PART 1

INTRODUCTION AND FIELD STUDIES

"I am greatly attracted by Hegel's scheme of thesis-antithesis-synthesis. Furthermore, I believe that an antithesis is most easily provoked by a categorical statement of a thesis, and that the issue is most readily solved by such a confrontation of an uncompromising thesis and antithesis that the ultimate synthesis is thus most quickly achieved." Mayr, 1982:9

"In science it is *observation* rather than perception which plays the decisive part. But observation is a process in which we play an intensely *active* part. An observation is a perception, but one which is planned and prepared. We do not 'have' an observation [as we may 'have' a sense experience] but we 'make' an observation. [A navigator even 'works' an observation.] An observation is always preceded by a particular interest, a question or a problem - in short, by something theoretical." Popper, 1972: 342.

CHAPTER 1

AN OVERVIEW OF PROBLEMS CONCERNING PLANT OPAL

Introduction

Up to the present plant opal studies have not been pursued with any vigour within Australia. This thesis attempts to establish a basis for future work by critically examining overseas studies and attempting to relate them to the situation within Australia.

Soluble silica from the soil solution is taken into plants, concentrated and deposited in the leaves, stem and roots in solid form. In due course the solid silica is returned to the soil. The movement of silica through the biosphere, and in particular through plants, is an important part of the general cycling of silica.

The presence of siliceous bodies in living plants was discovered in the mid-19th Century; although Iler (1974:743) recorded that "tabasheer", silica gel found in the hollow stems of bamboo, was reported during the fourteenth century by Odorico Porto, a contemporary of Marco Polo and was well known in China and India at an even earlier date. During the last 100 years these small particles have attracted the attention of many people; botanists originally, but in later years investigators from fields as widely diverse as pedology and archaeology. One of the earliest was Ehrenberg, a German microbiologist, who was sent dust samples collected on the Beagle's sails by Charles Darwin. In the 1840s and 50s Ehrenberg published illustrated works describing organic silica including phytoliths. Further work was undertaken in Europe by Grot (1896), Frohnmeyer (1914), Netolitsky (1929), Frey-Wyssling (1930), Prat (1936) and Tyurin (1937).

Nomenclature

The term "phytolith" is derived from the Greek "phyton" a plant, and "litos" a stone. It was applied to the siliceous bodies in living

plants by Ruprecht (1866) and was also mentioned by Struve (1835). This is not the only term used for such bodies, however. The term "opaline silica" is often used in British literature; "phytolite" and "phytolitharia" in Russian literature; and "grass opal" and "plant opal" in British, American and Japanese literature (Pease, 1967). In addition, opaline material is referred to as "silicified plant asleroschlereids" by Brydon (1963), and the terms "tabashir", "tabasheer" and "tabaschir" are specific to bamboo opal. "Biogenic opal" and "biogenetic opal" are general terms which include sponge spicules and diatoms as well as plant opal. In the field of botany, opaline silica is referred to as "siliceous structures", "silica deposits", "silica bodies", etc. More recently Stebbins has referred to them as "opalines" (1981:76).

In a paper entitled "Fossil Opal-Phytoliths and Phytolith Nomenclature", Baker used the term "phytolith" to mean mineral matter completely filling plant cells, lining or replacing cell walls; mineralized plant hooks, hairs, etc., casts of the epidermal cells in plants and "any other microscopic bodies of mineral matter secreted by a plant", both recent and fossil (1959c:305). While opal-phytoliths were the most common that he observed, Baker intended the term to cover "opal-phytoliths, calcite-phytoliths, and, if they do exist, apatite-phytoliths, chalcedony-phytoliths and quartz-phytoliths" (1959c:306).

In this thesis, the term "biogenic opal" is used to denote opal from all biological sources; diatoms, plant opal, etc. The term "plant opal" is used to encompass <u>all</u> opal derived from plants while "phytolith" refers to silt-sized plant opal having repetitive shapes - usually that derived from whole cell deposits; although sheet-like deposits are included. However, when referring to a specific author's work, the terms used in that work are retained where possible.

Uptake into plants

The uptake of silica into plants is dependent on many factors including the availability of silica in the soil and the species of plant involved. Most authors consider that monomeric silicic acid is the soluble form in soil solution available for uptake (Sangster and Parry, 1981). Some plants actively select silica; others appear to either passively accept or actively reject it.

The amount of silica present in plants varies between plants and between parts of the plant. In a study of the mineral composition of 175 species of plants, Takahashi and Miyake (1977) found that accumulators of silica existed in the Bryophyta, three classes of Pteridophyta and several families of Monocotyledoneae, but were not found in the Dicotyledoneae. The average silica content of 34 species which were accumulators was 1.96% while of non-accumulators (141 species) was 0.25%; but values of over 10% have been reported (e.g. Jones and Hay, 1975).

Many reasons have been advanced for the accumulation of silica in plants. While it appears to be a requirement of all organisms, the presence of silica in plants may serve to provide support and to strengthen against disease, fungal attack and the grazing of higher animals. Those plants which are accumulators appear to require large amounts of silica for vigorous growth while non-accumulators, although not requiring as much silica, need it during the reproductive stage (Takahashi and Miyake, 1977). Chen and Lewin (1969) showed that the shoots of the accumulator *Equisetum arvense* (Horsetail) collapse without silicon in solution. Jones and Handreck (1967) found that cultivars of rice high in silica are more resistant to pathogenic fungi attack. Plant opal appears in the fossil record in the lower to middle Eocene at the same time as the appearance of mammalian fossils having high-crowned

teeth (Stebbins, 1981:75).

Plant opal in soils

Plant opal has been shown to be preserved in acidic soils and to be resistant to weathering, at least in the larger diameter size - fraction. It has been identified in paleosols (e.g. Kurmann, 1985), in dusts (e.g. Baker, 1959a), in deep sea sediments (e.g. Kolbe, 1957; Poore, Steinmetz and Schrader, 1979; Melia, 1984; Locker and Martini, 1986; Stabell, 1986) and in sedimentary rocks (e.g. Jones, 1964). To date it has been used as an indicator of paleosols and past vegetation in archeological reconstructions.

There has been renewed interest in examining these small particles in both sediments and plants in the hope that they will shed light on a variety of problems in disciplines ranging from archaeology to medicine. However, while the application of new techniques has enabled better resolution of the morphology of organic silica, this has become a two-edged sword. The great morphological beauty and diversity of some of the plant opal has tended to obscure its other characteristics, while its source in the plants has proved an obstacle to regarding plant opal as a constituent of sediments in its own right.

Morphology

While the morphology of plant opal in monocotyledonous plants and in particular the Gramineae, has been examined in considerable detail (i.e. Smithson and Parry, 1964), that in the dicotyledonous plants has received less attention. This is in part due to its more fragile nature which makes it difficult to extract and to the smaller quantities present. While no species-specific shape has been detected for forest species, the consensus is that it is possible to identify plant opal belonging to the Gramineae to sub-family or even tribe in some cases

(i.e.. Twiss, Suess and Smith, 1969). Such work has been undertaken in rather limited numbers of sub-families, and is based on the botanical classification of the grasses, which itself may be open to question. Therefore it may be of dubious worth to attempt to apply the criteria for plant opal identification in regions outside the ones in which they were erected where little is known of plant opal. For example, in some of the recent comparisons which have been made between the Australian and North American species of stipoid flora, the Australian species are shown to be different in characteristics which include lemma epidermal patterns and the arrangement of silica bodies there-on (Barkworth and Everett, 1986).

The use of morphology to distinguish between grasses and forest species *per se* might, on the other hand, be possible. While any distinction based on the fragility of the forest species plant opal compared with the solid appearance of grass plant opal is not strictly quantifiable and, again, may not be universal, there is a real difference in the general anatomy of grasses and forest species which could be quantifiable and very useful.

Plant opal assemblages

The examination of plant opal assemblages diagnostic of a particular vegetation type is, as yet, in its infancy, both on a world-wide and on an Australian basis. While some work in the Gramineae has been published (i.e. Piperno, 1987), very little appears to have been done outside areas which have a dominantly grass vegetation. It is assumed in many of these studies that the plant opal assemblage derived from the topsoil characterises or is related to that in the modern vegetation growing on it. This has not been proven. On the contrary, even those who are working in this area find anomalies which would tend to negate what they are doing. Brown, who has erected a classification

for the identification of grasses from plant opal in soils commented that he had "sampled a number of grassland soils, lower A, upper A, sometimes middle A and in no instance did the lower A agree with the upper A. In no instance did the upper A agree with the contemporary grass cover" (1986:119). Since we have no real understanding of the survival and cycling mechanisms operating on plant opal within the soil, this is hardly suprising.

While the erection of an assemblage of plant opal characterising a particular vegetation association from the plants making it up is a difficult task, at least it should be possible to check that the plant opal assemblage in the topsoil under the association is association specific; which is what is being assumed in many assemblage studies. Are the opal assemblages from the soils in which two identical vegetation associations are growing identical, or are there other factors (perhaps pedological) which need to be considered? Do we know enough about soil-vegetation relationships to assume that a particular vegetation association will always be found growing in a soil in which these mechanisms are sufficiently similar to produce similar plant opal assemblages? These are surely questions to be answered before making the giagantic leap of using the modern opal assemblages in vegetation or soil to identify past associations from assemblages in sediments.

Durability

Plant opal has been identified in Quaternary and Tertiary sediments (Baker, 1959c, 1960c; Jones, 1964; Gill, 1967) and there is evidence that plant opal may survive in the near surface environment for long periods of time. The length of time that plant opal persists in Australian soil has been calculated by Baker (1959c) as 1,000 years. Jones and Beavers (1964) calculated that 5,133 years was needed to

accumulate the opal phytoliths present in the Illinois soils they examined, and Wilding (1967) calculated it would require 1,350 years to accumulate the opal phytoliths at his site. Radiocarbon dating of these phytoliths gave a carbon date of 13,300 ±450 years BP. While this suggests long term stability of the biogenic opal, it would appear that one or other of these methods, and probably both, are highly inaccurate. The C14 dating of phytoliths has similar problems to that of charcoal, i.e. phytoliths may accumulate from elsewhere, being transported by wind or water. Electron spin resonance dating of plant opal in sediments has been attempted but as yet the results are equivocal (Ikeya and Golson, 1985).

The problem with calculations of accumulation rates is that the weight percentage of plant opal in a particular soil fraction is multiplied by the percentage of that fraction in the total soil, or, in the case of some workers (e.g. Witty and Knox, 1964) calculations are based on one soil fraction only (in this case the 15-100 um; um = micron). In view of the contention by Jones and Beavers (1964) that over half of the total opal occurrs in the clay fraction, such calculations in soils with even a minor clay content must be viewed with caution.

In addition, little research has been directed at the processes which may intervene between accumulation within the litter and incorporation of the plant opal into the soil. Measuring accumulation rates from the litter fall or biomass studies may provide overestimates and, to date, no research has been done into the processes which may remove plant opal from the system before it is incorporated into the soil.

Ideally, rates of dissolution need also to be known. The solubility of amorphous silica increases slowly with increasing

temperature (Alexander, Heston and Iler, 1954; Krauskopf, 1956; Okamoto, Okura and Goto, 1957). Solubility also increases with decreasing particle size (Krauskopf, 1956), which becomes important when it is noted that at least 50-70% of the plant opal in soils is <5 um in diameter (Wilding and Drees, 1974). From pH 2 to pH 9, solubility is independent of pH, but above pH 9 it increases rapidly (Alexander *et al.*, 1954; Krauskopf, 1956; Elgawhary and Lindsay, 1972).

The presence of a protective coating on the surfaces of plant opal has been suggested. Suess (1966) found evidence of a thin outer layer enclosing the plant opal, which he suggested was composed of birefringent organic fibres similar to the insoluble silicon-cellulose compound which Engel (1935 quoted in Suess, 1966) found composing the cell walls of rye. His basis of comparison was morphological (from photomicrographs), and this, along with the optical evidence and the brown staining of plant opal by iodo-potassium-iodide, was taken as meaning that the opal was enclosed in a cellulose-like sheath which appeared to be rapidly removed from the plant opal once they were released from the plant into the soil. Suess ruled out dissolution of the sheath, and attributed its removal to abrasion.

The role of aluminium chemisorbed on the surface of plant opal was examined by Bartoli and Wilding (1980). They found a positive relationship between surface area and dissolution, and an inverse relationship between aluminium content and surface area-dissolution. Bartoli (1985) found the surface silicon:aluminium ratio very low in comparison with the ratio for the whole sample, and attributed the low solubility of plant opal in soils to the chemisorbed aluminium on their surfaces. Kaufman *et al.* (1981) offered a mechanism for the deposition of silica in plants which envisaged a membrane surface within the cell to which the silica particles attached, or the production by the cell of

cationic molecules which coat the first layer of particles in order that the surface might attract the next layer of colloidal particles. The presence of an aluminium-silica surface coating is thus quite possible.

Many believe that, given a long enough period of time, a mineralogical change will occur transforming amorphous silica into microcrystalline quartz in the near surface environment. Time-dependent aging processes have been investigated in biologically derived cherts, where there appears to be a progressive increase in the ordering of silica which can be broadly correlated with the age of the sediment (Greenwood, 1973; Weaver and Wise, 1974). Beavers and Stevens (1958) reported the replacement of opaline phytoliths by chalcedonic silica in paleosols, observing all stages in transformation from unaltered opal with marginal chalcedonic alteration to completely altered paramorphs of chalcedony (see also Hunt, 1985). Jones and Hay (1975) suggested that the burning of vegetation might result in the production of crystalline plant opal and their addition to the soil, a line of investigation which seems well worth pursuing, particularly in the Australian environment.

Distribution in sediments

The use of plant opal in paleobotany, archaeology, paleoclimatology, etc., requires not only an understanding of its morphological, chemical and physical properties, but also an understanding of its relationship to the sediment in which it is found. What are the processes to which the opaline material is subjected within soil materials? Obvious processes include dissolution and mechanical abrasion. Others which are hinted at in the literature, but which have been little investigated, include mixing by soil fauna and movement through soil voids. The distribution of plant opal with depth in soils has been examined in several studies, but their relevance outside the

area of study is questionable. The distribution according to soil type is an even more questionable area.

Most studies find a concentration of plant opal in the topsoil with a decline in abundance with depth (Witty and Knox, 1964; Verma and Rust, 1969; Wilding and Drees, 1971; Yeck and Gray, 1972). Concentrations at depth within a sediment are taken as pointing to the presence of a former topsoil (Beavers and Stephens, 1958; Jones and Beavers, 1963b; Pease, 1967; Dormaar and Lutwick, 1969; Gould, Anderson, McClellan, Coleman and Gumsey, 1979; Sase, 1981; Retallack, 1981; Evans, 1982). The amount of plant opal material found (usually confined to the coarse silt fraction) has been correlated with "soil maturity" (Beavers and Stephen, 1958), rate of loess accretion (Jones and Beavers, 1963), internal drainage-catenary position (Jones and Beavers, 1964a, b) and differences in vegetation type e.g. grasslands versus forest (Wilding and Drees, 1971).

The work on distribution of plant opal between soils and down the soil profile has been largely pursued in the United States where the loess areas have provided an ideal site for these studies. When found in anything other than the surface layer, distribution down the profile has been related to gradual accretion of loess allowing plant growth to continue. The mixing action of fauna is accepted in a few papers (e.g. Jones and Beavers, 1964a) but not investigated. The differences in distribution of plant opal between similar soils (similarity being expressed in terms of belonging to the same Soil Group and which may or may not be a real similarity) has been related to speed of loess accumulation, differences in soils internal drainage, and differences in vegetation history; this last having more than a little circularity in its logic.

In addition, there is a considerable difference of opinion in the

literature as to the downward mobility of plant opal. Bartoli and fellow workers studied the distribution of plant opal in podzols (Bartoli and Guillet, 1977; Monrozier and Rapaire, 1980) and stated unequivocally that plant opal migrated across the A2 and accumulated in the Bh, where the presence of the Bs (hardpan) was a barrier to further migration. This point is disputed by Rovner (1986) and it needs further investigation since much of the work in archaeological and paleoenvironmental reconstructions relies on the non-movement of the plant opal between layers of sediment. Limited lateral movement is accepted, but its full effects are not considered.

Research

Despite over a century of research the study of plant opal is still in its infancy. The reasons for this are complex and include:

1. Fragmentation of research; botanists study plant opal in the plant, pedologists consider it when it reaches the soil, archaeologists and paleoecologists endeavour to use the disarticulated plant opal as a tool.
2. The size range of the opaline particles; such small particles mean that the development of techniques for separation, morphological study, etc., have had to wait for the development of the appropriate technology.
3. The very slow awakening to the relevance of plant opal; it is still not perceived as making an important contribution to sediments since the amount present in all parts of the silica cycle is not known. Its potential as a marker in sediments has not been fully explored despite it being a major biological input of silica to sediments.
4. Much of the research waiting to be embarked upon is pure research, and this is not seen in the present climate as being as

relevant as applied; thus researchers are tending to start at the wrong end - to use the plant opal as a tool rather than to complete investigations into its properties which would then enable its more effective use.

Summary

There are three distinct areas of investigation into plant opal which can be identified:

1. Botanical work examining the plant opal *in situ* which has concentrated on the Gramineae.
2. Studies of disarticulated plant opal in sediments which have been mainly concerned with the characteristics of the opal after extraction - its mineralogy, chemistry, or its relationship to soil "type". Its function as a dynamic part of the soil has been little studied except in podzols.
3. User-oriented research, also based on the Gramineae, which is being undertaken by workers with archaeological and paleoenvironmental interests. This research is largely morphological and based on the work of Twiss *et al.* (1969). The resultant reconstructions are based on plant opal morphology, often associated with other lines of evidence such as pollen studies.

What results is a conceptual split between the biological and earth sciences approaches with the users falling into the gulf between. The weaknesses lie in the applied work which relies on the use of the disarticulted plant opal shapes found in sediments and the supposition thet they can be traced back into the host plant or plant community.

The very little current Australian research into plant opal falls into the first and third categories although in past years the investigations into silica in the oat plant of L.H.P. Jones (with

others) at the CSIRO Division of Plant Industry, Melbourne (1963-1966) represents pioneering work on the biological side, and the work of Baker falls into the earth sciences category. Baker examined plant opal as a soil constituent which might distinguish between soils (1959b), but he ascribed the differences in his sediment plant opal assemblages to vegetation differences without referring his work back into the extant vegetation. It is only through a better understanding of the dynamics of the plant opal-sediment relationship that plant opal can be used to unravel complex environmental problems.

How much silica is cycled through the biosphere? Silica is utilised by most if not all organisms for reasons which are not always clear. Further investigations into the amount of plant opal and its distribution in a wide range of sediments, the mechanisms leading to those distribution patterns, its dissolution rates in varying environments, its contribution to soil water, etc., are needed. Research is also needed into plant opal's physical properties; the relationship between occluded elements within the plant opal and the sediment in which the plant is growing, surface properties and their relationship to plant opal formation, the effects of bush fire on mineralogy, and so on. The relationship between plant opal assemblages in the present-day vegetation and the assemblages in the sediments in which they are growing needs further exploration to examine the basic premises upon which this work has been based.

These queries can be placed into two main areas where initial research effort should be concentrated:

1. All aspects of plant opal cycling - amount, size, shape, distribution, and, most importantly, the interactions of plant opal with soil processes since this understanding will define the limits to the uses to which plant opal may be put.

2. Understanding the relationships between the plant opal in a species or community and the plant opal assemblage in a sediment on which that species or community is growing. This second area is in reality a subset of the first, but since most current research is user oriented it is a topic which deserves some prominence.

It is these two areas which this thesis begins to explore in the Australian environment.

Aims and arrangement of thesis

Aims:

1. To evaluate current trends in plant opal research and their applicability.
2. To evaluate the use of disarticulated plant opal as a constituent of sediments which may shed light on processes at the plant/litter/soil interfaces.

Arrangement

The thesis is divided into 4 Parts:-

Part 1: Introduction and field studies.

The first part of the thesis outlines a series of field-based studies which progress from simple observations made in Chapter 2 through to more complex examinations arising from these.

Chapter 2 describes three initial field studies undertaken at Oxford Falls which examine the morphology of plant opal in a small vegetation community and its expression and distribution in the underlying sediments.

Chapters 3, 4 and 5 outline a series of field investigations conducted in the Pilliga State Forests which explore aspects of the points arising from the initial field studies. Chapter 3 examines the amount of plant opal available in the litter layer for incorporation

into the soil; Chapter 4 looks at the amount and distribution of the plant opal in the soil; and the assemblages of plant opal in the litter, topsoil and within the soil are compared in Chapter 5.

The observations made in the Pilliga field sites then lead to Chapter 6 which considers the process of fire and its effects on plant opal assemblages.

Part 2: Field, laboratory and analytical techniques.

Chapter 7 outlines the problems which arise in studying plant opal in plants and sediments and the methods used in this thesis to separate and examine the plant opal. Chapter 8 discusses the litter study undertaken in the Pilliga State Forests, outlining the field and laboratory methods used and placing it within the context of similar studies in Australia.

The key used in the field studies is central to this thesis. Chapters 9 and 10 examine the current trends in the erection of plant opal keys and presents the Keys used in this thesis.

Part 3: Implications for research.

Chapters 11 and 12 review the observations made in this thesis and their implications for both paleoecological and pedological studies.

Part 4: Appendices

The appendices contain descriptions of soils and flora, and several extended discussions of peripheral but never-the-less important questions raised in this thesis which, if included in the main body of the work, might obscure the arguments presented.

Published papers relevant to this thesis are appended.

CHAPTER 2

INITIAL FIELD STUDIES: OXFORD FALLS

Introduction

Three related studies were undertaken; to examine the range of plant opal morphology in Australian species of vegetation compared with those reported in the literature; to examine extraction techniques both from sediments and plants; and to examine the characteristics and distribution of plant opal in sediments.

The first study was conducted in a small vegetation community of two co-dominant species in order to reduce the time required to sample and process samples. Only the leaves were examined and a very simple flotation technique was used to separate plant opal from the sandy sediment, thus eliminating the necessity for time-consuming heavy liquid separations although the possibility of sample bias was increased.

The plant opal distribution within a soil was the subject of the second study. This also led to the further development of separation techniques which are reported in Part 2.

The third study arose directly from the results of first. It considered one plant opal shape which was found to be present in several species in the study area and in several of the families of one species from a second field area in north-western New South Wales.

The main results of the studies have been published (Hart 1988a, 1990) and copies of these papers appear in Appendix H.

The Field Sites

General

Oxford Falls is a small semi-rural suburb 17 km to the north of Sydney, New South Wales, grid reference 337267 on the Hornsby 1:25 000 Orthophotomap Sheet (Figure 2.1B). The study was conducted in a small catchment on Crown Land which is designated as Recreation Reserve and

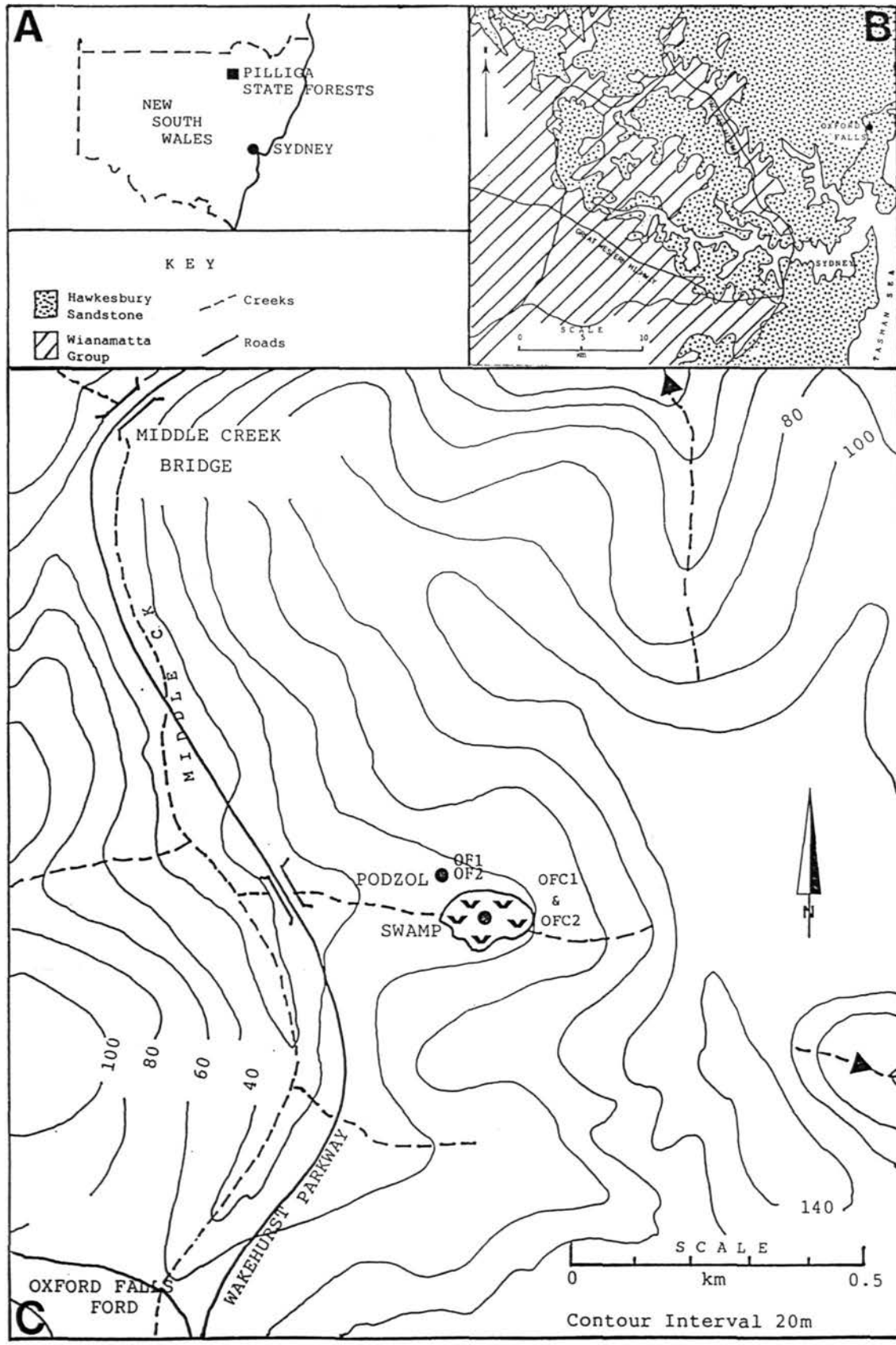


FIGURE 2.1: A: MAP OF N.S.W. SHOWING BOTH STUDY AREAS
B: LOCATION OF OXFORD FALLS
C: TOPOGRAPHY OF OXFORD FALLS SITE

which has been heavily utilised as such by the surrounding suburbs (Figure 2.1C). The area was last disturbed by fire in 1979.

