step Number 2.. EPIMAT

| | | | | | |
|---|---|---|---|---|---|
| Multiple R | .82245 | Analysis of Variance | | | |
| R Square | .67642 | | DF | Sum of Squares | Mean Square |
| Adjusted R Square | .64560 | Regression | 2 | 196.20035 | 98.10018 |
| Standard Error | 2.11410 | Residual | 21 | 93.85798 | 4.46943 |

F = 21.94916 Signif F = .0000

------------------ Variables in the Equation ------------------

| Variable | B | SE B | Beta | Correl | Part Cor | Partial | T | Sig T |
|---|---|---|---|---|---|---|---|---|
| QUARTZ | .204819 | .033507 | .760244 | .737717 | .758789 | .800125 | 6.113 | .0000 |
| EPIMAT | -.631888 | .215736 | -.364277 | -.317265 | -.363580 | -.538549 | -2.929 | .0080 |
| (Constant) | 25.330639 | 1.074011 | | | | | 23.585 | .0000 |

## Bungil Formation, n = 9.

* * * *  M U L T I P L E   R E G R E S S I O N  * * * *

Correlation, 1-tailed Sig:

| | COREPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | DEPTH | AGE |
|---|---|---|---|---|---|---|---|---|
| COREPOR | 1.000 | .539 | -.905 | -.364 | .186 | -.499 | -.849 | .543 |
| | .999 | .067 | .000 | .168 | .316 | .086 | .002 | .065 |
| QUARTZ | .539 | 1.000 | -.718 | -.887 | -.136 | .066 | -.635 | .063 |
| | .067 | .999 | .015 | .001 | .363 | .433 | .033 | .436 |
| CEMENT | -.905 | -.718 | 1.000 | .588 | -.244 | .328 | .916 | -.596 |
| | .000 | .015 | .999 | .048 | .264 | .195 | .000 | .045 |
| EPIMAT | -.364 | -.887 | .588 | 1.000 | .030 | -.063 | .393 | .059 |
| | .168 | .001 | .048 | .999 | .470 | .436 | .147 | .440 |
| MEANSIZE | .186 | -.136 | -.244 | .030 | 1.000 | -.028 | .007 | .685 |
| | .316 | .363 | .264 | .470 | .999 | .471 | .493 | .021 |
| SORTING | -.499 | .066 | .328 | -.063 | -.028 | 1.000 | .396 | -.290 |
| | .086 | .433 | .195 | .436 | .471 | .999 | .145 | .224 |
| DEPTH | -.849 | -.635 | .916 | .393 | .007 | .396 | 1.000 | -.508 |
| | .002 | .033 | .000 | .147 | .493 | .145 | .999 | .081 |
| AGE | .543 | .063 | -.596 | .059 | .685 | -.290 | -.508 | 1.000 |
| | .065 | .436 | .045 | .440 | .021 | .224 | .081 | .999 |

Variable(s) Entered on Step Number 1.. CEMENT

| | |
|---|---|
| Multiple R | .90532 |
| R Square | .81960 |
| Adjusted R Square | .79383 |
| Standard Error | 4.82400 |

Analysis of Variance

| | DF | Sum of Squares | Mean Square |
|---|---|---|---|
| Regression | 1 | 740.10290 | 740.10290 |
| Residual | 7 | 162.89710 | 23.27101 |

F = 31.80364  Signif F = .0008

------------------ Variables in the Equation ------------------

| Variable | B | SE B | Beta | Correl | Part Cor | Partial | T | Sig T |
|---|---|---|---|---|---|---|---|---|
| CEMENT | -1.910535 | .338779 | -.905320 | -.905320 | -.905320 | -.905320 | -5.639 | .0008 |
| (Constant) | 32.235645 | 2.038844 | | | | | 15.811 | .0000 |

## Griman Creek Formation, n = 26.

**** MULTIPLE REGRESSION ****

Correlation, 1-tailed Sig:

| | COREPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | DEPTH | AGE |
|---|---|---|---|---|---|---|---|---|
| COREPOR | 1.000 | .158 | -.805 | .441 | -.114 | -.094 | .102 | .083 |
| | .999 | .220 | .000 | .012 | .290 | .324 | .310 | .344 |
| QUARTZ | .158 | 1.000 | -.124 | .167 | -.179 | -.175 | .685 | .630 |
| | .220 | .999 | .274 | .207 | .191 | .196 | .000 | .000 |
| CEMENT | -.805 | -.124 | 1.000 | -.518 | -.118 | .297 | -.242 | -.219 |
| | .000 | .274 | .999 | .003 | .282 | .070 | .117 | .141 |
| EPIMAT | .441 | .167 | -.518 | 1.000 | .265 | -.270 | .308 | .286 |
| | .012 | .207 | .003 | .999 | .095 | .091 | .063 | .078 |
| MEANSIZE | -.114 | -.179 | -.118 | .265 | 1.000 | -.541 | -.160 | -.186 |
| | .290 | .191 | .282 | .095 | .999 | .002 | .217 | .181 |
| SORTING | -.094 | -.175 | .297 | -.270 | -.541 | 1.000 | -.104 | -.063 |
| | .324 | .196 | .070 | .091 | .002 | .999 | .307 | .380 |
| DEPTH | .102 | .685 | -.242 | .308 | -.160 | -.104 | 1.000 | .991 |
| | .310 | .000 | .117 | .063 | .217 | .307 | .999 | .000 |
| AGE | .083 | .630 | -.219 | .286 | -.186 | -.063 | .991 | 1.000 |
| | .344 | .000 | .141 | .078 | .181 | .380 | .000 | .999 |

