DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

REPT.BK.NO. 87/63

REPORT ON TENTH CLAY MINERALS SOCIETY CONFERENCE, SYDNEY 8-10 DECEMBER 1986 AND TEXT OF PAPER, SOUTH AUSTRALIAN PALYGORSKITE - POTENTIAL AND PROBLEMS.

GEOLOGICAL SURVEY

by

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and

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MINERAL RESOURCES

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DME.145/82

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DEPARTMENT OF MINES AND ENERGY
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SOUTH AUSTRALIAN PALYGORSKITE - POTENTIAL AND PROBLEMS

ABSTRACT

Palygorskite (attapulgite) is widely developed in Miocene sediments of inland South Australia, and is recorded from -

- Namba Formation of the Tarkarooloo Basin.
- Garford Formation infilling the Garford Palaeochannel, a Tertiary palaeodrainage system of northwestern South Australia.
- Etadunna Formation of the Lake Eyre Basin.
- Billakalina Clay Member of the Mirikata Formation, and associated palaeodrainage channels on the northern margin of the Gawler Craton.

Reconnaissance sampling of the Namba and Garford Formations suggests that these units have commercial potential.

Palygorskite, always intimately associated with dolomite, was deposited in shallow, alkaline playa lakes and ponded drainage channels with a warm to sub-tropical climate, moderate to high rainfall and seasonally arid conditions. Origin is similar to the extensive, commercially important palygorskite-sepiolite deposits of Florida, USA. Palygorskite formed by authigenic alteration of montmorillonite, which is abundant in the underlying Cretaceous sediments, and/or by direct precipitation from solution.

Huge quantities of easily mineable palygorskite are present in the Tarkarooloo Basin and in the Garford Palaeochannel but commercial suitability has yet to be established. Six palygorskite samples from four Tarkarooloo Basin localities gave water absorbency values ranging from 30 to 65 percent, too low for an industrial absorbent. Water absorbency was directly related to palygorskite content. The same samples recorded exceptionally high surface

area measurements and would be suitable for use as industrial catalysts.

Twelve samples from four lakes within the Garford Palaeochannel gave water absorbencies ranging from 37 to 100 percent, and this area has considerable potential to supply industrial absorbents. Although the presence of palygorskite is necessary for good water absorbency, the actual values appear to be related to dolomite content. The most absorbent samples contain about equal amounts of palygorksite and dolomite. The effect of dolomite content on water absorbency has yet to be determined.

Further exploration and testing of palygorskite deposits in the Tarkarooloo Basing and Garford Palaeochannel is warranted, as is reconnaissance sampling of other palygorskite-bearing sediments in South Australia.

INTRODUCTION

The Australian Clay Minerals Society is an informal grouping of mineralogists, geologists, chemists, physicists, geomorphologists and soil scientists interested in clay minerals, the last group being predominant. The only organised function of the society is a biennial conference.

The 10th Biennial Conference was held in Sydney at the Department of Applied Geology, University of New South Wales from 8 to 12 December, 1986.

The conference comprised two days of formal paper presentation separated by a one day Field Conference to the western Sydney Region, and followed by a two day field excursion to the Hunter Valley.

The text of the paper presented to the conference, together with the accompanying slides in the form of plates and figures, is included, together with a selected bibliography for South Australian palygorskite deposits.

78 delegates, see Appendix A, registered for the first three days of the conference and about 30 people attended the two day post-conference field excursion.

The program and abstracts for papers and posters presented at the conference are included in Appendix B.

Field Notes for the one day Field Conference and the two day Post-Conference Excursion make up Appendices C and D respectively.

The main item for discussion at the Business Meeting held on 8 December 1986 concerned the possibility of Australia hosting the 1993 International Clay Mineral Society Conference.

A questionnaire seeking people willing to assist in the organisation of such a conference has subsequently been circulated. As an international conference would probably be held in Sydney the organising committee should be based in that city, perhaps with some involvement from Canberra based members. However, Departmental assistance has been offered to organisation of any field excursions proposed to include South Australia.

The Conference was extremely well run and successful, mainly due to the Organising Committee and the sponsors, the Department of Applied Geology, University of N.S.W. and Commercial Minerals Limited. A pleasing feature was the attendance of a larger than usual number of industrial minerals geologists from both industry and government, the Bureau of Mineral Resources being a notable exception. This interest in economic utilisation of clay minerals and zeolites was particularly noticeable on the two day Post-Conference excursion.

Most people attending this excursion expressed a desire to meet regularly to discuss a broad range of industrial and extractive minerals and formation of an Australian Industrial Minerals Society along the lines of the Clay Mineral Society has been proposed.

A questionnaire will be circulated to industry, government organisations and universities in an attempt to determine the level of support for such a group, and the most satisfactory method of establishment.

The 11th Biennial Conference of the Clay Minerals Society will be held in Brisbane in 1988, on a date to be fixed, probably November, and at least one delegate from this Department should attend.

TEXT OF TALK

Palygorskite, also known as attapulgite, is one of the so called active clays. The mineral's most familiar role is keeping the family cats' bottom dry. Apart from being the main constituent of many pet-litters, palygorskite is also widely used as an industrial absorbent, as a catalyst and in oil drilling. For many years all palygorskite was imported from the U.S.A. but a few years ago a deposit was opened up at Lake Nerramyne near Geraldton in W.A. to supply Australia's requirements. However, with the high cost of transport in Australia several companies are seeking commercially viable absorbent clay deposits closer to the main Australian markets.

SLIDE 1 - State map (Reproduced here as Figure 1).

In South Australia, palygorskite is recorded from a number of inland Tertiary lacustrine basins and palaeodrainage channels including - from the east -

- the Tarkarooloo Basin east of the Flinders Ranges
- the elongate Pirie-Torrens Basin on the western side of the ranges
- the large Lake Eyre Basin in the far north
- the very small Millers Creek basin north of Woomera; and
- palaeodrainage channels in the northwest and west of the State, including the Garford Palaeochannel.

This presentation will concentrate on the Tarkarooloo Basin and the Garford Palaeochannel because these areas are the best known geologically and because they are the only basins where any sampling for commercial palygorskite has been carried out.

SLIDE 2 - Lake Millyera (Reproduced here as Plate 1).

In the Tarkarooloo Basin, lacustrine Namba Formation of Miocene age generally crops out around salinas such as this one near Lake Frome - the Flinders Ranges are in the background. Namba Formation comprises clay, fine sand and carbonate and is generally less than 25 m thick but is developed over an area of about 30 000 km^2.

SLIDE 3 - Cliff Section, Lake Millyera (Reproduced here as Plate 2).

In the lower part of the sequence smectite clay predominates, passing up into an alternating sequence of palygorskite and dolomite. Palygorskite is always closely associated with dolomite. Massive dolomite often caps low scarps around the edges of the lakes.

SLIDE 4 - Palygorskite clay bed (Reproduced here as Plate 3).

Although widely distributed, brownish-green palygorskite-rich beds such as this one are only 2 to 3 m thick at most and the lateral continuity of individual beds has not been determined.

Within individual beds, main impurities are very fine-grained quartz, and minor smectite and illite. The contact between palygorskite beds and overlying dolomitic silt and massive dolomite is generally sharp as in this case;

SLIDE 5 - Palygorskite with dolomite (Reproduced here as Plate 4).

although carbonate mottles and nodules such as this one do occur within palygorskite.

SLIDE 6 - State map (Fig. 1).

Southwest of Coober Pedy is the Garford Palaeochannel, a Tertiary drainage feature about 150 km long but only a few kilometres wide that drained the southwestern margin of the Great Artesian Basin. Garford Palaeochannel was active in the Early and Middle Tertiary but with increasing aridity during the Late Tertiary the channel dried up and became choked with sand.

SLIDE 7 - Jubilee Lake (Reproduced here as Plate 5).

Recent erosion has produced a string of salinas along the old drainage feature and Tertiary sediments are now exposed only in these lakes and in low marginal cliffs as seen here.

Tertiary sedimentation within the palaeochannel commenced with lignitic sand and clay of Eocene age.

SLIDE 8 - Cliff section, PB Lake (Reproduced here as Plate 6).

These sediments are everywhere overlain by a sequence of green and grey smectite clay and fine sand passing up into white palygorskitic dolomite with interbeds of green palygorskite. The dolomite-palygorskite sequence is called Garford Formation presumed, by analogy with palygorskite sequences elsewhere, to be of Miocene age.

In this section white Garford Formation is overlain by gypsified Pleistocene sand.

SLIDE 9 - State map (Fig. 1).

In both the Tarkarooloo Basin and the Garford Palaeochannel, palygorskite was deposited, with dolomite, in shallow alkaline lakes under conditions of high rainfall with seasonal aridity. In both areas, palygorskite is believed to have formed by -

- diagenic alteration of pre-existing smectite; and
- direct precipitation, with dolomite, from solution.

Most-smectite is believed to have been derived by erosion of surrounding smectite-rich Cretaceous rocks, here coloured green, and subsequent redeposition in the Tertiary lake. In the Tarkarooloo Basin, there is some evidence for neo-formation of smectite from illite and kaolinite within the magnesium-rich lake.

SLIDE 10 - Scanning Electron Microscope (SEM) Photograph (Reproduced here as Plate 7).

The intimate association of palygorskite and dolomite suggests direct precipitation of both minerals from magnesium saturated waters under evaporitic conditions. This SEM photo of dolomite from the Garford Palaeochannel provides striking evidence for direct precipitation of palygorskite as acicular overgrowths on spheres of poorly crystalline dolomite.

Palygorskite content of this sample is about 15%. Slide width is 4 microns.