Geology:

Oxford Falls is situated on the Hornsby Plateau (100-200 m a.s.l.), part of the Permo-Triassic Sydney Basin (Bembrick, Herbert, Scheibner and Stuntz, 1980). The Hawkesbury Sandstone which underlies the area is deeply incised by creeks flowing towards the Narrabeen Lagoon at sea level.

The Hawkesbury Sandstone is a flat-lying Middle Triassic quartz sandstone of fluvial origin containing thin mudstones (Conaghan, 1980; Conaghan and Jones, 1975). Conaghan and Jones recognised two sandstones; a more friable, finer grained massive facies and a sheet facies. The mudstone facies comprises many thin, recessively weathered mudstones and siltstones.

Climate:

Rainfall in the area is 1000 to 1200 mm annually with around 60% of the annual rainfall falling between January and June. Temperatures are mild (see Tables 2.1 [data for Sydney] and 2.2 [data for North Parramatta], Bureau of Meteorology, 1988).

Soils:

Northcote (1966) mapped the area at a scale of $1:1x10^6$ as a dissected sandstone plateau of moderate to strong relief with yellow leached earths, siliceous sands and shallow, stony duplex soils where interbedded shales were exposed.

Soils on the Plateau were mapped by Walker (1972) at a scale of 1:75 000 as the Hawkesbury Association (stony, shallow soils). The main soils mapped were Yellow Podzolics, Lithosols (which he referred to as Skeletal Soils) and Alluvial Soils (Alluvial Deposits).

The Soil Conservation Service of New South Wales has mapped the

Table 2.1: CLIMATIC RECORDS, SYDNEY
Sydney Regional Office
Station 066062, Lat 33 deg, 52 min S; Long 151 deg, 12 min E; Elevation 42m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
DAILY TEMP C	(127 years of record)												
mean max	25.7	25.6	24.6	22.2	19.2	16.7	16.0	17.6	19.7	21.9	23.6	25.1	21.5
mean min	18.5	18.6	17.4	14.6	11.4	9.2	7.9	8.8	10.9	13.4	15.5	17.4	13.6
RAINFALL mm	(128 years of record)												
mean	102	113	135	124	121	131	11	80	69	78	81	78	1212
RAINDAYS No	12	12	13	12	12	12	10	10	11	12	11	12	139

Table 2.2: CLIMATIC RECORDS, PARRAMATTA
Parramatta Nth Office
Station 066124, Lat 33 deg, 48 min S; Long 151 deg, 1 min E; Elevation 60m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
DAILY TEMP C	(19 years of record)												
mean max	28	27.6	26.3	23.9	20.2	17.3	17	18.7	21	23.3	25.2	27.5	23
mean min	17.6	17.7	16.2	13	10	7.6	6.1	7.2	9.2	12.2	14.1	16.2	12.3
RAINFALL mm	(19 years of record)												
mean	118	102	129	70	64	84	38	53	52	81	80	64	935
RAINDAYS No	11	11	11	8	9	9	6	8	8	11	11	9	112

Records from "Climatic Averages Australia"
Meteorological Summary July 1988
Bureau of Meteorology

study site at a scale of 1:100 000 as the Oxford Falls Soil Landscape Unit, comprising "moderately deep to deep (50->150 cm) Earthy Sands (Uc5.23), Yellow Earths (Gn2.84, Gn2.94), Siliceous Sands (Uc1.21) on slopes; deep (>200cm) Leached Sands (Uc2.12), Podzols (Uc2.32, Uc2.36) and Grey Earths (Gn2.81) on valley floors" (Chapman and Murphy 1989:78). Nomenclature in parenthesis refer to Northcote (1974) Principle Profile Forms (PPF).

Recently, Mitchell and Humphreys (1987), working in the same catchment as this study, recorded typical soils to include Earthy Sands and Lithosols (similar to the Entisol order in Soil Taxonomy [Soil Survey Staff, 1975]) and Yellow Podzolics (similar to the Ultisol order). They described the evolution and decay of litter dams and microterrace forms after fire in the catchment, incorporating them into a model of soil formation which includes the processes of rainwash and bioturbation and explains the genesis of texture contrast soils in the Sydney Basin (Bishop, Mitchell and Paton, 1980).

Detailed descriptions of the soils in the study area are found in Appendix B. Generally the catchment soils comprise a topsoil of sandy material overlying clayey subsoils derived from shale lenses and kaolin dykes (duplex soils; Northcote, 1974) or slightly weathered to unweathered sandstones (uniform soils; Northcote, 1974).

Vegetation:

Vegetation on the Hornsby Plateau comprises a rich and diverse flora although the Hawkesbury Sandstone is low in nutrient status; in particular phosphorus (Beadle, Evans and Carolin, 1972). The vegetation at the site is a woodland (after Specht, 1970) of *Eucalyptus haemastoma, E. gummifera,* and *E. sieberi* with understory species of *Banksia, Grevillea* and *Hakea.* In the centre of the ampitheatre of

sandstone shelves is a *Gahnia sieberana* and *Gleichenia dicarpa* swamp approximately 100 m x 75 m in area, dammed by a dyke (Figure 2.1C). This swamp and a two metre wide transition zone around it comprised the study site.

Swamps are a common feature on the Hawkesbury Sandstone and are caused by impeded drainage, often by shale beds (Buchanan, 1980). On the Hornsby Plateau, swamps have been classified into shrub-swamps and sedge-swamps by Pigeon (1938), and it is into this later category that the study area swamp falls.

Buchanan described similar swamps on the Lambert Peninsula, also on the Hornsby Plateau, some 15 km north of the study area. Buchanan considered that cycles of swamp build up and destruction brought on by climatic changes were apparent in the Sydney swamps. She described the conditions for swamp formation as a gentle slope and the presence of puggy material in the swamp catchment to supply a slow seepage of water in dry conditions. Four vegetation types were described, dependent upon soil moisture and divided according to the characteristic height and abundance of some of the larger species. The Oxford Falls swamp falls into the second of the categories - "Swamp: vegetation dense" (Buchanan, 1980:86), or mid-height closed herbfield (Specht, 1970).

Field study 1: The morphology of plant opal in vegetation and sediments

The aims of this study were:

1. to isolate and quantify the plant opal present in the leaves of species in a small vegetation community,
2. to examine the plant opal isolated to determine if any morphology is diagnostic of a particular species and
3 to examine the morphology of plant opal in the sediment the species is growing in, in order to determine the characteristics of plant opal which survives in sediments.

Materials and methods

Samples of the two dominant species in the swamp (*Gahnia sieberana* and *Gleichenia diacarpa*) comprising all material above a 1 m^2 area of ground, were collected for dry weight estimations, and samples of mature leaves were collected from each of the ten major species for plant opal extraction by sulphuric acid digestion and potassium trioxide oxidation. Details of the method used are to be found in Chapter 7.

Two sediment cores, OFC1 and OFC2 (see Appendix B), 155 mm long and 20 mm in diameter and situated 500 mm apart were removed from the centre of the swamp. Each core comprised organic sediment and bands of clean white sand, charcoal, and muddy sand. The particle size distribution of the 0-20 mm section of OFC2 was found to be sand: 52%, silt: 47% and clay: <1% (see also Appendix G, Table G1 for details of the particle size distribution of OFC1). The sand fraction was examined for plant opal presence under a petrological microscope and was found to contain a few large pieces. A later separation of plant opal from the sand fraction was made using zinc bromide, and the resulting plant opal examined under the Scanning Electron Microscope (SEM) [Plate 8A and B]. See Chapter 7 for techniques.

The simple washing technique described in Chapter 7 and in Hart (1988a) was used to separate the silt-sized opal from the silt and clay.

Since the main aim of this study was to compare the disarticulated plant opal from sediments with that from plants, a simple morphological key identifying plant opal shapes, which was a precursor of the main key employed in this thesis, was used. It is described in detail in Hart (1988a) and in Chapter 10. The abundance of each shape class on two to three SEM stubs covered with plant opal from each of the ten species and the two sediment cores was assessed by comparing the amount in each class with the total amount of plant opal on each stub.

The decision to use an abundance measure instead of a point counting method was made since this was regarded as a pilot study only, and the time factor was important. It is a method which has been used in earlier studies (Twiss *et al.*, 1969; Geis, 1973) although most modern studies employ counts of 200 grains or more (Piperno, 1987).

The shapes of plant opal observed in each species and in the sediment are recorded in Table 2.3, and their occurrence rated according to abundance (Geis 1973). Representatives of each shape in the various species were photographed and appear Hart 1988a.

Results

While this study was by no means exhaustive, the results demonstrated several interesting points.

(i) Amount of plant opal

The mean percentage by dry weight of plant opal material contained in the leaves ranged from 0.10 - 2.45% (Table 2.4). *Eucalyptus gummifera, Banksia oblongifolia* and *Casuarina distyla* (now *Allocasuarina distyla*; Robinson, 1991) were common species bordering the swamp while the remainder were found in the swamp. Plant opal was present in all the species, although only a trace was found in *Leptospermum flavescens* (now *L. polygalifolium*).

The largest amounts of plant opal were produced by *Gahnia sieberana*, *Entolasia stricta*, *Pteridium esculentum* and *Gleichenia dicarpa*. When the abundance in each morphological class in these four species is compared with the abundance in the sediment (Table 2.3), it can be seen that the more delicate shapes disappear, leaving those more robust shapes to dominate the top 20 mm of the sediment. This explains the abundance of sphere aggregates in the sediment despite the fact that they have abundance only in *Entolasia stricta*; spheres (*Gahnia sieberana*) etc.; and the disappearance of the thin sheets although they

Table 2.3: Abundance of each class of phytoliths in the species examined and in the sediment in the swamp

VA, very abundant; A, abundant; F, few; R, rare; N, not observed

From Hart (1988)

Species	Sphere aggregates	Spheres	Compound spheres	Cups	Stomata	Fan-shaped	Rods			Thin sheets				Thick sheets		Dumbbell
							Smooth	Marked	Dendriform	Spiked	Scrolled	Plain	Bulbous	Regular	Irregular	
Xanthorrhoea resinosa	N	A	N	F	N	N	F	R	R	N	R	VA	N	N	A	N
Gahnia sieberana	N	N	N	N	A	N	F	F	A	N	N	A	VA	N	A	N
Entolasia stricta	VA	F	N	A	N	F	A	VA	R	VA	N	F	N	N	N	N
Eucalyptus gummifera	N	VA	A	N	N	N	N	N	N	N	N	F	N	F	F	N
Leptospermum flavescens	N	A	N	N	N	N	F	F	F	N	F	VA	N	N	F	N
Banksia aspleniifolia	N	A	N	F	F	N	F	F	F	N	F	VA	F	A	A	N
Acacia schinoides	F	F	N	F	A	N	A	A	F	N	R	A	A	F	F	N
Casuarina distyla	A	A	A	F	N	N	N	F	F	F	N	VA	F	N	A	N
Pteridium esculentum	N	R	N	F	N	N	F	F	A	N	N	VA	N	N	VA	N
Gleichenia dicarpa	N	A	N	N	N	N	F	N	N	N	N	VA	N	F	N	N
Soil																
Two cores (simple preparation)	A	A	N	R	F	N	R	A	A	A	R	F	F	N	VA	R

Table 2.4: Quantity of plant opal in leaves, and cover of each species

Species	Plant opal in leaves (% of dry wt) Mean	s.d.	Percentage cover
Xanthorrhoea resinosa	0·33	0·091	Trace
Gahnia sieberana	1·78	0·662	30
Entolasia stricta	1·52	0·489	1
Eucalyptus gummifera	0·10	0·069	1
Leptospermum flavescens	Trace		5
Banksia aspleniifolia	0·21	0·312	1
Acacia schinoides	0·40	0·687	5
Casuarina distyla	0·33	0·509	5
Pteridium esculentum	2·45	0·171	10
Gleichenia dicarpa	1·71	0·502	40

From Hart (1988)

are abundant in three of these species.

(ii) Plant opal assemblages

In the sediment, most of the plant opal was found in the suspension from the fractionation technique described above, but both fractions and the sand were examined for assessments of frequency. In sediments much of the plant opal is difficult to distinguish from clays and other weathered material, particularly once it has been subjected to dissolution within the sediment, thus the abundance in each class is an underestimation but does identify those forms which are less subject to dissolution in sediments.

The cells from which plant opal are derived are difficult to deduce in plant isolates and even more so in soils and sediments where the plant opal may have undergone dissolution and mechanical breakdown. As it was intended that these investigations lead to a key for the identification of the plant opal which could be used in soils and sediments, it was decided to adopt a morphological scheme similar to that of Wilding and Drees (1974).

Many of these shapes have been described previously. Geis (1973) considered spheres to be the vesicular infillings of cell lumen or vesicles budding from a silicified cell wall. In addition to spheres, Wilding and Drees (1974) described silicified stomata, and cups which ranged in diameter from 2-10 um which they considered to represent silicified epidermal or mesophyll cells. The fan-shaped phytoliths described in the present study appear to be the silicified bulliform cells described by Parry and Smithson (1964), and the dumb-bell is often considered diagnostic of the Panicoideae (e.g. Twiss *et al.*, 1969).

The main points

1. Plant opal assemblages

Identification of the two co-dominant species from the sediment plant opal assemblage would be impossible since morphologies which were abundant in the species, such as plain thin sheets, were not abundant in the sediment and the sediment contained large numbers of sphere aggregates for example, which were not observed in isolates from either species.

2. Survival in sediments

The forms with a small surface area to volume ratio, such as irregularly shaped thick sheets, appear to survive in the sediment, whereas the thin sheets, which were very abundant in most species examined, were rare or few.

The abundance of any form in sediment is also a function of its overall abundance in the contributing species but the dominance of a particular species at a site does not necessarily mean that it will contribute plant opal which will survive or be identifiable in the sediments.

3. Reference collections

Reference collections are both time consuming and costly to erect, and to examine all the extant vegetation at a site is near impossible. An important contributing species might be missed, particularly in this case, since the amount of plant opal material brought into the swamp either by wind or water was probably large; thus the contributions of vegetation from the entire catchment should be considered as contributing to the swamp plant opal assemblage.

4. The species specific phytolith

Gahnia sieberana is a member of the Cyperaceae family and as such is expected to contain a species specific phytolith. However, this

phytolith, described in the key as a bulbous thin sheet, was found in other species examined. Suprisingly, only a few were found in the sediment.

Field study 2: Distribution of plant opal in a soil

Plant opal is considered to be concentrated in the surface layer of soils (Beavers and Stephen, 1958; Jones and Beavers, 1964b; Kondo and Iwasa, 1981). However, its distribution within the a soil is of interest, since it may point to the methods by which plant opal is dispersed throughout the soil. The distribution of plant opal in a podzol at the Oxford Falls site was examined.

Material and methods

This site was located about 30 m north of the swamp (Figure 2.1C, profile OF2). The podzol was a little unusual in that the organic and iron pans were to be found within the underlying coarse-grained Hawkesbury Sandstone. The vegetation at the site was a low shrubland, and the surface was covered with a thick layer of litter. The shallow A1 was a black organic sand, under which lay a bleached A2. The organic pan was found at the interface with the sandstone with the iron pan below it. Both were convoluted. A full description is given in Appendix B (Profiles OF1 and OF2).

Samples were taken in the soil down to the pans at 10 cm intervals. Plant opal was extracted from the whole samples using the heavy liquid sodium polytungstate (as outlined in Chapter 7), and the results corrected for purity and graphed (Table G23, Figure 2.2).

Results

It was found that there was a maximum of plant opal in the A1, with plant opal content decreasing until an area just above the pans, where it increased.

It has been previously observed that an area of finer material is

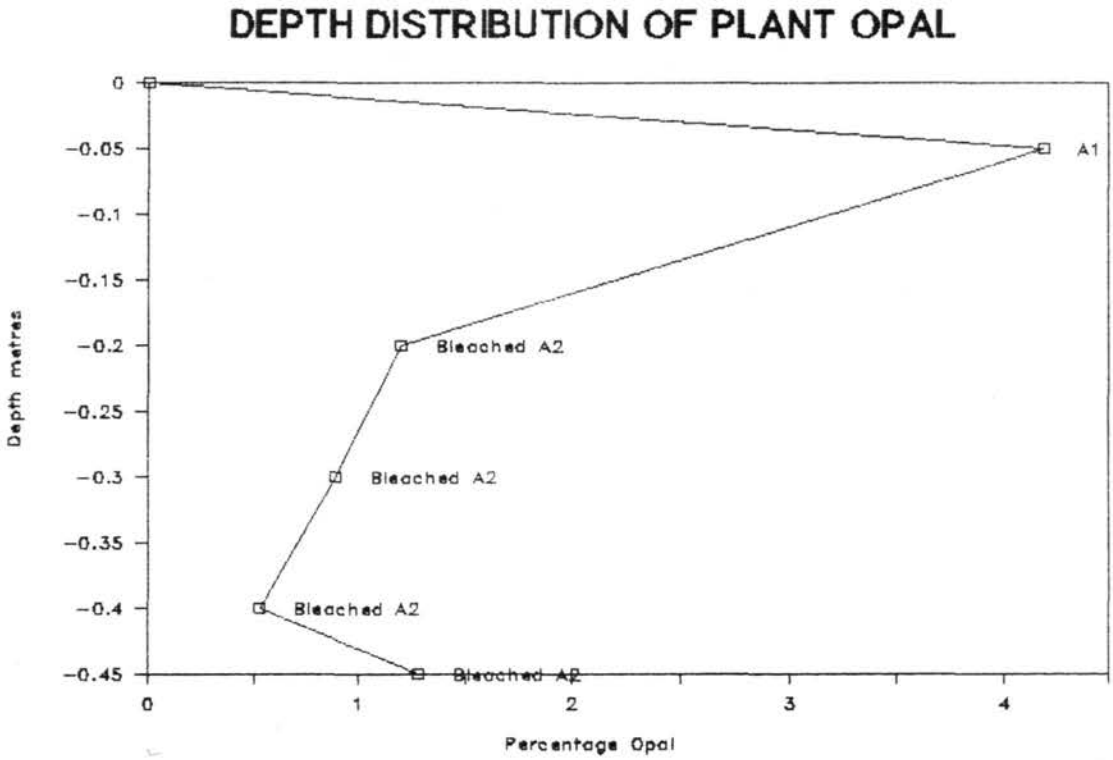


FIGURE 2.2 DEPTH DISTRIBUTION OF PLANT OPAL IN SOIL, OXFORD FALLS PODZOL PROFILE OF2

commonly found just above pans in the podzols in the Sydney Basin (Humphreys, 1976). Humphreys examined the fabric in podzols similar to the one sampled above. He found the A horizon fabric to have large voids with very few finer sized particles in the voids. In the B and C horizons the fabric had smaller voids with an increase in fine sands and silts partly filling the voids. Near the boundary with the organic pan, Humphreys observed a change in the A horizon fabric comprising an increase in the smaller sized grains filling the voids. He suggested that in the podzol the finer particles move downwards and concentrate in the pans and B horizon. If this is the case, the movement of plant opal down the profile through the relatively porous A horizon can be envisaged, with the opal concentrating in the area just above the pans. Plate 10A-D shows that the plant opal in the organic pan is as fresh looking as that in the A1 and A2.

Field Study 3: The species specific phytolith

Some plant species are believed to contribute unique phytolith shapes in quantity to soils and sediments and thus they have been used as vegetation indicators in archaeological and palaeo-environmental work. The Cyperaceae have long been held to make such a contribution (Mehra and Sharma, 1965; Norton, 1966; Metcalf, 1971; de Pomar, 1972; Dahlgren and Clifford, 1982; Rovner, 1983; Kondo and Sase, 1986; Ollendorf, Mulholland and Rapp, 1987; Piperno, 1987; Pearsall, 1989).

The "Cyperaceae-type" phytolith has been described by these authors as a cone lying on a plate, often surrounded by nodular satellite bodies. Pearsall has recently stated that Cyperaceae phytoliths are "taxonomically significant" (1989:325) and one of the indicators of taxa important in ecological studies (1989:341).

Field study 1 revealed that the "Cyperaceae-type" phytolith was also to be found in several species from Dicotyledonous families in quantities ranging from abundant (*Acacia schinoides*, Mimosaceae), to few (*Banksia oblongifolia*, Proteaceae; *Casuarina distyla*, Casuarinaceae [*Allocasuarina distyla*]). A further study examined in more detail the occurrence of this phytolith in the three species in which it was detected and its occurrence in the Mimosaceae in areas outside the field site.

Materials and methods

At the Oxford Falls swamp mature leaves from the above listed three species and *Gahnia sieberana* (Cyperaceae) were collected again for this investigation.

The location of the second study area, the Pilliga Forests, north of Coonabarabran in semi-arid north-western New South Wales, is also shown in Figure 2.1A. The Forests cover a large area extending from the lower foothills of the Warrumbungle Range to the Namoi River and comprise the most extensive dedicated native forests remaining in New South Wales (for details of the Pilliga field site see Chapter 3).

The mature leaves of eight members of the Mimosaceae family were collected from the Pilliga East State Forest. These and the leaves collected from the Oxford Falls site were washed, dried, the plant opal extracted and mounted on stubs for SEM and light microscopy (Chapter 7). Counts of the "Cyperaceae-type" phytolith were made for all species with the phytoliths mounted in Canada Balsam (200 counts/slide, at 300X under a standard petrological microscope).

Results

Some of the results of this study are reported in Hart 1990, a copy of which can be found in Appendix H. These results are extended below.

1. Morphology

Few details of the morphology of the "Cyperaceae-type" phytolith have been published, apart from descriptions similar to those discussed above. de Pomar (1972) is one of the few who has published details of measurements of the phytolith, although such details can be obtained from published SEM micrographs (see below). What is obvious from the descriptions, however, is the need for morphology to be carefully described so that such measurements are comparable.

The "Cyperaceae-type" phytolith consists of a *conical body* terminating in an *apex*, standing on a *plate*, with *satellites* situated within 2 um of the base of the cone. Some authors include plates containing rows of conical bodies (Ollendorf *et al.*, 1987).

Plates 8G and H and Plate 9A-H are SEM micrographs of the "Cyperaceae-type" phytoliths from *Acacia* sp. from the Pilliga State Forests. When compared with Figure 2 from Hart (1990) it can be seen that the "Cyperaceae-type" phytoliths from all families are indeed similar. All conical bodies are smooth, with pointed apices and with similar shape and spacing on the plate. They are photographed at around 2,000x magnification and do not present any individual differences which would distinguish one family from another.

The mean and median basal diameters of the conical bodies for all species examined and from various published SEM micrographs of Cyperaceae species are given in Table 2.5. *Acacia schinoides* shows a slight deviation in both mean and medial basal diameters, but one would hardly like to pin a specific identification on such a minor point. It is to be noted that the basal diameters in the *Acacia* spp. from the Pilliga included some at 10 um; thus this is not a difference which would serve to separate out the Mimosaceae family. It may be a species difference or simply due to the low sample numbers.

Table 2.5: THE MEAN AND MEDIAN BASAL DIAMETERS OF CONICAL BODIES (from S.E.M. micrographs)

Species	Mean basal diameter (uM)	SD	Median basal diameter (uM)	n
Gahnia sieberana (family Cyperaceae) (MU# 50534/35)*	5.50	2.64	5.40	35
Acacia schinoides (family Mimosaceae) (MU# 50530/31)	3.71	1.76	3.60	50
Banksia oblongifolia (family Protaceae) (MU# 50528/29)	5.22	2.16	5.70	47
Casuarina distyla (family Casuarinaceae) (MU#50532/33)	4.58	2.56	4.75	19
**Cyperaceae sp various	6.69	3.02	5.00	19

* : Number of sample held in School of Earth Sciences Museum
** from: Kondo & Sase (1989); Ollendorf *et al.* (1987)

Table 2.6: THE SIZE AND NUMBERS OF CONICAL BODIES WITH SATELITES (from S.E.M. micrographs)

Species	Basal diameter		Proportion of conical bodies with satellites	Average number of satellites/ conical body	n
	mean uM	range uM			
Gahnia sieberana (family Cyperaceae) (MU# 50534/35)*	8	6 -10	0.2	2	35
Acacia schinoides (family Mimosaceae) (MU# 50530/31)	5	4 - 7	0.2	2	50
Banksia oblongifolia (family Protaceae) (MU# 50528/29)	6	3 -10	0.4	2	47
Casuarina distyla (family Casuarinaceae) (MU#50532/33)	7	5 - 9	0.5	2	19

* : Number of sample held in School of Earth Sciences Museum

The "Cyperaceae-type" phytolith is to be found with either individual or rows of conical bodies on the plate. A row may comprise conical bodies of similar or varying size (this does not appear to be family or species specific [cf Plate 9D and H]). Individual conical bodies may have formerly been part of a row which has broken up (Plate 8G), although the bulbous bodies from *A. spectabilis* appear on individual plates (Plate 8H and 9A). Each may be embedded in a near circular plate or in a plate clearly showing the point where it broke away from the row. In either case it can be envisaged that after a period of time within the sediment, such distinctions may become blurred.

