

SYNTHESIS AND CONCLUSIONS

The Ipswich Basin (Fig 6.1) contains a basal sequence of felsic and mafic volcanic rocks which together with the Agnes Water Volcanics (Day *et al.*, 1982), Aranbanga Beds (Day *et al.*, 1982; Stephens, 1986, 1992), Mount Byron Volcanics (Day *et al.*, 1982), Muncon Volcanics (Day *et al.*, 1982; Stephens, 1992), North Arm Volcanics (Ashley & Andrew, 1992; Ashley & Dickie, 1988; Day *et al.*, 1982), and numerous plutonic rocks, form a major silicic igneous province of Late Triassic age in southeast Queensland and northeast New South Wales. Further south in New South Wales, magmatism of a similar age produced the plutons and volcanics in and to the north of the Lorne Basin, including the Werrikimbe ignimbrite (228-222 Ma) (Veevers *et al.*, 1994a).

6.0 Tectonic Setting in the Late Triassic

Recent studies of the Triassic magmatism have been carried out by Stephens (1992) and Gust *et al.* (1993, 1996). This work has enabled models to be proposed for the tectonic development of eastern Australia during the Late Triassic. Stephens (1992) proposed a model whereby the eastern Australian crust during the Triassic consisted entirely of accreted Palaeozoic crust. Gust *et al.* (1996) suggested that from the Mid Carboniferous to the Mid Triassic there were repeated cycles of convergence and extensional tectonics related to subduction, which migrated to the east. The last phase of subduction occurred from about 250-230 Ma (Gust *et al.*, 1996), resulting in extensive orogenic calc-alkaline volcanism and magmatism throughout eastern Australia, with a peak at about 240 Ma (Stephens, 1992). This activity waned over the next 10 Ma, with the last orogenic intrusions in eastern Australia being emplaced at about 230 Ma (Stephens, 1992) during a transition from subduction to back-arc extension, including transtensional tectonics (O'Brien *et al.*, 1994). This manifested itself with the development of volcanic and epiclastic basins in eastern Australia, including small pull-apart and rift-related basins such as the Ipswich Basin.

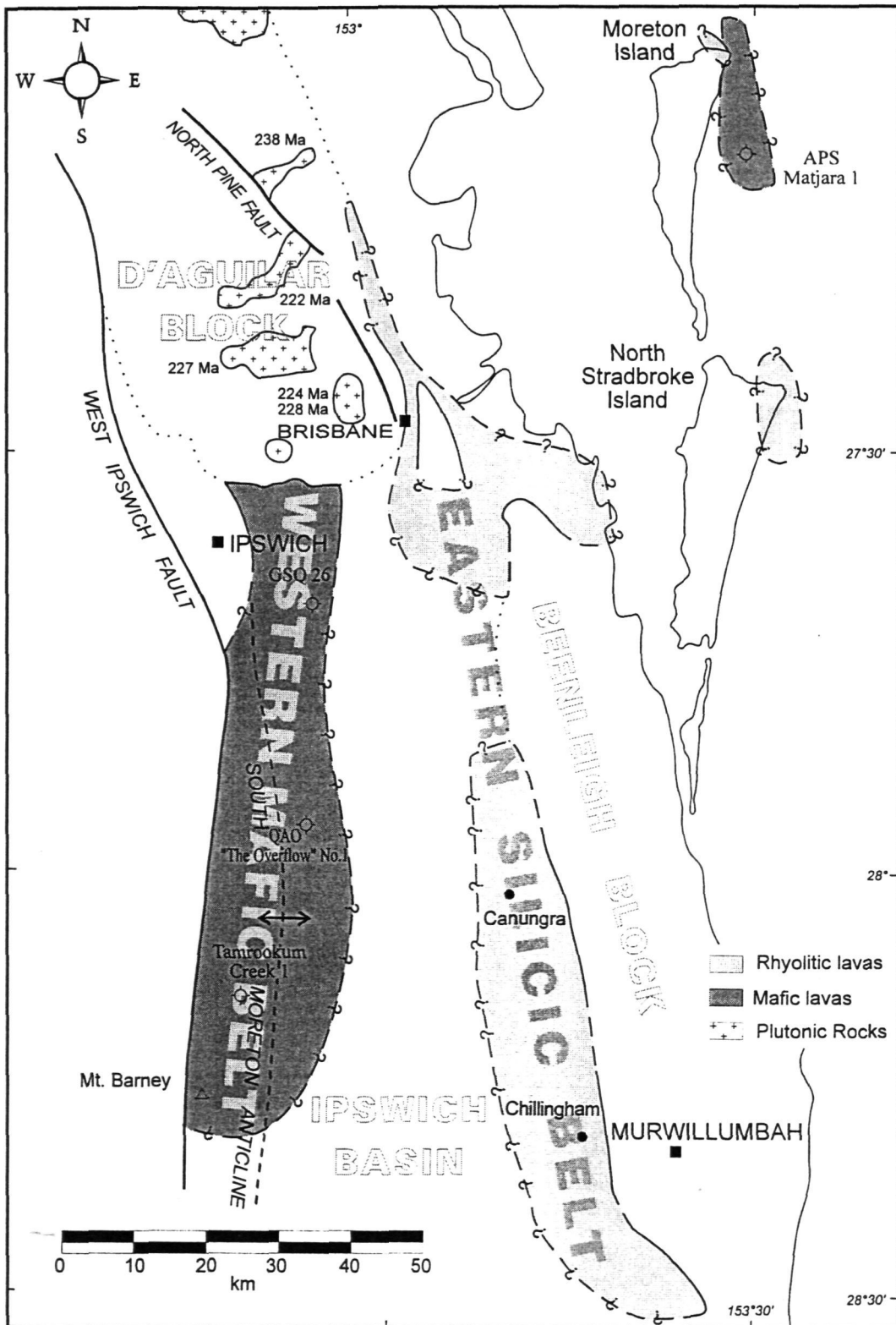


Figure 6.1 Schematic distribution of early mafic volcanism, and later silicic volcanism in the Ipswich Basin, and plutonism in the adjacent D'Aguilar Block. Dotted lines indicate the boundaries of structural blocks and/or the Ipswich Basin. Dashed lines with question marks indicate the unknown limits to the volcanic belts. The West Ipswich Fault and South Moreton Anticline are after O'Brien *et al.* (1991), and the plutonic rocks and North Pine Fault are after Whitaker and Green (1980). The re-calculated date of the Enoggera Granite is 228 ± 7 Ma (C.G. Murray, *pers. comm.*, 1997).

6.1 Plutonic Rocks of the D'Aguilar Block

I postulate that the granites were intruded into the South D'Aguilar Block before the inception of the Ipswich Basin (230 Ma) by accepting the oldest radiometric date, 238 Ma (K/Ar) from the Dayboro Tonalite (Cranfield *et al.*, 1976) as the minimum age of the plutons, and adjudge all other younger dates as being reset by the magmatism associated with the Ipswich Basin. This explains the age anomaly across the North Pine Fault between the Mount Samson Granodiorite (224 Ma) (closest to the volcanic rocks) and the Dayboro Tonalite (238 Ma) (farthest from the volcanic rocks). Shaw's (*pers. comm.*) biotite Rb/Sr date of 150 Ma from the Mount Samson Granodiorite indicates a reset. The only way to resolve the problem conclusively would be to obtain U/Pb zircon ages on both the Brisbane Tuff and the plutons of the D'Aguilar Block.

The plutonic rocks possess a distinctive volcanic-arc signature (lower TiO_2 , Y, Nb) which preceded the volcanic rocks of the younger Ipswich Basin, with their within-plate signature. The granites in the South D'Aguilar Block were probably part of a volcanic-arc, and the succeeding Ipswich Basin volcanics were part of a back-arc rift basin superimposed on the arc. The South D'Aguilar Block occupied the high ground overlooking the valleys in which the Ipswich Basin volcanics were deposited, in a geography similar to that of today, although of much greater relief. The granites were not unroofed until the Late Triassic, as evident by granite clasts deposited in the 213 Ma (Norian) (Veevers *et al.*, 1994a) Bundamba Group of the Clarence-Moreton Basin (Cranfield *et al.*, 1989).