Turning now to the commercial potential of these palygorskite deposits; it is apparent that huge reserves are available but remoteness of the deposits will limit development, if any, to only a few areas.

There are some other problems regarding clay quality.

SLIDE 11 - Hand augering (Reproduced here as Plate 8).

There has been only limited testing of a few samples from scattered locations in the Tarkarooloo Basin and the Garford Palaeochannel. In all cases, samples were taken either from outcrop, or from shallow hand auger holes and most contain 2-8% salt derived from the surface salt crust of the modern day salinas.

Either low salt clay will have to be found or salt will have to be removed if there is to be commercial development of these deposits.

SLIDE 12 - Chemical analyses (Reproduced here as Fig. 2).

The very high Na_2O content of the three South Australian clays on the right hand side of this table reflects the high salt content. Deposits sampled are of two types -

- green palygorskite clay rock with varying amounts of very fine quartz sand impurity; and
- white palygorskitic dolomite.

All Tarkarooloo Basin samples, and a few samples from the Garford Palaeochannel are of the green clay type - palygorskite content ranges up to 80%.

Most Garford Palaeochannel samples are of the white dolomitic type - palygorskite content varying from 15 to 40%.

Generally, green clay has properties typical of palygorskite, several of the purer samples have very strong interaction with water and easily meet American Petroleum Institute (API) requirements for drilling mud. These green clays also satisfy surface area and activation specifications for commercial palygorskite and would be suitable for many industrial uses including catalysts. Although not tested, it is unlikely that the dolomitic samples would satisfy these specifications.

SLIDE 13 - Absorbency, Tarkarooloo Basin Samples (Reproduced here as Figure 3).

When it comes to the all important water and oil absorbency tests there are some rather strange results.

The green palygorskitic clay, that is all samples from Tarkarooloo Basin and one from Garford Palaeochannel have unacceptably low water absorbency compared to commercially marketed palygorskite, with absorbency being directly related to palygorskite content.

To give wet strength, that is coherence when immersed in water, green clays had to be calcined at about 650°C compared with 150-400°C normally used for palygorskite. This high temperature obviously resulted in partial collapse of the characteristic 'bundle of straws' structure with resultant loss of absorbency. Calcining also resulted in oxidation of iron producing an unacceptable red colour in calcined clay,

SLIDE 14 - Absorbency, Tarkarooloo Basin and Garford Palaeochannel samples (Reproduced here as Figure 4).

By contrast, dolomitic samples show moderate to high absorbencies, samples with highest absorbency containing only 15-35% palygorskite. Unfortunately these samples were also calcined at about 650°C prior to testing and a proportion of the absorbency is due to slaking of dololime produced by calcination.

SLIDE 15 - Calcined samples (Reproduced here as Plate 9).

The red sample on the right is calcined green clay with 40% water absorbency compared with a commercially available product in the centre and calcined palygorskitic dolomite, with 100% water absorbency on the left. Although of acceptable colour, the dolomitic material is probably not suitable for use as pet littler - poor pussy may get a bit warm around the nether regions if she squatted on calcined dolomite. This material could be used if the heat given off by slaking was not a problem.

SLIDE 16 - Absorbency, Tarkarooloo Basin and Garford Palaeochannel samples, (Fig. 4).

Hence we have to find either a deposit with both palygorskitic dolomite and green clay and produce two products - or preferably find palygorskite that has high wet strength when calcined at low to moderate temperatures. A lower calcination temperature is required both to minimise collapse of the palygorskite structure, and to reduce energy costs.

It is significant that the W.A. material contains about 10% dolomite and it would appear that this dolomite imparts wet strength to the clay at the calcination temperature of about 300°C. The ideal clay, 80-90% palygorskite and 5-10% dolomite, would have high absorbency, and be suitable for drilling muds and industrial catalysts.

Unfortunately this ideal composition has not yet been recorded, samples tested to date contain either minimal if any dolomite, or conversely dolomite is the dominant mineral.

However given the huge area involved, it is highly probable that material similar in composition to the Western Australian clay is present in the Garford Palaeochannel and, recent BMR drilling in the Lake Eyre Basin has shown thick sequences of palygorskite, some containing accessory amounts of dolomite.

The possibility of blending dolomite and palygorskite to produce a commercial product also needs to be investigated. To date, SADME has tested only about 20 samples, hardly representative of a total basin area of over 30 000 km^2.

Further study is needed into the relationship between properties and composition of these aborbent clays.

Obviously many samples of various composition need to be tested through a range of calcining temperatures to determine optimum composition and temperature.

SADME is unable to carry out this study at present and to date private companies who have expressed interest in these deposits have carried out only limited testing and walked away a little disappointed. Any person(s) interested in carrying out a complete study of these palygorskite clays, and extending this study to other known palygorskite occurrences would be assured of assistance in the form of supply of samples, and of course the cats of Australia would be eternally grateful.

SLIDE 17 - Commercial cat litter (Reproduced here as Plate 10).

L Barnes

R. S. Robertson

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APPENDIX A

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APPENDIX B

PROGRAM AND ABSTRACTS FOR PAPERS AND POSTERS

PROGRAM

MONDAY 8TH DECEMBER

9:00 Welcome and opening

SESSION 1: WEATHERING

Chairperson
F.C. Loughnan

9:15 The Roles of Iron and Aluminium in Weathering
(R.A. Eggleton)

9:35 Weathering and Soil Formation of the Tibooburra Granite
(J. Pender, A.J. Koppi)

9:55 Electron Microscopical Aspects of Hornblende Alteration during Hydrothermal Activity and Weathering
(Q. Wang, R.A. Eggleton)

10:15 Discussion

10:35 Morning Tea

SESSION 2: PEDOGENIC PROCESSES

B. Davey

11:00 Influence of Heat from Bush Fires on Mineralogical Transformations in some Australian Soils
(R.W. Fitzpatrick, R.J. Coventry)

11:20 A Mechanism for the Formation of Soluble Fe^{3+}-Al and Si-Al Hydroxy Complexes Mobilised in Soils (R.M. Taylor)

11:40 Differential Clay Movement on Hillslopes - a New Hypothesis for the Formation of Soils with Texture Contract
(D.J. Chittleborough)

12:00 Discussion

12:20 Lunch

SESSION 3: ZEOLITES

E. Slansky

2:00 Natural Zeolites: Properties, Occurrence and Use - a Review
(S. Pecover)

2:20 Use of Natural Zeolites in Agriculture and Aquiculture
(P. Fredrickson)

2:40 Zeolite Bearing Rocks of the Tamworth Belt: Commercial Prospectivity
(S. Pecover)

3:00 Discussion

3:20 Afternoon Tea

SESSION 4: TECHNIQUES F.I. Roberts

3:45 Measurement of Soil Moisture at Sand/Clay Interfaces
(D.J. Wilson)

4:05 Thermal Transformation of Clays as Revealed by 27Al, 29Si and 31P High Resolution Solid State Nuclear Magnetic Resonance Spectroscopy)
(M.A. Wilson, J. Stephens, S.A. McCarthy)

4:25 Clay Mineralogical Changes Resulting from Treatment with Various Salts of Moisture Sensitive Rocks by Cationic Treatments
(A. Shayan, C.J. Lancucki)

4:45 Discussion

5:00 Business Meeting

TUESDAY 9TH DECEMBER

FIELD EXCURSION

WESNESDAY 10TH DECEMBER

SESSION 5: PROPERTIES AND FORMATION OF CLAY AND ASSOCIATED MINERALS C. Ward

9:00 New Data and a Revised Structural Model for Ferrihydrite
(R.A. Eggleton, R.W. Fitzpatrick)

9:20 Interaction of Silicate and Phosphate with Iron Oxides
(D.J. Lewis)

9:40 Clay (Soil) Phosphates in the Alluvium of Shoalhaven River
(E. Slansky)

10:00 Clay Minerals in Southeast Queensland
(W. Cooper)

10:20 Discussion

10:40 Morning Tea

SESSION 6: PROPERTIES AND FORMATION OF CLAY AND ASSOCIATED MINERALS (cont). F.I. Roberts

11:00 Mayfield Revisited; the Geology of a Deep Weathering Profile at the Mayfield Kaolinite Quarry, N.S.W.
(J.M. Fetherston)

11:20 Kaolinite $(CH_3)_2$ XO Intercalates: X=S, SE
(J.G. Thompson, M. Raupach)

11:40 South Australian Palygorskite: Potential and Problems
(L.C. Barnes, R.S. Robertson)

12:00 The Microstructure of Clays in Clay Shales
(R. Seedsman)

12:20 Discussion

12:40 Lunch

SESSION 7: APPLIED CLAY MINERALOGY D. Nichol

2:00 Clay Mineral Reactions in Oil Shale Processing
(J.H. Patterson)

2:20 Pillared Clay Catalysts
(P.J. Collin)

2:40 Properties of Watheroo (W.A.) Bentonites
(R.J. McLaughlin)

3:00 Discussion

3:20 Afternoon Tea

SESSION 8: APPLIED CLAY MINERALOGY (cont.) E. Slansky

3:40 Synthetic Cobalt Clays as Fischer Tropsch Catalysts
(T.W. Turney)

4:00 The Benficiation of Kaolin Clay using a Superconducting High Gradient Magnetic Separation (HGMS) Facility
(M.S. Rahman, A.J. Richards, L.M. Besley)

4:20 The Benficiation Potential of N.S.W. Kaolins
(J.L. Anderson, J.R.S. Kmetoni)

4:40 Discussion

AUTHOR INDEX

PAPERS

THE ROLES OF IRON AND ALUMINIUM IN WEATHERING

Richard A. Eggleton

Geology Department, Australian National University

A knowledge of the crystal chemical characteristics of iron and aluminium is essential to the understanding of weathering processes. Both elements may be surrounded by tetrahedral and octahedral ligands of O or (OH), and iron may undergo oxidation and reduction. In igneous rocks, Al is largely in tetrahedral coordination, in clays it is octahedral. This change in coordination requires wholesale rearrangement of cation-oxygen linkages, which prevents the secondary mineral from inheriting complete structural units from the primary mineral. Iron in igneous rocks is largely ferrous, becoming oxidised during weathering. Clay minerals may inherit iron octahedra provided Mg loss can compensate for the charge increase caused by iron oxidation.