Satellites were found around many of the larger conical bodies in all species (e.g. Plate 8G and 9B-D, F-H). The mean basal diameter of conical bodies surrounded by satellites and the average number around each is given in Table 2.6. The average number surrounding a conical body was 2, but ranged from between 0 and 4. There appears to be no feature of the satellites (size, shape, disposition around the conical body) which would separate the families.

2. Numbers of "Cyperaceae-type" phytoliths in each species

Table 2.7 summarises the results of the point counting in each of the species examined. The proportion of the "Cyperaceae-type" phytolith on each slide with a standard error (95% confidence level), and the mean percentage (with standard deviation) of "Cyperaceae-type" phytoliths in each species is given.

While *Gahnia sieberana* (family Cyperaceae) has the greatest abundance of the "Cyperaceae-type" phytolith (48%), the numbers present in *Acacia schinoides* (12%) and to a lesser extent in *Banksia oblongifolia* (2%) are by no means insignificant. *Casuarina distyla* [*Allocasuarina distyla*], while containing a trace of the "Cyperaceae-

Table 2.7: POINT COUNTING RESULTS; "CYPERACEAE TYPE" PLANT OPAL

Species	Proportion*	Mean %	SD	n
Oxford Falls				
Gahnia sieberana				
sample 1	0.465 ± 0.067			213
		48.15	2.33	
sample 2	0.498 ± 0.031			261
Acacia schinoides				
sample 1	0.113 ± 0.044			226
		11.9	0.85	
sample 2	0.125 ± 0.041			248
Banksia oblongifolia				
sample 1	0.021 ± 0.009			236
		1.8	0.42	
sample 2	0.015 ± 0.009			202
Casuarina distyla				
sample 1	trace			200
sample 2	trace			200
Pilliga				
Acacia deanei ssp. deanei (MU# 50541)**	0.018 ± 0.009	1.8		226
A. lineata (MU# 50542)	0.009 ± 0.006	0.9		212
A. triptera (MU# 50543)	trace			200
A. calamifolia (MU# 50538)	trace			200

* Cyperaceae type : All opal (95% confidence level)
** : Number of sample held in School of Earth Sciences Museum (samples from Oxford Falls have same MU# as in Table 2.5)

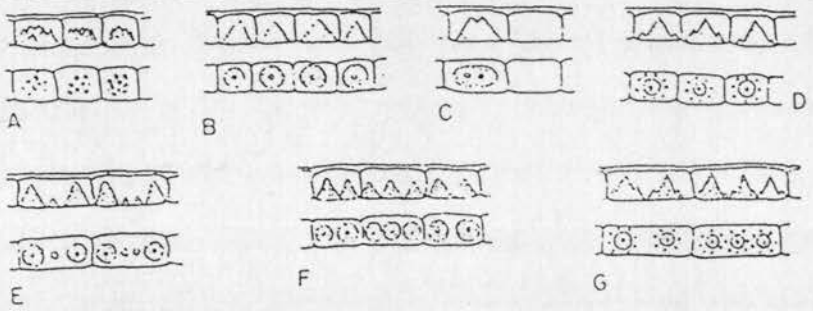
type" phytolith, did not contain a significant amount.

In four of the eight Pilliga species examined from the Mimosaceae family the "Cyperaceae-type" phytolith was found. Two species, *Acacia deanei* ssp. *deanei* and *Acacia lineata*, contained a significant proportion (1-2%) of the "Cyperaceae-type" phytolith. In addition, one (*Acacia spectabilis*) contained an interesting bulbous variation.

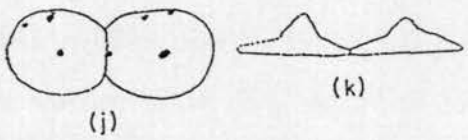
Discussion

The morphology of the "Cyperaceae-type" phytolith examined in this study is similar in morphology to that shown in the SEM micrographs of Ollendorf *et al.* (1987) Figure 4A, Kondo and Sase (1986) Plate III, and in many other authors' drawings (Figure 2.3). In the literature both single cones on a plate **and** rows of cones have been indicated as species specific to the Cyperaceae. Where they are single cones, the plate edges are not necessarily represented as being smooth. From the small number of species examined at the site of the present study, it is apparent that the "Cyperaceae-type" phytolith is to be found in dicotyledonous families, and in significant amounts. The three families Mimosaceae, Protaceae and Casuarinaceae are very important families with representative species covering most of Australia. In particular, the *Acacia* is a widespread genus, and the presence of this phytolith in the genus is important to note, particularly in archaeological and paleo-environmental studies.

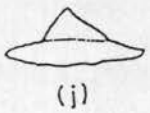
The Australian national floral emblem is the Wattle (*Acacia* spp., or more specifically *A. pycnantha* or Golden Wattle). There are approximately 900 species of *Acacia* in Australia (White, 1986) and it is to be found in all continents except Europe (where it has been introduced and is often known as "mimosa") and Antarctica (Boland, 1984). It occurs in most areas of Australia which support vegetation, often in dense stands, and is part of what White described as



A-G: Conical silica bodies in various taxa of Cyperaceae
(From Metcalfe, 1971; in Dahlgren & Clifford, 1982:89)

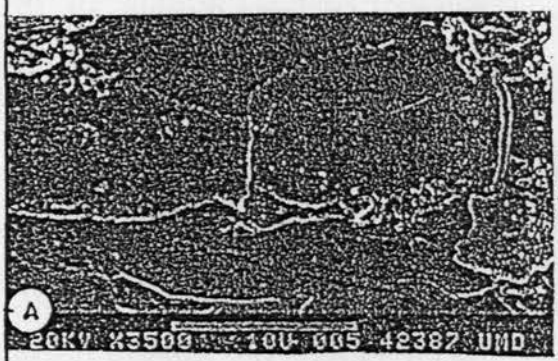


Cyperaceae conical shapes viewed from different orientations (Fig. 3.3, p 57)

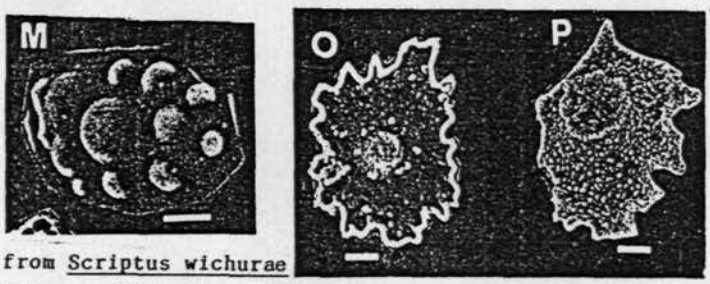


conical to hat-shaped phytolith from the Cyperaceae (Fig. 3.2, p 55)

From Piperno, 1987.



Scanning electron micrograph of Scriptus holochoenus phytolith.
Ollendorf et al., 1987:130



Phytoliths from Scriptus wichurae
From Kondo & Sasa, 1986, Plate III
(bar is 5 µm)

Figure 2.3: PUBLISHED ILLUSTRATIONS OF THE CYPERACEAE-TYPE PHYTOLITH (SOURCES WITH EACH ILLUSTRATION)

"characteristically Australian vegetation", which was "derived from ancestral Gondwanan flora" and includes "Acacias growing as Wattle trees in woodland or as Mulga in arid regions; Casuarinas on river banks;.....and Banksias in the heathlands" (1986:43). She also comments that the Acacias are almost as widespread and visible as the genus *Eucalyptus*. Acacias are characteristic of the arid and semi-arid areas of Australia and common in the sub-humid (Boland, 1984).

While Banksias and Casuarinas are to be found mainly in Australia, both occur in Papua New Guinea and Indonesia (Boland, 1984). Banksias thrive in acidic soils of poor quality; some in swamps, others on rocky ridges. Similarly, Casuarinas are to be found in a variety of environments, mainly occurring early in the ecological sucession of new sites (Boland, 1984). The pollen record of the Acacias goes back to the Late Oligocene (25 million years ago), while that of the Banksias and Casuarinaceae first appears much earlier, in the Palaeocene [65 million years ago] (White, 1986).

When compared on a percentage of dry weight of leaves basis, the *Gahnia sieberana* produced 1.78 $\pm$ 0.662% plant opal while *Acacia schinoides* produced 0.40 $\pm$ 0.687% (Table 2.4). When the difference in the percentage of the "Cyperaceae-type" phytolith present in each (48.15% cf. 11.90%; Table 2.7) is added, it is obvious that there is a very large difference in the amount of the phytolith that would be produced by each species per unit area.

In the dicotyledonous families the proportion of phytoliths (plant opal of repetitive shape) to amorphous plant opal is very low. This leads to a corresponding magnification of the importance of the "Cyperaceae-type" phytolith with its obvious repetitive shape. While the amount of plant opal material in forest species is low in comparison with grasses and sedges, substantial numbers of the "Cyperaceae-type"

phytolith present in a sediment cannot be taken in isolation to indicate the former presence of sedges. Collaborating evidence in the form of pollen is needed; and since phytoliths are often utilised when pollen is not available to indicate environmental conditions, this severely limits its usefulness.

In many studies the "Cyperaceae-type" phytolith has been used to denote a sedgeland environment and is considered by archaeologists and palaeo-environmentalists to be the distinctive phytolith shape which is diagnostic of the Cyperaceae family. Piperno (1987) used the "Cyperaceae-type" phytolith, among others, to denote the transition from mangrove vegetation to fresh-water swamp in a core from deposits in Panama. Additional evidence was available in the form of abundant Cyperaceae pollen, and this formed part of the evidence for the progress from succession and disturbed ground to a slash-and-burn agriculture.

In her study, Piperno commented on the small amount of "Cyperaceae-type" phytoliths found (less than 10% in Recent deposits and very much less in earlier [1987:210]). There are indications that this is a phytolith which is not preserved in large quantities. Despite the fact that the "Cyperaceae-type" phytolith was found in four of the ten species initially examined in field study 1 reported above, and comprised around 48% of the phytoliths from one of the co-dominant species which contributed plant opal to the swamp, few survived in the swamp sediments. This can be attributed to their general platey morphology; they may be removed from the sediment in surface flow, or be easily broken up or subjected to dissolution. Such factors may make the recovery rate of the "Cyperaceae-type" phytolith low in sedgeland environments.

Given the generally low survival rate of the type under sedge vegetation, one might be tempted to assume that this was the case for

the "Cyperaceae-type" phytolith no matter what its origin, and that its occurrence in sediments would therefore point to sedge vegetation. This assumption cannot be made, however, in view of the probable geomorphic and pedological differences between the environments concerned. Insufficient is known about the factors affecting phytoliths once they have been released into sediments to be able to generalise in this way.

Summary

From these three initial field studies, the following points arise:

1. The amount of plant opal being deposited is large. In the first study, the dry weight of leaves in 1 m^2 was found to be 477 g for *Gahnia sieberana* and 195 g for *Gleichenia dicarpa*. If the average life of a leaf is 1 year, then the contribution of plant opal to the swamp sediment on an annual basis by these two species would be 8.49 gm^{-2} and 3.33 gm^{-2} respectively. The swamp is 7500 m^2 in area with *Gahnia sieberana* covering 2250 m^2 and contributing around 19 kg per annum, and *Gleichenia dicarpa* covering 3000 m^2 and contributing around 10 kg per annum. Thus these two species alone would contribute about 30 kg per annum (4 $gm^{-2}year^{-1}$) of plant opal material. In addition, the swamp receives material transported in from elsewhere in the catchment in runoff and as aeolian additions, and loses material similarly.

2. The distribution of plant opal in the soil may contain patterns which contribute to the understanding of the processes plant opal undergoes once it is in the soil. The rise in plant opal content before a barrier (in this case podzol pans) for example, may point to plant opal migration within a soil.

3. A phytolith cannot be accepted as species specific without careful examination of the local vegetation, particularly in an environment where very little prior research into plant opal morphology

of what might be unique vegetation has been undertaken.

Conclusions

Australian plants and sediments contain a range of plant opal which may not be strictly comparable with those reported in the overseas literature. The study of the species specific phytolith raises the question as to whether the vegetation history of this continent might be sufficiently different from elsewhere to have had an effect on plant opal morphology. Due to this, any studies utilising plant opal must do so with care. This does not preclude the utility of plant opal, however.

The processes which affect plant opal before and after it is incorporated into the soil have been little examined. The erection of an opal assemblage from the topsoil for use as diagnostic of a particular vegetation is an area of research which has prominence overseas. There are many questions to be answered before such techniques can be used confidently.

Can a vegetation community give a unique plant opal signature which is recognisable in topsoils? Leaving aside the question of what effects differing soil types might have on such an assemblage, the first step is to look at vegetation communities on similar soils for the answer. This is the topic which is taken up in the field studies arising from the initial observations reported in this Chapter.

CHAPTER 3

PILLIGA FIELD STUDIES I: PLANT OPAL IN LITTER

Introduction

On completion of the initial studies discussed in Chapter 2 it became apparent that there were several areas of plant opal study which required closer examination in the Australian environment. These were:

A. the amount and morphology of plant opal available for entering the soil,

B. the differences in plant opal production and morphology between different vegetation communities and

C. the processes which might influence firstly the plant opal entering the soil and, secondly, its distribution in the soil.

The Pilliga Forests in north-west New South Wales were chosen as the area in which to conduct this work for the following reasons:

1. the surface geology of the area is non-marine, Jurassic sandstone, similar in many ways to the geology of the first study area on Hawkesbury Sandstone,
2. the vegetation has elements of similarity with that of the first field site despite the difference in climate,
3. the vegetation comprises a mosaic of differing vegetation communities, and
4. it is a very isolated area.

The first two points are of interest if comparisons between areas are to be made. The pattern of vegetation in the forest meant that it was possible to examine several changes in vegetation communities over a very small area. The fact of its isolation allowed for instrumentation of sites without fear of human interference; a problem which besets

field experiments close to settlement. The Forestry Commission of New South Wales were most co-operative in preventing forestry work in the study site, with only one minor disturbance occurring during the period of the study.

There are several projects being conducted in the Forests in addition to those reported in this thesis. These are:

1. a detailed examination of soil stratigraphy,
2. soil-vegetation relationships, with particular reference to soil moisture and salinity and
3. research into historical documentation of vegetation changes in order to distinguish between the climatically driven and man-induced.

The author of this thesis has input into 1 and 3. Where material from these projects has been used in this thesis, this has been indicated in the acknowledgements.

The Pilliga

(a) Location

The State Forests of the Pilliga are the largest single area of dedicated native forest in the State of New South Wales. They are situated north of Coonabarabran in the north of the State, and cover an area of 400,000 ha (Figure 3.1).

The Forests are situated on the foothills and plains which extend north from the Warrumbungle Range and west from the Nandewar Range. Drainage in the area is north and north-west into the Namoi and Gwydir Rivers. Elevations range from about 800 to 180 m above sea level.

(b) Geology

The main surface geology comprises the upper Jurassic Pilliga Sandstone and derived sediments. The sandstone is quartzlithic with associated conglomerate, siltstone and shale beds and is of fluvial

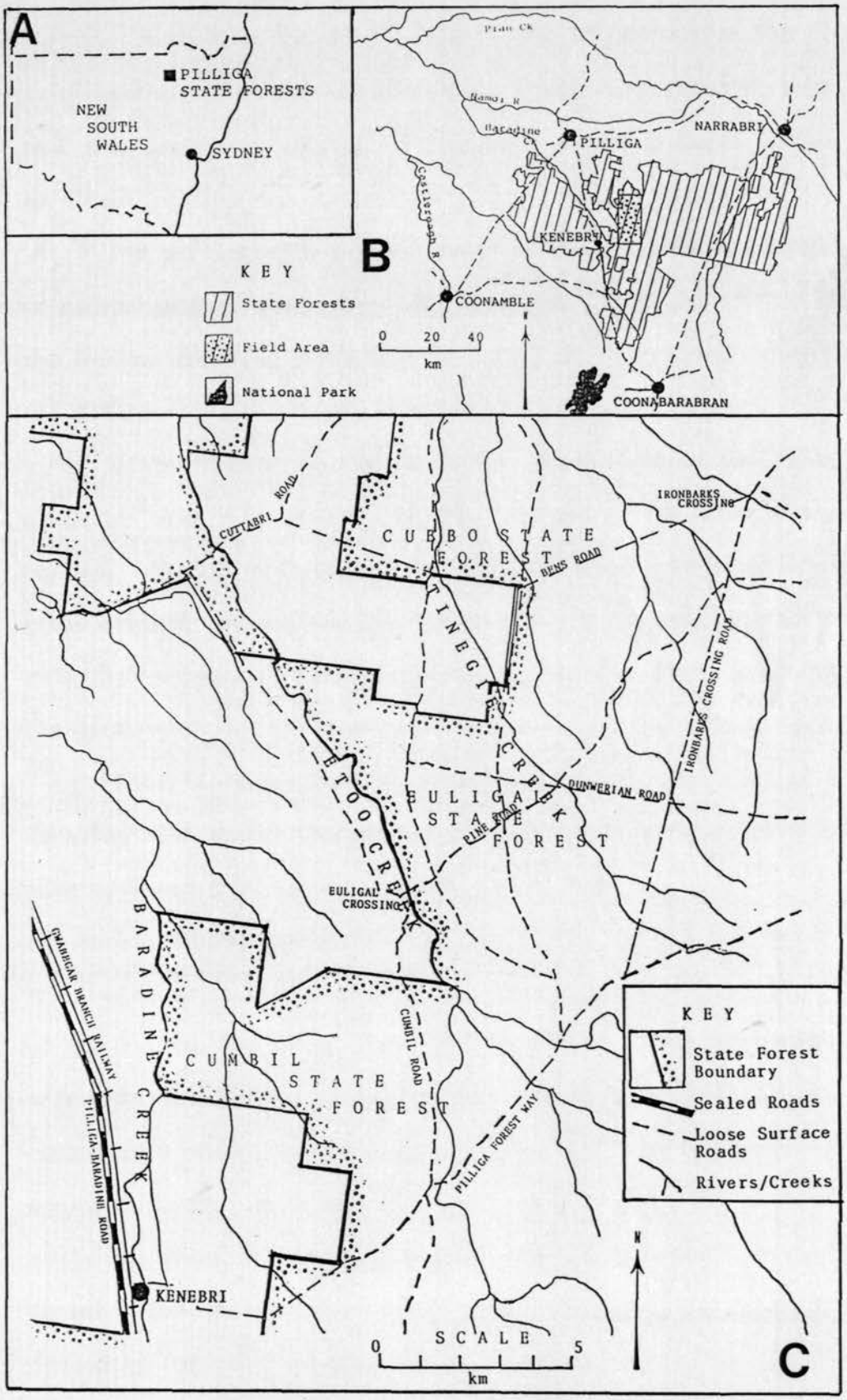


FIGURE 3.1: A: MAP OF N.S.W. SHOWING STUDY AREA
B: PILIIGA STATE FORESTS
C: DETAIL OF STUDY SITE

origin. Bedding is relatively flat (five to ten degree dip to the north-west) with little outcropping. These form aquifer beds which feed into the Surat section of the Great Artesian Basin (Brown, Campbell and Crook, 1977).

The Warrumbungle Ranges are basalts, trachyte and pyroclastic volcanic remnants which were active between 16.6 and 13.5 million years ago (Potassium/Argon dating).

(c) Climate

Climatic averages for Baradine, 20 km west of the field site, are given in Table 3.1. Annual rainfall is around 625 mm with a summer maximum. Variation in annual rainfall is great, with periods of both great drought and extreme wet being common. Summers are hot and winters mild, with regular frosts occurring in winter. Winds are commonly from the south-west.

Details of the rainfall and temperature variations at the Baradine station for the period of study are given in Table 3.2. The area suffered from severe drought during 1985-86.

(d) Soils and vegetation

The soils are generally solodic in nature. Details of the soils of the Pilliga are to be found in Appendix A. The vegetation is a sclerophyllous closed to open-forest with a heath understory. It comprises a mosaic of white cypress pine (*Callitris columellaris*) and eucalypt forest, with Bull oak (*Casuarina leuhmannii*) on heavier clay soils and areas of broom plain dominated by *Melaleuca uncinata*. The Forestry Commission (1986) lists "Forestry Types" as "Leagues", including Cypress Pine-Eucalypt mixes of various kinds and "Other Types" which include Broom Plain, Belah Scrub (*Casuarina cristata*) and Mallee (*Eucalyptus viridis*). Species lists may be found in the Management Plan

Table 3.1: CLIMATIC AVERAGES FOR BARADINE FORESTRY
Station 053002, Latitude 30 deg 57 min S, Longitude 149 deg 4 min E
Elevation 302.0 m

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
DAILY TEMP													
MEAN (21 years of record)													
deg C													
Maximum	33.1	32.5	30.1	25.9	20.7	17.2	16.3	18.0	21.2	25.7	29.2	32.2	25.2
Minimum	18.2	18.1	15.2	10.2	6.4	3.6	2.0	3.3	5.9	10.2	13.0	16.0	10.0
RAINFALL (42 years of record)													
MEAN													
mm	92	75	50	34	48	41	36	44	42	60	50	53	625
RAINDAYS	7	6	5	4	5	6	6	6	6	7	6	6	70

Records from: "Climatic Averages Australia"
Meteorolgy Survey July 1988
Bureau of Meteorology

Table 3.2: RAINFALL (mm) 1980 - 1991, BARADINE FORESTRY
Station 053002

MONTH	1980	1981	1982	1983	1984	1985	1986	*1987	*1988	*1989	*1990	*1991	AVERAGES
JAN	104.4	2.0	58.6	87.2	198.4	3.2	38.8	98.6	133.5	29.6	58.7	120.7	77.8
FEB	57.6	64.6	15.5	26.3	83.9	33.0	0.0	48.0	72.4	32.0	30.5	48.5	42.7
MAR	21.4	0.4	94.9	33.0	30.0	10.0	0.0	123.2	5.2	50.0	28.8	54.2	37.6
APR	4.4	9.3	1.4	61.8	68.4	66.0	22.2	5.6	143.1	135.2	201.5	1.2	60.0
MAY	94.4	134.1	36.8	178.1	5.8	40.2	44.2	35.4	34.5	99.5	88.3	147.7	78.3
JUN	33.2	28.3	4.8	27.5	0.1	32.0	0.0	41.0	26.7	107.6	16.0	82.2	33.3
JUL	31.1	81.9	6.6	44.8	97.1	9.6	127.3	59.1	80.8	61.4	54.6	46.1	58.4
AUG	22.4	10.1	0.0	69.0	38.8	136.2	58.5	96.5	60.0	14.8	15.9	2.5	43.7
SEP	0.0	21.2	11.2	71.3	31.9	19.6	49.6	15.9	77.8	1.4	22.1	16.0	28.2
OCT	35.1	111.1	19.2	52.1	24.8	61.2	38.4	46.6	2.2	52.4	53.9	39.1	44.7
NOV	0.0	79.1	16.6	102.7	62.0	59.2	71.1	45.5	31.8	38.7	4.4	33.8	45.4
DEC	65.9	38.6	37.2	31.6	42.6	64.5	30.9	73.3	71.4	52.0	30.1	171.8	59.2
TOTALS	469.9	580.7	302.8	785.4	683.8	534.7	481.0	688.7	739.4	674.6	604.8	763.8	609.1

Records from Baradine Forestry
* *Study Period*

for Pilliga Management Area (Forestry Commission, 1986) and Mitchell, Rundle and Students (1982).

(e) Fauna

Due to a great diversity of habitat, the Forests support a wide range of fauna including monotremes, marsupials, placental mammals and birds. Introduced species include horses, pigs, goats, cats, foxes and rabbits. Species lists may be found in the Management Plan for Pilliga Management Area (Forestry Commission, 1986) and Mitchell *et al.*, (1982).

(f) History

A discussion of the history of the area is of relevance in a project such as this where the length of time a particular pattern of vegetation has been present and contributing plant opal to the soil is an important consideration. This question of vegetation stability in the Pilliga State Forests has been examined in Norris, Mitchell and Hart (1991) [copy attached in Appendix H] and is extended to cover the area discussed in this thesis in Appendix A. In addition to providing timber, the Forests are also used for some grazing, beekeeping, charcoal production, the harvesting of broom for urban fencing, gravel extraction and recreation.