Variable(s) Entered on Step Number 1.. CEMENT

| | | | | | |
|---|---|---|---|---|---|
| Multiple R | .80520 | Analysis of Variance | | | |
| R Square | .64835 | | DF | Sum of Squares | Mean Square |
| Adjusted R Square | .63370 | Regression | 1 | 816.61860 | 816.61860 |
| Standard Error | 4.29593 | Residual | 24 | 442.91987 | 18.45499 |

F = 44.24919 Signif F = .0000

------------------ Variables in the Equation ------------------

| Variable | B | SE B | Beta | Correl | Part Cor | Partial | T | Sig T |
|---|---|---|---|---|---|---|---|---|
| CEMENT | -.871775 | .131054 | -.805200 | -.805200 | -.805200 | -.805200 | -6.652 | .0000 |
| (Constant) | 32.529848 | 1.216520 | | | | | 26.740 | .0000 |

Samples containing <50% detrital quartz;   n = 161.

Correlation, 1-tailed Sig:

| | COREPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | DEPTH | AGE | DEPENV |
|---|---|---|---|---|---|---|---|---|---|
| COREPOR | 1.000 | .158 | -.440 | .062 | -.016 | -.130 | -.531 | -.440 | -.122 |
| | .999 | .023 | .000 | .218 | .421 | .050 | .000 | .000 | .062 |
| QUARTZ | .158 | 1.000 | -.314 | .359 | -.236 | .220 | .333 | .501 | -.059 |
| | .023 | .999 | .000 | .000 | .001 | .002 | .000 | .000 | .228 |
| CEMENT | -.440 | -.314 | 1.000 | -.353 | .239 | .014 | -.079 | -.284 | .052 |
| | .000 | .000 | .999 | .000 | .001 | .428 | .161 | .000 | .255 |
| EPIMAT | .062 | .359 | -.353 | 1.000 | -.262 | .019 | .177 | .352 | .033 |
| | .218 | .000 | .000 | .999 | .000 | .407 | .012 | .000 | .338 |
| MEANSIZE | -.016 | -.236 | .239 | -.262 | 1.000 | -.270 | -.137 | -.424 | .156 |
| | .421 | .001 | .001 | .000 | .999 | .000 | .042 | .000 | .024 |
| SORTING | -.130 | .220 | .014 | .019 | -.270 | 1.000 | .220 | .215 | .035 |
| | .050 | .002 | .428 | .407 | .000 | .999 | .002 | .003 | .330 |
| DEPTH | -.531 | .333 | -.079 | .177 | -.137 | .220 | 1.000 | .782 | -.090 |
| | .000 | .000 | .161 | .012 | .042 | .002 | .999 | .000 | .129 |
| AGE | -.440 | .501 | -.284 | .352 | -.424 | .215 | .782 | 1.000 | -.077 |
| | .000 | .000 | .000 | .000 | .000 | .003 | .000 | .999 | .164 |
| DEPENV | -.122 | -.059 | .052 | .033 | .156 | .035 | -.090 | -.077 | 1.000 |
| | .062 | .228 | .255 | .338 | .024 | .330 | .129 | .164 | .999 |

Variable(s) Entered on Step Number 5..    DEPENV

| | |
|---|---|
| Multiple R | .82758 |
| R Square | .68488 |
| Adjusted R Square | .67472 |
| Standard Error | 4.19943 |

Analysis of Variance

| | DF | Sum of Squares | Mean Square |
|---|---|---|---|
| Regression | 5 | 5940.97832 | 1188.19566 |
| Residual | 155 | 2733.45892 | 17.63522 |

F = 67.37629    Signif F = .0000

------------------------------ Variables in the Equation ------------------------------

| Variable | B | SE B | Beta | Correl | Part Cor | Partial | T | Sig T |
|---|---|---|---|---|---|---|---|---|
| DEPTH | -.006683 | .001988 | -.251670 | -.531115 | -.151600 | -.260722 | -3.362 | .0010 |
| CEMENT | -.635841 | .062467 | -.502422 | -.440387 | -.458950 | -.632958 | -10.179 | .0000 |
| AGE | -.123049 | .017478 | -.579751 | -.439831 | -.317438 | -.492236 | -7.040 | .0000 |
| QUARTZ | .187715 | .027373 | .365926 | .157874 | .309204 | .482470 | 6.858 | .0000 |
| DEPENV | -1.464983 | .469988 | -.141293 | -.121700 | -.140545 | -.242872 | -3.117 | .0022 |
| (Constant) | 46.058477 | 2.433367 | | | | | 18.928 | .0000 |

Samples containing <5% cement; n = 35.