Iron appears to be stabilized in non-crystalline alumino-silicate gel, where some may be in tetrahedral coordination. A change from reducing to oxidizing conditions releases H^+ by ferrolysis, and this may allow Fe to act as a weathering catalyst through repeated oxidation and reduction. The actual pathway is probably complex, but the result is:

$$4Fe^{2+} + 10H_2O + O_2 - 4Fe(OH)_3 + 8H^+$$

or

$$4Fe^{2+} + 6H_2O + O_2 + 4FeO(OH) + 8H^+$$

Iron may comprise up to 50% of the cations in the non-crystalline product of feldspar weathering, but only 10% of the clay mineral end product. These aspects of Fe and Al crystal chemistry will be discussed in relation to the weathering of the major rock forming minerals.

WEATHERING AND SOIL FORMATION ON TIBOOBURRA GRANITE

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The Tibooburra profile is situated on granite parent material, surrounded by granite outcrops in the far north-west of New South Wales. The profile consists of a shallow, gritty, calcareous topsoil overlying a band of carbonate-rich material which rests on a disintegrated granite (saprolite) layer. The saprolite contains a layer of precipitated calcite - having permeated in solution from the upper horizon. Carbonate in the profile has arisen from aeolian deposits of calcareous dust, thought to have originated from South Australian coastal regions. Other evidence of aeolian activity includes small, subrounded wustenquartz grains.

Granite parent material, in order of abundance, contains plagioclaise feldspars, quartz, potassium feldspars, biotite and hornblende with a small amount of chlorite and accessory minerals such as zircon, apatite and epidote. By microprobe analysis, light microscope and SEM work and XRD analysis, weathering patterns and products of the dominant minerals have been determined.

In the lower sprolite layer plagioclase feldspars have become highly pitted and etched, with sericite and Na-rich material within the feldspar remaining relatively unweathered. K-feldspars show a lesser degree of weathering in that etching of the cleavage is more pronounced but pitting is absent.

Biotite has lost K and Fe, and optically, is paler in colour and exfoliated to varying degrees. XRD work suggests a mica/smectite interstratification developing. Large, needle-shaped crystals of an iron-rich mineral have formed between layers of the biotite.

Hornblende has shown least resistance to weathering, having altered to a smectitic material in the saprolite.

Chlorite has decreased in proportion from rock to saprolite, but chemical composition of the mineral is little altered.

The presence of fresh hornblende, biotite and feldspars in the upper horizon indicates a recent deposit of colluvium from nearby granite slopes. The freshness and angular form of the material suggest granite outcrop weathering has been mainly physical.

The Quarternary period has had a succession of humid and arid climates leading to alternating soil forming and erosional episodes. Granite material presently exposed was previously under influence of more intense weathering conditions, and probably buried under a deep soil layer. As climate became drier vegetation became sparse and wind erosion led to widespread stripping of soil from the landscape, leaving bare rock outcrops.

The Tibooburra profile is now a product of the mixing of calcarious aeolian material and colluvium deposited on the stripped granite landscape. Redistribution of carbonate and mild chemical weathering of minerals under arid conditions have further developed the profile.

ELECTRON MICROSCOPICAL ASPECTS OF HORNBLENDE ALTERATION DURING HYDROTHERMAL ACTIVITY AND WEATHERING

A. Wang and R.A. Eggleton
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Hornblende in mafic monzonite sampled at Mt. Dromedary, Narooma, N.S.W., has been studied by both SEM and HTEM revealing a variety of secondary products formed through the processes of hydrothermal alteration and weathering.

During the hydrothermal stage (300°C), hornblende has been transformed to chlorite, by a topotactic structural modification of 2 chlorite layers (14A) replacing 3 amphibole 1-beams (9A). This replacement is considered with respect to reaction mechanisms requiring high energy to form a brucite inter-layer by taking off the surrounding tetrahedral double chains and bonding the remaining brucite layer to neighbour tetrahedral double chains by shifting 1/4[100] along X^*. In addition all Ca has been released from amphibole to elsewhere from sphene, calcite etc.

The other distinctive feature of the altered hornblende is the formation of a wide variety of intergrowth microstructures of chain-width disordered pyriboles. In most cases the terminations of those disordered pyriboles are coherent, obeying 2 rules presented by Veblen and Buseck. If the rules are violated, the "zipper" terminations are usually associated with planar faults along (110) having displacements 1/4[010] and/or 1/4[100].

TEM evidence suggests the weathered hornblende contains a complex secondary assemblage, including such phases as 10A talc-like material, smectite, kaolin mineral and Fe- and Ti oxides. 10A talc-like material is topotactically formed at hornblende grain boundaries and extends into the inner part of the crystal at places having widened channels along the cleavages. Two types of 10A layered products have been recognized by their orientation relationships with parental amphibole, (010) type, layers parallel to Y axis of pyribole and rarer (110) type, layers parallel to [110] of hornblende. Smectite is found at mid- and late stage of weathering, replacing 10A layered material to form more or less random orientation distribution. Kaolin appears to be the final products of all secondary phases of weathered hornblende, forming as distinctive tubes and nodules.

INFLUENCE OF HEAT FROM BUSH FIRES ON MINERALOGICAL TRANSFORMATIONS IN SOME AUSTRALIAN SOILS

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R.J. Coventry
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The presence of specific iron and titanium oxides in soils indicate the environment and phenomena that have contributed to their formation. Although the geochemistry and mineralogy of Fe and Ti oxides in Australian soils have been studied intensively in the past, by comparison very few studies have been carried out on their formation and transformation by burning. Detailed work on the influence of heat from burning could provide a better understanding of some aspects of the unresolved genesis of maghemite, hematite and rutile in soils.

The aim of this investigation is to study the transformation and formation of various pedogenic minerals in soils that have known conditions of burning (i.e. in burnt and adjacent non-burnt field sites and in laboratory experimental studies). The implication of these results will be discussed in the light of mineralogical and pedo-geomorphological data of soil profiles with high contents of ferruginous gravels in the Torrens Creek area, north Queensland, particularly with respect to mixing of gravels.

The various iron, titanium and layer-silicate minerals in the samples were identified and estimated using X-ray diffraction, light optical, DTA-TG, chemical, magnetic and electron optical methods. We have studied the mineralogical transformations of goethite, maghemite, anatase, gibbsite and kaolinite during micro-scale simulation of burning in the laboratory and in the products from burnt field sites. The amount of maghemite, hematite and rutile formed was found to be a function of (i) the degree (i.e. rate) and duration of heating, (ii) the type and amount of source mineral, (iii) the mineralo-chemical properties of the source mineral (e.g. degree of Al-substitution of goethite and hematite), and (iv) the type and amount of organic matter initially present. Results suggest that the temperatures of soils during woodland burning range from 300 °C to 700 °C and may reach up to 1200 °C.

The present study indicates that the influence of bush fires on mineralogical transformations in Australian soils is possibly more widespread than was previously believed and suggests that there is a need for caution when interpreting the mode of formation of iron and titanium oxides.

A MECHANISM FOR THE FORMATION OF SOLUBLE Fe(III)-Al AND Si-Al HYDROXY COMPLEXES MOBILISED IN SOILS

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Evidence has been given in the last few years to suggest that podzol genesis may partly be explained by migration of Si, Al and Fe in mixed inorganic sols rather than being completely dependent on transportation involving organic ligands. The ability of these inorganic sols to explain some of the observable features in soils has been previously demonstrated in the laboratory by other workers.

This present work enables the reactions involved to be quantified so that the effects of variations in the environment on this mobilisation can be studied. This technique involves the chemical process of *Induced Hydrolysis* developed in this laboratory. Fully hydrolysed Fe(III) as flocculant precipitate (ferrihydrite) reacts at pH values 4-4.2 with Al hydroxy species in solution at this same pH. A yellow-brown sol is formed which is stable against precipitation at this pH for long periods (>6 months), even in the presence of 1 molar NaCl. Thus the precipitated Fe(III) phase is peptised and is therefore mobile. On extrapolation to a soil, this phenomena can explain the transportation of Fe(III) within a profile at pH values where it is normally precipitated.

A similar effect occurs with Si and Al. Si precipitated as silicic acid at a pH around 4-4.2 can react with Al in solution at the same pH causing the formation of a mobile, mixed Si-Al hydroxy species. When the correct Si/Al ratio is used, proto-imogolite is formed.

In both cases cited above, the Al in solution is hydrolysed when the fully hydrolysed second species is added at the same pH, and the rate of alkali addition necessary to maintain the initial present pH gives a measure of the rate of the reaction. This information extends further our knowledge of the inorganic processes involved in pedogenesis.

DIFFERENTIAL CLAY MOVEMENT ON HILLSLOPES - A NEW HYPOTHESIS FOR THE FORMATION OF SOILS WITH TEXTURE CONTRAST

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The University of Adelaide

A large area of the South Mount Lofty Ranges is mantled by yellow podzolic soils developed over arkosic sandstones. These soils have strong texture contrast characterised by coarse sandy A horizons overlying B horizons high in clay. Their origin has been ascribed to clay illuviation. However, in addition to this process, considerable prior weathering of the sandstone would have to have taken place in order to generate enough clay for translocation. Principle components of the sandstone are quartz (70%) and microcline (25%) of fine sand size.