The Pilliga field site

Location

The field site is situated in the Pilliga East Forest (grid reference 711500mE 6605800mN on the Topographic Map, Cubbo, 1st edition 1:50 000 series, 8736-N, 1974). Preliminary investigations covered the area between Ironbarks Crossing Road in the east and Etoo Creek in the west (Figure 3.1). The main field sites are in an area between Ironbarks Crossing Road in the east and Greens Road in the west. Sites are scattered along Dunwerian and Pine Roads, with the main sites discussed in this thesis centred on Dunwerian Road (Fig 3.2). In 1951 a

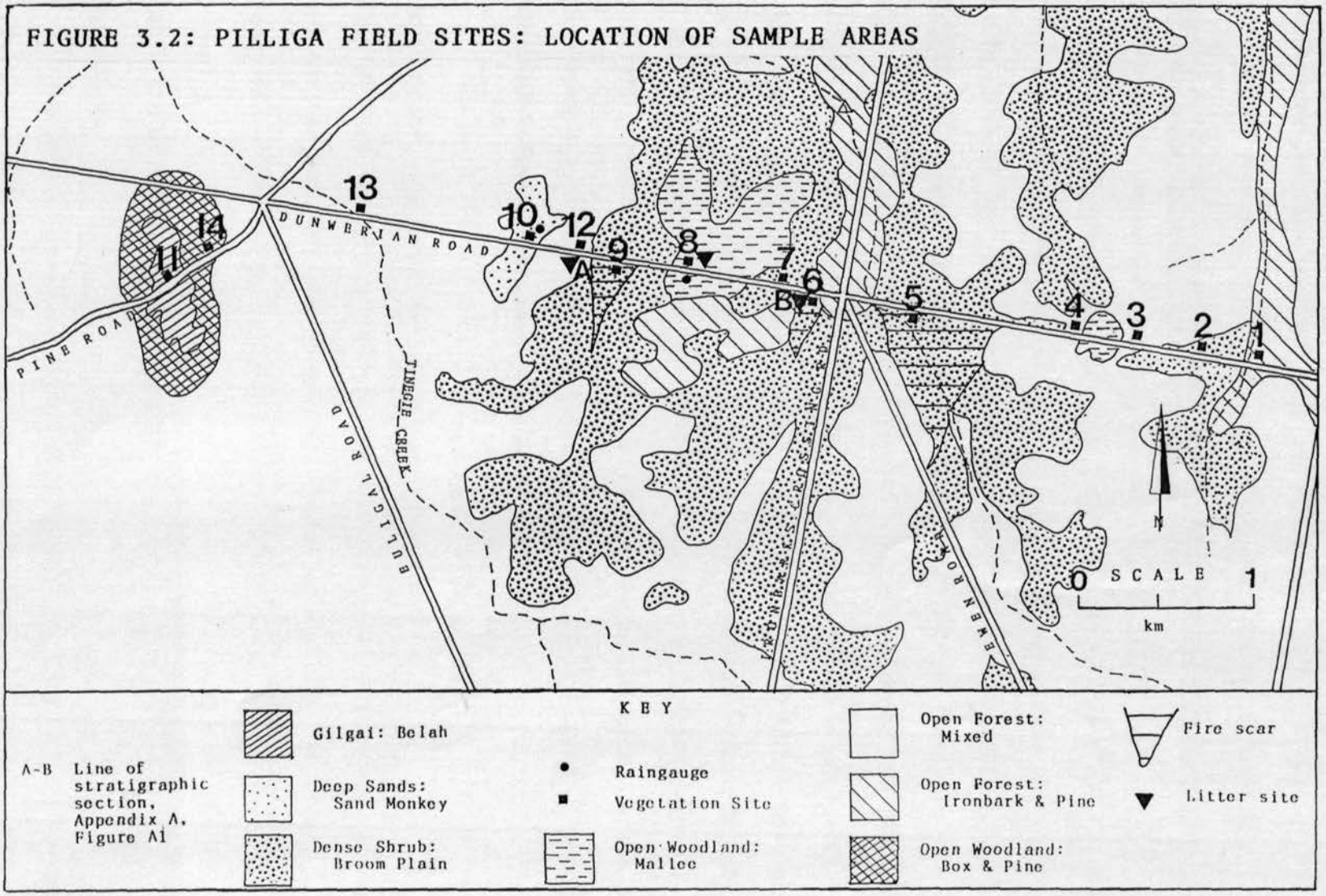


FIGURE 3.2: PILLIGA FIELD SITES: LOCATION OF SAMPLE AREAS
DUNWERIAN ROAD
PINE ROAD
BULIGAL ROAD
TINEGIE CREEK
EBEN ROAD
13
14
11
10
12
9
8
7
6
5
4
3
2
1
A
B
N
0 SCALE 1
km
KEY
A-B Line of stratigraphic section, Appendix A, Figure A1
Gilgai: Belah
Deep Sands: Sand Monkey
Dense Shrub: Broom Plain
Raingauge
Vegetation Site
Open Woodland: Mallee
Open Forest: Mixed
Open Forest: Ironbark & Pine
Open Woodland: Box & Pine
Fire scar
Litter site

fire affected the entire study area. In 1966/77, fires were located along Dunwerian Road in the areas indicated on Figure 3.2. They affected parts of each broom plain. Where samples were taken from areas affected by the 1966/67 fire, this is indicated.

Field work was conducted here from late 1986 to 1991, mainly between March and October of each year.

Climate

By way of comparison with the Baradine figures, rainfall for the field site was recorded in two areas; the sand monkey (Site 10) and the mallee (Site 8) for the duration of the main field work (Table 3.3).

Geology, topography and soils

Mitchell *et al.*, (1982) mapped this area as part of the Cubbo Land System. Sandstone outcrops are limited here to low ridges while lower slopes are covered in alluvial sands. Water courses are mainly filled with sand (Plate 22B). Slopes are very low (<8°, commonly 2-5°). On the rocky ridges yellow earths [after Stace *et al.*, 1968] (Gn2.2; Principle Profile Form [PPF] after Northcote, 1974) may occur, while on the slopes and flats solodized solonetz (Dy2.42, Db1.42) occur in sands overlying *in situ* weathered sandstones and shales.

The main field area extends from a ridge comprising outcrops of conglomerate, downslope through sandstone and onto alluvium. The alluvial area includes an area of coarser sand (the sand monkey, a local term derived from the aboriginal description of the sandy area; see Plate 16B) which appears to be a terrace remnant, Euligal Creek, and an area of gilgai (clay areas of hollow and hump topography; see Plate 16A). The soil stratigraphy of the main field area is discussed in Appendix A.

The main sites discussed in this thesis are Sites 7, 8, 9 and 12. Details of the vegetation and soils of all sites are in Appendix B and

Table 3.3: RAINFALL RECORD DURING STUDY PERIOD
Sites 8 (mallee) and 10 (sand monkey)

Date	Week	Site 7: mallee		Site 10: sand monkey	
		mm	cumulative mm	mm	cumulative mm
11/12/87	0.0	0.0	0.0	0.0	0.0
18/03/88	14.0	198.0	198.0	187.0	187.0
30/04/88	21.0	134.5	332.5	136.5	323.5
04/05/88	22.0	3.5	336.0	1.0	324.5
12/05/88	35.0	140.0	476.0	152.0	476.5
02/10/88	43.0	97.5	573.5	110.0	586.5
25/02/89	63.0	130.0	703.5	172.0	758.5
10/05/89	73.0	117.5	821.0	174.0	932.5
15/07/89	82.0	180.0	1001.0	229.0	1161.5
29/09/89	99.0	33.5	1034.5	53.5	1215.0
05/03/90	122.0	162.0	1196.5	201.0	1416.0
03/06/90	135.0	253.5	1450.0	259.5	1675.5
25/09/90	153.0	113.0	1563.0	132.0	1805.5

C; the main sites are discussed in detail here.

Site 7: The upper broom plain

Site 7 is situated on the east flank of the ridge on Pilliga Sandstone and, near the western boundary, in the conglomerate facies of the Pilliga Sandstone. This is a broom plain which encircles the ridge; on the ridge itself in conglomerate the vegetation is Narrow-leafed ironbark (*Eucalyptus crebra*), with a heath understory.

The broom plain vegetation comprises very low heath (2-5 m tall) of *Melaleuca uncinata*, *Acacia triptera* and *Calytrix tetragona*. The ground cover comprises mainly lichen and moss mats between the shrubs. Some of the site, on the south side of Dunwerian Road, was last burned in 1966/67.

The soil (see Profile PF7i, Appendix B) comprises a brown sandy loam with an earthy fabric (after Northcote, 1974) over a reddish brown mottled harsh sandy clay subsoil derived *in situ* from conglomerate (up slope) or sandstone. The depth of soil is up to 1 m, and it is underlain by weathered bedrock. The topsoil contains many faunal channels and charcoal. The A2 is bleached, and a perched water table is often found above the clay subsoil. During wet periods the entire topsoil quickly saturates. The broom plains appear to provide the headwaters of the creeks.

Site 8: The mallee

Site 8 occurs on the upper western slope of the ridge in Pilliga Sandstone. It is so called after the habit of the vegetation (mallee = many stemmed). Its boundary with the surrounding broom plain is abrupt, occurring within 5 m (Plate 11). Vegetation is a closed to open-woodland with crowns just touching comprising *Eucalyptus viridis* (Green mallee) as the dominant tree, growing in the mallee form to a height of about 7 m. The shrub layer is dominanted by *Dodonaea viscosa* ssp.

cuneata (hopbush), while the herb layer contains various grasses (Plate 12).

The soil's (Profiles PF8) surface comprises a layer of bark, litter and wood which is much thicker in places than elsewhere in the study site. The surface is covered with workings from ants and termites, large nests of which inhabit the soil, and dead vegetation. At the base of trees large mounds of termite and ant workings partly bury the bases of trees and bushes up to a depth of 200-500 mm, giving a hummocky appearance to the surface. Large holes and cones which are the entrances and workings of various species cover the hummocks, and the workings cover the litter layer, burying the litter. The cones are loosely composed of pellets of material bought up from the soil by the workers of each species; thus they are of a transient nature and during rain are destroyed only to be quickly rebuilt (Plates 18-21).

The topsoil is a very bioturbated brown earthy loam containing large amounts of charcoal. It includes a conspicuously bleached, cemented A2 which penetrates down the sides of columns of the subsoil (Plate 13A). Plate 14A and B show the surfaces of the domes. These vary in size up to 300 mm in diameter and are covered with small quartz pebbles. The subsoil is a brown, sometimes mottled harsh sandy clay with a columnar structure derived *in situ* from the underlying Pilliga Sandstone. It is a very dense material which is difficult to penetrate. White to grey sandstone with clay lenses occurs at about 1 - 1.5 m depth (Plate 13B).

Site 9: Lower broom plain

This broom plain is a continuation of the one on which Site 7 is located. The vegetation is similar to that of the upper broom plain, with slight differences in the species present. The dominant acacia here is *A. tindaleae* (Golden-top wattle) with *A. triptera* (Spur-wing

wattle) in some areas. Some commercial broom cutting has been undertaken on parts of this site; these were avoided in sampling programs.

Soils are similar but deeper than in Site 7. The topsoil is a brown sandy loam to clay loam containing charcoal and quartz pebbles. The A2 is bleached and often very wet. A perched water table is common. The subsoil is a harsh sandy clay above alluvium.

Site 12: Forest

Site 12 is a pine/ironbark association adjacent to the broom plain. Again, the boundary between the two communities is abrupt (Plate 15). The slope is very gentle (2-5°). Vegetation comprises a mid-height open-woodland (10 - 20% cover) of *Callitris glaucophylla* (height to 15 m) and *E. crebra* (height to 20 m) with *A. tindaleae* in the shrub layer and a mixed herb layer containing many grasses.

The surface of the site is covered with litter comprising leaves, bark, twigs, branches and uprooted trees. This is an area which has been cut by Forestry in the past, and early during the study period it was accidentally disturbed by cutters, destroying sampling sites and necessitating their relocation on the site.

The soil is a sandy loam topsoil over a sandy clay or clayey sand subsoil. There is a good cover of litter on the surface with large pieces of charcoal often appearing as a layer under the litter. The dark brown to black organic sandy loam topsoil has a highly porous, earthy fabric, and the A2 is often conspicuously bleached. The subsoil is a sandy clay to a clayey sand (Profiles PF12ii, iii). The pH throughout is acid, and these soils have an intermittent columnar structure.

Field Study: The amount of plant opal available in the litter

Introduction

There is no reason why particulate opal cannot be considered in the same way as any other component in vegetation which is available for cycling. The techniques used to examine the production of magnesium or calcium, for example, can be used to examine the production, at a community level, of particulate silica.

The plant opal cycle is probably most conveniently entered by considering how much plant opal is produced by plants. This varies between species, between individual plants, and within individual plants according to maturity and position in the plant. It also varies with the availability of silica, moisture and other environmental factors.

In any one plant community if a measurement of the productivity of that community in terms of annual production of biomass can be made, individual components of the biomass can then be examined for plant opal production and an estimate of annual plant opal production for the community at that stage of its development can be made.

Appendix E outlines the composition and decay of litter in the Australian environment and techniques for its study.

Aims of the study

A study was conducted which investigated the production of plant opal in three forest sites over three years. The aim was to examine the differences in the amount of plant opal available for cycling in various communities; thus the amount of biomass produced on an annual basis, the amount of plant opal contained in that biomass and a measure of the store of plant opal on the ground in the litter layer at any one time was required.

Annual Production

For the purposes of the present study there were two ways of

obtaining the necessary production figures. Net primary production could be calculated (e.g. Whittaker and Woodwell, 1971). Every plant in the community could be sampled for plant opal content, the number of this species in a given area estimated, its average life span determined and the total opal contribution arrived at; generally a time consuming if not impossible task.

The second method is to sample the amount of plant opal entering the cycle via the litter layer. This omits grazing loses and net loses by litter movement, but these are assumed to be balanced by similar movement into the system. A measure of the amount of litter which falls should thus give a biomass production rate, and sampling the litter for plant opal should give an estimate of the amount entering the cycle.

The amount entering by way of the root systems must not be forgotten, although this is much harder to quantify. Root biomass can be estimated (Jenik, 1971); however, this does not give a production rate, nor a decay rate for roots, which may be very variable.

The measurements required, then, are annual litter fall including the contribution of all layers of vegetation in the community, and the annual contribution from roots. This second component was omitted from the present study due to time constraints and the problems of methodology; thus it is the above ground production of silica only which has been examined.

The amount of litter in storage

The litter on the ground can be measured and the amount of plant opal it contains determined to give an estimate of the amount in this storage compartment. A detailed account of the methods used in this study is presented in Chapter 8.

Materials and methods

1. Plant opal content of litter components

The collection of litter and its division into components is outlined in Chapter 8. Litter trays for Site 7 were located on a 1966/67 fire affected area. The plant opal content of the litter was determined from three subsamples of each component. The plant opal was extracted using wet-ashing techniques and the purity of each extraction was assessed by point counting methods (Chapter 7). Some subsample results were discarded if the purity of the sample fell below a reasonable percentage - reasonable depending upon the source of the subsample. For example, extractions from leaves were generally found to be fairly pure, while twigs and bark samples were generally contaminated by large amounts of mineral material which was possibly wind blown or splashed onto the twigs and bark before they fell. Similarly, despite careful cleaning, the herb biomass was found in many cases to contain additional mineral material trapped on grass leaves. For this reason two subsamples from the biomass in Site 7 were discarded.

The mean plant opal content of each of the litter components was calculated (Table 3.4), and the amount of plant opal contributed annually in each component calculated from the annual litter fall of that component (Table 3.5). The amount of plant opal contributed by the biomass was similarly calculated, and it was considered that such a contribution was likely to represent the annual input from this source.

2. Plant opal content of the bulk litter samples

Collection of these samples is outlined in Chapter 8. Each collection was made from parts of the sites which had not been burnt in the 1966/67 fire so that they were comparable. Litter was collected from Site 9 in addition to Sites 7, 8 and 12. The plant opal content was determined for each bulk sample by weighing each component and

Table 3.4: PLANT OPAL CONTENT OF LITTER COMPONENTS (AS A PERCENTAGE OF DRY WEIGHT)

SITE	SAMPLE #	COMPONENT					
		Leaves	Twigs	Bark	Faecal	Residue	Biomass <10cm
7: Broom Plain	1	0.10	1.92	5.02	as 8	0.49	11.06
	2	0.07	2.05	4.31		*	*
	3	0.06	*	*		0.52	*
	Average	0.08	1.99	4.67	10.46	0.51	11.06
	SD	0.02	0.09	0.50		0.02	
8: Mallee	1	0.18	2.18	0.58	10.48	0.74	6.90
	2	0.24	2.10	*	11.04	0.26	6.88
	3	0.32	*	0.18	9.85	0.45	2.63
	Average	0.25	2.14	0.38	10.46	0.48	5.47
	SD	0.07	0.06	0.28	0.60	0.24	2.46
12: Forest	1	0.42	1.81	4.46	as 8	0.42	12.44
	2	0.36	2.57	*		0.48	8.63
	3	0.35	3.78	*		0.15	7.86
	Average	0.38	2.72	4.46	10.46	0.35	9.64
	SD	0.04	0.99			0.18	2.86

* Sample discarded

SITE #	WEIGHT (g/sq.m)	COMPONENT										TOTAL WEIGHT	
		Leaves	Twigs >1cm	Twigs <1cm	Twigs Total	Bark	Faecal	Residue	Total Trays g/sqm/yr	Total Trays kg/ha/yr	Biomass below 10cm	g/ sq.m/yr	kg/ ha/yr
7	Weight	4.71	7.14	27.26	34.40	0.17	1.27	59.97	100.52	1005.20	23.00	123.52	1235.20
	% *	3.81	5.78	22.07	27.85	0.14	1.03	48.55			18.62		
	Wt Opal	0.00	0.14	0.54	0.68	0.01	0.13	0.31	1.13	11.35	2.54	3.68	36.80
	% Opal	0.08	1.99	1.99	1.99	4.67	10.46	0.51	1.13		11.06	2.98	
8	Weight	99.49	58.87	65.70	124.57	27.26	1.86	87.77	340.95	3409.50	10.67	351.62	3516.18
	% *	28.29	16.74	18.69	35.43	7.75	0.53	24.96			3.03		
	Wt Opal	0.25	1.26	1.41	2.67	0.10	0.19	0.42	3.63	36.34	0.58	4.22	42.18
	% Opal	0.25	2.14	2.14	2.14	0.38	10.46	0.48	1.07		5.47	1.20	
12	Weight	50.84	23.65	39.38	63.03	4.18	0.90	109.69	228.64	2286.40	56.38	285.02	2850.20
	% *	17.84	8.30	13.82	22.11	1.47	0.32	38.49			19.78		
	Wt Opal	0.19	0.64	1.07	1.71	0.19	0.09	0.38	2.57	25.72	5.44	8.01	80.07
	% Opal	0.38	2.72	2.72	2.72	4.46	10.46	0.35	1.13		9.64	2.79	

* Percentage of litter tray and biomass combined

Table 3.5: AVERAGE ANNUAL LITTER FALL BY COMPONENT

determining its proportion in the bulk sample. Samples were then taken which contained each component in the correct proportion. Plant opal content was then determined as discussed above (wet ashing). Results are presented in Table 3.6.

Results

Annual amount of plant opal

The total production of plant opal in the components of the litter collected in the litter trays, i.e. that material above 10 cm in height, is about 1% in all three sites, thus the amount of plant opal available for cycling is directly proportional to the litter production of these forest species. The plant opal content of the leaves is highest in Site 12 and lowest in Site 7 which may be a direct reflection of the leaf type, surface area, etc. While the amount of bark litter is high from Site 8, it appears to have the least plant opal - however, the bark figures are to be treated with caution since that from Site 12 came from one sample only and the two samples from Site 7 had many impurities which may be underestimated by point counting methods.

The amount of material in the herb layer below 10 cm height is very important, since these species produce a larger amount of plant opal in comparison with forest-shrub species. The forest (Site 12) is fairly open and has a considerable herb layer, as does the broom plain, although in this case the vegetation is dense. In comparison, the mallee has a sparse herb layer. This is reflected in both the contribution the herb layer makes to the total percentage plant opal in each site, and to the overall finding that less plant opal appears to be available for cycling in the mallee than in the forest despite the larger litter fall collected in the trays in the mallee.

The amount of plant opal in storage on the ground at any one time (Table 3.6) demonstrates several interesting points. The purity of all

Table 3.6: OPAL CONTENT OF BULK LITTER SAMPLES, PILLIGA SITES
(weight in g/sq.m)

SITE		COMPONENT					TOTAL	OPAL % DRY	WEIGHT OPAL IN LITTER
		Leaves	Twigs	Bark	Faecal	Residue	g/sq.m	WEIGHT	g/sq.m
7	Broom Plain	0.00	88.10	15.81	13.41	512.03	629.34	2.57	16.17
8	Mallee	156.45	284.32	68.85	14.48	677.02	1201.12	1.37	16.46
9	Broom Plain	2.86	104.83	2.93	4.98	373.02	488.62	1.37	6.69
12	Forest	144.00	881.09	4.29	5.01	696.69	1731.07	0.87	15.06

plant opal samples after extraction was around 80% (Table G28), and the figures given in Table 3.6 have been corrected for this. The amount of litter on the broom plains was well under half that of the mallee and forest sites and are comparable since all collections were made outside areas affected by the 1966/67 fires. The amount of opal in the litter varies between the two broom plains which may be due to either a species difference or sampling bias.

The mallee and the forest sites produced 1201 and 1731 gm^{-2} of litter respectively. In the litter collections reported in Chapter 8, the mallee produced more litter in storage than the forest; however the results in the present study are within the standard deviations for both sites and this demonstrates the variability of the litter cover at this site. The amount of plant opal in storage in the litter layer at these sites is in excess of 15 gm^{-2}.

Conclusions

In one fairly small area of the forest lie three vegetation communities, very close to each other (since the broom plain continues downhill around the mallee it adjoins both it and the forest site) producing widely differing amounts of plant opal which is then available for cycling.

The total litter (tray fall plus biomass under 10 cm) is higher in the mallee than in the forest, and evidence discussed in Chapter 8 demonstrates that these two sites are in steady state. However, the amount of plant opal available differs due to the larger amount of material in the herb layer in the forest.

The litter fall in the upper broom plain is lower by a factor of 2 or 3 than the mallee or forest. This lower litter fall is also reflected in the smaller amount of litter in storage on both broom plains, and the generally smaller amount of plant opal available for

cycling.

Once the litter has come to rest on the forest floor it begins to decay. Two processes are active - disintegration and decomposition. The coarse fragments are slowly reduced in size by soil and litter fauna, decomposed by a variety of bacteria and fungi, and the litter and its enclosed plant opal is slowly incorporated into the underlying soil. Leaving aside any processes which might occur at this stage to further vary the amount of opal entering the soil (but see Chapter 6), Chapter 4 examines the distribution of plant opal in the mallee soil, and processes within the soil which may give rise to that distribution.

CHAPTER 4

PILLIGA FIELD STUDIES II:

THE DISTRIBUTION AND MOBILITY OF PLANT OPAL IN SOILS

Introduction

This chapter examines the distribution of plant opal in the mallee soils in the Pilliga Forest Site 8, and asks how such a distribution has been brought about.

The distribution of plant opal in soils has been considered by several workers, particularly in the United States (Table 4.1). Most studies find a concentration of plant opal in the topsoil and a decline in abundance with depth. Concentrations at depth within a sediment are taken as pointing to the presence of a former topsoil.

Quantities of plant opal separated from surface horizons of soils vary markedly from reports of horizons 5 to 30 cms thick consisting entirely of plant opal (Riquer, 1960, in Pease, 1967), to amounts of the order of 0.24 to 0.73% in surface soils in the United States (Fehrenbacher, White, Beavers and Jones, 1965).

Distribution in Loess areas

The work of Beavers *et al.* (1958-64) was undertaken on soils developed in loess in Illinois, and was conducted by Beavers at various times with Stephens, Johnson, and Jones. In these works the opal was extracted from the coarse silt, or 20-50 um size range using heavy liquids. The amount of phytolith material in the whole sample was then calculated by multiplying the proportion of opal in the silt fraction by the proportion of this fraction in the soil. This, of course, assumes that the opal is evenly distributed throughout all size ranges, which is contrary to most reports.

Initially, the amount of plant opal material found was correlated with soil maturity (Beavers and Stephen, 1958) [increased soil maturity

Table 4.1: THE DISTRIBUTION OF PLANT OPAL IN SOILS
REPORTS FROM THE LITERATURE

AUTHOR	DATE	LOCATION	SOIL (described as)	SIZE RANGE	DEPTH	PLANT OPAL CONTENT
Kanno & Arimura	1958	Japan		20-200um		30 - 60%
Beavers & Stephen	1958	Illinois, USA	loess	20-50um	A horizon B horizon	1.39 - 4.28% <0.5%
Riquer*	1960	East Africa	basaltic		A2 horizon 5-30cm	all
Jones, Hay & Beavers	1963	W Illinois & E Iowa, USA	Wisconsinian Loess & Till	all	to 41.6ft to 60.8ft	continuous spasmodic
Jones & Beavers	1963	Illinois, USA		20-50um	surface	
Jones & Beavers	1964a	Illinois, USA	various	20-50um	0-10 inches 10-20 inches 20-30 inches	0.24 - 2.11% 0.12 - 1.26% 0.03 - 0.42%
Jones & Beavers	1964b	Illinois, USA	Brunizem & GB Podzolic	20-50um	surface	0.28 - 0.97%
Witty & Knox	1964	N Central Oregon, USA		whole soil	0-35 inches	0.02 - 2.89%
Fehrenbacher et al.	1965	United States		silt	surface	0.24 - 0.73%

* In Pease 1967

Continued

Table 4.1: THE DISTRIBUTION OF PLANT OPAL IN SOILS
(CONT'D) REPORTS FROM THE LITERATURE

AUTHOR	DATE	LOCATION	SOIL (described as)	SIZE RANGE	DEPTH	PLANT OPAL CONTENT
Verma & Rust	1969	SE Minnesota, USA	biosequence in till	5-20um 20-50um	all	0.04 - 9.63% 0.01 - 3.45%
Wilding & Drees	1971	Ohio, USA		20-50um	0-50cm >50cm	0.1 - 0.3% <0.03%
Yeck & Gray	1972	Oklahoma, USA	upland	5-50um	A horizon B horizon	1.17 - 9.54mg/g 0.58 - 3.73mg/g
Wilding & Drees	1973	Ohio, USA		5-20um 20-50um	A1 horizon (0-12cm)	0.5 - 2.8% 0.7 - 2.5%
Norgren	1973	Oregon, USA	grassland			>20%
Wilding et al.	1977	Ohio USA & Sthn Ontario, Canada	Alfisols	5-20um	-	5 - 10 x 20 - 50um fraction
Kondo & Iwasa	1981	Amazon region, S America	Latosols	10-200um	A horizon B horizon	0.54 - 0.91% 0.14 - 0.17%

was based on the increased distance of each soil from the loess source, and also was correlated with loess depth]. Amounts of plant opal ranged from 0.77 - 1.23% of the topsoil and less than 0.5% of the subsoil. In these same soils, Jones, Hay and Beavers (1963) found that the distribution of opal phytoliths with depth was either continuous or in discrete bands, depending upon rate of loess deposition and the ability of grasses to grow continuously while loess was deposited. When loess deposition was high, grasses were unable to grow.