* * * * M U L T I P L E R E G R E S S I O N * * * *

Correlation, 1-tailed Sig:

| | COREPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | DEPTH | AGE | DEPENV |
|---|---|---|---|---|---|---|---|---|---|
| COREPOR | 1.000 | -.021 | -.605 | .082 | -.157 | -.205 | -.277 | -.322 | -.373 |
| | .999 | .452 | .000 | .320 | .184 | .118 | .053 | .030 | .014 |
| QUARTZ | -.021 | 1.000 | -.234 | .349 | -.524 | .510 | .832 | .764 | -.375 |
| | .452 | .999 | .088 | .020 | .001 | .001 | .000 | .000 | .013 |
| CEMENT | -.605 | -.234 | 1.000 | -.345 | .405 | -.091 | -.029 | -.092 | .238 |
| | .000 | .088 | .999 | .021 | .008 | .301 | .434 | .299 | .084 |
| EPIMAT | .082 | .349 | -.345 | 1.000 | -.030 | -.065 | .191 | .250 | .195 |
| | .320 | .020 | .021 | .999 | .433 | .356 | .136 | .074 | .130 |
| MEANSIZE | -.157 | -.524 | .405 | -.030 | 1.000 | -.328 | -.377 | -.538 | .279 |
| | .184 | .001 | .008 | .433 | .999 | .027 | .013 | .000 | .053 |
| SORTING | -.205 | .510 | -.091 | -.065 | -.328 | 1.000 | .591 | .448 | -.092 |
| | .118 | .001 | .301 | .356 | .027 | .999 | .000 | .003 | .299 |
| DEPTH | -.277 | .832 | -.029 | .191 | -.377 | .591 | 1.000 | .864 | -.154 |
| | .053 | .000 | .434 | .136 | .013 | .000 | .999 | .000 | .189 |
| AGE | -.322 | .764 | -.092 | .250 | -.538 | .448 | .864 | 1.000 | -.104 |
| | .030 | .000 | .299 | .074 | .000 | .003 | .000 | .999 | .277 |
| DEPENV | -.373 | -.375 | .238 | .195 | .279 | -.092 | -.154 | -.104 | 1.000 |
| | .014 | .013 | .084 | .130 | .053 | .299 | .189 | .277 | .999 |

Variable(s) Entered on Step Number 3.. DEPENV

| | |
|---|---|
| Multiple R | .76290 |
| R Square | .58202 |
| Adjusted R Square | .54157 |
| Standard Error | 6.09347 |

Analysis of Variance

| | DF | Sum of Squares | Mean Square |
|---|---|---|---|
| Regression | 3 | 1602.77408 | 534.25803 |
| Residual | 31 | 1151.04135 | 37.13037 |

F = 14.38871 Signif F = .0000

------------------------------ Variables in the Equation ------------------------------

| Variable | B | SE B | Beta | Correl | Part Cor | Partial | T | Sig T |
|---|---|---|---|---|---|---|---|---|
| CEMENT | -.699061 | .145396 | -.576197 | -.605036 | -.558289 | -.653577 | -4.808 | .0000 |
| AGE | -.083828 | .024310 | -.403558 | -.321582 | -.400398 | -.526521 | -3.448 | .0016 |
| DEPENV | -2.901610 | 1.253136 | -.277806 | -.373003 | -.268867 | -.383990 | -2.315 | .0274 |
| (Constant) | 45.999996 | 5.175570 | | | | | 8.888 | .0000 |

## APPENDIX 5.1. CORRELATION MATRIX, ANTI-IMAGE CORRELATION (AIC) MATRIX, UNROTATED AND ROTATED VARIMAX AND OBLIMIN FACTOR PATTERN/STRUCTURE MATRICES OF DIFFERENT FORMATIONS AND SUBSET OF SAMPLES

CORRELATION MATRIX:

| | TSPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | LOGPERM | AGE | DEPTH |
|---|---|---|---|---|---|---|---|---|---|
| TSPOR | 1.00000 | | | | | | | | |
| QUARTZ | .67671 | 1.00000 | | | | | | | |
| CEMENT | .41911 | .42736 | 1.00000 | | | | | | |
| EPIMAT | -.06076 | .18386 | -.06301 | 1.00000 | | | | | |
| MEANSIZE | -.23239 | -.20632 | -.02114 | .26435 | 1.00000 | | | | |
| SORTING | .11338 | .40784 | -.01951 | -.04708 | -.44151 | 1.00000 | | | |
| LOGPERM | .74868 | .61694 | .16655 | -.01090 | -.43799 | .23030 | 1.00000 | | |
| AGE | .33076 | .54964 | .34052 | .32211 | .41368 | -.05471 | .12537 | 1.00000 | |
| DEPTH | .12557 | .47748 | .31859 | .26448 | .30477 | .01680 | -.07703 | .69516 | 1.00000 |

KAISER-MEYER-OLKIN MEASURE OF SAMPLING ADEQUACY = .67895

BARTLETT TEST OF SPHERICITY = 217.38216, SIGNIFICANCE = .00000

1-TAILED SIG. OF CORRELATION MATRIX:

' . ' IS PRINTED FOR DIAGONAL ELEMENTS.

| | TSPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | LOGPERM | AGE | DEPTH |
|---|---|---|---|---|---|---|---|---|---|
| TSPOR | . | | | | | | | | |
| QUARTZ | .00000 | . | | | | | | | |
| CEMENT | .00110 | .00088 | . | | | | | | |
| EPIMAT | .33594 | .07826 | .33022 | . | | | | | |
| MEANSIZE | .05040 | .07317 | .44146 | .03043 | . | | | | |
| SORTING | .21414 | .00149 | .44595 | .37142 | .00039 | . | | | |
| LOGPERM | .00000 | .00000 | .12139 | .46974 | .00065 | .05199 | . | | |
| AGE | .00888 | .00001 | .00724 | .01038 | .00127 | .35149 | .19036 | . | |
| DEPTH | .18997 | .00020 | .01135 | .03036 | .01483 | .45342 | .29554 | .00000 | . |

FACTOR MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| QUARTZ | .93313 | | |
| TSPOR | .80162 | | |
| LOGPERM | .67624 | -.51545 | |
| AGE | .65061 | .63193 | |
| CEMENT | .57028 | | -.48658 |
| MEANSIZE | | .83441 | |
| DEPTH | .52672 | .63790 | |
| SORTING | | -.45510 | .64385 |
| EPIMAT | | .47710 | .53631 |

PATTERN MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| TSPOR | .88734 | | |
| CEMENT | .70981 | | |
| LOGPERM | .70254 | | |
| QUARTZ | .67499 | | |
| DEPTH | | .78425 | |
| AGE | | .76536 | |
| EPIMAT | | .71170 | |
| SORTING | | | .84853 |
| MEANSIZE | | .49146 | -.61644 |

ROTATED FACTOR MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| TSPOR | .88224 | | |
| CEMENT | .70096 | | |
| LOGPERM | .70090 | | .47294 |
| QUARTZ | .69988 | .46627 | |
| DEPTH | | .79905 | |
| AGE | | .79398 | |
| EPIMAT | | .68485 | |
| SORTING | | | .84116 |
| MEANSIZE | | .49986 | -.66320 |

STRUCTURE MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| TSPOR | .89600 | | |
| QUARTZ | .76797 | .47567 | |
| LOGPERM | .73597 | | .49339 |
| CEMENT | .67945 | | |
| AGE | | .81897 | |
| DEPTH | | .81364 | |
| EPIMAT | | .66549 | |
| SORTING | | | .83747 |
| MEANSIZE | | .52025 | -.68782 |

CORRELATION MATRIX:

| | TSPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | LOGPERM | AGE | DEPTH |
|---|---|---|---|---|---|---|---|---|---|
| TSPOR | 1.00000 | | | | | | | | |
| QUARTZ | .49021 | 1.00000 | | | | | | | |
| CEMENT | -.75394 | -.12369 | 1.00000 | | | | | | |
| EPIMAT | .42590 | .16713 | -.51793 | 1.00000 | | | | | |
| MEANSIZE | -.13162 | -.17911 | -.11847 | .26533 | 1.00000 | | | | |
| SORTING | -.22897 | -.17492 | .29698 | -.27014 | -.54064 | 1.00000 | | | |
| LOGPERM | .86067 | .27617 | -.79763 | .36761 | -.23289 | -.07343 | 1.00000 | | |
| AGE | .45401 | .63004 | -.21907 | .28586 | -.18631 | -.06275 | .22043 | 1.00000 | |
| DEPTH | .49234 | .68527 | -.24224 | .30804 | -.16013 | -.10393 | .25059 | .99064 | 1.00000 |

KAISER-MEYER-OLKIN MEASURE OF SAMPLING ADEQUACY = .67886

BARTLETT TEST OF SPHERICITY = 202.40046, SIGNIFICANCE = .00000

1-TAILED SIG. OF CORRELATION MATRIX:

' . ' IS PRINTED FOR DIAGONAL ELEMENTS.

| | TSPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | LOGPERM |
|---|---|---|---|---|---|---|---|
| TSPOR | . | | | | | | |
| QUARTZ | .00551 | . | | | | | |
| CEMENT | .00000 | .27359 | . | | | | |
| EPIMAT | .01503 | .20724 | .00336 | . | | | |
| MEANSIZE | .26079 | .19065 | .28218 | .09510 | . | | |
| SORTING | .13026 | .19637 | .07033 | .09099 | .00218 | . | |
| LOGPERM | .00000 | .08602 | .00000 | .03233 | .12611 | .36073 | . |
| AGE | .00991 | .00028 | .14114 | .07843 | .18107 | .38035 | .13961 |
| DEPTH | .00531 | .00006 | .11657 | .06289 | .21729 | .30669 | .10846 |

PATTERN MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| LOGPERM | .99626 | | |
| CEMENT | -.92957 | | |
| TSPOR | .83377 | | |
| EPIMAT | .45549 | | |
| DEPTH | | .97568 | |
| AGE | | .96547 | |
| QUARTZ | | .82609 | |
| MEANSIZE | | | .90351 |
| SORTING | | | -.81540 |

STRUCTURE MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| LOGPERM | .94234 | | |
| CEMENT | -.91614 | | |
| TSPOR | .91369 | .53813 | |
| EPIMAT | .56858 | | .50564 |
| DEPTH | | .97209 | |
| AGE | | .95286 | |
| QUARTZ | | .82767 | |
| MEANSIZE | | | .87718 |
| SORTING | | | -.82693 |

PC EXTRACTED 3 FACTORS.