Accordingly I interpret the plutonic rocks as associated with an earlier separate episode of magmatism, perhaps related to the Early-Middle Triassic plutonism of the New England Batholith (Gust *et al.*, 1993, 1996)

6.2 Interpreted Geophysical Data

6.2.1 Magnetic Data

Wellman *et al.* (1994) compiled and interpreted gravity and magnetic data over the Clarence-Moreton Basin, which, overlapping the Ipswich Basin, include data relevant to the northern 160 km of the Ipswich Basin (Fig 6.2).

6.2.1.1 The D'Aguilar Block, Northbrook Block, and Esk Trough

Granites of the D'Aguilar Block feature prominently in the magnetic data on the northern third of the map (Fig 6.2), and are responsible for anomalies 1 (Neurum Tonalite), 4 (Dayboro Tonalite), 6 (Mount Samson Granodiorite), 7 (Samford Granodiorite), 9 (Enoggera Granite), and 10 (Karana Quartz Diorite). The magnetic anomalies suggest a sub-surface connection between the Enoggera Granite and the Samford Granodiorite. The North Pine Fault, which is inferred to dislocate the Mount Samson Granodiorite and the Dayboro Tonalite, shows prominently on magnetic data, truncating both intrusions. The Bracalba Fault, the inferred eastern boundary of the D'Aguilar Block, truncates the Dayboro Tonalite in the magnetic data, a feature not observed in outcrops, and supports the idea that the D'Aguilar Block is fault bounded, and that the granites, whose chemistry is distinct from the Ipswich Basin volcanic rocks, are restricted to this structural block.

The western margin of the D'Aguilar Block is marked by a prominent magnetic anomaly, probably caused in part by a Permian serpentinite belt emplaced along the western limit of the block, and also in part by the mafic volcanic rocks of outliers of the Esk Trough west of the D'Aguilar Block. Other anomalies in this region correspond with the bifurcating West Ipswich Fault / Great Moreton Fault, whose segments isolate the magnetically weak marine sedimentary rocks of the Northbrook Block (2). The Esk Trough (3), a prominent magnetic high, reflects the extensive mafic volcanic rocks and ultramafic intrusive rocks.

6.2.1.2 Tertiary Igneous Activity

Most of the anomalies in the southern half of the map can be attributed to Tertiary magmatism (Fig 6.2). Feature 14 corresponds to the Focal Peak volcanic centre, 17 to the Mount Barney Igneous complex, 20 to the Mount Warning Volcanic centre, 19 to the Lamington Plateau, and 18 to lava flows near the coast, both related to Mt Warning. Feature 18 is interpreted by Wellman *et al.* (1994) as a steep-sided Tertiary intrusion, but basaltic lava crops out at least on the on-shore portion of this anomaly. Feature 22 corresponds with the outcrop of a hitherto unrecorded granite intruding the Clarence-Moreton Basin and Chillingham Volcanics, probably related to the nearby

Tertiary Mount Warning Complex. Anomalies 21 are probably small Tertiary volcanic centres.

6.2.1.3 Anomalies of Uncertain Origin

Two prominent offshore anomalies in the northern half of the map are worth comment. Feature 5 is an elongate anomaly in Moreton Bay between Moreton Island and Redcliff. No outcrops, islands, or offshore drill holes hint at its source. Given the presence of Tertiary lava flows at Redcliff, it is most likely that this anomaly is related to Tertiary magmatism.

Feature 8 extends offshore from Stradbroke Island and presumably continues eastward of Wellman *et al.*'s (1994) map area. The anomaly coincides with the part of the island which contains the rhyolitic lavas, and a weak gravity anomaly. No other rhyolitic lavas of the Ipswich Basin have discernible magnetic anomalies associated with them, and the strong anomaly near Stradbroke Island may indicate the source pluton for these volcanic rocks.

6.2.1.4 Ipswich Basin

The South Moreton Anticline (Fig. 6.2, O'Brien *et al.*, 1991) correlates with a prominent magnetic anomaly. A steep magnetic gradient east of the anticline corresponds with the asymmetrical geometry (shallow to the west, steep to the east) inferred for the anticline by Korsch *et al.* (1989) from available seismic data. West of the anticline a gentle anomaly perhaps indicates a thinner, gently-dipping portion of the Ipswich Basin, possibly containing a younger sedimentary sequence without mafic volcanic rocks.

In the northern section of the basin where Korsch *et al.* (1989) interpreted seismic data, a considerably thinner sequence of Ipswich Basin sedimentary rocks is inferred west of the anticline, as suggested by the magnetics. Surface mapping in the area shows that the Ipswich Basin rocks west of the anticline contain no volcanic rocks, most apparently belonging to the volcanic-free Brassall Subgroup. Contrasting with this, further to the south an apparently thick sequence of sedimentary and volcanic rocks was intercepted in Tamrookum Creek No. 1 (Korsch *et al.*, 1989), west of the anticline and

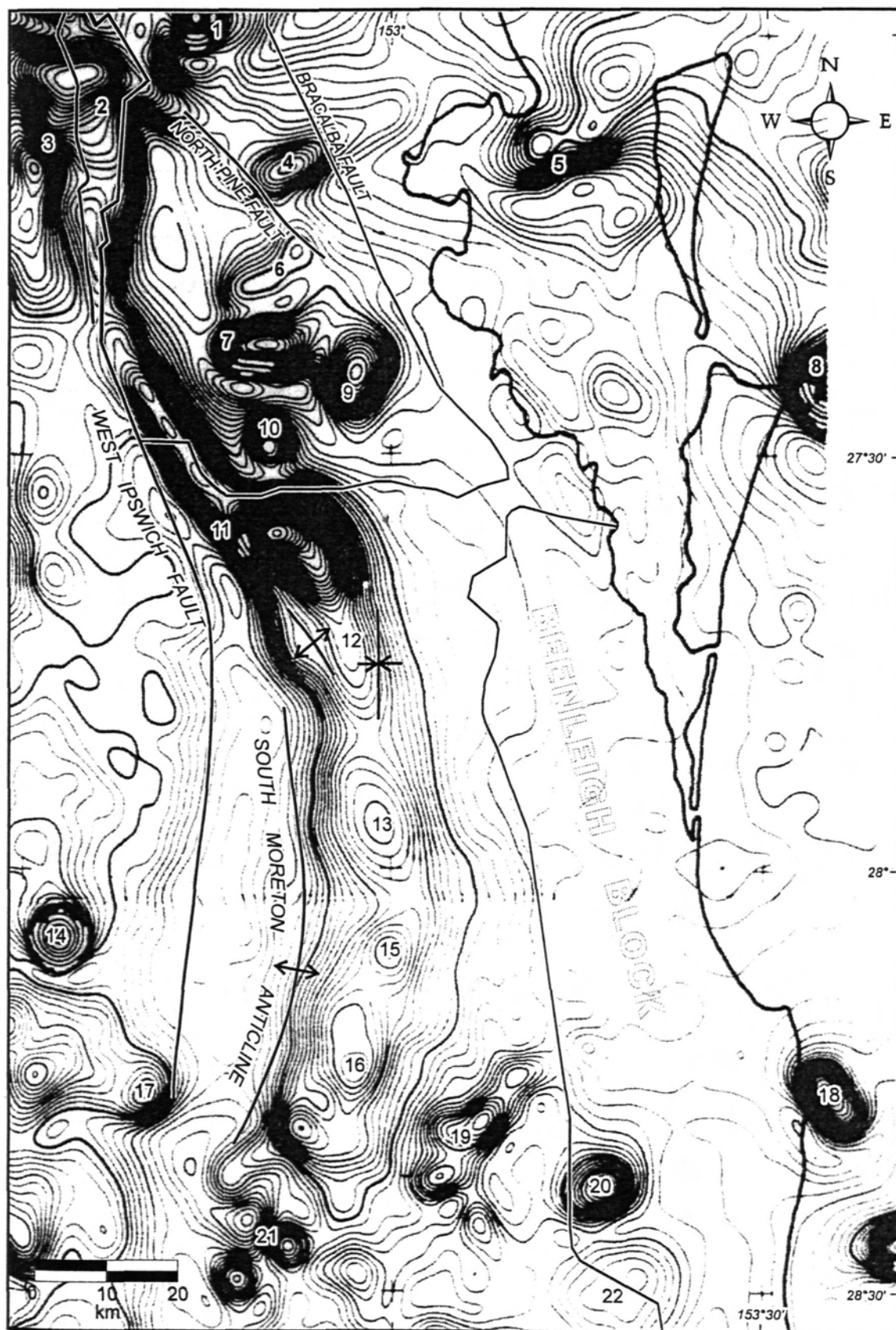


Figure 6.2 Medium-wavelength total magnetic-intensity anomalies, filtered to remove wavelengths less than 0.2 degrees (contour interval 20 nT) over the Ipswich Basin area (after Wellman *et al.*, 1994). Numbered features are discussed in the text and on table 2.2. Map base is the same as figures 6.1 and 6.3.