Jones and Beavers (1964a, b) correlated the differences in opal content between similar soils to differences in internal drainage. The highest concentration in surface layers occurred in the middle of the drainage sequence, i.e. in moderately well to imperfectly drained conditions, and, while they considered that greater silicate weathering in well or poorly drained soils might be a factor in this difference, they favoured the higher productivity of the vegetation as being responsible. This, they also pointed out, occurred in the mid-catenary position. In addition, they found that while phytoliths were concentrated in the surface horizons of Planosols, they occurred down to 20 inches depth in Brunizems and Gray-Brown Podzolic soils. This difference they attributed to either loess deposition rates or to differential mixing by soil fauna between the soils (but had no data to support this contention).

Pease (1967) and Dormaar and Lutwick (1969), used the presence of phytoliths to indicate the A horizons of paleosols. Pease (1967) examined the usefulness of phytoliths in the identification of paleosols and in recreating vegetation history in a thesis written in the United States. He looked at the abundance of phytoliths and their shapes in representative vegetation of the area and separated phytoliths from the A horizons of six soils and the A horizons of four paleosols by heavy

liquid separation. He found 0.008 to 0.03% by weight in the present soils and a trace to 0.001% by weight in the paleosols. He suggested that wind movement of silt and clay size phytoliths and removal of A horizons during deposition of new soil materials was responsible for the lack of phytoliths in the paleosols and that in the area where he was working phytoliths were not a useful indicator of paleosols.

Verma and Rust (1969) examined 6 soils in southeastern Minnesota which were in similar topographic positions and moderately well drained. They found that grass opal sites were the most productive and that the highest concentrations of plant opal were in the surface horizons.

Wilding and Drees (1971) studied the distribution of biogenic opal in Ohio soils formed on loess, till and outwash deposits. It had been observed (for example by Witty and Knox, 1964) that grassland phytoliths were ten times more abundant in soils than forest phytoliths, this being ascribed to their different morphology. In an examination of the 20-50 um size fraction of fifty-five profiles, Wilding and Drees found phytoliths of Gramineae origin to be most abundant. They found 0.1 - 0.3% phytoliths in the surface layers, and less than 0.03% in the soil below 50 cm. In contrast to the findings of Jones and Beavers (1964a) outlined above, where mid-catenary soils were found to have the highest opal content, Wilding and Drees found that "no evident differences in opal content were noted among toposequence members" (1971:1008).

Wilding and Drees compared their Ohio soils data with data from soils in Illinois (Jones and Beavers, 1964a) and Minnesota (Verma and Rust, 1969), and concluded that, despite limitations imposed by differences in climate, geomorphic position, plant species and soils, relative indices of prairie stability and luxuriance could be erected. Since 5 to 10 times as much opal had accumulated in the Mollisols of

Illinois and Minnesota as in the Mollisols of Ohio, they concluded that this could be converted into years of prairie vegetation, and that Minnesota and Illinois had had 2,000 to 5,000 years of prairie impact compared to 150 to 550 years for Ohio.

The work on distribution between soils and down the soil profile has been largely pursued in the United States where the loess areas have provided a suitably uniform background for these studies. The differences between similar soils (similarity being expressed in terms of belonging to the same Soil Group and which may or may not be a real similarity) have been related to speed of loess accumulation, differences in soils internal drainage, and differences in vegetation history; this last introducing a degree of circularity into the argument.

Plant opal was generally found to accumulate in the surface layer. When plant opal was found to be accumulated lower in the profile this was taken to indicate the presence of a buried soil. When distributed throughout the profile, this was attributed to the action of soil fauna (with no data or observations appearing to have been made in any work), or to the gradual accretion of loess allowing concurrent plant growth (Jones and Beavers, 1964).

Distribution in Australian Soils

Investigations into the distribution of opaline silica in Australian soils have been very few indeed. Brewer (1956) commented on the presence of diatoms and sponge spicules in the A1 and A2 of some Victorian soils; these being re-identified as plant opal after some exchange of views between Brewer and Leeper. Baker (1959b) found that some topsoils he examined contained 2.5 % plant opal, while whole soil (depth) samples contained 1 - 2 %.

Brewer, while preparing the micro-morphological comments

accompanying many of the soil profiles described in The Handbook of Australian Soils (Stace *et al.*, 1968), gave estimates of the abundance of phytoliths in each depth interval examined (Table 4.2). This reinforced the impression that the topsoil contained a higher proportion of phytoliths. Of the eighty-six soils described by Brewer, nineteen recorded phytoliths to the full soil depth. Of these ninteen, four were among the five soils described in the Handbook under the Great Soil Group classifications Black Earths, Chernozems and Prairie soils (vertisols in Soil Taxonomy, 1975). Rovner (1986) commented that vertisols may be a special case, since plant opal is found throughout theses profiles and may be due the process of "argyllo-pedoturbation" (1986:25). Brewer found that, in the remaining soils, phytoliths were common in thirteen of the topsoils, and very rare in twenty-one.

The estimation of the plant opal content of soils

The extraction of the opaline silica from the entire size range of soil materials is made difficult due to the tendency for clay sized particles to flocculate. Unfortunately, it is believed that the <5um fraction contains 50-75% of the plant opal in soils (Wilding and Drees, 1974), and the usual methods of calculating plant opal content in a soil, i.e. that of multiplying the amount of opal present in one size fraction by the percentage of that size of material in the soil as a whole, grossly underestimates the true plant opal content.

It is interesting to note that Rovner advocates the use of the whole soil sample from which to extract "the entire phytolith assemblage without size differentiation. Taxonomically significant phytoliths come in all sizes.....Unless all sizes are recovered, significant morphological and taxonomic information may be lost." (1983:240). This is indeed the case, but, given the problems outlines above, it is a mistake to think that utilising standard extraction methods as they now

Table 4.2: ABUNDANCE OF PHYTOLITHS IN AUSTRALIAN SOILS
DETERMINED BY MICRO-MORPHOLOGY

C: Common F: Few O: Occasional R: Rare VR: Very Rare

Great Soil Group	Profile #	Abundance	Notes	Soil Depth (cm)	Phytoliths depth (cm)
Siliceous sands	A	*			
	B	O	less frequent with depth	245	127
Earthy sands	A	O	absent with depth	110	10
Grey B.& Red Calc.	A	VR	"	58	20
	B	VR		78	57
Desert loams	A	O		90	all?
	B	VR		180	all?
	C	VR		138	12
	D	VR		68	8
	E	VR		85	40
Grey, Br & Red clays	A	R		152	86
	B	O	VR at 158 paleosol?	190	10
	C	C		150	120
	D	C	R at 20; C at 29; O at 60; VR at 120	120	120
	E	VR		90	40
	F	O	F at 20; O at 50	110	50
	G	O	VR at 13	184	30
	H	VR		14	? 8
	I	VR		180	60
	J	O	VR at 10	90	10
	K	F	VR at 130	180	180
	L	VR		72	25
	M	VR		88	?88
Black Earth	A	VR		150	150
Chernozems	A	O	R to 45; VR to 75	90	75
Prairie Soils	A	O	R to 25; VR to 60	90	?90
	B	C	R at 30; O at 60 (F in restricted areas); VR at 90	90	90
	C	O	R to VR (30); VR at 60 & 70	70	70
Solonetz	A	C	O at 10, VR at 60	95	?95
Solodized Solonetz & Solodic soils	A	O	VR at 38; VR at 140	230	140
	B	VR	R at 48 & 60; absent at 79	94	79
	C	F	O at 11 & 30; VR at 38	107	?38
	D	F	C at 20; R at 25	63	25
Soloths	A	F	C at 20	244	?46
	B	C	O to VR at 45; VR at 90; VR at 120; absent at 140	150	140
	C	F	C at 15; O to R at 50	180	180
	D	F	less F by 20; VR at 50; none by 60	150	?60
	E	F	R at 20	40	40

continued

Table 4.2: ABUNDANCE OF PHYTOLITHS IN AUSTRALIAN SOILS
(CONT'D) DETERMINED BY MICRO-MORPHOLOGY

C: Common F: Few O: Occasional R: Rare VR: Very Rare

Great Soil Group	Profile #	Abundance	Notes	Soil Depth (cm)	Phytoliths depth (cm)
Solonized brown soils	A	O	R at 10; absent by 20	200	20
	B	R		125	?24
	C	VR		120	10
	D				
	E	VR		120	?6
	F				
Red-brown earths	A	R		176	?70
	B	O	VR at 20	80	80
	C	C	R at 46	90	90
	D	C	less F at 60	110	110
	E	O	VR at 20	150	150
Non-calcic brown soils	A	C	R at 20	90	?90
Chocolate soils	A	O		85	?85
	B	C	R at 20	100	?100
Brown earths	A	?	R at 90; absent at 100 not mentioned 0-70	150	100
Calcareous Red earths	A	VR		102	?20
	B	R	VR at 30;	90	60
	C				
	D				
	E	R	O at 10; R at 130	130	130
	F	O	VR at 20;	168	?80
Red earths	A	O	less F to 30	180	?30
	B	VR		148	46
	C	VR		81	30
	D	R		51	?51
Yellow earths	A	C	VR at 10;	118	?74
Terra Rossa soils	A	O	VR at 30	60	60
Euchrozems	A	R	VR at 10; none at 20	84	10
Xanthrozems	A	VR		140	?10
Krasnozems	A	F	C at 10; O at 20 VR at 40	120	?60
	B	VR	none by 30	180	20
Grey-brown podzolic	no micro-morphology				
Red podzolic	A	F	C at20; VR at 35	100	35
Yellow podzolic	A	F	less F at 25; O at 40; less at 50	105	50
	B	R	R at20	180	20
	C	C	O at 50; none at 75	120	50
Brown podzolic	A	O	R at 10;90; R at 105	180	?135

continued

Table 4.2: ABUNDANCE OF PHYTOLITHS IN AUSTRALIAN SOILS
(CONT'D) DETERMINED BY MICRO-MORPHOLOGY

C: Common F: Few O: Occasional R: Rare VR: Very Rare

Great Soil Group	Profile #	Abundance	Notes	Soil Depth (cm)	Phytoliths depth (cm)
Lateritic podzolic	A	O	R at 30; VR at 60	180	60
	B	O	less F at 10	100	?24
	C	R	VR at 38; none at 60	64	38
	D	R		120	?5
Gleyed podzolic	A	C	R at 50;90; VR at 120	200	120
Podzols	A	C	R at 80; VR at 100	190	100
Humus podzols	no micro-morphology				
Peaty podzols	no micro-morphology				
Alpine humus soil	A	VR	none at 60	120	40
Humic Gleys	A	C	O at 10	80	?80
	B1	?	O at 30; O at 210; VR at 215 (not mentioned above 30)	215	215
	B2	R	F at 30; less at 60	60	60
	C	F	C at 20; O 30-90; VR at 120	190	190
	D	F	O at 8; F at 75; R-VR at 110	190	190
Neutral to Alkaline peats	no micro-morphology				
Acid peats	no micro-morphology				

From Stace et al. (1968)

stand will yield the full plant opal content of the soil or sediment. The repeated use of calgon, for example, might indeed remove some of the more fragile plant opal; this should be checked.

The movement of plant opal in soils

Rovner (1983) disscussed the durability of phytoliths in soils; in particular their dissolution and breakage. He stated that a variety of factors biased soil phytolith assemblages - movement by animals in faeces, transportation by wind and water, and downward mobility. It should be mentioned, however, that research into most of these mechanisms has yet to be conducted.

One of the major problems yet to be addressed in plant opal research is this question of the mobility of plant opal once it has been incorporated into the soil. Rovner, in a paper entitled "Downward percolation of phytoliths in stable soils: a non-issue", suggested that the literature reveals an "overwhelming consistency of phytolith stability within the A Horizons of soil profiles and at most to the top of the B Horizon, below which the quantity of phytolith drops off exponentially" (1986:24).

In the same volume of papers, Rovner commented that phytoliths could be tagged with stable isotopes and deposited on a soil profile, washed down with a garden hose to see what happens to them in terms of downward percolation (1986:132). Such an experiment on a smaller scale has been considered in this chapter.

1. The distribution of plant opal in Site 8 soils

Before considering the mobility of plant opal, the plant opal distribution pattern in the soils of the mallee site (Site 8, Pilliga) was investigated. These soils have been described in full in Chapter 3 and Appendices A and B.

Materials and methods

In an initial sampling of the dome material and the subsoil (Table G24), it was found that there was about the same amount of opal in the silt fractions of both samples, but since the proportion of silt in the domes was almost double that of the clay, this gave a higher proportion of opal in the dome material than in the subsoil when multiplied together. The subsoil contained considerably more clay, and just how much opal was present in this fraction could not be determined. The opal was not corrected for purity, and it was subsequently found that purity can range from 50% upward. The subsoil sample included faunal channels.

A second series of samples were taken. In addition to sampling the soil material (Profile PF8iv) in the A1, A2 and B horizons (away from obvious faunal channels), samples of the material deposited by termites above the ground (sheeting) and within fresh faunal channels in the B were taken. The sand/silt/clay distribution of the samples were established (Table G5, Appendix G) and the plant opal content of the silt was determined (corrected for purity). The proportion of opal was multiplied by the proportion of silt in the sample (Table G5) and graphed against depth (Figure 4.1B). The percentage clay in each sample was similarly graphed (Figure 4.1A). The sheeting figures are recorded at +20 mm; i.e. they are above the ground surface.

Results

The proportion of silt multiplied by the proportion of plant opal gives a decrease in the amount of plant opal between the topsoil and the domes and a further decrease in the subsoils. A cement-like material (the bleached A2) forms domes above the clay subsoil and it was considered that this may also impede the mechanical movement of plant opal down the profile in a similar manner to the podzol pans described

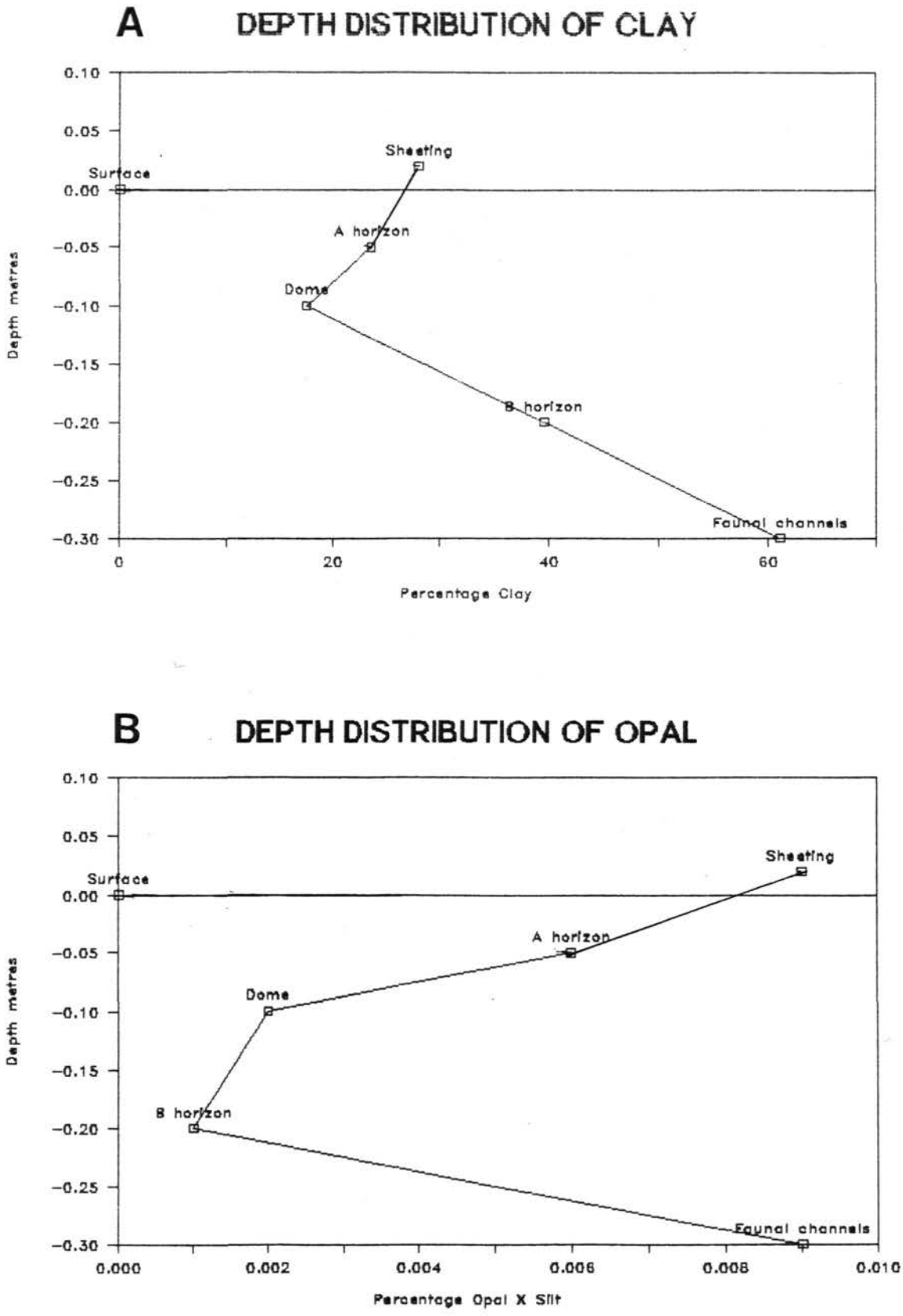


FIGURE 4.1: DEPTH DISTRIBUTION OF PLANT OPAL AND CLAY, PILLIGA MALLEE PROFILE PF8i

above in Chapter 2. However, the question of a damming effect by the domes is really not resolved, particularly since the clay fraction in either case contains an unknown amount of plant opal and there is less clay in the domes than in the topsoil.

Figure 4.1 highlights that the maximum plant opal content is in the sheeting above the ground surface and the faunal channels within the subsoil. This demonstrates a mechanism for the suprisingly high proportion of plant opal found in the subsoil. The faunal channels also contained the highest proportion of clay (which may contain even more plant opal) while the sheeting, which was similar in particle size distribution to the upper topsoil, contained substantially more plant opal content than it.

Conclusions

Using the silt x clay method to calculate opal content, the distribution of plant opal within the soil generally declines with depth. If the faunal channels within the soil and the faunal sheeting above the soil are also examined it can be seen that they contain the largest proportion of plant opal. When the distribution of clay, which contains an unknown (but probably very large) proportion of plant opal is also considered, there can be no doubt that it is the faunal materials which contain the largest amount of plant opal.

The distribution of plant opal within a soil may be influenced by three processes. Firstly, in areas where alternating periods of stability followed by rapid deposition occur, plant opal may become concentrated in layers within the soil (loess, river flood plains, etc.). Secondly, the opal may be transported deep into the soil by soil fauna. While this method has been discussed previously, its occurrence has not been shown. This appears to be a major process in the mallee soil. Thirdly, the plant opal might be transported mechanically through

the profile. This is a process which appears to be occurring in the podzol examined in Chapter 2 and possibly in the mallee soil.

2. Studies into the mobility of plant opal in soils

(i) The movement of plant opal by soil fauna

Observations at Site 8, the mallee, carried out over a period of several years, demonstrated that the soil fauna, which were very active in the soil, were responsible for the removal of large quantities of litter. As discussed in Chapter 3, some 3516 kg/ha/yr of litter falls at this site. It is very quickly incorporated into the soil by fauna including termites, who build sheeting under which they begin to break up the litter. The floor of the mallee is consequently not as litter covered as would be expected (Plate 18A).

Termite and ant activity is much more evident at this site compared with the upper broom plain (Site 7). The percentage cover of faunal holes in 16 random 25 cm^2 quadrats at both sites was recorded, and it was found that 15% of the ground in the mallee was composed of faunal holes as against 2.5% in the broom plain. The holes in the mallee were mainly those of termites, who built up the ground adjacent to trees, giving the surface in many places a raised, spongy appearance (Plate 18B). Similarly, all fallen twigs (Plate 19A) and logs were rapidly covered by sheeting, and reduced to fragments by termites (Plate 19B to 21A). Plate 21B shows a fragment of termite nest which has incorporated undecomposed leaves.

Sheetings are constructed by termites of excreta or soil particles cemented together with excreta or saliva and serve to either construct covered runways or to cover the food (Lee and Wood, 1971). Little is known of the actual termite species present at the site, since this was outside the scope of the thesis (although they are believed to be *Coptotermes* spp). Most are observed to be subterranean species which

are litter and grass eaters. Ants were also very active in this area.

In the subsoil many faunal channels were found, mainly between peds. The channels were lined with black granular materials (Plate 10A) and contained faecal pellets tightly packed into the void (Plate 10B).

Methods and materials

A measure of the amount of bioturbation by messo-fauna at each level in the soil profile was made by assessing the percentage faunal channels in samples.

A series of undisturbed soil samples were excavated in Kubiena tins down the Site 8 profile adjacent to Profile PF8ii. Samples were taken in boxes 500 mm^3 at depths 0-50 mm, 50-100 mm, 100-150 mm and 150-200 mm, covering the A1, A2, domes and top of the B horizon (Figure 4.2A).

The samples were impregnated with Carbowax 6000, and sliced into 100 mm thick horizontal slices with a Kerosene-cooled diamond saw. The resultant surfaces were examined for faunal channels.

Those channels which were considered to be fresh were traced onto a sheet of plastic film. The channels used were of a similar colour and fabric - they were the darkest in colour, with fresh margins and which did not cross over other channels. Channels down to about 1 mm diameter were included.

The plastic film outlines of the slices and channels were photocopied onto squared paper. The percentage covered by channels in each slice was calculated and the results graphed (Figure 4.2B).

Results

The graph shows a general falling off in the channel proportion through the topsoil with a slight increase above the dome. The dome is notably an area of few channels - those which pass through this cement-like layer are large. Beneath the dome there is a slight rise, with the

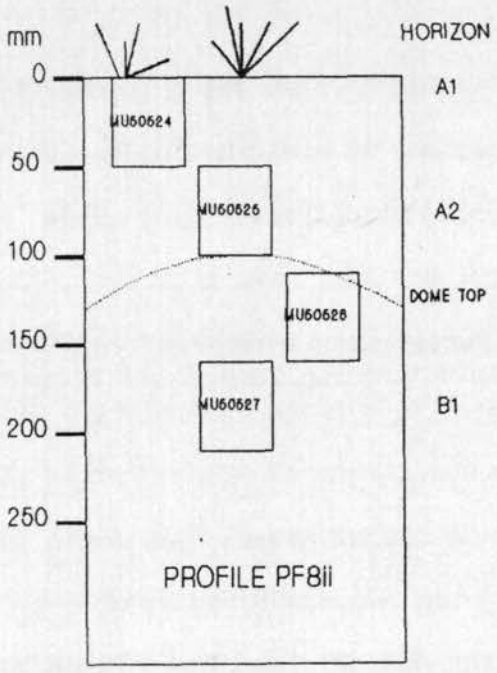


FIGURE 4.2A: DISTRIBUTION OF KUBIENA TINS

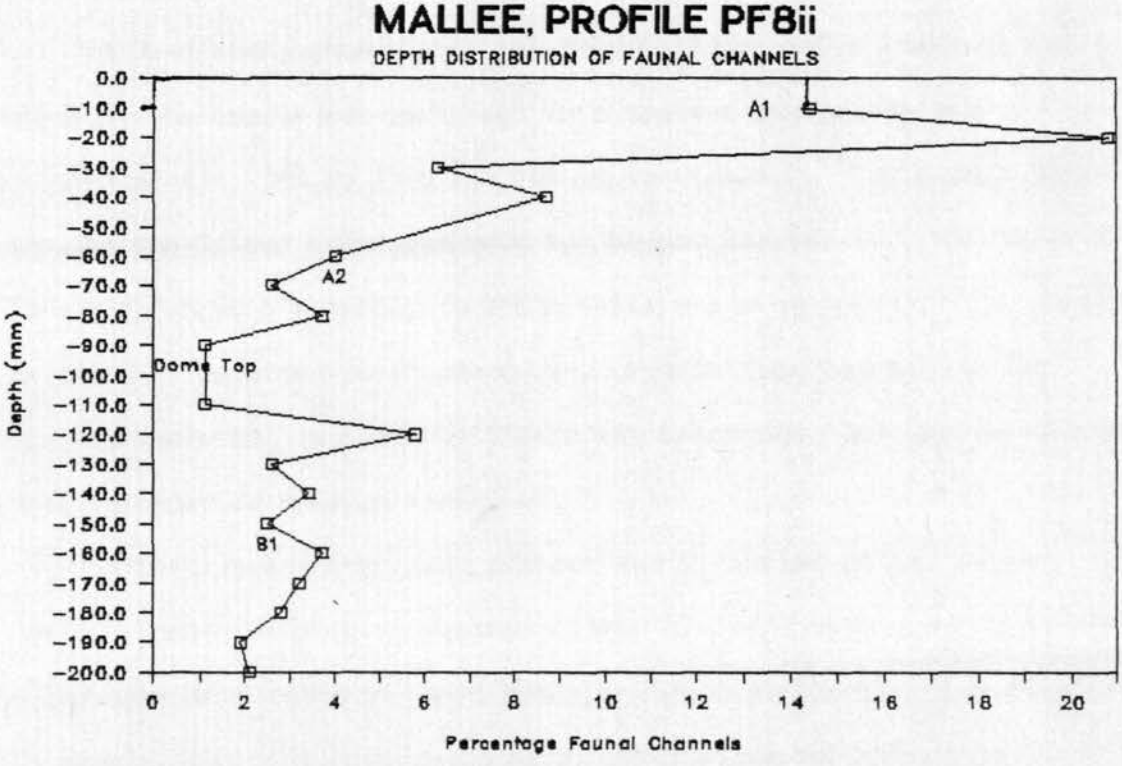


FIGURE 4.2B: DISTRIBUTION OF FAUNAL CHANNELS

remainder of the upper subsoil containing a fairly stable proportion of channels.