FACTOR MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| TSPOR | .89011 | | |
| DEPTH | .77035 | .47675 | |
| LOGPERM | .74610 | | -.56701 |
| AGE | .73615 | .50349 | |
| CEMENT | -.72225 | .51479 | |
| QUARTZ | .65966 | | |
| EPIMAT | .57237 | | |
| MEANSIZE | | -.67929 | .60639 |
| SORTING | | .55931 | -.55544 |

ROTATED FACTOR MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| LOGPERM | .95036 | | |
| CEMENT | -.90706 | | |
| TSPOR | .86131 | | |
| EPIMAT | .50817 | | .46711 |
| DEPTH | | .95738 | |
| AGE | | .94339 | |
| QUARTZ | | .81328 | |
| MEANSIZE | | | .88786 |
| SORTING | | | -.81829 |

Samples containing detrital quartz content ≥ 50%; n = 50.

## - - - - - - - - - - - - - - - - - - - - - - - - F A C T O R   A N A L Y S I S - - - - - - - - - - - - - - - - - - - -

CORRELATION MATRIX:

| | TSPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | LOGPERM | AGE | DEPTH | DEPENV |
|---|---|---|---|---|---|---|---|---|---|---|
| TSPOR | 1.00000 | | | | | | | | | |
| QUARTZ | -.24807 | 1.00000 | | | | | | | | |
| CEMENT | -.14316 | .22785 | 1.00000 | | | | | | | |
| EPIMAT | -.26925 | -.04456 | -.12624 | 1.00000 | | | | | | |
| MEANSIZE | -.23694 | -.35487 | .10813 | .14614 | 1.00000 | | | | | |
| SORTING | -.12114 | .29613 | .03938 | -.19471 | -.43859 | 1.00000 | | | | |
| LOGPERM | .66482 | .31213 | -.06347 | -.13095 | -.45958 | .09477 | 1.00000 | | | |
| AGE | -.27838 | .46380 | .42430 | .07681 | -.00831 | .08939 | -.14700 | 1.00000 | | |
| DEPTH | -.41336 | .61760 | .48632 | -.01313 | .00617 | .12052 | -.18065 | .89338 | 1.00000 | |
| DEPENV | .02895 | -.40553 | -.08376 | .13610 | .14383 | -.15066 | -.24995 | -.30420 | -.41055 | 1.00000 |

KAISER-MEYER-OLKIN MEASURE OF SAMPLING ADEQUACY = .54572

BARTLETT TEST OF SPHERICITY = 243.05424, SIGNIFICANCE = .00000

1-TAILED SIG. OF CORRELATION MATRIX:

' . ' IS PRINTED FOR DIAGONAL ELEMENTS.

| | TSPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | LOGPERM | AGE | DEPTH | DEPENV |
|---|---|---|---|---|---|---|---|---|---|---|
| TSPOR | . | | | | | | | | | |
| QUARTZ | .04119 | . | | | | | | | | |
| CEMENT | .16064 | .05576 | . | | | | | | | |
| EPIMAT | .02933 | .37931 | .19118 | . | | | | | | |
| MEANSIZE | .04879 | .00572 | .22739 | .15560 | . | | | | | |
| SORTING | .20101 | .01839 | .39301 | .08771 | .00072 | . | | | | |
| LOGPERM | .00000 | .01367 | .33074 | .18235 | .00039 | .25635 | . | | | |
| AGE | .02514 | .00035 | .00107 | .25182 | .47715 | .26852 | .15417 | . | | |
| DEPTH | .00142 | .00000 | .00017 | .46395 | .48304 | .20223 | .10466 | .00000 | . | |
| DEPENV | .42090 | .00174 | .28154 | .17299 | .15951 | .14816 | .04001 | .01586 | .00153 | . |

PC EXTRACTED 4 FACTORS.

FACTOR MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 | FACTOR 4 |
|---|---|---|---|---|
| DEPTH | .94354 | | | |
| AGE | .84901 | | | |
| QUARTZ | .74443 | | | |
| CEMENT | .53842 | | | |
| DEPENV | -.51080 | | | |
| LOGPERM | | .84554 | | |
| MEANSIZE | | -.74521 | | |
| TSPOR | -.47091 | .61872 | .49398 | |
| SORTING | | | -.62905 | |
| EPIMAT | | | | .77106 |

ROTATED FACTOR MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 | FACTOR 4 |
|---|---|---|---|---|
| DEPTH | .92409 | | | |
| AGE | .86096 | | | |
| QUARTZ | .73233 | | | |
| DEPENV | -.57795 | | | |
| CEMENT | .53569 | | | .52232 |
| LOGPERM | | .91169 | | |
| TSPOR | | .83813 | | |
| SORTING | | | .85931 | |
| MEANSIZE | | | -.73704 | |
| EPIMAT | | | | -.85905 |