Table 6.1 Features associated with the magnetic and gravity maps.

Feature	Interpreted Source
1	Neurum Tonalite
2	Northbrook Block
3	Esk Trough
4	Dayboro Tonalite
5	Tertiary basalts ?
6	Mount Samson Granodiorite
7	Samford Granodiorite
8	Granitic pluton (associated with the Stradbroke Island rhyolites) ?
9	Enoggera Granite
10	Karana Quartz Diorite
11	West Ipswich Fault / western limit of Ipswich Basin
12	Volcanic rocks beneath the Ipswich Basin or an early mafic dominated rift-related sub-basin (cut by GSQ Ipswich 26)
13	Volcanic rocks beneath the Ipswich Basin or an early mafic dominated rift-related sub-basin (cut by QAO No.1 "The Overflow")
14	Focal Peak (Tertiary volcanic centre)
15	Volcanic rocks beneath the Ipswich Basin or an early mafic dominated rift-related sub-basin
16	
17	Mount Barney (Tertiary volcanic centre)
18	Unnamed Tertiary volcanic rocks
19	Lamington Plateau (Tertiary volcanic lava flows of 20)
20	Mount Warning Complex (Tertiary shield volcano)
21	Unnamed Tertiary volcanic centres
22	Unnamed/unmapped Tertiary granite associated with 20.

of feature 16. Magnetic data here show a pattern similar that in the north, implying a thinner and non-volcanic succession; to the east, the anticline again has a steep magnetic anomaly. The comparatively thick sedimentary rocks with mafic and felsic volcanic rocks in Tamrookum Creek No. 1 suggest that the South Moreton Anticline and the inferred faults delimiting it confine the older portions of the Ipswich Basin (including

the volcanic rocks) in the north.

The West Ipswich Fault is defined in the outcrop immediately west of Ipswich where it corresponds with a strong magnetic anomaly along the western limit of the Ipswich Basin, caused by mafic rocks and the steep dip adjacent to the fault. O'Brien *et al.*'s. (1991) interpreted path of the fault south of Ipswich is indicated by weak anomalies, which stop near Mount Barney. As well as defining the western limit of the Ipswich Basin, the fault also delimits the Northbrook Block from the D'Aguilar Block, best seen in the magnetic data. A strong anomaly extends from the outcrop of the West Ipswich Fault west of Ipswich through to the mapped start of the South Moreton Anticline (feature 11). This anomaly corresponds with a series of unnamed faults and fault segments sub-parallelizing the West Ipswich Fault on the 1:100,000 geology map (Cranfield *et al.*, 1981), which separate the Marburg Formation of the Clarence-Moreton Basin in the west from older Mesozoic formations in the east, mainly the Ripley Road Sandstone. GSQ cross-sections (Cranfield *et al.*, 1981) traversing these faults do not show any sub-surface Ipswich Basin material to the west. The implication of the GSQ mapping is that this series of unnamed faults and fault segments corresponds with the southern extension of the West Ipswich Fault, and it therefore follows that the interpreted sub-surface position of the West Ipswich Fault as indicated by Korsch *et al.* (1989), and O'Brien *et al.* (1991, 1994) may be incorrect. Given this, the true position of the West Ipswich Fault would be east of its position as indicated on figure 6.2, and close to the edge of the prominent anomaly indicated on the map (feature 11).

The highly magnetic anomalies east of feature 11 correspond with the surface outcrops of Ipswich Basin sedimentary rocks, and probably owe their intensity to the near sub-surface occurrences of the mafic Weir Basalt, Sugars Basalt and equivalents. Features such as the Spring Mountain Anticline (west of feature 12) prominently break this anomaly. Compounding and accentuating the magnetic anomalies east of 11 are several Tertiary basalt lava flows.

Wellman *et al.* (1994) interpreted features 12, 13, 15, and 16 as sedimentary troughs capable of containing Late Permian to Late Triassic volcanic rocks. He suggested that these anomalies were typical in shape and magnitude of troughs, and found that these areas also correspond with weak gravity lows and, where seismic data

are available, with features which could be interpreted as troughs. These anomalies also coincide with areas of the Ipswich Basin which are known from both drill hole data and seismic data to be the deepest portions of the basin, areas which are known to contain mafic volcanic rocks, and areas whose stratigraphy indicates they are the oldest portions of the basin. Wellman *et al.* (1994) suggests that these basins correspond with the South Moreton Syncline, a feature whose name could not be identified in other texts or on any maps, however, what may be their synclinal axis corresponds with Cranfield *et al.*'s (1981) Logan River Syncline (east of 12 on figure 6.2). This axis, if it is a real feature, could be the depicentre of the basin, and probably also correspond with the rifts which initiated the basin.

Using seismic profiles Korsch *et al.* (1989) and O'Brien *et al.* (1991) have interpreted a "rift sequence" underlying the Ipswich Basin and Esk Trough, and assigned it a Middle Triassic age. It is probable that parts of anomalies 12, 13, 15, and 16 may represent this older rift sequence, or alternatively older, deeper sub-basins of the Ipswich Basin. Drill hole GSQ Ipswich 26 (Almond, 1982), which intercepted more than 300 m of mafic and felsic volcanic rocks not exposed elsewhere in the Ipswich Basin, occurs within feature 12, and rocks from the deepest portions of this drill whole have a unique volcanic-arc chemistry as opposed to the intra-plate chemistries of other volcanic rocks of the basin. The occurrence of unique older rocks not exposed in surface outcrop within GSQ Ipswich 26, provides circumstantial support for an older sub-basin occurring at 12. Whether this sub-basin is a feature associated the Ipswich Basin or if it is older than the Ipswich Basin and associated with the inferred Mid-Triassic "rift sequence" of Korsch *et al.* (1989) and O'Brien *et al.* (1991) is unresolvable at this stage. The unique arc-related chemistry of these older rocks is very atypical for the Ipswich Basin, and hints at a different origin for these particular rocks, and therefore provides some tangential geochemical evidence suggesting that the sub-basins may pre-cede the Ipswich basin proper by sufficient enough time to warrant their separation into a different basin entity.

Drill hole QAO "The Overflow" No.1 (Siller, 1963; Houston, 1967a) which intercepted more than 400 m of mafic volcanic rocks without reaching basement was drilled in feature 13. Insufficient data exist from this drill hole to determine if these

volcanic rocks are chemically more similar to the Ipswich Basin or the anomalous volcanic rocks within GSQ Ipswich 26, however, their stratigraphic position implies that they are part of the mafic sequence within the Ipswich Basin. This does not however preclude the possibility that anomalous rocks may exist at depth, and therefore the sub-basin may also represent a pre-Ipswich Basin feature.

6.2.2 Gravity Data

Gravity data collected over the Ipswich Basin and presented by Wellman *et al.* (1994), lack the resolution of the magnetic data set, the average grid spacing of data points being approximately 5 km. Because of the coarse resolution, identification of specific anomalies is more difficult.

The D'Aguilar Block (1) (Fig 6.3), which contains numerous granitic plutons has a series of discordate highs, which cannot be readily correlated with individual plutons or other features. The position of the Baracalba Fault, which forms the eastern margin of the block, is prominent on the gravity data. Less prominent is the West Ipswich/ Great Moreton Fault which forms the western boundary of the fault. Neither the Northbrook Block (2) or the Esk Trough (3) to the west of the D'Aguilar Block are readily discernable from the gravity data. Several of the Tertiary magmatic centres, including Focal peak (14), Mount Barney (17) and Mount Warning (20) form prominent anomalies on the southern half of the map.