A detailed study of the Crafers loamy sand (typichaploxeralf) was undertaken to explain the development of the texture profile. There were no macromorphological features (e.g. clay skins) which indicate clay movement and petrological investigation failed to reveal any evidence of vertical redistribution of clay to account for the clay maximum immediately above the parent material. Nor was there any evidence for downslope movement of sand-size material to account for the coarse surface texture.

X-ray fluorescence spectrometry and electron microprobe analysis showed a progressive increase in weathering of both the feldspar and quartz up the profile.

It was hypothesized that the texture profile is the result of

1. in situ physical and chemical weathering, greatest in the surface and least in the lower B horizon ; and
2. lateral removal of weathering products, principally of clay size; clay loss is greatest in the A1, least in the B3.

Kaolinite and vermiculite are the dominant products of the feldspar weathering but there is evidence of transformation of vermiculite to illite in the surface horizons. Titanium appears to be mobile in this soil.

NATURAL ZEOLITES
OCCURRENCE, PROPERTIES AND USE
A REVIEW

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Natural zeolites are crystalline hydrated alumino-silicates containing alkali and alkaline earth cations in an infinite three-dimensional crystal framework. They were first discovered in 1756 by the Swedish mineralogist Freiherr Axel Fredrick Constedt who named them from the Greek zein and lithos, meaning boiling stones, in allusion to their tendency to froth and to give off water when heated in an open tube.

There are more than 45 distinct species of natural zeolites and they occur in rocks of diverse age, type, and geological setting. Once thought to be confined mainly to cavities in basaltic igneous rocks, zeolites are now known to occur as major constituents of many bedded volcaniclastic rocks. Research into the ion exchange and adsorption properties of natural and synthetic zeolites has lead to a multitude of end use applications in such areas as pollution control, energy conservation, and agriculture.

Occurrence

Zeolites occur most extensively in sedimentary rocks and may form under a variety of conditions and in a number of geological environments. Typical environments include:

1 Hydrologically open and closed systems
(eg clinoptilolite, analcime, chabazite, mordenite, erionite, and phillipsite).
2 Burial metamorphic environments
(eg clinoptilolite, mordenite, heulandite, stilbite, and laumontite).
3 Hydrothermal alteration zones
(eg clinoptilolite, mordenite, analcime, heulandite, stilbite, wairakite, and laumontite).
4 Deep sea sediments
(eg clinoptilolite and phillipsite).
5 Surface weathering environments
(eg phillipsite, chabazite, natrolite, and analcime).

Zeolites are mainly formed by the reaction of volcanic glass with groundwater, lake, or seawater. However, other silicate minerals such as clays, feldspars, and quartz may also act as starting materials. Zeolites form most readily in alkaline environments where high pH favours a high silica solubility and the activity of Ca, Na, and K is greatest. This may occur over a range of pressure-temperature conditions.

The largest and potentially most valuable zeolite deposits are those formed in the open and closed water systems of volcaniclastic rocks.

Open system deposits are those formed by the reaction of volcanic glass with meteoric groundwaters. In thick tuffaceous strata they commonly show vertical mineralogical zonation reflecting local changes in the chemistry of circulating groundwaters.

The upper layers of burial metamorphic deposits are mineralogically similar to those of the open system type. However, in open system deposits a sharp contact may separate the unaltered glass zone from the zeolite zones. In burial metamorphic deposits the contact is more gradational and a thick transitional zone may be present.

Closed hydrological systems such as saline, alkaline lakes developed on volcaniclastic deposits commonly show lateral mineralogical zonation. Volcanic ash exposed at the margins of shallow saline, alkaline lakes commonly grades inwards through a succession of zones from unaltered glass at the margin to a zeolitized zone, and then to a zone of potassium feldspar at the centre of the lake.

The most prospective zeolite-bearing rocks in New South Wales occur within altered dacitic and rhyodacitic Carboniferous rocks of the Tamworth Shelf. These rocks were probably subjected to hydrologically open conditions at the time of deposition (forming clinoptilolite and mordenite) and were later modified by the effects of burial metamorphism (forming laumontite).

Properties

Natural zeolites are characterized by having very open silicate frameworks with networks of channels or pores which lead to large central cavities. These cavities are filled with loosely bonded cations such as sodium, potassium, calcium, magnesium, strontium, or barium which are surrounded by water molecules. Varying amounts of silicon in the structure may be replaced by aluminium, giving the structure a net negative charge which is balanced by the resident cation(s).

Zeolites are able to lose and gain water reversibly and to exchange constituent cations without major structural change. Molecules with diameters larger than the channel apertures are excluded from entering the cavities, thereby allowing the zeolite structure to be used as an effective molecular sieve.

Void volumes in dehydrated zeolites can be as high as 50%, making them excellent adsorbents. The surface area available for adsorption ranges up to several hundred square metres per gram and some zeolites are capable to adsorbing up to 30% of their own dry weight (Mumpton 1977).

Use

The ion exchange, adsorption, and molecular sieving properties of natural zeolites allow them to be used in a wide variety of industrial and agricultural applications. Natural zeolites have been successfully used in a number of pollution control applications, including the storage of radioactive waste, sewage effluent treatment, and the removal of toxic heavy metals from industrial waste waters. The removal of sulphur dioxide from the gas emission stacks of oil and coal-fired power plants has also been achieved using natural zeolites.

Energy conservation applications utilizing natural zeolites, include purification of natural gas and the production of oxygen-enriched gas streams through the selective adsorption of nitrogen from air, rather than by cryogenic methods.

Solar energy is perhaps the most abundant and least exploitable form of energy available. Efficient use of the sun's energy is commonly hampered by the lack of efficient heat exchangers. Chabazite and clinoptilolite because of their capacity to take up and release large amounts of water reversibly are able to exchange enough solar energy to cool small buildings (Sand and Mumpton 1977).

Perhaps the largest potential market for natural zeolites is in agriculture. The pronounced ammonium selectivity of zeolites such as clinoptilolite is the basis of a number of agricultural applications. These include:

1. The removal of ammonium ions from recirculating waters used in fish culture systems.
2. Nitrogen binding in sandy or nutrient-poor soils by increasing ion exchange capacity and promoting the slower release of ammonium ions from applied fertilizers.
3. Dietary supplements for swine, poultry, ruminants, and fish to increase feed efficiencies and body weights by binding ammonium ions and protein in the digestive systems.
4. The deodorising of animal excrement especially where intensive livestock raising is carried out, by capturing ammonium and other odouriferous molecules.

Natural zeolites have also been found to be useful as anticaking agents, pesticide, and herbicide carriers and in the preservation of food. Although a large body of research data exists that indicates the usefulness of natural zeolites in areas such as soil science and animal nutrition, conflicting research findings indicate the need for much more definitive work to be carried out. The accurate characterization of zeolitic materials coupled with a clear understanding of the conditions under which they are being used is crucial for the development of viable zeolite-based agricultural products (Pond and Mumpton 1983).

At present large deposits are being exploited in at least 16 countries with the largest number of mines being in the United States, followed by Japan and the Soviet Union.

To date exploration for suitable zeolite deposits in Australia has been largely overlooked. The Department of Mineral Resources is presently carrying out a study of zeolite-bearing rocks occurring in New South Wales to determine the state's potential commercial prospectivity. This work has generated considerable exploration interest in the Carboniferous rocks of the Tamworth Shelf in central northern New South Wales. If commercially viable deposits are found in these rocks then a variety of zeolite-based agricultural and industrial products could be developed for what is virtually on untapped market in Australia.

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USES OF NATURAL ZEOLITES IN AGRICULTURE AND AQUACULTURE

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The wide ranging properties and the potential uses of natural zeolite minerals in water treatment, soil improvement, odour control, animal feed additives, gas scrubbing, gas and hydrocarbon separation, paper additives and solar energy collection have been the subject of numerous reviews and conferences and have led to increasing levels of interest in the use of natural zeolites in NSW. As a result of this the NSW Department of Mineral Resources initiated an investigation in 1985 of the occurrence, properties and uses of natural zeolites from this State.

The potential is enormous for bulk uses of high grade zeolites in agriculture and aquaculture if such deposits can be found and marketed cheaply.

A summary of the areas in which natural zeolites have been used overseas will be given and the important physical and chemical properties of zeolites, which affect their usefulness in agriculture and aquaculture will be discussed.

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ZEOLITE BEARING ROCKS OF THE TAMWORTH SHELF: COMMERCIAL PROSPECTIVITY

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Geological Survey of N.S.W., Sydney.

In New South Wales Carboniferous rocks belonging to the Tamworth Shelf are known to contain potentially economic concentrations of zeolite minerals.

During the early Carboniferous, formation of the Tamworth Shelf developed through the thick accumulation of marine volcanogenic lithic sandstones, siltstones, mudstones, and minor oolitic limestones. Volcanism throughout the Carboniferous produced a general marine regression with marine sediments being gradually replaced by prograding wedges of conglomerate, fluvial volcanogenic sandstones, and later glacigene sediments. Contemporaneous silicic volcanism produced mainly ash flow and ash fall deposits of rhyolitic and dacitic composition which are interbedded with both the marine and non marine volcanogenic sediments (Roberts 1985).