The distribution of plant opal in the profile follows a similar pattern (Figure 4.2B), with a maximum in the topsoil and a falling off into the subsoil. While this investigation looked at larger messo-faunal channels only, it would seem that the activities of fauna which include the backfilling of channels with faecal pellets, could be responsible for the distribution pattern of plant opal.

The ability of soil fauna to move plant opal is also demonstrated by the presence of plant opal in the carton of tree-nesting termites (Plate 10G and H) and sheeting (Plate 40A and B).

(ii) The pervection of plant opal through soils

In order to examine if it is possible for plant opal to be transported through soil materials, a small experiment involving the washing of such material through a soil column was attempted.

Materials and Methods

An undisturbed sample of the topsoil from Site 8 (mallee) was removed. The sample was contained in a topless and bottomless cylindrical tin, 120 mm long and 100 mm in diameter. The sample taken included the litter layer and down to 100 mm, leaving a 20 mm rim of tin protruding above the sample in which water could be ponded. The sample comprised A1 material which was a very organic loam (particle size analysis Table G5, Appendix G). Care was taken that the sample remained moist in order to prevent cracking.

A thin layer of Miocene diatoms was sprinkled on top of the sample. These distinctive diatoms (Plate 37) were used since they are in the same size range as plant opal, are very distinctive and alien to the sample, and of similar material. The diatoms were obtained from the Middle Miocene Chalk Mountain Formation, Warrumbungle Mountains, New

South Wales (Holmes, Holmes and Martin, 1982). They were collected from Chalk Mountain from the diatomite layer uncontaminated by organic material.

A layer of candle wax was applied to the base of the tin to prevent the soil falling through, and a few drainage holes inserted to allow water to pass through freely. The tin was placed on a tripod and filled with water to the brim with care being taken not to disturb the litter and diatoms. Water was allowed to flow through the soil and drip out into a beaker placed beneath the tripod. Over a period of three months around 200 mL of water was added at weekly intervals to simulate repeated wetting and drying cycles.

At the end of this time, the sample was oven dried at 80°C and solidified using Aralydite DY026 and Hardner LC249 (kindly donated by Ciba-Gigey Australia Ltd.) in the proportions 100:57 which was added over a period of 45 minutes, the time taken for solidifiation to occur. It was left to harden for 3 days and then sliced to provide surfaces for thin sections to be made which were then examined under a standard petrological microscope.

Results

Diatoms were detected in the slides to a depth in the sample of approximately 70 mm. Plate 38A and B shows such diatoms and their typical location. They were found adhering to the side of vertical voids penetrating the sample from the surface; that is faunal channels and large cracks.

Discussion

The flow of suspended particles through soil is an area of considerable interest where contamination of soils by toxic materials is suspected (Vinter and Nye, 1985). White (1985) examined the evidence for the transport of suspended matter through soil macropores in

undisturbed soils. Macropores (30 to 3000 um diameter) comprise only a small fraction of the soil volume (0.001 to 0.05). Rainfall rates of between 1 and 10 mm hr^{-1} have been suggested as sufficient to initiate flow in micropores (Beven and Germann [1982] quoted in White [1985]).

The movement of clay particles through soils (pervection) has been considered by many. Brewer and Haldane (1957) poured clay-size material (<2um) in 0.7% suspensions into pure quartz sand under varying conditions and found that clay accumulated within the pores between the sand grains. Similarly Swindale (1960) illustrated the illuviation of dispersed clays through a column of sand. The limited movement of clay particles through soils is not a disputed idea. Opal, being less reactive, should move in a less inhibited fashion.

The question of the movement of plant opal through soils has been discussed by Rovner (1984) who considered, from his examination of the literature, that such movement was not a serious problem. In particular he cites the evidence from literature of phytolith content being one hundred times lower at twenty inches than it is at ten and states that "This drastic fall-off curve is the typical, almost universal condition in all studies noted" (1984:24).

The soils examined in the studies quoted by Rovner often show a rise in plant opal content which is interpreted as another layer of loess at depth. In one paper not quoted by Rovner, Verma and Rust (1969) found such a rise in three of the six soils studied which they said could be due to recent deposition of loess or alternatively to either differential mixing by sail fauna or restriction to the downward movement of the phytoliths by a material of higher bulk density.

In one cited study (Bartolli and Guillet, 1977), Rovner contends that the abstract is at variance with the meaning of the article. "Anyone who reads the translation of this article in the abstract and

sees it for a case for downward percolation is apparently not reading the rest of the article." (1984:25).

Bartolli and Guillet studied the distribution of pollen and phytoliths in a podzol down to the Bs (hardpan) "which created an obstacle for the migration of pollen and phytoliths" (1977:353). They write of an increase in the density of aggregates (phytoliths-organic material-silicates) favouring the migration of the phytoliths across the A2. The comment is made that the vegetation history obtained from the phytoliths is shorter due to their rapid migration. In a second paper concerned with phytoliths and podzols, Bartoli, Monrozien and Rapaire (1980) state that phytoliths migrate across the eluvial horizon (A2) and accumulate in the Bh (humic layer). These authors most definitely appear to be making a case for the dowward migration of plant opal.

Summary

This experiment demonstrates that it is possible for opaline material the size of plant opal to be mechanically transported through soil via the normal cracks and channels within it.

Conclusions

Plant opal is not found on the surface of soils in a completely exposed state; it is more likely that it is gradually exposed as it passes through the guts of several soil animals. Such animals may begin the incorporation of the opal into the soil, and the pervection experiment shows that it is possible for it to move considerable distances within the soil in a short period of time.

The problem is not whether plant opal moves, but how much. In soils where bioturbation is a dominant process, the movement of plant opal may be considerable. It was noted that the subsoil of the mallee soil contained a high proportion of plant opal in the silt fraction as did the domes but it was the faunal channels within the subsoil where

the plant opal content of the silt fraction was very high; as high as in the topsoil or the sheeting. The high proportion of clay in this material when compared with the surrounding subsoil, would seem to indicate the actual plant opal content of the faunal channels is very high indeed; hardly suprising given that the soil fauna backfilling such channels with faecal pellets are usually litter eaters.

Thus the distribution of plant opal is not as simple as first thought. Leaving aside the special case of continuous or interrupted deposition of soil materials, while there is a tendency for a concentration of plant opal in the upper topsoil, there are patterns within this concentration due to migration of plant opal, the blocking effect of denser soil layers and the influence of soil fauna.

The effects of these processes must be taken into consideration when assessing the degree of movement of plant opal and its effect on opal assemblages and the interpretation of them. The plant opal assemblages of the litter layer and topsoils are considered in the following chapter and the soil plant opal assemblages within the mallee soils in particular are discussed in view of the above findings.

CHAPTER 5

PILLIGA FIELD STUDIES III: PLANT OPAL ASSEMBLAGES

Introduction

In the first study in Chapter 2 the plant opal assemblages in the vegetation and sediment of a small swamp were examined for similarities. It was found that although this was a very simple community, the relationships between the plant opal assemblages were complex. The delicate shapes present in the vegetation seem not to survive in sediments.

In order to further explore these relationships, the plant opal assemblages in both the soil and litter in several vegetation communities in the Pilliga Forests were examined.

1. Topsoil assemblages

Aims of this study

The mosaic vegetation of the Pilliga offers ideal conditions in which to test the hypothesis that like vegetation communities will produce like plant opal assemblages and unlike communities unlike assemblages in the topsoil. In the study area the climate and geology are held constant and the vegetation communities are distinctive in terms of dominant species and structure.

For the purposes of this study the plant opal assemblages from the topsoil beneath three vegetation communities were examined; broom plains (Sites 2, 6, 7 and 9), mallee (Site 8) and forest (Site 12). These three vegetation communities were described in the Chapter 3.

The broom plains and mallee vegetation have a consistent relationship to topography and geology. The mallees are found below the ridge line on the west slope while the broom plains are found encircling the ridges, occupying the upper and middle slope positions to the east and the middle and lower slope positions on the west. The forest is of

ironbark and cypress pine. Details of the species and their abundance in each community are given in Appendix C.

It was the aim of this study to establish plant opal assemblages for each community and to assess the degree of similarity or difference between them. In detail, the aims were:

1. to examine the degree of similarity in the assemblages erected from two separate samples from the same site,
2. to examine the similarity between assemblages from the broom plain sites and
3. to compare assemblages from the three vegetation communities.

Method

Sampling

Pinch samples of sediment were taken at each site; one set from each of Sites 2, 6, 8, 9 and 12, and 2 sets from Site 7. Figure 5.1 shows the location at each site where, over a 100 m^2 sampling grid, 10 samples of identical volume were taken from the surface soil after litter had been removed. The method is described in more detail in Chapter 7. The samples were amalgamated, split, and processed to remove the silt sized plant opal as outlined in Chapter 7.

Microscope slides were prepared of each sample (Chapter 7). Counting utilised the key outlined in Chapter 8.

Presentation

All plant opal over 2 um diameter was counted; counting continuing until around 200 counts of regular plant opal types were made (Table 5.1). The regular types included all lobates, saddles, double outlines, cones, rods, regular 2 and 3 dimensional sheets, hairs, prickles and spheres. "Regular" means that similar shapes ocurred in the sample repetitively. These shapes were given a morphological number and were used to erect the plant opal assemblage diagrams. These are

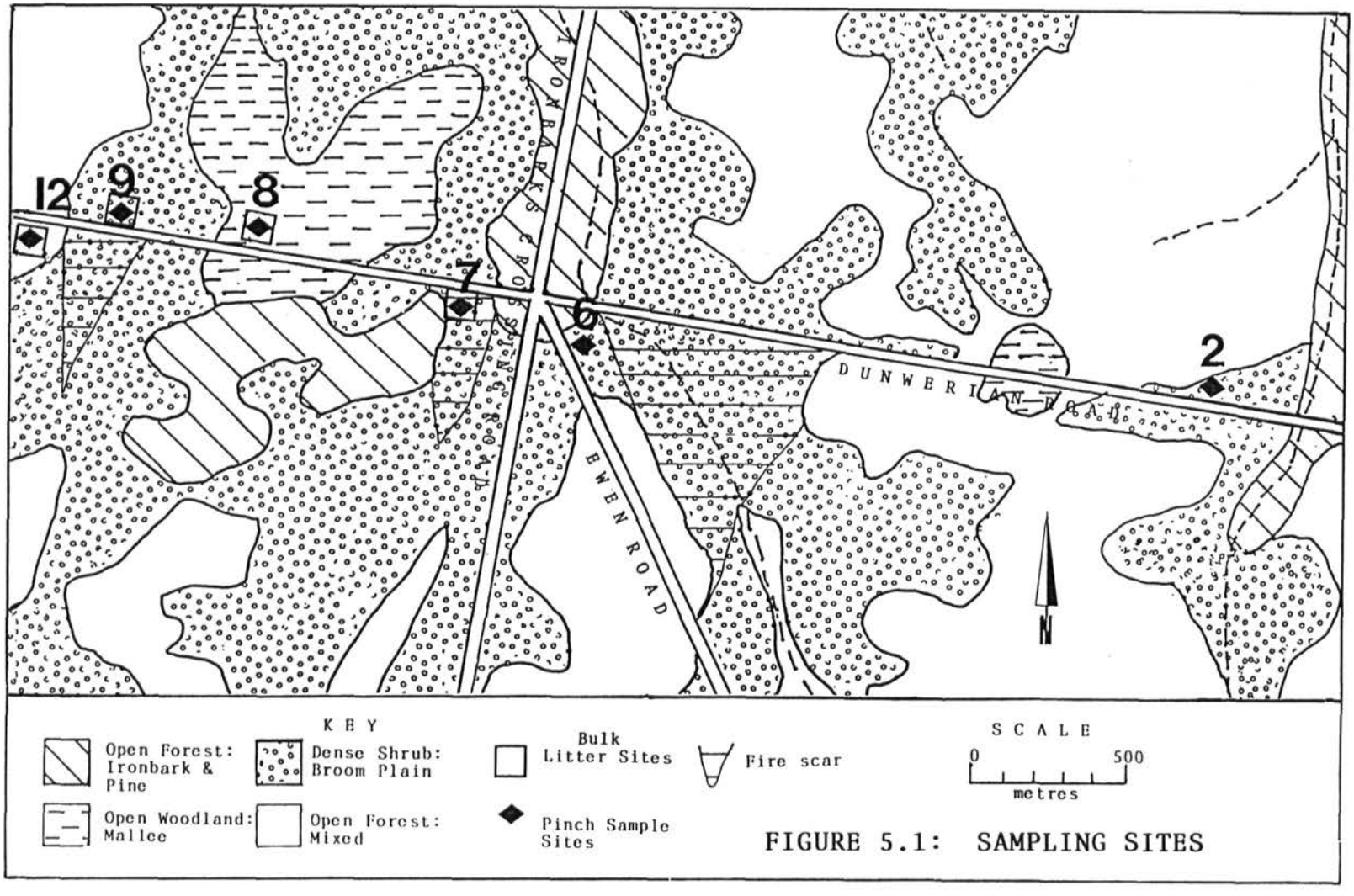


FIGURE 5.1: SAMPLING SITES

Table 5.1: MORPHOLOGICAL TYPE AND NUMBER USED IN ASSEMBLAGE DIAGRAMS

Morphological Type		Morph #
REGULAR TYPES		
Lobates	bilobates	1
	polylobates	2
	crosses	3
Saddles		4
Dble Outlines		5
Cones		6
Rods: thick	smooth	7
	spiked	8
	jigsaw	9
	ridged	10
	rough	11
Rods: thin	smooth	12
	spiked	13
	jigsaw	14
	ridged	15
	rough	16
Rods: platey	jigsaw	17
	sinuous	18
Sheets 2D reg	honeycomb	19
	plain	20
	perforated	21
	bulbous	22
Sheets 3D reg	smooth	23
	rough	24
	honeycomb	25
	verrucose	26
Hairs & Prickles	long	27
	short	28
	gourds	29
Spheres: single	smooth	30
	spiked	31
	rough	32
	indented	33
	verrucose	34
Spheres: compound	smooth	35
	spiked	36
	rough	37
	indented	38
NONREGULAR TYPES		
Sheets 2D nonreg		
Sheets 3D nonreg	smooth	
	rough	
Unclassified silica		
Other silica		

cumulative frequency diagrams of morphological type. The remaining categories of 2 and 3 dimensional nonregular sheets, unclassified silica and other silica were counted as "nonregular" types. In the case of the sheets and unclassified silica, the shapes were of isolated ocurrence. Nonregular sheets, for example, were either irregular shapes which only appeared once, or pieces of sheets. The plant opal assemblage diagrams are given here; the raw data appears in Appendix G. The degree of similarity between any two plant opal assemblage was assessed using the Kolmogorov-Smirnov (K-S) two tail test at the 0.05 significance level (discussed in Chapter 8; raw data presented in Appendix G, Tables G7 and G8).

Results

1. Replication of results.

The degree of reproducibility between assemblages from the one site erected from different pinch samples is displayed in Figure 5.2 (derived from Table G7). The pinch samples were from Site 7, the upper broom plain. While there is some divergence of the curves (in particular, 7b2 contains more three-dimensional sheets) they are drawn from identical populations (K-S critical value = 0.13, D = 0.10).

2. Comparison of the broom plain assemblages

Figure 5.3 (derived from Table G7) shows the plant opal assemblage curves erected for each of the broom plains. Table 5.2 gives results of the Kolmogorov-Smirnov test (derived from Table G8).

Site 9 demonstrates obvious differences from the remaining sites, particularly if sample 7b2 is used. Site 9 is part of the same broom plain as Site 7, but is located downslope. The main differences between the broom plains in actual plant opal percentages are displayed in Table 5.3. In this table morphological shapes 1 to 6 are grouped together as grass short-cells for convenience. Site 9 has more lobates and cones,

FIGURE 5.2
COMPARISON OF PLANT OPAL ASSEMBLAGES

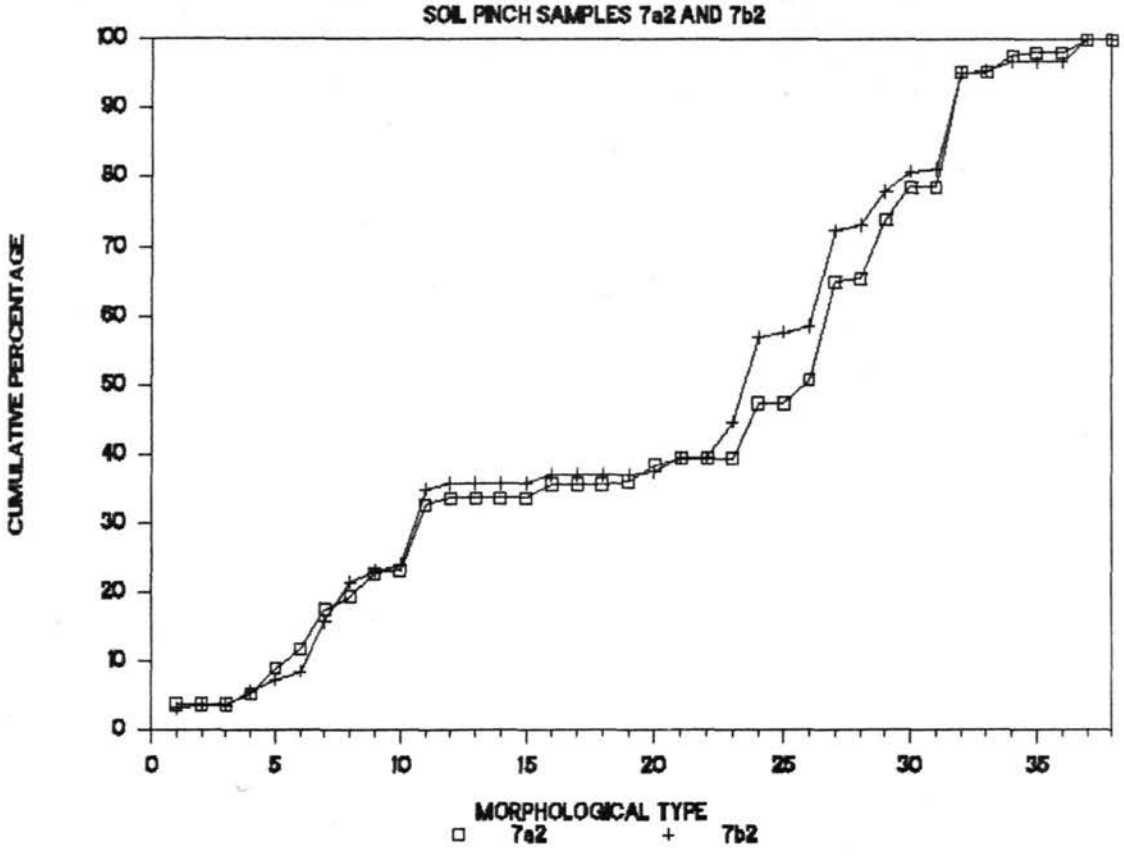


FIGURE 5.3
COMPARISON OF PLANT OPAL ASSEMBLAGES

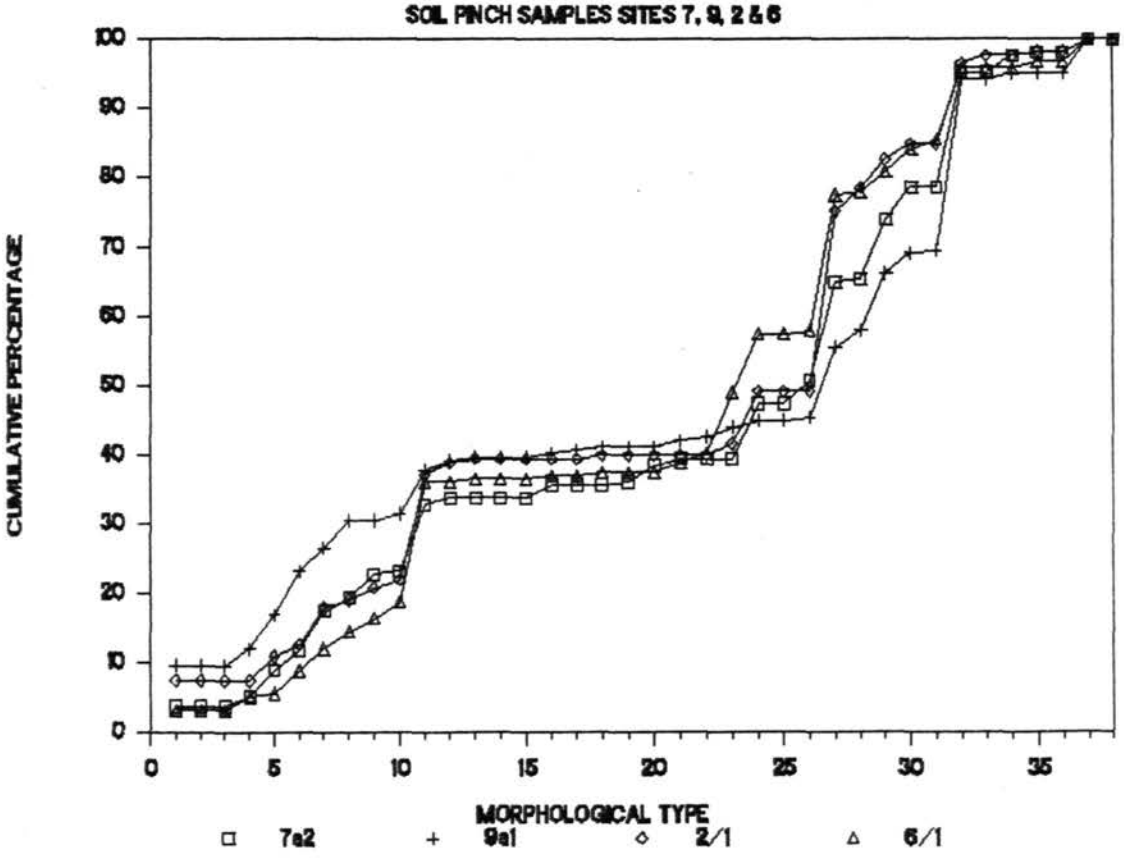


Table 5.2: Kolmogorov-Smirnov two tail test results: Broom plains

Site Comparisons	D	Critical Value a=0.05
7a2 & 9	0.11	0.13
7b1 & 9	0.16	0.13*
7a2 & 2	0.13	0.14
7a2 & 6	0.13	0.13*
9 & 2	0.21	0.14*
9 & 6	0.22	0.13*
2 & 6	0.09	0.14

* not drawn from same population

Table 5.3: DIFFERENCES BETWEEN PINCH SAMPLES

	REGULAR TYPES				NONREGULAR TYPES		
Sample #	% grass short-cells	% 2D sheets	% 3D sheets	% hairs & prickles	% 2D nonreg sheets	% 3D nonreg sheets	% other silica
7a2	11.8	3.8	11.4	23.2	5.1	9.8	6.6
7b2	8.5	2.4	13.8	19.5	9.8	9.5	5.6
9	23.2	1.5	1.5	20.7	9.8	6.8	10.5
2	12.7	0.0	9.2	33.5	38.7	7.3	2.6
6	8.9	2.8	17.3	22.9	29.1	3.4	1.5
8	27.9	1.0	2.4	13.0	5.5	0.0	15.8
12	23.3	1.5	8.8	10.3	5.5	1.7	10.2

and fewer regular three-dimensional sheets (Plate 23B). Apart from percentage of sheets, the ornamentation is also different. The upper broom plain (Site 7) contains more rough surfaced sheets (Plate 23A). These range from very pitted sheets to the highly ornamented surfaces, and may be due to species differences between the two sites. When the plant opal other than the regular shapes is considered, Site 9 has more other biological opal than Sites 2 and 6, although only a little more than Site 7.