In general, the Ipswich Basin is dominated by gravity lows, with features identified by Wellman *et al* (1994) as "sedimentary troughs", identifiable on the gravity map as poorly defined, anomalously low areas (features 12, 13 , 15, and 16). East of the South Moreton Anticline, the contour lines stack, suggesting an asymmetric shape for the anticline, with a steep gradient towards the basin centre, and a shallow dip west of the anticline. The West Ipswich Fault corresponds with a steep gravity gradient at the western limit of the Ipswich Basin. The eastern section of the Ipswich Basin near the Beenleigh Block shows a uniform gradient stepping out of the inferred older portion of the basin, and extending back to Beenleigh Block, suggesting that the Beenleigh Block may dip shallowly underneath the basin. A small gravity anomaly (8) offshore from Stradbroke island correlates with a strong magnetic anomaly, perhaps indicating the

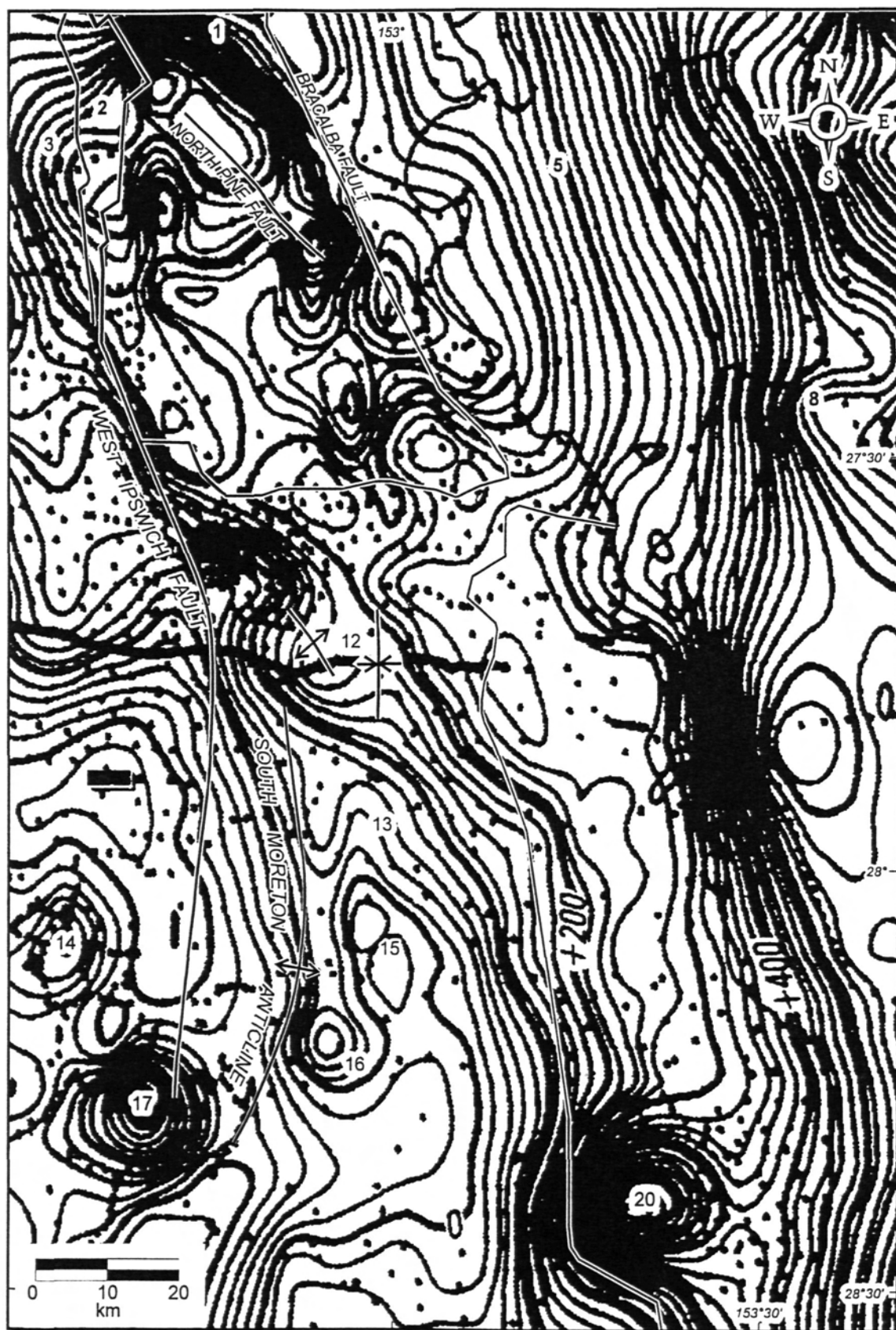


Figure 6.3 Bouguer gravity anomalies (contour interval 20 $\mu\text{m.s}^{-2}$) over the Ipswich Basin area (after Wellman *et al.*, 1994). Numbered features are discussed in the text. Map base is the same as figures 6.1 and 6.2.

presence of source pluton for the Stradbroke Island rhyolitic lavas.

6.3 Basin Evolution

The basin developed along a series of parallel north-south dextral strike-slip faults (Korsch *et al.*, 1989; O'Brien *et al.*, 1991, 1994), two sets of which, the West Ipswich Fault and the East Richmond Fault, probably initiated the rifting. In the first phase of activity, which may have pre-dated the Ipswich Basin proper (Fig 6.4a), bi-modal calc-alkaline volcanic rocks were erupted into rifts, and the granitic plutons emplaced into the D'Aguilar Block, uplifted between faults. Volcanic rocks were deposited in two areas, the main one close to the axis of the South Moreton Anticline, and bounded by the West Ipswich/East Richmond fault systems, and the second in a now offshore sub-basin east of Moreton Island.

The second period of activity (Fig 6.4b) marks the clear start of the Ipswich Basin, was slightly more extensive than the first, and was located in the same two regions. Intra-plate mafic rocks were sub-aerially erupted, probably due to re-activation of the West Ipswich / South Moreton Anticline/East Richmond fault systems, accompanied coarse clastics. Subsidence east of the South Moreton Anticline resulted in a thicker sequence. The region west of the anticline was possibly another sub-basin.

The third phase of development of the Ipswich Basin (Fig 6.4c) was marked by the wider deposition across the basin accompanied by the initiation of silicic volcanism, centred around a new north-south axis east of the western mafic belt to form the new eastern limit of the basin along a fault indicated by field studies. The western mafic belt was succeeded by epiclastic detritus shed from the Palaeozoic highs and by volcanic detritus from the east, and few primary silicic volcanic rocks. Deposition was now occurring basin-wide, although local variations in products existed, except in the north where the South Moreton Anticline still formed a barrier.

The final phase of development of the Ipswich Basin (Fig 6.4d) occurred after the cessation of volcanic activity and is represented by the basin-wide deposition of fluviatile-lacustrine sedimentary rocks of the Brassall Subgroup, including the entire South Moreton Anticline. The major depocentre was still in the west.