Zeolite minerals such as clinoptilolite, mordenite, heulandite, stilbite, and laumontite occur throughout the Tamworth Shelf rocks. However clinoptilolite and mordenite appear to be more prevalent towards the top of the sequence, while laumontite appears to increase towards the base. At the time of deposition, rocks containing a high vitric component may have undergone devitrification to clinoptilolite and mordenite in response to an open hydrological system. As the overprinting effects of burial metamorphism developed in response to a thickening sedimentary pile laumontite may have replaced existing clinoptilolite, mordenite, and unreacted volcanic glass. As a result of these processes economic concentrations of clinoptilolite appear to be confined mainly to the upper parts of the Tamworth Shelf stratigraphy. The most prospective formations examined to date by the Department of Mineral Resources include:

Tamworth Region
- Rocky Creek Syncline
  - Lark Hill Fmn
  - Rocky Creek Conglomerate
  - Clifden Fmn
- Werrie Syncline
  - Taggarts Mountain Ignimbrite
  - Currabubula Fmn

Hunter Region
- Waverley-Rouchel District
  - Rossmore Fmn
  - Isismurra Fmn
  - Waverley Fmn
- Dungong-Paterson District
  - Seaham Fmn
  - Paterson Volcanics
  - Mt Johnstone Fmn
  - Gilmore Volcanic Gp
- Carrowbrook-Rouchel District
  - Mt Johnstone Fmn
  - Isismurra Fmn
- Raymond Terrace District
  - Grahamstown Lake Fmn
  - Italia Road Fmn

The highest recorded concentration of clinoptilolite to date are from ashfall tuffs associated with glacigene sediments in the Grahamstown Lake Formation, Raymond Terrace. Rocks exposed in the old Eggleton quarry near Seaham contain between 35% and 84% by weight of clinoptilolite (J Taylor pers. comm. 1986) and show ammonium exchange capacities of between 37 and 140 meq/100g (Fredrickson 1985).

The higher ion exchange values of these rocks compares favourable with zeolitic tuffs currently being exploited in Japan and Hungary. However Carboniferous zeolitic rocks examined so far are much harder and denser than material being mined overseas. Furthermore, their porosity is lower and in some cases the crystallite size of zeolite phases is considerably greater. This results in a lower specific area available for reaction and indicates that fine grinding may be required for optimum results.

Zeolite-bearing Carboniferous rocks in New South Wales are structurally more complex than zeolite-bearing rocks being mined overseas. Folding and faulting may pose access and mining problems with a corresponding increase in costs. However, zeolitic Carboniferous rocks have a higher attrition resistance than overseas material and may be very useful in applications where finely divided zeolite is an advantage such as in pelletized stock feeds, soil conditioners, odour control reagents, pesticide and herbicide carriers, and in anticaking applications.

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B20

MEASUREMENT OF SOIL MOISTURE AT SAND/CLAY INTERFACES

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Multigroup diffusion code calculations are used to determine the thermal neutron flux arising from a point source in a soil and water system. By repeating the calculation with several different water densities the variation of flux with water density can be established at any point in the system. This allows the construction of calibration curves for neutron probes of differing geometry.

Spatial variation of the nuclear characteristics of the soil allows the calculation of the neutron flux in more complex systems such as a sand/clay interface.

The response of a neutron moisture probe as it passes through such an interface is considered and the difficulties of interpretation are discussed.

THERMAL TRANSFORMATION OF CLAYS AS REVEALED BY ^{27}Al ^{29}Si AND ^{31}P HIGH RESOLUTION SOLID STATE NUCLEAR MAGNETIC RESONANCE SPECTROSCOPY

Michael A. Wilson, John Stephens and Sharon A. McCarthy
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High resolution solid state nuclear magnetic resonance spectroscopy is a useful technique for studying the types of coordination of aluminium, silicon and phosphorus in minerals. Its full potential will be realised in studying poorly ordered materials which give little or no X-ray diffraction information since n.m.r. does not rely on any long range order in samples. In this paper some of the underlying theory to the method will be described and examples of its use in studying thermal transformations of imogolite, protoimogolite, kaolinite and apatite will be presented. Imogolite is decomposed at 350°C into materials with ^{29}Si resonances at -113, (quartz), -90ppm (layered silicate) and -84ppm. Aluminium coordination is tetrahedral. Protoimogolite decomposes at much lower temperatures into poorly ordered material with a resonance at -87ppm. Aluminium again is octahedrally coordinated. Kaolinite is transformed into metakaolinite at 700°C, and contrary to literature suggestions metakaolinite is shown to contain octahedral aluminium. At higher temperatures mullite, alumina and quartz can be detected by n.m.r. It is shown that these transformations can also be followed when coal is combusted.

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CLAY MINERALOGICAL CHANGES RESULTING FROM TREATMENT WITH VARIOUS SALTS

A. Shayan and C.J. Lancucki

CSIRO Division of Building Research, Melbourne

Cubes measuring approximately 12 x 12 x 12 mm were cut from various rock spalls and treated with 0.15 M salt solutions containing either of Na, K, Ca, Al salts. The treatment was a repeated weekly wetting/drying process and continued for 70 weeks. Associated length change of companion rock prisms were also measured. Results indicate that whereas expansion on wetting increased with progressive cycling in the presence of Ca, Al and particularly Na, it decreased in the presence of K. Rocks which did not contain secondary clay minerals showed a consistent behaviour as far as the effect of cations on expansion is concerned, but the effect of the K-salt on clay minerals in these rocks was not consistent. Whereas the strong basal reflection of clay (15 Å) in one basalt had been drastically reduced into a hump together with a small shift in the spacing, in another similar basalt the intensity of the reflection was not affected, although the shift to the lower spacing had occurred. The expansion of both these rocks was, nevertheless, reduced considerably due to the treatment.

The difference in behaviour of these clays may be attributed to their compositional variation, but this needs further investigation.

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NEW DATA AND A REVISED STRUCTURAL MODEL FOR FERRIHYDRITE

Richard A. Eggleton,

Geology Department, Australian National University

Robert Fitzpatrick,

CSIRO, Division of Soils, Glen Osmond, S.A.

Synthetic 2-line and 6-line ferrihydrite samples prepared from ferric nitrate solutions have bulk compositions $Fe_4(O,OH,H_2O)_{12}$ and $Fe_{4.6}(O,OH,H_2O)_{12}$ respectively. The composition depends on crystal size, which averages 20 Å for the 2-line and 35 Å for the 6-line variety. EXAFS spectra indicate the presence of tetrahedral ferric iron, a conclusion supported by heating experiments which show the development of maghemite after heating to 300°, followed by the formation of hematite at higher temperatures. These two reactions are recorded on DTA traces by exotherms at 350° and 450° C. Transmission electron microscopy shows that 2-line ferrihydrite has no Z-axis regularity but does have a hexagonal 2.54 Å lattice fringe structure. 6-line ferrihydrite forms faceted crystals, with a 9.4-Å C-axis only detectable in dark field. In bright field, 2.54 Å lattice fringes show greater atomic regularity than is seen in 2-line ferrihydrite. Analysis of the XRD pattern from 6-line ferrihydrite suggests a structure based on double-hexagonal close-packed oxygens, with 36% Fe in tetrahedral sites. Selective chemical dissolution, surface area measurements and magnetic susceptibility are consistent with the recorded properties of ferrihydrite.

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INTERACTION OF SILICATE AND PHOSPHATE WITH IRON OXIDE

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The surfaces of goethite samples (α-FeOOH) particularly when freshly synthesized from reagent grade chemicals, have been shown to be very reactive. Such goethite preparations have been used extensively as model substrates for adsorption studies in which reactive anions such as phosphate, molybdate, arsenate, oxalate, selenite and fluoride have been used. Many of these ions as well as silicate have been shown to interact with most soils, with the hydrous oxides of iron and aluminium usually suggested as the principal adsorbent.

Infra-red spectroscopy of pure goethite samples has shown that several different types of hydroxyl groups exist at the surface. Addition of phosphate fluoride or arsenate results in interaction with the A type hydroxyl (coordinated to only 1 iron atom) eventually eliminating this peak (at 3485 cm^{-1}) from the spectrum, but with little or no effect on the remaining hydroxyls (peak at 3660 cm^{-1}).

This paper will show that addition of silicic acid, at concentrations sufficiently low to ensure existence as monomeric Si, or alternatively as silicate anions (i.e. at high pH values) also causes a decrease in the peak ascribed to A type hydroxyls but in contrast to the other ions, Si interacts equally well with the B/C peak. Furthermore, other peaks are generated at 3712 and 3695 cm^{-1} the intensity of which are directly related to the amount of Si adsorbed. The presence of these peaks can be used to indicate, at least semiquantitatively, the extent of interaction between Si and the goethite surface.

Data will also be presented for competition between P and Si
a) when added to the goethite at the same time, or
b) when added sequentially.

A comparison will be made to the behaviour of P and Si when added to lepidocrocite (γ-FeOOH).

B25

CLAY PHOSPHATES IN ALLUVIUM OF THE SHOALHAVEN RIVER

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Clay or soil phosphates are mostly hexagonal alumino(ferro)phosphates or alumino(ferro)phosphates and sulphates or arsenates isostructural with hydrated aluminosulphates of the alunite group of minerals. The cationic composition controls their unit cell dimensions: there is a linear relationship between the ionic radii of the prevailing cations and the ratio a/c of the unit cell, from the lowest c/a ratio of crandallite (Ca) to the highest c/a ratio of gorceixite (Ba). Although first found in diamond bearing sands of Brazil these minerals are relatively widely distributed in soils and clays often in association with kaolinite.