Sites 2 and 6 are very similar and their differences from Sites 7 and 9 vary. Site 2 contained no two-dimensional regular sheets and both Sites 2 and 6 contained a large number of three-dimensional regular rough sheets (Plate 24A and B). Both Sites contained many more two-dimensional irregular sheets than Sites 7 or 9.

It is possible that these variations in assemblages are reflecting a real difference in vegetation between the broom plains. While the general habit and species composition is similar, there are divergences which will be discussed below.

3. Comparison between broom plain, mallee and forest

Figure 5.4 (derived fron Table G7) shows the assemblages for Sites 7 (upper broom plain), 9 (lower broom plain), 8 (mallee) and 12 (forest). The location of the sampling grid for each site is shown on Figure 5.1.

The K-S results are shown in Table 5.4 (derived from Table G8) and actual differences between the assemblages shown in Table 5.5. Site 8 (mallee) is different from Site 7 (upper broom plain). Site 8 contains many more lobates and double outlines, fewer two and three-dimensional sheets, hairs and prickles and three-dimensional irregular sheets. It contains nearly three times more other biogenic silica.

Sites 9 and 12 are different. Site 12 (forest) has more of the

FIGURE 5.4
COMPARISON OF PLANT OPAL ASSEMBLAGES

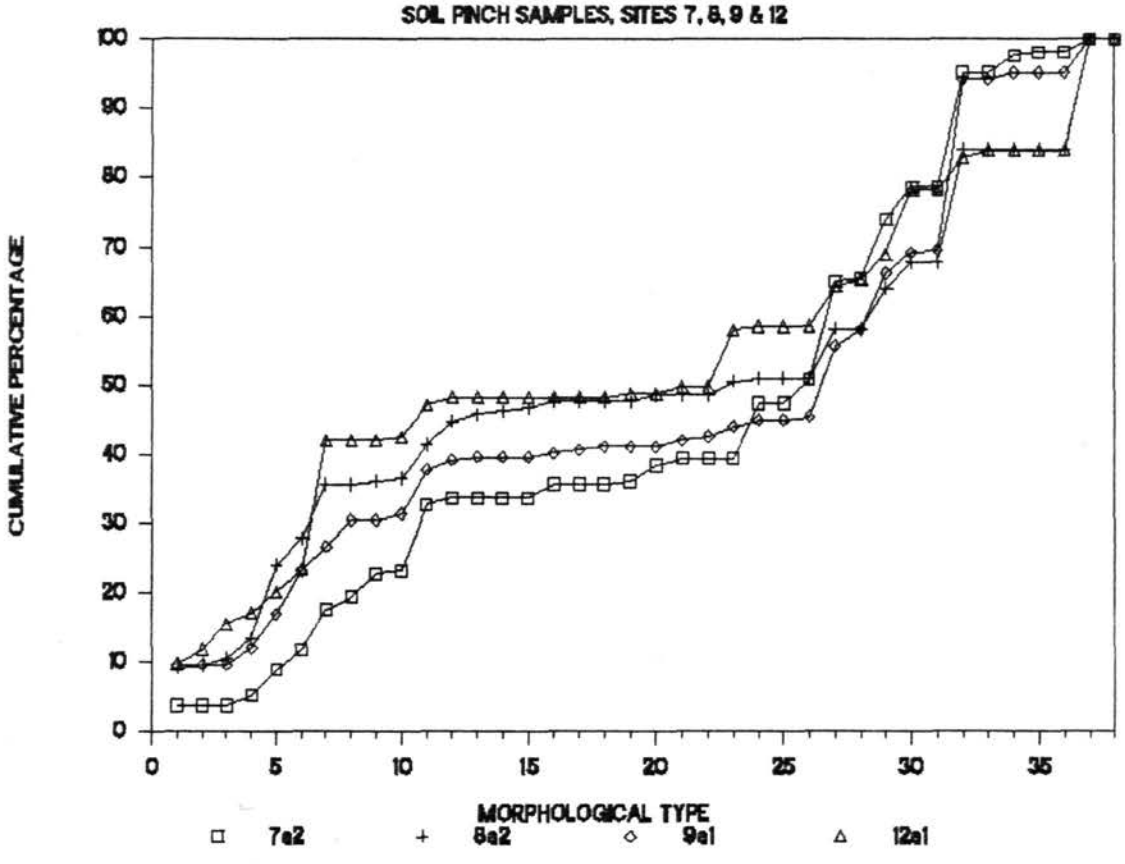


Table 5.4: Kolmogorov-Smirnov two tail test results: Soil pinch samples

Site Comparisons	D	Critical Value a=0.05
7 & 8	0.16	0.13*
7 & 9	0.11	0.13
7 & 12	0.10	0.14
8 & 9	0.11	0.13
8 & 12	0.10	0.14
9 & 12	0.15	0.14*

* not drawn from same population

three-dimensional regular sheets and fewer hairs and prickles and two and three-dimensional irregular sheets. It is of note that the saddles, double outlines, cones, two-dimensional sheets and other biogenic opal percentages are similar, although Site 12 has a higher percentage of lobates.

Site 8 (mallee) has similarities with both 9 and 12. Lobate, saddles, and cone percentages are similar, although a higher percentage of double outlines was found in Site 8. If the classification of Twiss *et al.* (1969) is followed, each site displays a mixture of plant opal from various grass families. However, Site 12 appears to be dominantly panicoid, Site 8 dominantly festucoid and Site 9 has an intermediate distribution. The possibility that such a distribution is related to moisture cannot be ruled out, with festucoid occupying the moister areas and panicoid the drier (Twiss, 1986). This would be reinforced by the other biological opal, mainly diatoms, where Site 8 has many more than Site 12, perhaps indicating the moisture regime differences between the sites. In addition, the canopy at Site 12 is much more open.

Discussion

Several interesting questions emerge from this one brief comparison of assemblages. There is the question of reproducibility. It seems that there is broad reproducibility between samples from two sets of pinch samples at the one site (7a2 cf. 7b2), but interestingly, using the K-S test, this does not mean that each is sufficiently identical to the other to produce the same results when compared with another site.

There is a difference between broom plains which requires closer examination, since these communities are very distinctive.

A difference between Sites 8 (mallee) and 12 (forest) has been shown despite their statistical similarity. Site 12 has a mix of plant opal which could point to a more open site, while Site 8 may be more

moist. It would need many more such comparisons within this Forest to be able to say definitely these were the assemblages representing these vegetation types in this environment.

2. The plant opal assemblages within the soil

Aims of this study

Plant opal assemblages are usually derived from pinch samples of the topsoil. These then provide modern analogues for the interpretation of assemblages from other sources such as buried soils horizons, swamp cores, etc., (Piperno, 1987). Under many conditions the topsoil of a paleosol may not be available or missed during sampling (e.g. Fredlund, 1986) and the subsoil or lower topsoil sampled. A problem which may be significant, then, arises if there is variation in assemblage patterns within the soil. This study examined that possibility.

Methods

A set of samples from Profile PF8iv at Site 8 was taken from the termite sheeting above the litter layer, A1, A2, B horizon and faunal channels within the B (see Chapter 4). Plant opal was separated from each sample, mounted on slides, and plant opal morphology counted and presented as described earlier in this Chapter and in Chapter 7.

The plant opal assemblage diagram is given here, the raw data appears in Appendix G. The degree of similarity between any two assemblages was assessed using the Kolmogorov-Smirnov (K-S) two tail test at the 0.05 significance level (Appendix G, Tables G19 and G20).

Results

The assemblages of plant opal at Site 8 are shown in Figure 5.5 (derived from Table G19) and compared statistically in Table 5.5 (derived from Table G20).

The assemblages in the topsoil and general subsoil are not significantly different, however, neither the particle size distribution

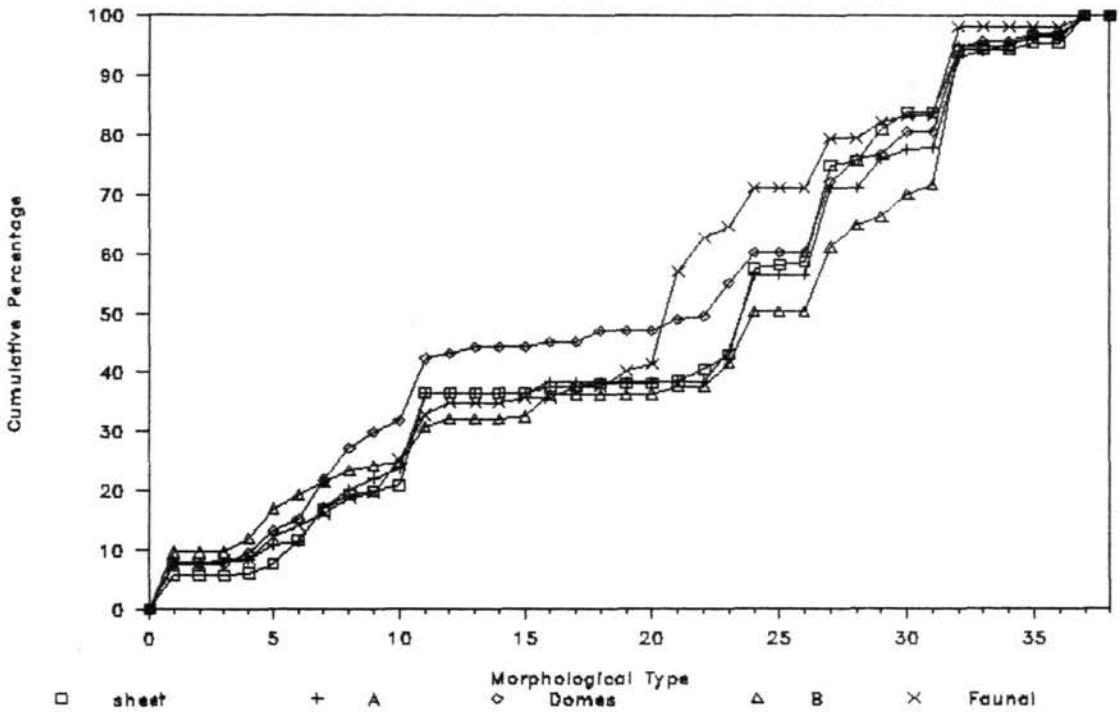


FIGURE 5.5: PLANT OPAL ASSEMBLAGES, SITE 8

Table 5.5: Kolmogorov-Smirnov two tail test results: Assemblages Site 8

Comparisons		D	Critical Value a=0.05
sheeting &	A horizon	0.06	0.14
"	domes	0.12	0.13
"	B horizon	0.15	0.14*
"	faunal	0.22	0.16*
A horizon &	domes	0.11	0.13
"	B horizon	0.10	0.13
"	faunal	0.24	0.16*
domes &	B horizon	0.13	0.13
"	faunal	0.13	0.16
B horizon &	faunal	0.25	0.16*

* not drawn from same population

(Table G5) nor the assemblages of the subsoil and the faunal channels contained in the subsoil are similar. The faunal channels contain a higher proportion of clay, and the assemblage contains a high proportion of hairs and prickles and bulbous sheets, possibly due to the diet of the fauna creating them (termites?). Similarly, the particle size distribution and the assemblage of the faunal channels are very different from the topsoil; reinforcing the idea that the plant opal is derived from a particular source.

The sheeting and the A horizon assemblages are very similar as are their particle size distributions (Table G5), demonstrating that the termites are using the topsoil in the construction of the sheeting rather than material from the subsoil.

Conclusions

This study demonstrates that some soil fauna are capable of moving material into the subsoil, possibly by-passing the topsoil altogether. The main soil fauna operating in the subsoil at this site are termites, and such activities may in some cases lead to a partitioning of the available plant opal between different layers of a soil. Thus the topsoil may, over time, be receiving a completely different assemblage of plant opal from the subsoil. If the subsoil were sampled for comparitive purposes, samples drawn from areas which had high faunal activity might lead to false conclusions about the nature of both the soil and the vegetation history.

Summary

This brief examination of plant opal assemblages in the soil raises many problems and solves none. In particular:

1. Are the differences in topsoil assemblages pedological rather than botanical? Sites 7 and 9 vegetation communities (broom) are very similar, but is some factor related to the soil changing the

assemblage as it enters the soil - by selective dissolution or removal by some other agent (faunal) for example? The examination of plant opal assemblages from different materials within the soil would seem to indicate that soil fauna can influence the plant opal assemblages.

2. Is the difference due to some environmental factor - fire, topography, moisture, causing a subtle shift in vegetation species?

The problem is, of course, that neither of these suggestions are independent. The answer might lie in an examination of the litter layer and a comparison of the assemblages therein between sites.

3. Plant opal assemblages in litter

Before its incorporation into the soil, plant opal lies in the litter layer for some years. The litter layer is, in fact, the best place to examine the vegetation assemblage, since it may be assumed that most of the plant opal entering the soil (apart from that contributed by the roots or atmospheric inputs) passes through it. In many studies the extensive and time-consuming gathering of a reference collection of the vegetation, often taking many years to complete, was a necessary pre-requisite. It is possible that, despite great care, an important contributor of plant opal might be missed. It is possible that sampling the litter layer may be one way of circumventing this lengthy procedure, producing an assemblage giving the mix of opal which most approaches that which is available for incorporation in the soil.

It is also possible that during the time the opal resides in the litter layer, processes at work within the litter change the plant opal and that by comparing the assemblage in the litter with that in the

immediately underlying soil, some start may be made to understanding the nature of these processes.

Aims of this study

The study aimed to

1. erect assemblages of the plant opal present in the litter at each site and compare them to see if they reflected the broad differences in vegetation and
2. to compare the litter and underlying soil assemblages (from the pinch samples) to see if they are in any way changed.

Method

Sampling

At Sites 7, 8, 9 and 12 the litter layer to just above the depth where a little mineral soil was to be found mixed with it was removed from 10 x 1/16 m^2 random quadrats located in the same general area as the pinch samples were taken from (Figure 5.1). The litter was carefully washed, dried, weighed, sorted into components, reweighed and two subsamples comprising 1/100th of each component were taken, mixed and plant opal extracted as outlined in Chapter 7. The opal was mounted on slides for the point counting of 200 pieces of regular plant opal, using the same key as for the pinch samples.

In addition, the plant opal from three species of *Acacia* growing on the sites was extracted (see Chapter 7) and the assemblages of plant opal erected for each species.

Results

(i) General

Detailed results are to be found in Appendix G, Tables G10 and G11. Using the same morphological classes as for the pinch samples, the cumulative frequency of plant opal for each site was graphed (Figure 5.6, derived from Table G10) and the comparisons between each site

FIGURE 5.6

COMPARISON OF PLANT OPAL ASSEMBLAGES

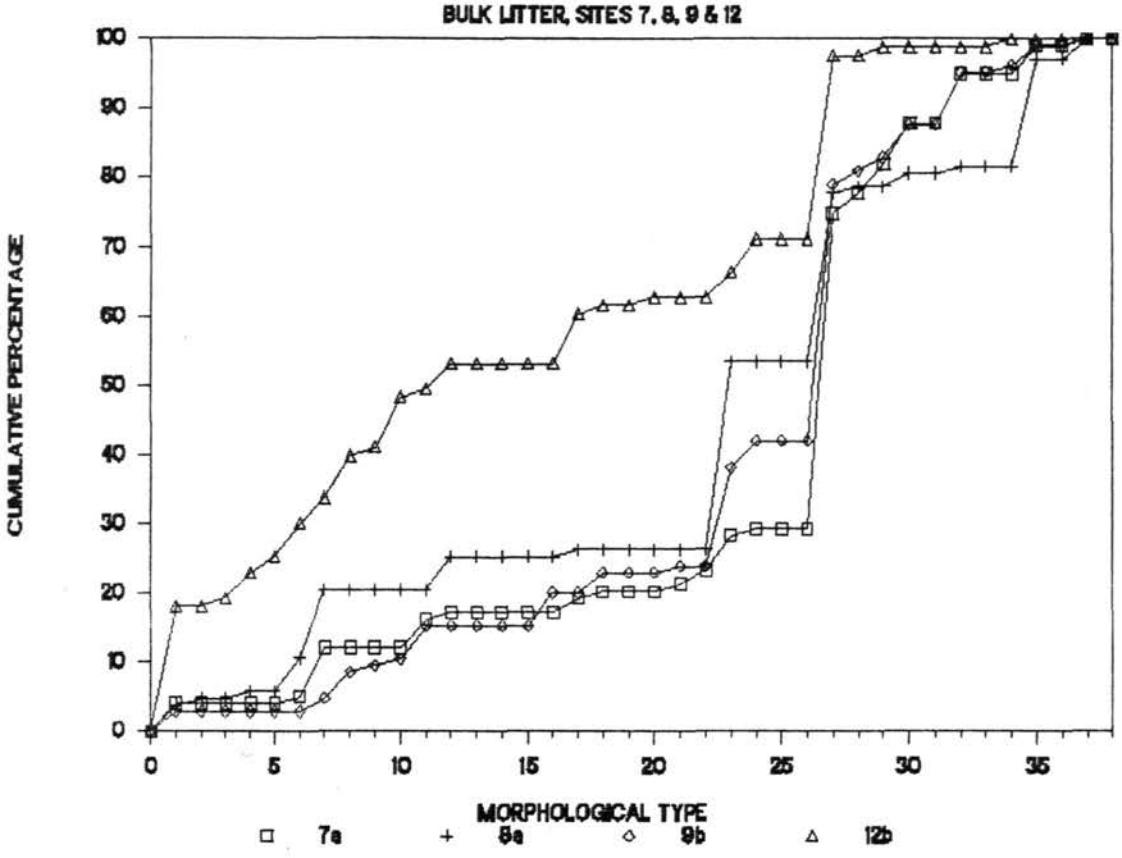


Table 5.6: Kolmogorov-Smirnov two tail test results: Bulk Litter

Site Comparisons	D	Critical Value a=0.05
7 & 8	0.27	0.19*
7 & 9	0.15	0.23
7 & 12	0.35	0.24*
8 & 9	0.17	0.23
8 & 12	0.28	0.24*
9 & 12	0.32	0.24*

* not drawn from same population

Table 5.7: DIFFERENCES BETWEEN BULK LITTER SAMPLES

	REGULAR TYPES				NONREGULAR TYPES		
Sample #	% grass short-cells	% 2D sheets	% 3D sheets	% hairs & prickles	% 2D nonreg sheets	% 3D nonreg sheets	% other silica
7	5.1	3.0	6.0	52.0	38.6	6.3	1.1
8	10.7	0.0	27.2	25.3	52.9	2.1	0.8
9	2.9	1.0	18.1	40.0	58.8	1.4	0.7
12	30.1	1.2	8.4	27.7	63.7	4.1	0.4

assessed statistically (Table 5.6 derived from Table G11). This showed that that the mallee litter assemblage differed from the upper broom plain but not from the lower broom plain, and that the forest assemblage differed from both the broom plains and the mallee. In other words, the litter assemblages from different vegetation communities are indeed different in most cases when assessed in this manner.

The litter assemblage most different is that from Site 12, the forest. This assemblage is statistically different from all others and notably, it contains more lobates, reinforcing the idea that these are due to the openess of the site compared with others (Table 5.7, which, as in Table 5.3, has morphological shapes 1 to 6 combined). Sites 7 and 9 (the broom plains) litter assemblages are similar. When analysed further, there are differences in the numbers of lobates and regular sheets (Table 5.7). Site 7 contains bulbous two-dimensional sheets (from *A. triptera*?) and fewer smooth three-dimensional sheets. Site 8, the mallee, while it is similar to Site 9 (lower broom plain), contains more cones and fewer hairs and prickles than either of the broom plain sites. Cones are in Twiss *et al's.* (1968) festucoid class, and reinforces the findings in the soil pinch assemblage that this site might be more moist.

These similarities and differences would seem to be reflecting the vegetation at each site. One species in particular which is different at some of the sites is the *Acacia*.

(ii) *Acacia* assemblages

Plant opal assemblages for three species of *Acacia* are shown in Figure 5.7 (derived from Table G12). Table 5.8 lists the morphological types and numbers used in this assemblage diagram. It omits the lobates, saddles, double outlines and cones of the assemblages used in the previous diagrams, since these shapes were not found in the *Acacia*.

FIGURE 5.7

COMPARISON OF PLANT OPAL ASSEMBLAGES

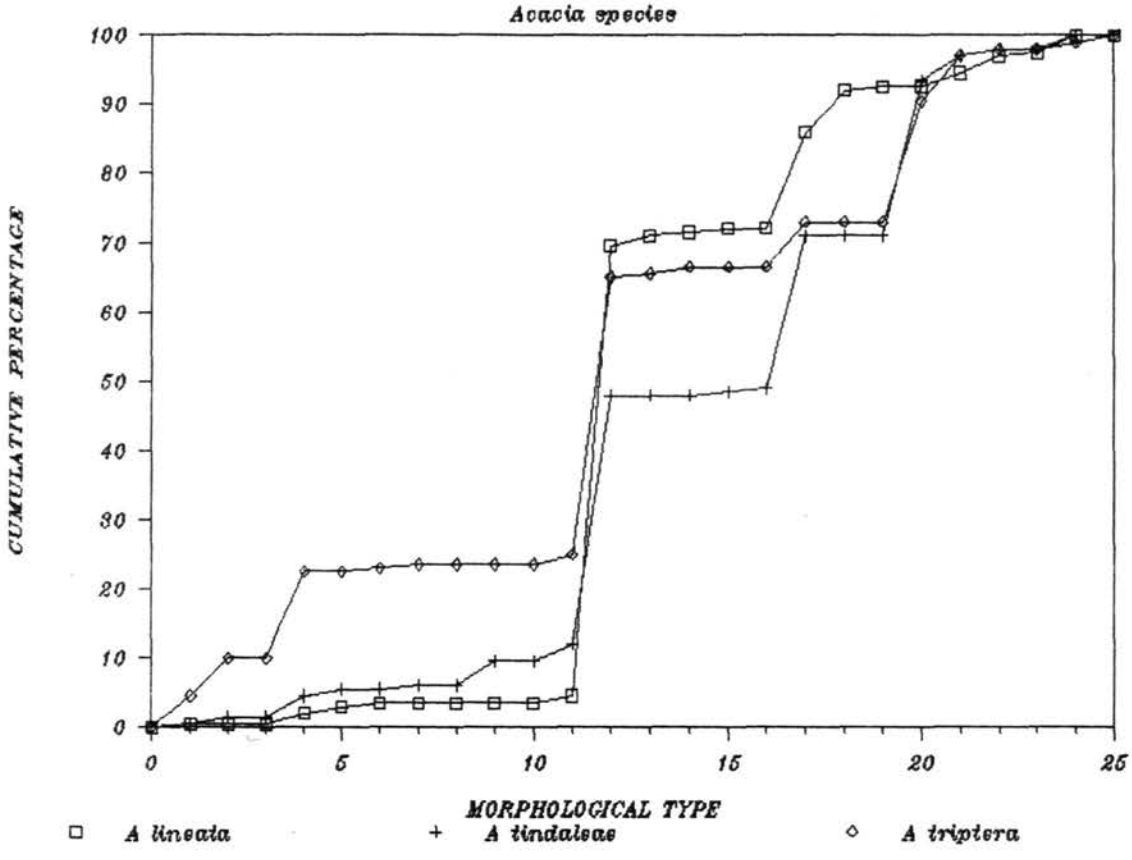


Table 5.8: MORPHOLOGICAL TYPE AND NUMBER USED IN ACACIA ASSEMBLAGE DIAGRAM

Morphological Type		Morph #	Morphological Type		Morph #
RODS: THICK	smooth	1	SHEETS: 3D, REGULAR	smooth	14
	spiked	2		rough	15
	jigsawed	3		honeycomb	16
	ridged	4	SHEETS: 3D, IRREG	smooth	17
	rough	5		rough	18
RODS: THIN	smooth	6		honeycomb	19
	spiked	7		ridged	20
	jigsawed	8	HAIRS & PRICKLES	long	21
	ridged	9		short	22
	rough	10		gourd	23
SHEETS: 2D	honeycomb	11	SPHERES	all	24
	plain	12	UNCLASS		25
	bulbous	13			

The K-S test (Table 5.9, derived from Table G13) shows these three species are different in their plant opal assemblages, and Table 5.10 shows the dominant *Acacia* sp. present at each site (including 2 and 6) and its percentage cover (Appendix C).

One of the most startling differences between the three *Acacia* species is the incidence of ridged and rough ornamentation, particularly on thick rods and three-dimensional plates. *Acacia lineata* has only a few ridged rods, but on the whole the ornamentation is fairly smooth (Plate 25A). *A. tindaleae* contains some rods and many three-dimensional plates which are highly ornamented with ridges (Plate 25B), while *A. triptera* contains both rods and three-dimensional plates which are highly ridged (Plate 26).

Table 5.11 (derived from Table G10) shows the data for this ornamentation in the litter and soil pinch samples from each site. Site 8 (mallee), where *A. lineata* is found, contains very few ridged or rough plant opal in its assemblages. Site 7 (upper broom plain), where the *A. triptera* is found, contains the ornamented plant opal mainly in the soil, where around 10% of the opal has ridged or rough surfaces. The remaining sites have *A. tindaleae* as the dominant acacia, and their assemblages contain varying amounts of ornamented plant opal.