PATTERN MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 | FACTOR 4 |
|---|---|---|---|---|
| DEPTH | .91611 | | | |
| AGE | .86246 | | | |
| QUARTZ | .72369 | | | |
| DEPENV | -.59303 | | | |
| CEMENT | .53366 | | | -.51062 |
| LOGPERM | | .91224 | | |
| TSPOR | | .85825 | | |
| SORTING | | | -.90136 | |
| MEANSIZE | | | .69698 | |
| EPIMAT | | | | .85696 |

STRUCTURE MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 | FACTOR 4 |
|---|---|---|---|---|
| DEPTH | .93251 | | | |
| AGE | .85989 | | | |
| QUARTZ | .75479 | | -.48032 | |
| DEPENV | -.57805 | | | |
| LOGPERM | | .92319 | | |
| TSPOR | | .83712 | | |
| SORTING | | | -.84577 | |
| MEANSIZE | | -.47686 | .77521 | |
| EPIMAT | | | | .84300 |
| CEMENT | .53862 | | | -.54692 |

## Samples containing <50% detrital quartz; n = 161

CORRELATION MATRIX:

| | TSPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | LOGPERM | AGE | DEPTH | DEPENV |
|---|---|---|---|---|---|---|---|---|---|---|
| TSPOR | 1.00000 | | | | | | | | | |
| QUARTZ | .24806 | 1.00000 | | | | | | | | |
| CEMENT | -.22707 | -.31413 | 1.00000 | | | | | | | |
| EPIMAT | .00017 | .35895 | -.35295 | 1.00000 | | | | | | |
| MEANSIZE | -.12649 | -.23593 | .23860 | -.26164 | 1.00000 | | | | | |
| SORTING | -.12362 | .22025 | .01445 | .01861 | -.27009 | 1.00000 | | | | |
| LOGPERM | .71961 | .28975 | -.52083 | .07255 | -.25660 | -.09740 | 1.00000 | | | |
| AGE | -.32633 | .50079 | -.28389 | .35225 | -.42405 | .21524 | -.09721 | 1.00000 | | |
| DEPTH | -.36374 | .33341 | -.07856 | .17688 | -.13668 | .22048 | -.30851 | .78239 | 1.00000 | |
| DEPENV | -.09635 | -.05918 | .05218 | .03310 | .15604 | .03497 | -.14256 | -.07743 | -.08971 | 1.00000 |

KAISER-MEYER-OLKIN MEASURE OF SAMPLING ADEQUACY = .56234

BARTLETT TEST OF SPHERICITY = 641.02257, SIGNIFICANCE = .00000

1-TAILED SIG. OF CORRELATION MATRIX:

' . ' IS PRINTED FOR DIAGONAL ELEMENTS.

| | TSPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | LOGPERM | AGE | DEPTH | DEPENV |
|---|---|---|---|---|---|---|---|---|---|---|
| TSPOR | . | | | | | | | | | |
| QUARTZ | .00076 | . | | | | | | | | |
| CEMENT | .00189 | .00002 | . | | | | | | | |
| EPIMAT | .49916 | .00000 | .00000 | . | | | | | | |
| MEANSIZE | .05492 | .00129 | .00115 | .00040 | . | | | | | |
| SORTING | .05910 | .00250 | .42783 | .40738 | .00027 | . | | | | |
| LOGPERM | .00000 | .00010 | .00000 | .18020 | .00051 | .10950 | . | | | |
| AGE | .00001 | .00000 | .00013 | .00000 | .00000 | .00305 | .10996 | . | | |
| DEPTH | .00000 | .00001 | .16095 | .01240 | .04191 | .00247 | .00003 | .00000 | . | |
| DEPENV | .11203 | .22791 | .25547 | .33842 | .02404 | .32984 | .03562 | .16446 | .12889 | . |

## Samples containing <50% detrital quartz (contd.)

PC EXTRACTED 4 FACTORS.

FACTOR MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 | FACTOR 4 |
|---|---|---|---|---|
| AGE | .84828 | | | |
| QUARTZ | .72010 | | | |
| DEPTH | .63797 | -.56702 | | |
| MEANSIZE | -.59186 | | | |
| EPIMAT | .57217 | | .48499 | |
| CEMENT | -.54098 | -.47237 | | |
| LOOPERM | | .89222 | | |
| TSPOR | | .86435 | | |
| SORTING | | | -.45156 | .67839 |
| DEPENV | | | .64091 | .65696 |

ROTATED FACTOR MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 | FACTOR 4 |
|---|---|---|---|---|
| EPIMAT | .73398 | | | |
| AGE | .70137 | .48088 | | |
| CEMENT | -.69119 | | | |
| QUARTZ | .65678 | | | |
| TSPOR | | -.86908 | | |
| LOOPERM | | -.85686 | | |
| DEPTH | .47763 | .65247 | | |
| SORTING | | | .89323 | |
| MEANSIZE | | | -.58554 | |
| DEPENV | | | | .93865 |