The reported occurrence is in alluvial deposits of the Shoalhaven River about 50 km east of Canberra. There, the phosphates were found in the form of small nodules, brown or pale brown, yellow white or yellow gray, well rounded, up to several mm in size. The prevailing phosphate is close to florencite, $CeAl3(OH)6(PO4)2$, with unit cell parameters $a = 6.957(1)A$, $c = 16.27(2)Å$ (after least squares refinement). SEM analysis showed cerium to be the predominant RE element in the mineral. DTA curve of the florencite is characterized by a large endothermic reaction from 570 to 850°C and an exothermic peak at 1015°C. To throw light on the origin of the phosphates, an attempt was made to establish the stability of the crandallite group of minerals in aqueous solutions at normal temperature and pressure. Estimated free energy values had to be used in the absence of experimentally obtained values.

B26

CLAY MATERIALS IN SOUTHEAST QUEENSLAND

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Most ceramic industries in Queensland are established in the southeast, manufacturing principally bricks, clay pipes and pottery from a range of local materials. The rock units from which these materials are derived and in which is found clay suitable for ceramic purposes, occur in the majority of geological formations. Rocks in the Palaeozoic formations consisting of metamorphosed argillites and shales were the source of materials used in some of the older heavy ceramics industry of the region, while the younger materials including shales of the Mesozoic Coal Measures, Tertiary clays, shales and mudstones and alluvial clay deposited in Quaternary and Recent times are components in current clay product manufacture.

The ceramic properties of rock units and formations of importance as a source of clay materials are discussed and reference is made to the manufacturers using those materials.

B27

MAYFIELD REVISITED: THE GEOLOGY OF A DEEP WEATHERING PROFILE AT THE MAYFIELD KAOLINITE QUARRY, NEW SOUTH WALES

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A geological investigation of an area of 12 sq. km was carried out at Lower Boro, in the Southern Tablelands of New South Wales. The Mayfield Clay Quarry, which is situated within this area, has been developed to mine kaolinitic clays for use in the manufacture of house bricks.

These kaolinitic clays appear to have developed from the in situ weathering of the folded, intruded and metamorphosed silty sediments of the Late Silurian De Drack Formation. The clays constitute the pallid zone of a deep weathering profile which formed during the mid-Miocene and late Tertiary periods of deep weathering. The pallid zone is overlain in places by a mottled zone of sandy claystone and sandstone, which is then capped by a layer of ironstone.

At the Mayfield Quarry site, a large area of the developing profile has been stripped to the level of the pallid zone, prior to the first deep weathering event in the mid-Miocene. Fluvial quartz sand was then deposited unconformably over the eroded surface. Massive silcretes developed within these sands during the ensuing deep weathering periods.

Detailed mapping and x-ray diffraction techniques show that there are four principal clay types present in the quarry:

1. Dark grey and white, laminated, graphitic and generally well crystalline kaolinite. Often slightly sandy.

2. White sandy claystone with moderately to poorly crystalline kaolinite.

3. Green smectite derived from the weathering of a basic intrusive vein.

4. Transported, red to white, lateritic clay. Mainly moderately to poorly crystalline kaolinite with minor gibbsite.

The first two clays are the products of different deeply weathered lithologies of the De Drack Formation. These clays are mined and blended together to form a quality binding clay for use in the brick making industry.

B28

KAOLINITE:$(CH_3)_2XO$ INTERCALATES: X = S, SE.

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CSIRO - Division of Soils, Glen Osmond, S.A.

Dimethylselenoxide (DMSeO) formed three structurally resolved intercalates with kaolinite (d_{001} = 10.95, 11.26 and 11.38 Å). The 11.26 Å kaolinite:DMSeO intercalate was structurally analogous to the 3-D ordered kaolinite:DMSO intercalate (d_{001} = 11.22 Å). Infrared and solid state ^{77}Se nuclear magnetic resonance data indicated that all DMSeO molecules were equivalent in the structure, and therefore, that the 11.26 Å kaolinite:DMSeO intercalate structure was C-face centered. Structural model refinement from the XRD powder profile further supported this conclusion (*P*1, *a* = 5.195(1), *b* = 8.990(1), *c* = 11.946(2) Å, α = 91.33(1)°, β = 109.39(1)°, γ = 89.77(1)°). The kaolinite:DMSO intercalate structure was subsequently re-refined from XRD powder profile in C-face centered *P*1. The derived orientation of the DMSO and DMSeO molecules with respect to the basal plane in their respective intercalates was supported by polarised IR spectroscopy of uniaxial powder samples.

The 11.38 Å kaolinite:DMSeO intercalate was closely related to the 11.26 Å intercalate, the main differences being a 2-fold disorder in the orientation of the DMSeO molecule and less penetration of the kaolinite ditrigonal cavity by that molecule. The 10.95 Å kaolinite:DMSeO intercalate, displaying disorder parallel to [110], was obtained from the 11.26 or 11.38 Å intercalates by removal of some DMSeO.

SOUTH AUSTRALIAN PALYGORSKITE: POTENTIAL AND PROBLEMS

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Palygorskite (attapulgite) is widely developed in Miocene sediments of inland South Australia, and is recorded from -

- Namba Formation of the Tarkarooloo Basin.
- Garford Formation infilling the Garford Palaeochannel, a Tertiary palaeodrainage system of northwestern South Australia.
- Etadunna Formation of the Lake Eyre Basin.
- Billakalina Clay Member of the Mirakata Formation, and associated palaeodrainage channels on the northern margin of the Gawler Craton.

Reconnaissance sampling of the Namba and Garford Formations suggests that these units have commercial potential.

Palygorskite, always intimately associated with dolomite, was deposited in shallow, alkaline playa lakes and ponded drainage channels with a warm to sub-tropical climate, moderate to high rainfall and seasonally arid conditions. Origin is similar to the extensive, commercially important palygorskite-sepiolite deposits of Florida, USA. Palygorskite formed by authigenic alteration of montmorillonite, which is abundant in the underlying Cretaceous sediments, and/or by direct precipitation from solution.

Huge quantities of easily mineable palygorskite are present in the Tarkarooloo Basin and in the Garford Palaeochannel but commercial suitability has yet to be established. Six palygorskite samples from four Tarkarooloo Basin localities gave water absorbency values ranging from 30 to 65 percent, too low for an industrial absorbent.

Water absorbency was directly related to palygorskite content. The same samples recorded exceptionally high surface area measurements and would be suitable for use as industrial catalysts.

Twelve samples from four lakes within the Garford Palaeochannel gave water absorbencies ranging from 37 to 100 percent, and this area has considerable potential to supply industrial absorbents. Although the presence of palygorskite is necessary for good water absorbency, the actual values appear to be related to dolomite content. The most absorbent samples contain about equal amounts of palygorskite and dolomite. The effect of dolomite content on water absorbency has yet to be determined.

Further exploration and testing of palygorskite deposits in the Tarkarooloo Basin and Garford Palaeochannel is warranted, as is reconnaissance sampling of other palygorskite-bearing sediments in South Australia.

THE MICROSTRUCTURE OF CLAYS IN CLAY SHALES

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Interlayered illite/montmorillonite in shales is often present as large stacks of parallel oriented layers. These have been extensively studied recently using high resolution transmission electron microscopy to elucidate the mode of clay formation. In many shales the clay stacks are also visible under the scanning electron microscope. In shales from the Bowen Basin, stacks of illite/montmorillonite up to 50 microns thick are present. From visual estimation and XRD the clay contains approximately 75% illitic layers and 25% montmorillonitic layers.

Depending on the hydration state of the montmorillonite, the stacks may change in thickness by up to several microns; the associated pressures are believed to be very large. In rocks, which have a dense structure and 'brittle' cementation compared to soils, such deformations may be sufficient to damage the rock fabric with a resultant loss of strength. Significant decreases in tensile strength have been measured as a result of the crystalline swelling of the clay. The damage to rock fabric by this mechanism is believed to contribute to the large changes in strength with moisture in comparison with shales that do not contain expansive clays.

B32

CLAY MINERAL REACTIONS IN OIL SHALE PROCESSING

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General mineralogical studies have revealed that montmorillonite, kaolinite and mixed layer mica-montmorillonite type clays are likely to be significant in the processing of Australian oil shales. Relative amounts of these clays vary from deposit to deposit but the Tertiary oil shales in Queensland contain notably more montmorillonite and kaolinite than do Green River oil shales. The higher clay content and different clay mineralogy of Australian oil shales constitutes a significant area of difference from Green River oil shales, and warrants more study in relation to processing.

The clay minerals undergo endothermic dehydration, dehydroxylation and decomposition reactions during preheating, retorting, and spent shale combustion. Even more importantly they provide active surfaces for coking and/or cracking reactions of the primary oils during pyrolysis. For the Tertiary oil shales there are probably five types of clay mineral reactions which impact on oil shale processing:

(i) Dehydration-rehydration of inter-layer water from montmorillonite or mixed layered clays in the preheater.

(ii) Dehydroxylation of kaolinite during retorting and/or combustion.

(iii) Dehydroxylation of montmorillonite during combustion.

(iv) Solid state-recrystallisation type reactions of dehydroxylated clay residues and

(v) Cracking and/or coking type reactions of oil vapours on clay or dehydroxylated clay mineral surfaces.

Results of chemical and X-ray diffraction studies of Fischer assay and pilot plant samples of Condor, Stuart and Nagoorin oil shales will be used to illustrate the relevance of the above mineral reactions. It will be shown that the clays will play an important role in the processing of Australian oil shales in relation to, oil losses by coking and cracking, process enthalpy balances, trace element mobilisation to the oils, and oil quality for refining.