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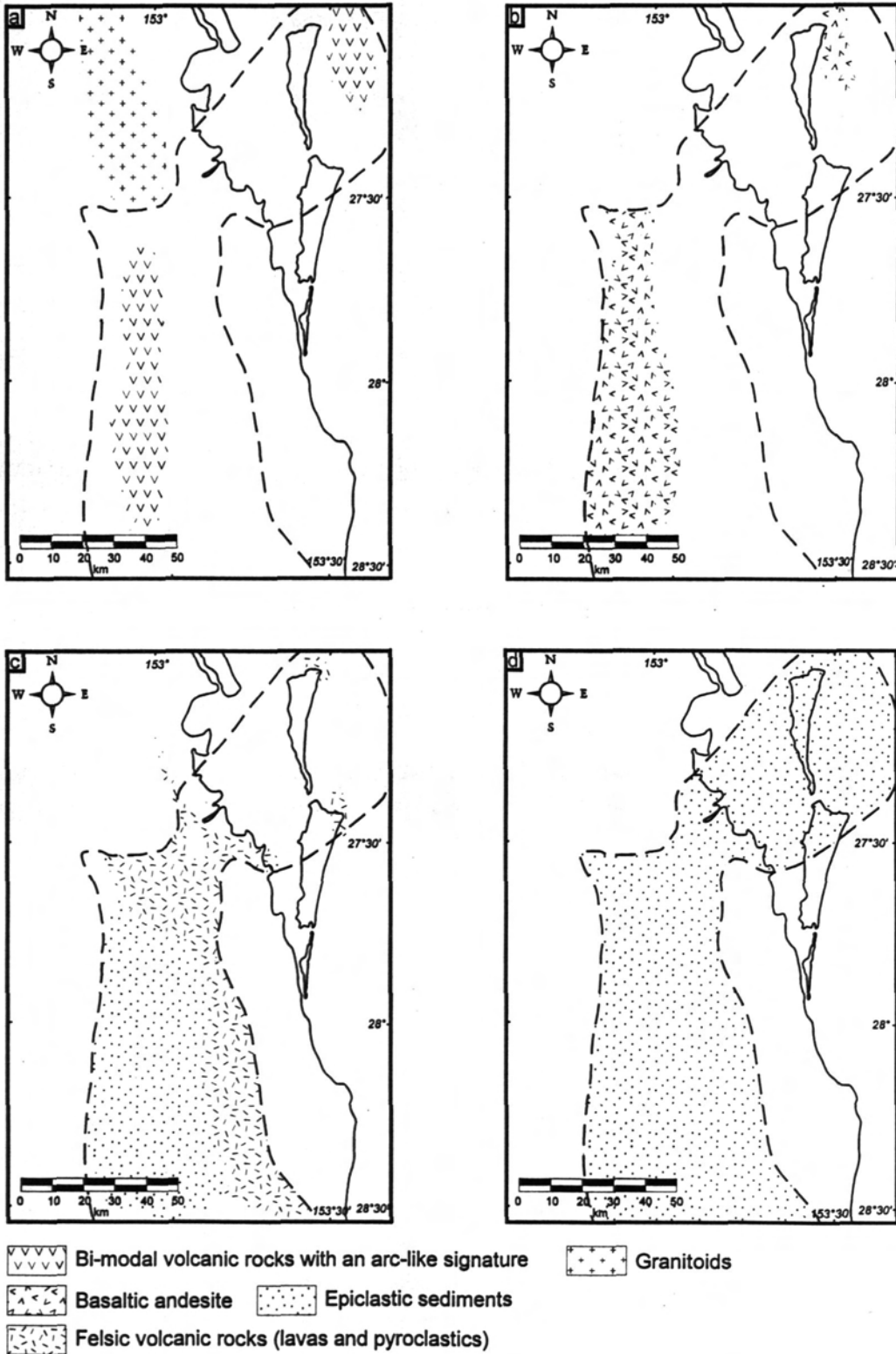


Figure 6.4 Progressive development of the Ipswich Basin. a) intrusion of granitoids into the D'Aguilar Block and the eruption of bi-modal calc-alkaline volcanic rocks in two sub-basins during early (possibly pre-Ipswich Basin) rifting; b) eruption of within-plate mafic rocks of the Ipswich Basin in two sub-basins; c) eruption of silicic volcanic rocks which coincide with the widening of the basin and the extensive deposition of clastic sediments elsewhere; d) cessation of volcanic activity and the basin-wide deposition of clastic sediments. Map base is the same as figures 6.1 and 6.2.

6.3.1 *West Ipswich Fault*

The Ipswich Basin, along with most of the Late Triassic basins of eastern Australia, is a north-south elongate basin which is at least in part fault-bounded (Fielding, 1996). Korsch *et al.* (1989) and O'Brien *et al.* (1991, 1994) suggest that the Ipswich Basin formed through extension associated with long-lived dextral strike-slip transtensional faults. Korsch *et al.* (1989) and O'Brien *et al.* (1991) argue that the West Ipswich Fault (Fig 6.1), which marks the western limit of the Ipswich Basin, was a fundamental structure, movement along which formed the older Esk Trough, the Ipswich Basin, and locally generated subsidence in the younger Clarence-Moreton Basin (Fig. 1.6). As demonstrated above (6.2), Korsch *et al.*'s. (1989) and O'Brien *et al.*'s. (1991, 1994) plotted position of the West Ipswich Fault may be erroneous, at least in the northernmost portions of the basin, because sedimentary rocks of the Ipswich Basin are truncated abruptly (by faults) east of this plotted position. Fault splays of Korsch *et al.*'s (1989) and O'Brien *et al.*'s (1991, 1994) West Ipswich Fault mark the western edge of the Ipswich Basin in the north.

6.3.2 *South Moreton Anticline*

Cranfield *et al.* (1976, 1982) interpret the anticline as being flanked by faults. O'Brien *et al.* (1994) interpret the South Moreton Anticline as a broad structural high in the basement over which the Mesozoic rocks were deposited, and suggest that en-echelon fold and faults on the crest of the anticline, and thrusts along the eastern margin of the anticline indicate that it is a positive flower structure generated by dextral movement along the faults. O'Brien *et al.* (1994) suggest that the Ipswich Coal Measures wedge out onto the South Moreton Anticline and that the Clarence-Moreton succession continues across it. This contradicts a) the cross-section drawn by Korsch *et al.* (1989) (Fig. 6.5a) which shows a thinner deposit of Ipswich Coal Measures continuing across the structure; b) field data which show Ipswich Basin rocks on both sides of the anticline; and c) drill hole data from Tarookum Creek No.1 which show Ipswich Basin rocks west of the anticline. O'Brien *et al.* (1994) interpreted that thermal relaxation in the latest Triassic led to general subsidence that allowed the Clarence-Moreton succession to overstep the anticline. Rocks west of the anticline in the northern

part of the basin differ from those to the south. Korsch *et al.* (1989) extrapolated a seismic section across the northern part to the entire basin. Their cross-section (Fig. 6.5a), also reflecting surface geology, shows a thin deposit of Ipswich Basin material to the west of the anticline. Dr. C. Murray (*pers. comm.*, 1997) suggests that this profile is not applicable to the basin because of problems associated with the sequence to the west of the anticline, including the thickness in Tamarookum Creek No. 1. However, in the region of Korsch *et al.*'s. (1989) seismic section, a much thinner sequence of Ipswich Basin rocks occurs west of the anticline as indicated by GSQ mapping (Cranfield *et al.*, 1976, 1982, 1989), and furthermore, this sequence comprises the non-volcanic Brassall Subgroup, the terminal sub-group of the basin, whereas the Koholo Subgroup and its volcanic material is restricted to the east of the anticline. Further to the south, at Tamarookum Creek No. 1, Koholo Subgroup equivalents, and significantly thicker Ipswich Basin deposits occur west of the anticline. This suggests to me that the South Moreton Anticline is not a simple basement high; that Cranfield *et al.*'s. (1976, 1982) interpretation of faults bounding the structure is correct; and furthermore that movement along the faults continued during the deposition of the Ipswich Basin, with early or more rapid subsidence occurring along faults east of the anticline. Geophysical data discussed earlier suggest that the anticline was asymmetrical, with steeper dips to the east of the anticline, and a shallow depression to the west of the anticline (Fig. 6.5b). The fault to the east of the anticline was probably the locus of continual movement, active through the deposition of the basin, and hence contributing to the steep dips east of the anticline. West of the anticline, any bounding fault probably had less movement along it, and hence a thinner sequence accumulated.

Geophysical data suggest that several sub-basins east of the anticline probably correlate with the volcanically dominated pre-Ipswich Basin sequence with a unique arc-like geochemistry (Fig. 6.5b). Such sub-basins are not evident to the west of the anticline, suggesting, as in Korsch *et al.*'s. (1989) cross-section (Fig. 6.5a), that the early rift-related rocks occur only east of the anticline. Dr. C. Murray (*pers. comm.*, 1997) disagrees with this suggestion, and suggests that Tamarookum Creek No. 1 intercepted volcanic rocks equivalent to this rift sequence. But the descriptions of this sequence are so poor that such correlations are speculative, and it is therefore equally valid to suggest

that the volcanic rocks in Tamrookum Creek No. 1 are related to the main Ipswich Basin volcanic rocks, and that equivalents of the older rift sequence may be confined to the west of the anticline. Geophysical data furthermore suggest a less complex structure for the basin west of the anticline, which may form a unique sub-basin.