PATTERN MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 | FACTOR 4 |
|---|---|---|---|---|
| EPIMAT | .78270 | | | |
| CEMENT | -.71952 | | | |
| QUARTZ | .60313 | | | |
| AGE | .60067 | -.54061 | | |
| TSPOR | | .86175 | | |
| LOOPERM | | .82443 | | |
| DEPTH | | -.69869 | | |
| DEPENV | | | .96902 | |
| SORTING | | | | .94007 |
| MEANSIZE | | | | -.56500 |

STRUCTURE MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 | FACTOR 4 |
|---|---|---|---|---|
| EPIMAT | .72069 | | | |
| CEMENT | -.71613 | | | |
| QUARTZ | .68986 | | | .45483 |
| AGE | .68124 | -.52919 | | .46834 |
| TSPOR | | .86184 | | |
| LOOPERM | | .83805 | | |
| DEPTH | | -.68519 | | |
| DEPENV | | | .91294 | |
| SORTING | | | | .86638 |
| MEANSIZE | | | | -.64006 |

Samples containing ≥ 5% cement; n = 35.

CORRELATION MATRIX:

| | TSPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | LOGPERM | AGE | DEPTH | DEPENV |
|---|---|---|---|---|---|---|---|---|---|---|
| TSPOR | 1.00000 | | | | | | | | | |
| QUARTZ | .34799 | 1.00000 | | | | | | | | |
| CEMENT | -.46535 | -.23446 | 1.00000 | | | | | | | |
| EPIMAT | .00373 | .34916 | -.34486 | 1.00000 | | | | | | |
| MEANSIZE | -.33301 | -.52395 | .40531 | -.02951 | 1.00000 | | | | | |
| SORTING | -.09427 | .50990 | -.09132 | -.06470 | -.32794 | 1.00000 | | | | |
| LOGPERM | .71933 | .44315 | -.59689 | .18688 | -.58110 | .10333 | 1.00000 | | | |
| AGE | .01233 | .76370 | -.09227 | .24982 | -.53847 | .44784 | .23100 | 1.00000 | | |
| DEPTH | .12438 | .83238 | -.02907 | .19054 | -.37710 | .59105 | .18772 | .86442 | 1.00000 | |
| DEPENV | -.46428 | -.37452 | .23785 | .19525 | .27863 | -.09208 | -.39030 | -.10370 | -.15358 | 1.00000 |

KAISER-MEYER-OLKIN MEASURE OF SAMPLING ADEQUACY = .59484

BARTLETT TEST OF SPHERICITY = 216.12640, SIGNIFICANCE = .00000

1-TAILED SIG. OF CORRELATION MATRIX:

' . ' IS PRINTED FOR DIAGONAL ELEMENTS.

| | TSPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | LOGPERM | AGE | DEPTH | DEPENV |
|---|---|---|---|---|---|---|---|---|---|---|
| TSPOR | . | | | | | | | | | |
| QUARTZ | .02026 | . | | | | | | | | |
| CEMENT | .00242 | .08760 | . | | | | | | | |
| EPIMAT | .49151 | .01990 | .02124 | . | | | | | | |
| MEANSIZE | .02530 | .00062 | .00786 | .43318 | . | | | | | |
| SORTING | .29506 | .00088 | .30093 | .35597 | .02723 | . | | | | |
| LOGPERM | .00000 | .00384 | .00008 | .14120 | .00013 | .27737 | . | | | |
| AGE | .47198 | .00000 | .29903 | .07390 | .00042 | .00349 | .09092 | . | | |
| DEPTH | .23827 | .00000 | .43416 | .13645 | .01277 | .00009 | .14009 | .00000 | . | |
| DEPENV | .00248 | .01333 | .08443 | .13050 | .05253 | .29942 | .01023 | .27664 | .18921 | . |

## Samples containing $\geq$ 5% cement (contd.)

PC EXTRACTED 3 FACTORS.

FACTOR MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| QUARTZ | .89908 | | |
| DEPTH | .76380 | .54502 | |
| AGE | .75891 | .51270 | |
| MEANSIZE | -.73779 | | |
| LOGPERM | .68734 | -.58100 | |
| SORTING | .52124 | .48271 | |
| TSPOR | .50915 | -.68923 | |
| CEMENT | -.49383 | .55174 | |
| EPIMAT | | | .88835 |
| DEPENV | | | .53141 |

ROTATED FACTOR MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| DEPTH | .93630 | | |
| AGE | .89845 | | |
| QUARTZ | .84295 | | |
| SORTING | .73394 | | |
| LOGPERM | | .88050 | |
| TSPOR | | .85885 | |
| CEMENT | | -.73104 | |
| DEPENV | | -.59787 | .50180 |
| MEANSIZE | -.51256 | -.55250 | |
| EPIMAT | | | .91485 |

PATTERN MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| DEPTH | .94935 | | |
| AGE | .90834 | | |
| QUARTZ | .82025 | | |
| SORTING | .75396 | | |
| LOGPERM | | -.87702 | |
| TSPOR | | -.87539 | |
| CEMENT | | .74742 | |
| DEPENV | | .58438 | .52207 |
| MEANSIZE | -.46485 | .50028 | |
| EPIMAT | | | .90975 |

STRUCTURE MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| DEPTH | .93617 | | |
| AGE | .90235 | | |
| QUARTZ | .88231 | -.45841 | |
| SORTING | .72084 | | |
| LOGPERM | | -.89587 | |
| TSPOR | | -.84893 | |
| CEMENT | | .73896 | |
| MEANSIZE | -.57360 | .60074 | |
| DEPENV | | .59522 | .50604 |
| EPIMAT | | | .91425 |

Samples containing <5% cement; n = 176.