B33

PILLARED CLAY CATALYSTS

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There is an increasing interest in the use of pillared clay catalysts for upgrading oil. This paper reports on the chemistry of aluminium species formed in aqueous aluminium chloride-sodium hydroxide solutions used in the synthesis of these catalysts. It is shown that the chemistry of such aluminium solutions is complex, and the $[Al_{13}O_4(OH)_{24}(H_2O)_{12}]^{7+}$, Al_{13}, cation is a relatively stable component. The Al_{13} species increases in concentration with increasing OH/Al ratio, accounting for approximately 80 percent of the total aluminium at a ratio of 2.3. At higher OH/Al ratios the concentration of Al_{13} decreases. The aluminium uptake by a bentonite pillared clay is shown to be positively related to the Al_{13} or the A_{13} + Al polymer content of the aqueous solution used in its preparation.

PROPERTIES OF WATHEROO (W.A.) BENTONITES

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In the region between Watheroo and Marchagee, approximately 200 km north of Perth, there are deposits of bentonitic clays that appear to have originated by precipitation from magnesium rich waters, by reaction with colloidal silica and minor alumina. The geological occurrence is as lacustrine deposits lying on the Proterozoic slates and Archaean metamorphics. Because of the method of their formation, the grain size is extremely fine and this gives very superior gelling properties and very strong absorption of organic material. The surface horizon of approximately 1.7 metres is underlaid by a cemented carbonate horizon, frequently dolomitic, and beneath this there are further clay/carbonate horizons.

SYNTHETIC COBALT CLAYS AS FISCHER TROPSCH CATALYSTS

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Cobalt-containing 1:1 layer and 2:1 layer clays has been prepared by hydrothermal treatment of basic cobalt hydroxysilicate gels, obtained by mixing cobalt salts with colloidal silica and a metal hydroxide. the particular phase formed is determined by the reactant ratios, temperature and the nature of the added metal hydroxide. In the presence of additional metal salts (eg. Al^{3+} or Cr^{3+}) cobalt chlorites have been obtained. On calcination and subsequent reduction in hydrogen, these chlorites prove to be particularly active catalysts for the formation of gaseous and liquid hydrocarbons from mixtures of hydrogen and carbon monoxide - the Fischer Tropsch Process. The relationship between clay structure and catalyst performance will be outlined.

THE BENEFICIATION OF KAOLIN CLAYS USING A SUPERCONDUCTING HIGH GRADIENT MAGNETIC SEPARATION (HGMS) FACILITY

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High gradient magnetic separation (HGMS), using conventional electromagnetic technology, have been in use in the white clay industry for many years to produce high quality kaolin clays by magnetically removing iron and other paramagnetic coloured impurities. The efficiency of the conventional HGMS for the removal of micron sized particles of only weak magnetic susceptibilities is limited by the magnetic field intensities produced by the simple electromagnets (2 tesla, 20000 gauss). The advent of superconducting HGMS technology offers considerable potential for the beneficiation of white clays. The superconducting magnet not only provides an immediate advantage by increasing the magnetic field intensities required for the removal of very fine (sub 10 micron) particles of weak magnetic susceptibilities, but also dramatically reduce the high energy cost of the removal of the particles, when compared to the power requirements of conventional electromagnets.

A laboratory scale superconducting HGMS facility for mineral beneficiation has been established at the CSIRO Division of Applied Physics. The superconducting magnet can generate magnetic field intensities of up to 9.5 tesla. (Details of the superconducting HGMS have been presented elsewhere in this Conference). Some preliminary trials for the benefication of kaolin clays, using the superconducting HGMS facility, have been carried out on a limited number of clay samples from Australian deposits. The trials were performed with water-borne slurries of the clay samples at magnetic field intensities of 2,4 and 7 tesla. The results from these preliminary trials on clay samples will be presented and discussed.

THE BENEFICIATION POTENTIAL OF NSW KAOLINS

J.L. Anderson and J.R.S. Kmetoni

Mineral Resources Development Laboratory,
NSW Department of Mineral Resources

The Mineral Resources Development Laboratory of the NSW Department of Mineral Resources is undertaking a project to determine the beneficiation potential of the major NSW kaolin deposits. The project is aimed at stimulating the further development of an export-oriented kaolin processing industry in New South Wales.

As part of that project a comprehensive range of beneficiation and evaluation techniques are being applied. The techniques include classification, delamination, flotation, magnetic filtration and chemical bleaching. The CSIRO Division of Applied Physics is also involved in the project in undertaking trials using high gradient magnetic separation

Beneficiation trials on material from a deposit of kaolinised granite from Elsmore, near Inverell, have been completed. Hydrocyclone classification produced a high quality china clay-type kaolin at a yield of 33%. Delamination of the kaolin increased the -5 um fraction from 80% to 98%. Magnetic filtration reduced TiO_2 content from 0.19% to 0.05% and Fe_2O_3 content from 0.33% to 0.20%. Overall, brightness was increased from 85% to 88%. Flotation also reduced TiO_2 content, though with a significant loss of kaolin.

POSTERS

A HIGH GRADIENT MAGNETIC SEPARATION (HGMS) FACILITY FOR MINERAL BENEFICIATION

L.M. Besley, M.S. Rahman and A.J. Richards

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A high gradient magnetic separation (HGMS) facility has been established at the CSIRO Division of Applied Physics. The facility is based around a superconducting magnet which can generate magnetic field intensities of up to 9.5 tesla (95000 gauss). Although operating at -269°C, the magnet surrounds a room-temperature working space of 100 mm diameter and 200 mm length in which the tests are made. The separations are effected on a ferromagnetic matrix of fine stainless steel wool through which the material to be treated is passed in a water-borne suspension. The superconducting magnet enables separations to be made for very fine (sub 10 micron) particles of only weak magnetic susceptibility. The system has been tested on the problem of the separation of tantalite mineral from a cassiterite ore, with considerable success. However, superconducting HGMS also has considerable potential for the beneficiation of white clays.

B40

SELECTED HYDROCARBON CRACKING BY PILLARED CLAYS

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Pillared clays have been prepared by cation exchange of partially hydrolysed aluminium salts with Na-montmorillonite. After appropriate pretreatment, these materials are active for hydrocarbon cracking, exhibiting low coking properties, and consequently, relatively long lifetimes. They are microporous and show a shape selectivity, preferentially cracking straight chain over branched chain hydrocarbons. This shape selectivity has been quantified by a "constraint index" similar to that used for zeolites.

B 41

ASSOCIATION OF TRANSITION ELEMENTS AND ACTINIDES WITH SYNTHETIC GOETHITE

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The close association of trace elements and radionuclides with crystalline iron oxides in soils and ore bodies is poorly understood. This study was undertaken to investigate the possibility of incorporation of Co, Ni, Cu, Zn, Cd, Pb, Th and U into the structure of goethite. The minerals were synthesised by introducing foreign element containing ferrihydrite at foreign metal concentrations between 0 and 10 mole % into 0.7 N NaOH and ageing at 70°C for 7 days.

The lath shaped type crystals became thinner and more elongated with increasing concentrations of Co, Cu, Zn and Cd in contrast to Ni and Pb which only caused minor changes in crystal size. Thorium led to an increase in crystal thickness while U had no detectable influence on crystal morphology. These findings are consistent with surface area results and XRD line broadening due to crystal size.

At an initial concentration of metals of 5 mole % goethite was the only mineral produced except for the Th- and U-systems where Thorianite (ThO_2) and Clarkeite ($Na_2U_2O_7.nH_2O$) respectively, were also formed. The foreign metal concentrations of goethites after oxalate extraction were all close to 5 mole % in the transition element systems. Much smaller concentrations were found in the Pb (2%)-, Th (1%)- and U (0.1%)-goethites. Prolonged extraction in 2 M HCl at 20°C revealed congruent dissolution except for the Ni-, Th- and U-goethites where preferential mobilisation of the foreign element took place. The initial dissolution rates ranged from 7 to 19×10^{-5} g Fe/m^2/hr depending on the amount and the kind of foreign metal incorporated.

The extent of metal incorporation was linearly related to changes in the d-spacings of crystals for Co- and Cd-goethites with increasing and decreasing values for Cd and Co, respectively. The changes induced by Co-incorporation were similar to those reported for Al. It was thus concluded that Co, even though introduced as Co (II), is incorporated as Co (III) with the same ionic radius as Al (III).

Surface charge examinations revealed the development of a small permanent charge of ca. + 0.3 meg/100g in the transition element substituted goethites. The incorporation of Pb caused a higher permanent positive charge of ca. 1 meg/100g which possibly indicates a different mode of incorporation. The actinide associated goethites exhibited a permanent negative charge of up to 1.7 meq/100g which is due to the presence of Thorianite and Clarkeite, respectively.

THE CHARACTERISATION OF SOME SOIL CLAYS FROM VERTISOLS NEAR NARRABRI, N.S.W.

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The CSIRO Division of Soils is undertaking a study of cracking clay soil, based on the Edgeroi 1:50000 map sheet near Narrabri, N.S.W. Typically, the <2 micron fraction of soils from that area consists of smectite, illite and kaolin. Smectites are generally characterised by the expansion of the basal spacing (001) when magnesium saturated and treated with glycerol.

When smectites are examined saturated with potassium, the basal spacing provides a further basis for characterisation. Barshad (1950) describes a basal spacing at 12 Å when potassium saturated air dry as typical of smectites. The collapse of some smectites to 10 Å K saturation air dry has lead Egashira _et_ _al_. (1982) to classify these as "high charge smectites" since they still expand on glyceration. At the other extreme, the presence of partial chloritic layers (as described by Weir & Rayner (1974)) may inhibit the collapse of smectites when K saturated air dry and when subsequently heated.

The oriented diffraction pattern of a Narrabri clay containing a "high-charge" smectite is illustrated in Fig. 1. The smectite peak at 19 Å when glycerated collapses to a 10 Å "high-charge" smectite and a 12 Å low charge smectite when potassium saturated and air dry. Further collapse is evident on heating to 110°C. In contrast, the presence of well developed chloritic interlayers in other samples is demonstrated by the heating sequence of a potassium saturated clay in Fig. 2.