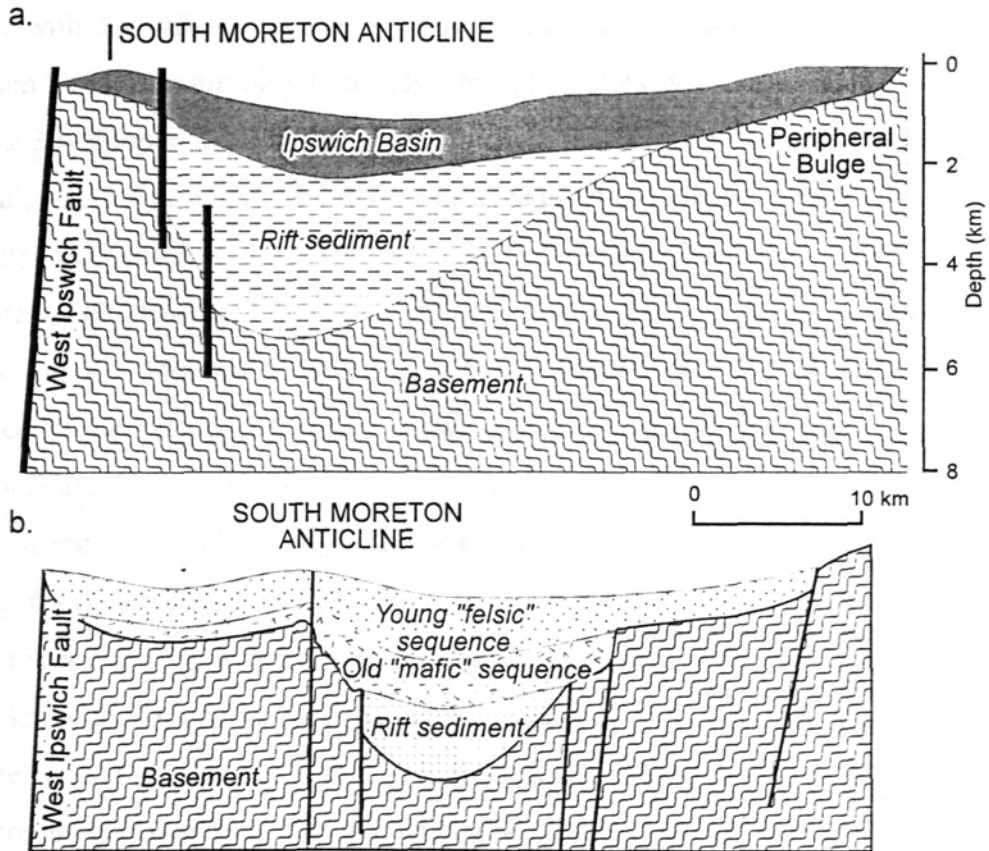


Figure 6.5 Interpreted cross-sections through the Ipswich Basin a) Korsch *et al*'s (1989) interpreted seismic section, which applies to the northern part of the basin; and b) my revised cross-section at latitudes 28°-28°30'. The "young felsic sequence" includes the Brassall Sub-group.

6.3.3 Structure of the Basin

Several fault controlled sub-basins formed local depocentres of the Ipswich Basin (Fig 6.6). As the development of the basin continued, deposition across the basin widened, but the depocentres correlating with the original sub-basins remained the focus for continual deposition.

As a generalization, volcanism in the Ipswich Basin developed in two main belts, in two distinct periods - an older westerly mafic-dominated (in parts bi-modal)

belt, and a more easterly, younger, silicic belt (Fig 6.1).

Korsch *et al.* (1989) and O'Brien *et al.* (1991) refer to a "rift sequence" at the base of the Ipswich Basin in the area of the South Moreton Anticline (Fig. 6.5a), and intercepted in drill hole Tamrookum Creek 1. They consider the "rift sequence" the same as the Chillingham Volcanics, which crop out 30-40 km to the east. I question this connection with the Chillingham Volcanics because rhyolitic lavas (such as in the Chillingham Volcanics) typically flow only a few kilometres away from the vent, far short of the 30-40 km to the South Moreton Anticline. Furthermore the "rift sequence" is bi-modal, whereas the Chillingham Volcanics are purely silicic. I correlate Korsch *et al.*'s. (1989) and O'Brien *et al.*'s. (1991) bi-modal "rift sequence" with the older bi-modal suite in GSQ Ipswich 26, which is similarly confined within the older western mafic belt (Fig 6.1). This sequence quite possibly pre-dates the Ipswich Basin, and geochemical studies of these rocks have shown them to have an arc-like signature, perhaps more analogous to rocks of the Esk Trough than to other rocks in the Ipswich Basin. These rocks probably belong to the first period of the development of the Ipswich Basin (Fig. 6.4a), or may pre-date it.

Mafic rocks in the Ipswich Basin (except for those near Moreton Island) occur within 15 km of the axis of the South Moreton Anticline (Fig 6.1). Korsch *et al.* (1989) and O'Brien *et al.* (1991) interpret from seismic data a fault on the eastern flank of the South Moreton Anticline as the major bounding fault of the "rift sequence", with the basin deposits thickening close to the fault, and thinning away from it to the Beenleigh Block in the east. But the geophysical data indicate that the geometry is more complex, with additional faults to the east (Fig. 6.5b). O'Brien *et al.* (1994) suggest that the East Richmond fault bounded the rift in New South Wales, but they did not attempt to extend it into Queensland. Extrapolated into Queensland, this fault would mark either the eastern edge of the pre-basin rift sequence or the eastern edge of the mafic belt, or both. O'Brien *et al.* (1994) suggest that the East Richmond Fault is a flower structure, so the possibility exists that both of the interpreted bounding faults may be related to the same fundamental structure.

The Ipswich Basin, as Korsch *et al.* (1989) point out, thins to the east, except for the Moreton Island - APS Matjara No. 1 area, where thicker sedimentary rocks occur. In

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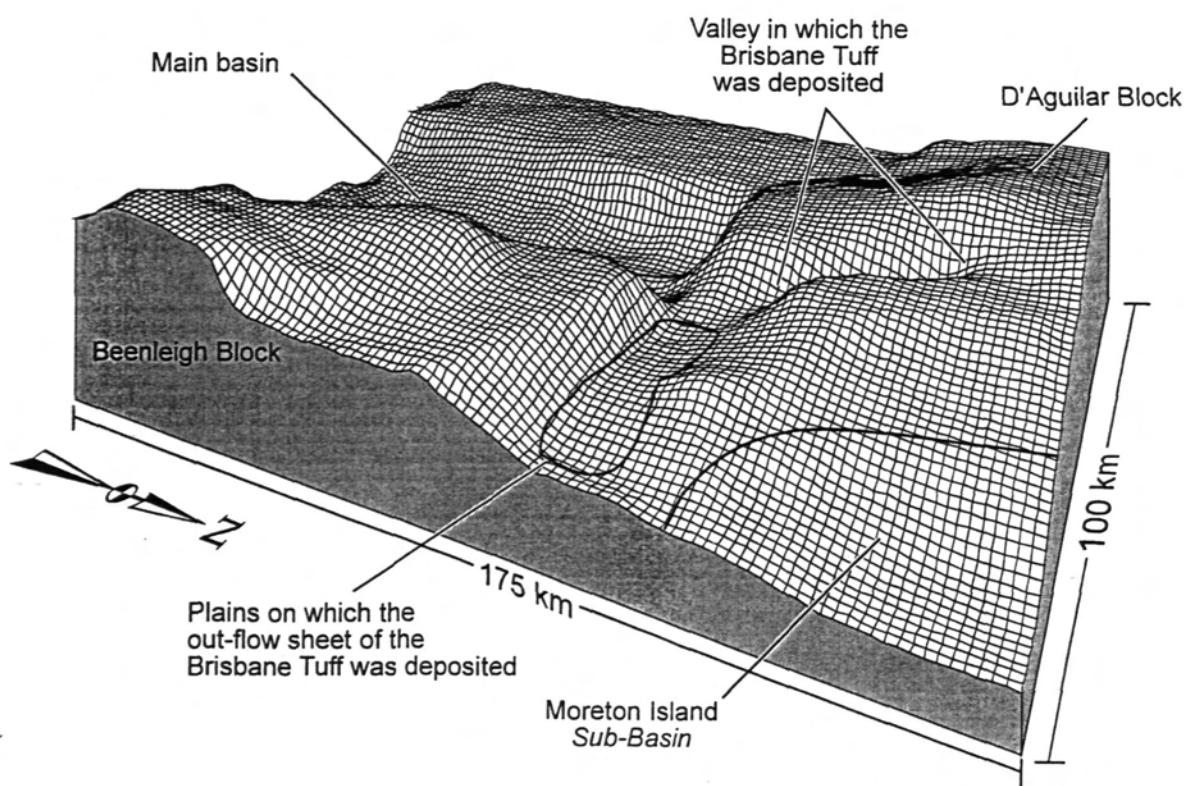
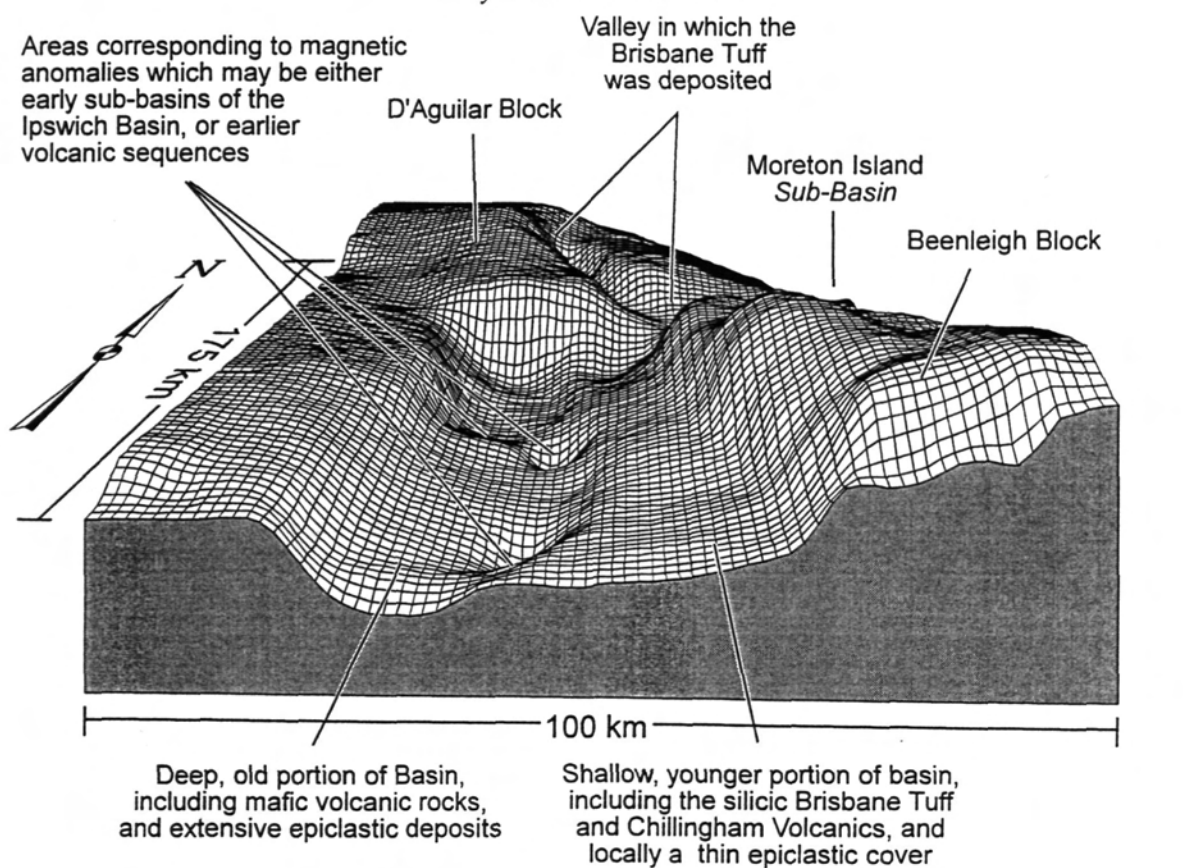