CORRELATION MATRIX:

| | TSPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | LOGPERM | AGE | DEPTH | DEPENV |
|---|---|---|---|---|---|---|---|---|---|---|
| TSPOR | 1.00000 | | | | | | | | | |
| QUARTZ | .40419 | 1.00000 | | | | | | | | |
| CEMENT | .24345 | .20135 | 1.00000 | | | | | | | |
| EPIMAT | -.05703 | .25462 | -.08670 | 1.00000 | | | | | | |
| MEANSIZE | -.20937 | -.28285 | .11948 | -.18971 | 1.00000 | | | | | |
| SORTING | .04699 | .34564 | -.01504 | .02381 | -.39212 | 1.00000 | | | | |
| LOGPERM | .76583 | .40517 | .04885 | -.06027 | -.24927 | .08252 | 1.00000 | | | |
| AGE | -.14678 | .55805 | -.00789 | .31800 | -.35500 | .24889 | -.12604 | 1.00000 | | |
| DEPTH | -.14665 | .52116 | .20098 | .18579 | -.15148 | .22934 | -.19270 | .82851 | 1.00000 | |
| DEPENV | -.19169 | -.37459 | -.18687 | -.05287 | .21719 | -.14557 | -.25134 | -.31252 | -.35643 | 1.00000 |

KAISER-MEYER-OLKIN MEASURE OF SAMPLING ADEQUACY = .63710

BARTLETT TEST OF SPHERICITY = 751.71584, SIGNIFICANCE = .00000

1-TAILED SIG. OF CORRELATION MATRIX:

' . ' IS PRINTED FOR DIAGONAL ELEMENTS.

| | TSPOR | QUARTZ | CEMENT | EPIMAT | MEANSIZE | SORTING | LOGPERM | AGE | DEPTH | DEPENV |
|---|---|---|---|---|---|---|---|---|---|---|
| TSPOR | . | | | | | | | | | |
| QUARTZ | .00000 | . | | | | | | | | |
| CEMENT | .00057 | .00368 | . | | | | | | | |
| EPIMAT | .22607 | .00032 | .12627 | . | | | | | | |
| MEANSIZE | .00265 | .00007 | .05712 | .00584 | . | | | | | |
| SORTING | .26785 | .00000 | .42149 | .37687 | .00000 | . | | | | |
| LOGPERM | .00000 | .00000 | .25986 | .21341 | .00042 | .13813 | . | | | |
| AGE | .02595 | .00000 | .45861 | .00001 | .00000 | .00043 | .04778 | . | | |
| DEPTH | .02606 | .00000 | .00374 | .00678 | .02238 | .00110 | .00520 | .00000 | . | |
| DEPENV | .00541 | .00000 | .00651 | .24292 | .00189 | .02695 | .00038 | .00001 | .00000 | . |

## Samples containing <5% cement (contd.).

PC EXTRACTED 3 FACTORS.

FACTOR MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| QUARTZ | .84287 | | |
| AGE | .77069 | -.50655 | |
| DEPTH | .71845 | -.50855 | |
| DEPENV | -.58425 | | |
| SORTING | .48463 | | |
| EPIMAT | | | |
| TSPOR | | .85722 | |
| LOGPERM | | .85077 | |
| CEMENT | | | .76552 |
| MEANSIZE | -.54780 | | .57291 |

PATTERN MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| DEPTH | .89206 | | |
| AGE | .75215 | | |
| QUARTZ | .66702 | | |
| DEPENV | -.57427 | | |
| LOGPERM | | .91704 | |
| TSPOR | | .90976 | |
| MEANSIZE | | | .73867 |
| CEMENT | .56462 | | .66283 |
| SORTING | | | -.53178 |
| EPIMAT | | | |

ROTATED FACTOR MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| DEPTH | .87538 | | |
| AGE | .76484 | | .45490 |
| QUARTZ | .69378 | | |
| DEPENV | -.57560 | | |
| TSPOR | | .91214 | |
| LOGPERM | | .91015 | |
| MEANSIZE | | | -.73841 |
| CEMENT | .50667 | | -.59223 |
| SORTING | | | .54861 |
| EPIMAT | | | |

STRUCTURE MATRIX:

| | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|
| DEPTH | .86735 | | |
| AGE | .79425 | | -.52447 |
| QUARTZ | .75591 | | |
| DEPENV | -.59793 | | |
| TSPOR | | .91422 | |
| LOGPERM | | .90752 | |
| MEANSIZE | | | .74222 |
| SORTING | | | -.56349 |
| CEMENT | | | .54834 |
| EPIMAT | | | -.46323 |