While one species alone is probably not responsible for the differences or similarities between sites, this examination of the *Acacia* spp. plant opal does demonstrate the possibility that, even in like communities, the shift in a species from one member to another might be responsible for a large shift in the plant opal assemblages if that species is high in opal content.

(iii) A comparison of litter and soil assemblages

For each site, the plant opal assemblage from the litter and the underlying soil has been graphed (Figure 5.8). In all cases the curves

Table 5.9: KOLMOGOROV-SMINOV TWO TAIL TEST RESULTS: ACACIA SPECIES

Acacia Comparisons	D	Critical value a=0.05
lineata & tindaleae	0.29	0.14*
lineata & triptera	0.25	0.14*
tindaleae & triptera	0.16	0.14*

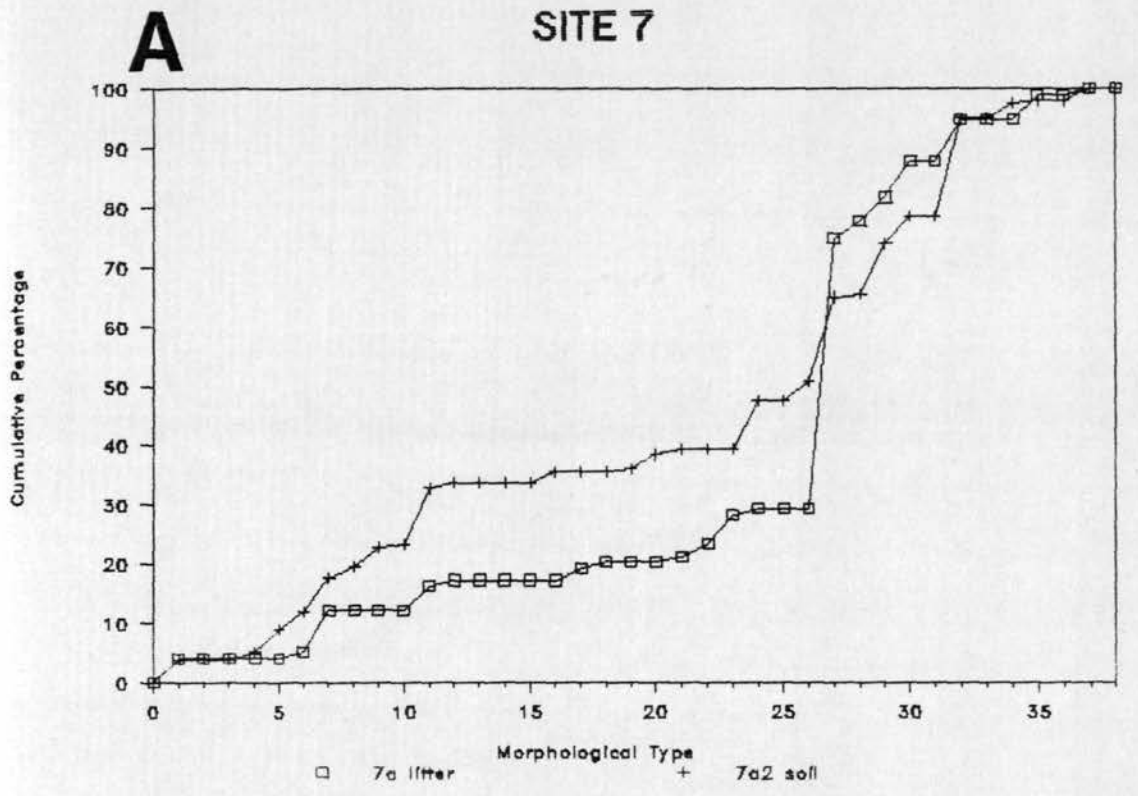
* not drawn from same population

Table 5.10: DOMINANT ACACIA SPECIES PRESENT AT EACH SITE

Site #	Vegetation type	Acacia Species	% cover
2	Broom plain	A. tindaleae	<5%
6	Broom plain	A. tindaleae	<5%
7	Broom plain	A. triptera	5%
9	Broom plain	A. tindaleae	5%
8	Mallee	A. lineata	<5%
12	Forest	A. tindaleae	<5%

Table 5.11: RIDGED PLANT OPAL IN ASSEMBLAGES

Morphology	Litter %				Soil %						
	7	8	9	12	7a2	7b2	8	9	12	2/1	6/1
ridged thick rods	0.0	0.0	1.0	7.2	0.5	0.8	0.5	1.0	0.5	1.2	2.3
rough 3D sheets											
regular	1.0	0.0	3.8	4.8	8.1	12.2	0.5	1.0	0.5	7.5	8.4
nonregular	2.1	0.0	0.7	0.0	9.1	6.8	0.0	5.1	0.0	6.4	2.1



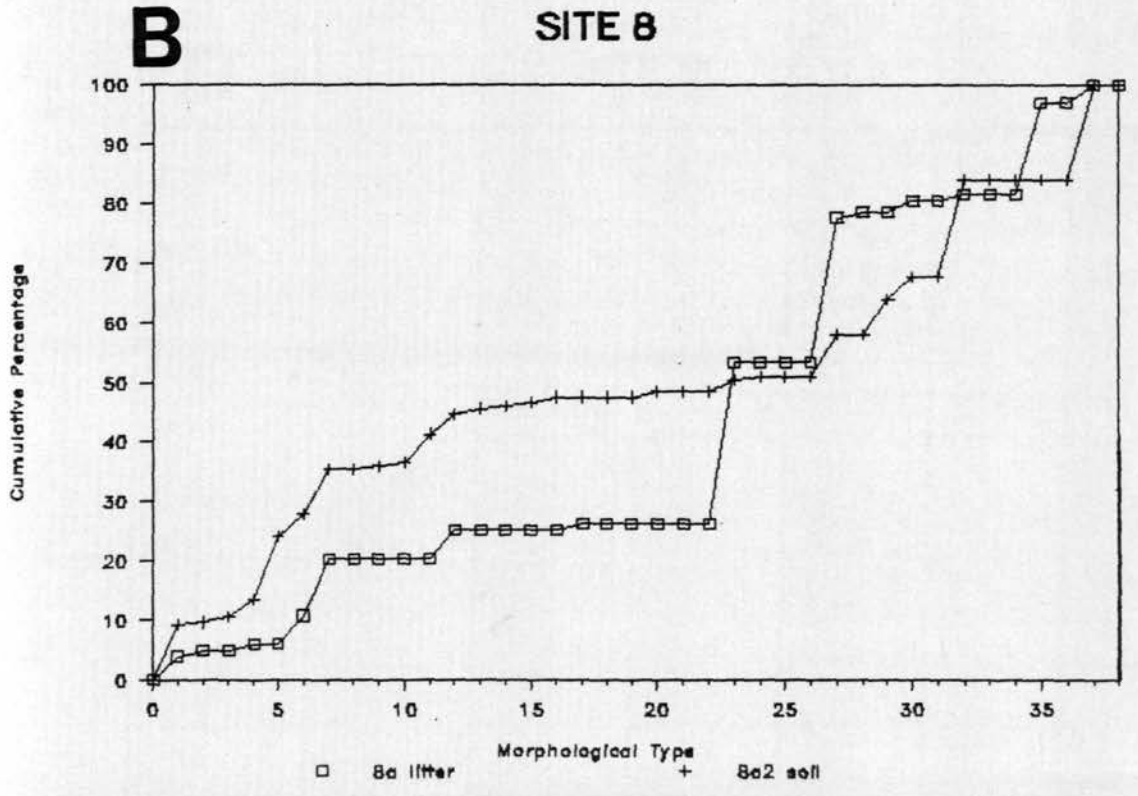
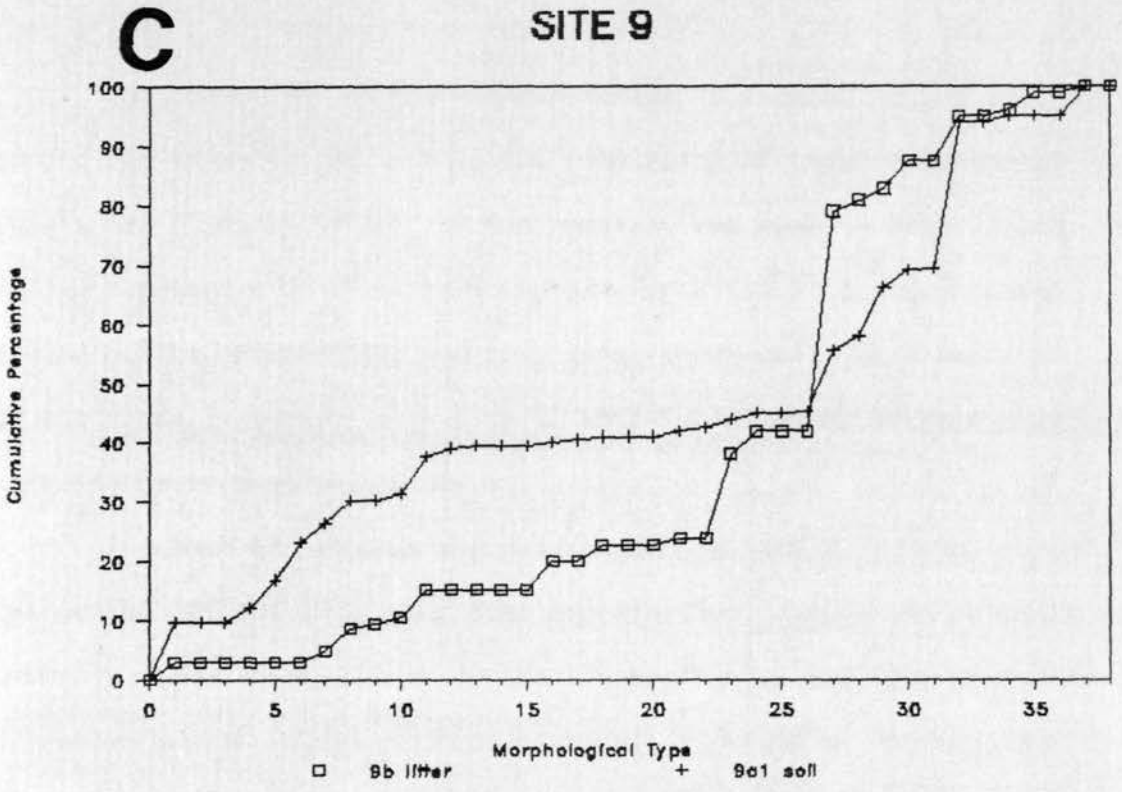


FIGURE 5.8: PLANT OPAL ASSEMBLAGES, PILLIGA LITTER AND SOIL



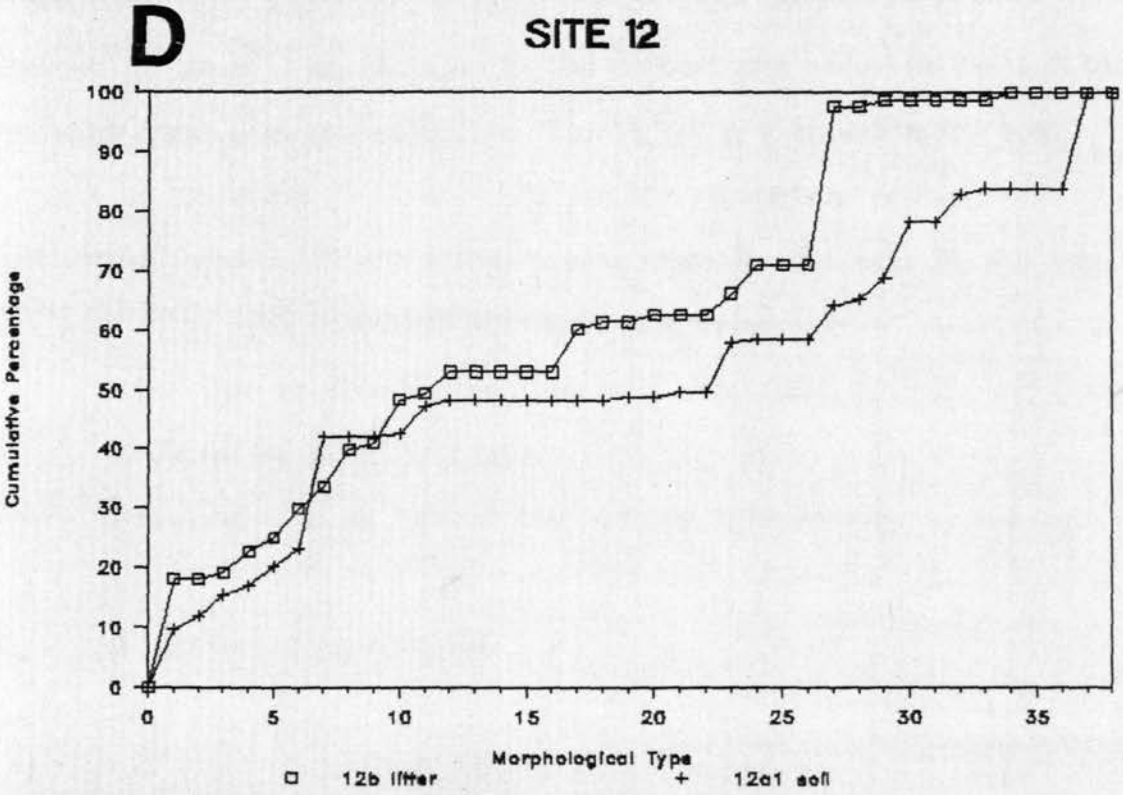


FIGURE 5.8: PLANT OPAL ASSEMBLAGES, PILLIGA LITTER AND SOIL, CONT'D

bear little resemblance to each other, and this is confirmed by the K-S test (Table 5.12, derived from Table G14).

The proportion of hairs and prickles is reduced in the soil by around 50% in each site. While the proportion of three-dimensional sheets has risen in Site 7, it has remained the same in Site 12 and fallen substantially in Sites 8 and 9. For Sites 7, 8 and 9 those silica bodies believed derived from grass short-cells have been concentrated in the soil; in Site 12 this is reversed, and the soil contains fewer than the litter.

If these differences are real and not affected by sampling and extraction difficulties, they need explaination. Hairs and prickles are probably mechanically broken in the litter layer. The fact that this breakdown appears to be uniform across all sites is an encouraging factor, since it suggests the remaining differences may be real.

The litter assemblages each contained a large percentage of two-dimensional sheets the percentage of which have been considerably reduced in the soil assemblages in the proportions shown in Table 5.13. Assuming these are representative figures for the assemblages, the process or processes which are reducing the percentage of two-dimensional sheets are not acting evenly, and may not even be the same for each site. The processes acting on the sheets may:

1. break them up and reduced them to a size range outside the limits of detection (i.e. to clay),
2. dissolved them as soon as they become incorporated in the soil, or
3. selectively removed them.

Table 5.12: Kolmogorov-Smirnov two tail test results: Litter cf soil

Site Comparisons	D	Critical Value a=0.05
7a2 soil & 7 litter	0.31	0.17
7b2 soil & 7 litter	0.32	0.16
8	0.25	0.16
9	0.27	0.16
12	0.21	0.18

Table 5.13: TOTAL (REGULAR + NON-REGULAR) TWO DIMENSIONAL SHEETS AS A PERCENTAGE OF THE WHOLE COUNT: (LITTER CF SOIL)

Site	% in Litter	% in Soil	Litter:Soil P
7	40.2	7a2: 8.0	5.0:1
		7b2: 11.5	3.5:1
8	52.9	6.2	8.5:1
9	59.2	10.8	5.5:1
12	64.0	6.8	9.4:1

Processes acting on the plant opal sheets

(a) Reduction in size

If the sheets are reduced in size between the litter and the soil, the soil will contain a size range of sheets which is distinctly different from that contained in the litter. While the breaking up of smaller plates will cause them to become too small to detect, the large plates will become smaller and be recognized as a bulge lower down in the size distribution.

The distribution of the surface area of two-dimensional sheets in the Site 8 (mallee) litter and soil was recorded (Table 5.14). Chapter 7 discusses the methods used for these measurements. There were very large multi-celled sheets in the litter. All of the sheets in the soil were under $5x10^3$ um^2 in surface area compared with 83% in the litter. The distribution of these sheets is graphed in Figure 5.9. Although the methods used to extract the opal from its surrounding tissue in the litter may break up the sheets more than the methods used to separate them from the soil, this difference remained and is considered a real one.

The results seem to show breaking up of the opal is a definite process occurring between the time it is deposited in the litter and the time it is incorporated in the soil. This needs testing in thicker litters than are found in the Forests, where progressive measurements can be made down the layer. However, the differences in the proportions between the sites seem to point to other processes going on as well; if breakup alone were resposible, it could be expected that the proportions of two-dimensional sheets in the soils compared with their litters would be similar between sites and this is not the case (cf. Tables 5.3 and 5.7).

Table 5.14: SURFACE AREA OF SHEETS, SITE 8 MALLEE
Litter (n=125) and Soil 0-50mm (n=50)

SA* range sq umx1000	Number in Litter (sample # MU 50585)	% in Litter	Number in Soil (sample # MU 50602)	% in Soil
0 - 4.999	104	83.2	50	100
5 - 9.999	7	5.6	0	0
10 - 14.999	2	1.6	0	0
15 - 19.999	2	1.6	0	0
20 - 24.999	4	3.2	0	0
25 - 29.999	3	2.4	0	0
30 - 34.999	2	1.6	0	0
35 - 39.999	0	0	0	0
40 +	1	0.8	0	0

Mean SA sheets in Litter	3,819.3 sq um
SD** sheets in Litter	8,592.8 sq um
Mean SA sheets in Soil 0-5cm	323.4 sq um
SD sheets in Soil 0-5cm	574.4 sq um

* SA = Surface Area
** SD = Standard Deviation

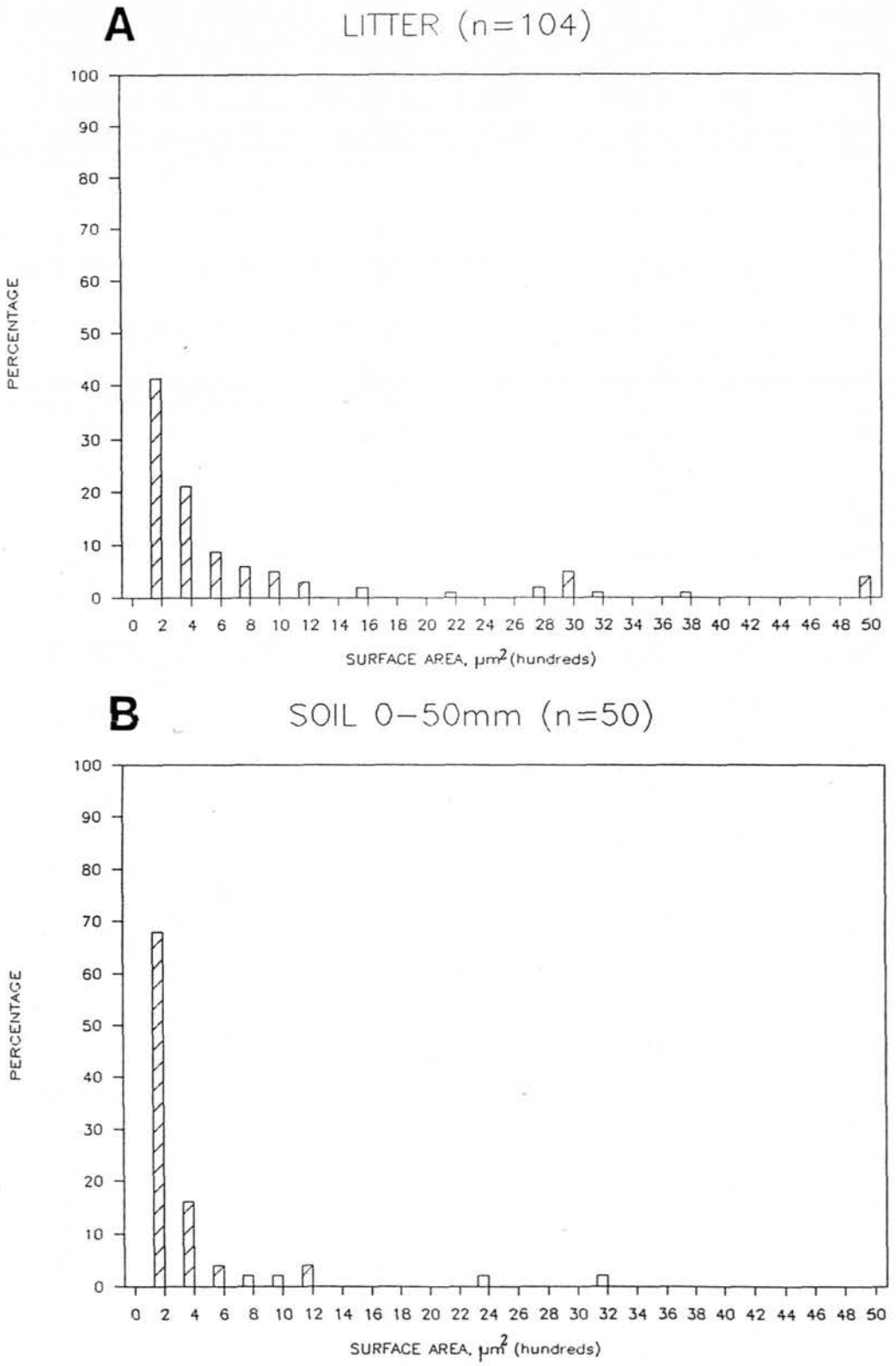


Figure 5.9: THE DISTRIBUTION OF SHEET SURFACE AREA UNDER 5,000 µm², SITE 8 MALLEE

(b) Dissolution

While the dissolution of small, clay-sized particles of opal may occur in the litter layer as well as in the soil, this particle-size is not under consideration here and the time taken for the litter to enter the soil (litter half lives of 2 to 5 years; see Chapter 8) is probably too short for the silt-sized material to be appreciably affected.

This question of dissolution was addressed by Piperno in her discussion of the modern sampling of soils for the Gatun Lake area in Panama (1987:163). In her sampling, Piperno found, despite large amounts of hair cells and bases being produced by the vegetation, these were not found at all in the modern sediments under this vegetation. This she attributed to the harsh tropical forest soil environment adversely affecting the solubility of these more fragile phytoliths through high soil temperatures, heavy rainfall, excessive leaching and high soil content of tanins derived from the breakdown of vegetation, which dissolve the silica.

In the Pilliga soils, while seasonally high soil temperatures might occasionally occur, these factors which may lead to accelerated solubility are not found. Perched water tables in Sites 7, 8 and 9 may occur seasonally; however, the topsoils in these sites are predominantly acid. Hairs and hair bases are found throughout the sediments in reasonable numbers, although, as has already been observed, at about 50% of the rate found in the litter.

(c) Removal

The bulk removal of litter would not affect the proportion of two-dimensional sheets entering the soil. All morphologies and sizes would be affected equally. While litter has been shown elsewhere to move on slopes (van Zon, 1980) the expectation would be that litter would move onto the site similarly and balancing outgoings.

The selective removal of one type of vegetation by fauna needs consideration, but here again many fauna would return the plant opal to the soil surface by way of faecal pellets, thus it could be expected again that the removals would be balanced by deposits over time. There are fauna, however, which both selectively remove some vegetation types and place it in storage away from the main cycling of nutrients. These are the ants and termites which are very active throughout the area, particularly in the mallee and the forest. Their storage of material both as food stores and as a building material is known to isolate material for over 50 years in some areas (Lee and Wood, 1971); but in the long term much of this material is returned to soil. However, the underground workings of some soil fauna including termites and ants are extensive, thus this removal process needs consideration. In addition, it has been shown that the plant opal assemblages of the topsoil and subsoil of the mallee soils are different from that of faunal channels, thus this sorting of plant opal by fauna is a process within the soil which needs further study.

The removal of plant opal is also possible during forest fires. This is a process which would remove most if not all of the litter lying on the soil surface, and also needs consideration in the Australian environment.

Conclusions

This study examined the plant opal assemblages under three different vegetation types in the one environment, both in the litter and in the soil. In only one of these, the broom plains, were multiple sites examined.

Pinch samples of the topsoil were not sufficiently similar, in the case of the broom plains, or different, in the case of the mallee, forest and broom plains, to be used to distinguish between vegetation

communities. On the other hand, the litter assemblages may more closely reflect the differences between the vegetation. The reasons for this as well as the differences between litter and soil assemblages in the same community, are probably very complex.

The hypothesis that like vegetation produces like plant opal assemblages, hinges on the degree of "likeness". In the study of the broom plains, it was found that this community, although similar in vegetation habit and dominant species (*Melaleuca* spp.) contained differences which, while not changing the character of the community, might lead to a shift in the plant opal assemblages if the changes occur in plants which are silica accumulators. In addition, comparison of the soil and litter layer assemblages indicates that there are processes at work in the upper soil and litter layer which have a great influence on the soil assemblage.

These processes are part of and affect the cycling of silica between vegetation, litter layer and soil. This chapter examined the processes where soil fauna might influence plant opal assemblages by moving parts of a particular species (grass leaves, wood) or whole species out of the general soil circulation and into storage or into faunal channels. Such processes are probably very important in the Australian environment.

Any event which affects vegetation can be expected to affect the plant opal assemblages in both litter and soil. In the Australian environment fire is a regular event which changes vegetation and may therefore affect the plant opal cycle. In the Pilliga field sites it was suspected that fire had an important influence on plant opal cycling, but the period elapsing since fire was 19 to 40 years, thus any effects could be expected to be difficult to detect. A recent fire was needed; and this is discussed in Chapter 6.