Figure 6.6 Interpreted block diagram for the Ipswich Basin. Details of construction in Appendix J.

APS Matjara No. 1, bi-modal volcanic rocks similar to those in GSQ Ipswich 26 and the overlying epiclastic rocks possibly represent another area of early rift sub-basin.

Between the Ipswich area and the Moreton Island - APS Matjara No. 1 area, only Brassall Sub-group equivalents exist, however, in the Moreton Island - APS Matjara No. 1 area both Kholo and Brassall Sub-group equivalents are represented. This break in the sequence between the two localities is strongly suggestive of two distinct sub-basins (Fig 6.6). But details of the structure of the sub-basin offshore from Moreton Island are obscure.

Most rocks of the eastern silicic belt (Fig 6.1) were emplaced in valleys. The valleys probably followed a fault which ran parallel with the long axis of the basin. Seismic data (Korsch *et al.*, 1989) indicate that in the area between Canungra and Chillingham, the Ipswich Basin sedimentary rocks thin and lap onto the Beenleigh Block. Magnetic and gravity data indicate faults in the western mafic belt, and confirm the simple structure of the eastern silicic belt. My mapping indicated faults marking the eastern edge of the basin in some areas. As discussed in Chapter 3, the Chillingham Volcanics are thought to have been erupted from a series of fault fissures along the axis of the basin. A small-throw fault has been interpreted to form the eastern boundary of the basin on the cross-section (Fig. 6.5b).

Insufficient evidence exists to suggest whether the rhyolitic lavas on Moreton and Stradbroke Islands are associated with a third basin-parallel structure, or indeed if more extensive silicic volcanism occurs in subcrop between Brisbane and the islands.

6.4 Basin Stratigraphy

The Ipswich Coal Measures, the principal group of the Ipswich Basin, is subdivided in the Ipswich area into the Kholo Subgroup and Brassall Subgroup (Fig. 1.5). The stratigraphic development of the Ipswich Basin has been divided into 4 conceptual stages, three of which correspond with different stages of the evolution of the basin. The first stage (Fig. 6.4a) corresponds with the oldest known rocks of the basin, which are a bi-modal suite of volcanic rocks, including calc-alkaline rhyolitic lavas, in drill holes APS 1 Matjara (south-east of Moreton Island) and GSQ Ipswich 26.

The emplacement of several large plutons into the D'Aguilar Block probably also occurred during this stage. This was followed (Fig. 6.4b) by what are the earliest deposits of the basin surficially exposed, sub-aerially erupted basaltic andesite lava flows and air-fall tuffs of the Sugars Basalt, Weir Basalt, and similar sub-aqueous flows on Moreton Island. These episodes of early volcanism are inferred to be associated with the initial rifting of the basin.

Coarse clastic sedimentary rocks followed this early volcanism, commencing in the westernmost sections, close to the West Ipswich Fault, elsewhere little deposition occurred. The coarse grained scree deposits, fanglomerates, and fluviatile sedimentary rocks of the Kholo Subgroup (Blackwall Breccia, Mount Crosby Formation, Colleges Conglomerate, and Cribb Conglomerate) signify a time of uplift and erosion during which the Ipswich Basin continued to form, with progressively more extensive deposition occurring as the basin grew to the east. During this period, extensive rhyolitic volcanism formed the basal fill of the basin further east near Brisbane and south through to the Mount Warning area. Products of this rhyolitic volcanism were the dominantly ignimbritic Brisbane Tuff near Brisbane, rhyo-dacitic air-fall tuffs and ignimbrites of the Mount Crosby Formation and Hector Huff, rhyolitic lavas and pyroclastic rocks of the Chillingham Volcanic, and isolated occurrences of rhyolitic lavas on Moreton and Stradbroke islands (Fig. 6.4c).

The Brassall Subgroup which followed marked a change to quiescent fluviatile-lacustrine activity and cessation of volcanism, during which most of the coal measures accumulated (Fig. 6.4d)

6.4.1 Early Volcanic Rocks Present Only In Drill Holes

320 m of undifferentiated volcanic rocks were intercepted at the base of GSQ Ipswich 26 (Fig. 4.9). Subunit E of this succession (rhyolitic lavas) has no correlatives in outcrop, and together with subunits A-D, a dominantly volcanoclastic sequence of basaltic, rhyolitic, and plutonic sources, mafic lavas, and minor air-fall tuff, probably represents earlier volcanic rocks or an earlier sequence of pre-Ipswich Basin volcanic rocks. Samples of rhyolite from GSQ Ipswich 26 subunit E, the stratigraphically oldest lava flow analysed for geochemistry, showed a distinctive volcanic-arc signature in its

trace element chemistry (lower TiO_2 , Nb, and Y), and its ϵNd content (+3.70632) is the most positive, indicating minimal involvement of old crust. Rhyolites in APS Matjara No. 1 are possibly equivalents to the Subunit E rhyolites, and the mafic rocks occurring below these rhyolites perhaps equivalent to subunits A to D.

6.4.2 *Sugars Basalt and Weir Basalt and their Equivalents*

The Weir Basalt and Sugars Basalt are of the same stratigraphic level and have a similar chemistry. Basaltic andesite lava flows and air-fall tuffs constitute the formations. The absence of hyaloclastites between most flows, the lack of interbedded epiclastic sedimentary rocks, and erosive contacts between eruptions indicate dominantly sub-aerial emplacement of the lavas.

The mafic rocks of Subunit F and scree deposits of subunit G are similar to the Weir Basalt, the Sugars Basalt, and the Blackwall Breccia, as are the 275 m of undifferentiated volcanic rocks at the base of GSQ DDH NS 93 at Cooneana Estate south of Ipswich.

Sub-aqueous mafic lavas (probably of basaltic andesite composition), interpreted to be the oldest exposed volcanic rocks on Moreton Island, are probably lateral equivalents of the Sugars Basalt and Weir Basalt.

6.4.3 *Silicic Volcanism*

During the major phase of silicic magmatism, the extensive pyroclastic deposits of the Brisbane Tuff and lavas and pyroclastic rocks of the Chillingham Volcanics were deposited. Less extensive occurrences of air-fall tuffs and ignimbrites in the Hector Tuff and Mount Crosby Formation occur in the Ipswich region. At least three generations of porphyritic lavas were emplaced from at least two domes on North Stradbroke Island at Adder Rock and South Headland, while on Moreton Island at least two generations of rhyolitic lava dome emplacement occurred following the earlier mafic lavas, and two tuffaceous arenites, probably representing re-worked tuffs, occur in the Ipswich Coal Measures on the island.

6.4.3.1 *The Brisbane Tuff*

6: Synthesis and Conclusions

Most of the Brisbane Tuff is composed of ignimbrites, although small volumes of pre- and post-ignimbrite deposits, such as air-falls and ground surges also occur in the unit.

The ignimbrites of the Brisbane Tuff are valley-fill ignimbrites, with the main body deposited in a confined north-south striking valley, while the ignimbrites near Carindale to the east were deposited in a shallow depression.

Although multiple flows constitute the Brisbane Tuff, they form a single cooling unit, and it is likely that they were emplaced as multiple flows from what was probably only a single eruptive event.

Flow direction data for the Brisbane Tuff (principally grain orientation, but also AMS) indicate a north-south flow direction along the main valley, and a westerly source for the Carindale body, but the location of the vent of the Brisbane Tuff is uncertain. The preferred location, based largely on the location of proximal facies, is near Kedron.

Fossil fumaroles, ranging in size up to 100 cm, are common through the Brisbane Tuff. The smallest fumaroles represent conduits and fissures through which gases escaped during welding and compaction, while the larger ones are probably areas where sustained and vigorous venting of gases occurred, probably due to the ignimbrite being emplaced over water.

The Brisbane Tuff, as with all felsic volcanic rocks of the Ipswich Basin, shows relative enrichment in normative quartz, caused by a combination of the original high-silica composition of the rocks, concentration of quartz phenocrysts during the eruption, and leaching of alkalis.

6.4.3.2 Chillingham Volcanics

The Chillingham Volcanics follow a single cycle of precursory pyroclastic eruptions and subsequent lava effusion, except in the south and centre where there are two cycles.

Pyroclastic rocks preserved in the Chillingham Volcanics include ignimbrite, air-fall tuff, and lesser pyroclastic surges.

Lava flows constitute most of the Chillingham Volcanics, and two generations of lava effusion exist in the Chillingham Volcanics, an early dome effusion phase

limited to central and southern areas, and a more extensive fissure-type lava flow phase occurring everywhere.

Lavas of fissure phase contrast with those of the early dome phase by lacking convolutions and folds in flow banding, and having a near horizontal flow banding parallelling the bedding of the underlying and overlying Triassic rocks. The northerly strike of vertically oriented zones (thought to reflect feeder dykes) also closely parallels the regional strike of the Chillingham Volcanics, and the direction of elongation of the Ipswich Basin itself, implying that the eruptive fissures may be related to deep structures associated with the rifting which led to the formation of the basin. Most documented examples of structurally controlled rhyolite emplacement, whether they be formed from synchronous eruption along a common fissure (such as the South Sister Volcano of Oregon, Scott, 1987), or sporadic emplacement of domes and flow exploiting a common pre-existing structural weakness such as a large fault (such as the Coso Volcanic Field in California, Duffield *et al.*, 1980), are commonly less extensive than the Chillingham Volcanics. Most of these features are limited to 10-20 km in strike length, whereas the Chillingham Volcanics have a strike length of more than 80 km. Barring the Tertiary basalts which break up the outcrop of the Chillingham Volcanics into four main bodies, the Chillingham Volcanics form an apparently continuous series of overlapping flows and domes, similar to fissure related eruptions where effusion occurs simultaneously along the entire fissure. Most structurally controlled non-fissure eruptions lack this overlapping near-continuous form, with gaps of several kilometres between individual flows and domes.

The Chillingham Volcanics exhibit a slight increase in their TiO_2 contents from north-south, with the exception of a large rhyolitic dome at Clarrie Hall Dam (in the southern part of the eastern silicic belt) which is enriched in TiO_2 , Zr, Rb, Pb, V and Cu and depleted in SiO_2 and Nb relative to other Chillingham Volcanics rocks.

6.4.3.3 Hector Tuff and Mount Crosby Formation

Two thin ignimbrite bodies separated by a shale make up the rhyodacitic Mount Crosby Formation, which cannot be conclusively correlated with the Brisbane Tuff. They are more dacitic, and their dense lithic clasts are different from those of the

Brisbane Tuff, suggesting separate eruptions.

The rhyo-dacitic Hector Tuff comprises air-fall tuff, ignimbrite, mudstone, arenite, and minor conglomerate, shale, and coal. The unit thins eastwards, accompanied by a reduction in the amount of primary pyroclastic rocks. The easternmost outcrops of the Hector Tuff were deposited into a fluvial system, typified by coarser volcanic detritus and occasional conglomerate, and lacking carbonaceous material and mudstone of the lacustrine dominated western occurrences.

Samples of the Hector Tuff and Mount Crosby Formation tuff are the most leached felsic rocks analysed, indicating some epiclastic reworking of the material and subsequent concentration of quartz.

6.5 Postulated Tectonic Environment Based on Geochemical Studies

Slight differences in the trace element and whole rock chemistries of the mafic rocks can be used to differentiate between each of the studied formations, however all have broadly similar chemistry. All mafic rocks of the Ipswich Basin are transitional sub-alkaline to alkaline in chemistry. The Ti-Zr-Y ternary diagram of Pearce and Cann (1973), indicate a calc-alkaline island-arc origin for the mafic rocks. The Zr/Y vs Zr diagram of Pearce and Norry (1979), the ternary Nb, Zr, and Y ternary diagram of Meschede (1986), the TiO₂, MnO, and P₂O₅ ternary diagram of Mullen (1983) (Fig. 5.5), and Pearce *et al.*'s (1977) whole rock ternary diagram of FeO, MgO, and Al₂O₃, suggest a within-plate setting.

Microprobe analysis of pyroxenes from the mafic rocks was not as conclusive as the whole rock geochemistry for defining the tectonic environment; however, a predominantly volcanic-arc signature was suggested for the samples based on Nisbet and Pearce's (1977) factor analysis.

εNd values ranged from +1.8 to +3.7 for the volcanic rocks, while the plutonic rocks of the South D' Aguilar Block are near zero (-0.2 to +0.3), indicating slightly more crustal involvement in the granite magmas than the Ipswich Basin volcanic rocks, and/or a different source rock.

The chemistry of the Ipswich Basin mafic rocks differs from either simple volcanic-arc mafic rocks or within-plate mafic rocks, although sharing features of both.

This “mixed” signature is thought to reflect the tectonic environment into which the mafic rocks were erupted, namely an area of back-arc extension occurring in a within-plate setting. Rocks with similar chemical characteristic to the Ipswich Basin mafic rocks (unusually high HFSE concentrations, and P_2O_5) have been documented in early stages of rifting in many provinces through geological time. Examples of young volcanic provinces with these characteristics include the Basin and Range Province of the western United States and the South Shetland Islands.

All felsic volcanic rocks of the Ipswich Basin, except for subunit E of GSQ Ipswich 26, have HFSE concentrations similar to within-plate rocks. Samples from GSQ Ipswich 26 subunit E, the stratigraphically oldest analysed lava flow, have a distinctive volcanic-arc signature in its trace element chemistry, and its ϵNd content is the most positive, indicating minimal crustal involvement.

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