Smectites are an important component of cracking clay soils. Further investigations will attempt to link the different types of smectite, as characterised by their behaviour when potassium saturated, to the geomorphic and genetic relationships of the soil.

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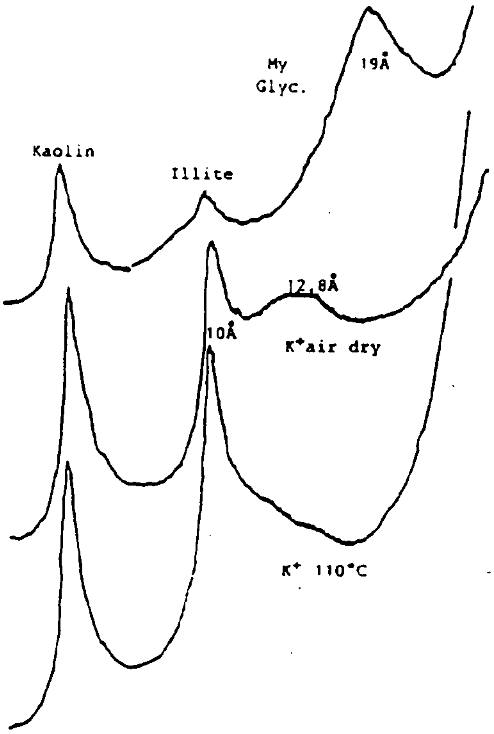

Fig. 1 X-ray Diffractograms of CP32 Myall Vale under various conditions

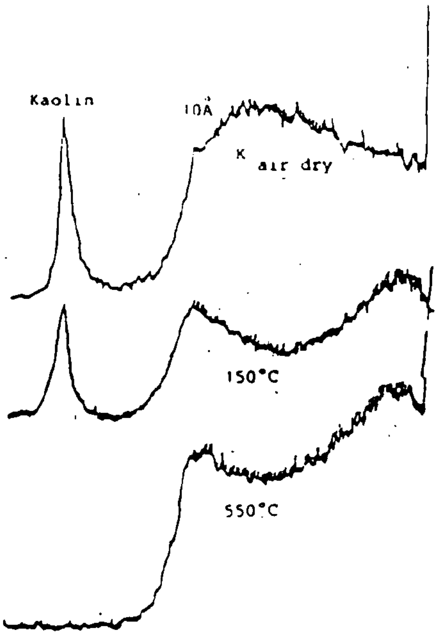

Fig. 2 X-ray Diffractograms of CM422 Auscott pit site K sat. oriented & heated

GEOLOGY OF THE CRESSFIELD BENTONITE DEPOSIT, UPPER HUNTER VALLEY, N.S.W.

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Located within the Upper Hunter Valley of New South Wales, the Cressfield bentonite deposit is a significant occurrence of calcium-magnesium montmorillonite. The bentonite bearing strata comprise the topmost Permian coal measures of the Murulla Beds, which are lateral equivalents of the Singleton Coal Measures.

The eight commercial bentonite seams at Cressfield vary in thickness from 0.5 m to over 3.0 m and consist of nearly pure montmorillonite which has both Ca^{2+} and Mg^{2+} on the exchange positions. The minor impurities detected within the bentonite include, kaolinite, quartz, feldspar, fresh biotite, anatase, barite, calcite and celestine.

Similar to many other bentonite occurrences, the Cressfield bentonite probably formed by subaqueous alteration of volcanic ash. Trace element abundance of the immobile elements Y, Zr and Nb indicate that the original ash was acid to intermediate in composition. Unlike the Na-bentonites of Wyoming, U.S.A., which were formed in a marine environment, the Cressfield bentonite environment of formation was terrestrial - possibly a shallow fresh water coal swamp. One of the bentonite seams has clastic textures indicating that some erosion and redeposition has taken place on a local scale. The interseam rocks, consisting of claystones, siltstones, sandstones, carbonaceous shales and coal contain high contents of montmorillonite. Volcanic activity has thus continued for a long period of time. The interseam sedimentary rocks may have formed during periods of either volcanic quiescence or high sediment influx.

Presence of petrified wood, together with a high quartz content in the interseam coal indicates remobilization of silica during the alteration of the volcanic ash or during diagenesis. Recent weathering also appears to have had an important affect on the bentonite. Chemical composition of the bentonites, and in particular the mobile elements illustrates variations which appear not to reflect variations in the composition of the original ash, but variations typical of a weathering profile. Superior rheological properties are associated with the more weathered uppermost seams.

INCOMPLETE INTERCALATION OF KAOLINITE

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Synthetic clay mineral intercalates have recently received much attention due mainly to the industrial potential of pillared clay catalysts and the analytical application of such intercalates by clay mineralogists and soil scientists. Kaolinite (d_{001} = 7.16 A) and its polymorphs accommodate small, highly polar organic molecules between the layers to give characteristic XRD basal reflections, e.g. DMSO (d_{001} = 11.2 A), formamide (d_{001} = 10.1 A), urea (d_{001} = 11.0 A), the first of which is now commonly used to distinguish kaolinite from other 7 and 14 A layered silicates (which do not form such intercalates) in mineral mixtures. It is notable that almost without exception 100% intercalation in not attained, but a suitable explanation of this phenomenon is lacking.

Direct observation of the extent and nature of kaolinite intercalation using TEM is usually not possible due to the instability of such intercalates both under vacuum and in the electron beam. However, it has been discovered that kaolinite:heavy alkali halide intercalates possess vacuum and beam stability comparable to kaolinite itself. Kaolinite:caesium bromide intercalate (d_{001} = 11.0 A) has been the subject of such investigation. Results show that most crystals are either fully intercalated or not at all. Occasionally full intercalation is observed only part way across the crystal. No partial intercalation (i.e. where every 2nd or 3rd interlayer is intercalated) was observed. Resistance to intercalation is not due to chemical composition. A two step intercalation process is proposed to explain the observations.

B 47

AGGREGATION OF INORGANIC COMPLEX PILLARS IN SYNTHETIC FLUROHECTORITE

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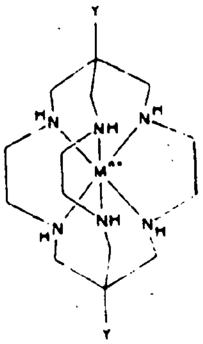
High-charged synthetic flurohectorite (exchange capacity is 1.5 mequiv per gram) was pillared by different cage compounds with general formula:



where M^{n+} is Co^{+3}, Ir^{+3}, Hg^{+2}
and Y= NH_2, NH_3^+, H.

The basal spacings of these compounds were in the range 16.4 - 17Å. Pillared flurohectorites obtained were stable under vacuum and heating at 110°C.

A primary aim of this work with heavy metals was to detect the lateral distribution of the pillars - as yet an unknown quantity for any pillared clay. In the flurohectorites large platelet sizes (typically > 10000 A) allows relatively well oriented samples to be prepared by air drying. Six orders of the c-axis are resolved and for Ir -hectorite the diffraction pattern in transmission (scattering vector in the layer plane) showed a peak at 9.6 Å, which is not observed in the reflection mode. We believe that this corresponds to interpillar distances. The shape of the peak corresponded to the aggregation of pillars on the clay surface. Surface area measured by N_2 adsorption is equal to 127 m^2 per gram and also indicates pillar aggregation. Calculations on the diffraction peak shape estimated the the diameter of the clusters in the range of 60 Å.

The poster will bring together the diffraction and gas sorption data in a model of the clay structure.

B 48

CLAY MINERALOGY OF SOME RED AND BROWN HARDPAN SOILS

M.J. Wright
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The poster will describe the typical field occurrence of red-brown hardpans in the deep regolith profiles of the Coober Pedy area of arid South Australia. Bulk mineralogical data and thin-section observations will be used to provide a focus for mineralogical investigations of the matrix materials, and in particular the clay fraction. The indurated characteristics of the hardpans and the origin of the clay minerals will be discussed in terms of geological and geomorphological relationships as well as pedogenic environments.

FIELD PORTABLE SPECTRORADIOMETER

The CSIRO Division of Mineral Physics and Mineralogy Remote Sensing Group is presently constructing a prototype short wave infrared spectroradiometer to operate in the region from 1.3 to 2.5 μm. In this region it is possible to distinguish some minerals from the wavelength positions of the combination tones and overtones of the fundamental OH stretching and bending vibrations. Phyllosilicates, carbonates, amphiboles, some sulphates and epidote can be distinguished in this spectral region. The instrument will be field-portable and designed largely for use by the mining industry for the identification and mapping of alteration mineralogy around ore deposits, in particular gold deposits. It is expected the instrument may utilize an expert systems software package which will extract the absorption features from the spectrum and hopefully identify the contained minerals. The goal is for the instrument to be marketed for between $15000 and $20,000. We have listed below the minerals for which we are developing expert systems package. We would like your opinions on any further minerals you feel we might be able to detect which are reasonably common, and would be of interest.

Al OH minerals
Kaolinite
Dickite
Montmorillonite
Sericite/Muscovite
Pyrophyllite
Illite
Alunite

Carbonates
Calcite
Dolomite
Magnesite

Fe OH minerals
Jarosite
Fe chlorite

Mg OH minerals
Talc
Mg Chlorite
Amphibole group
Epidote
Vermiculite

Sundry
Dry lichen

Please contact Chris Horsfall (02) 8878631 if you have any suggestions for further minerals.

APPENDIX C

Notes to accompany a field conference to the western part of the Sydney region.

9 December 1986.

ITINERARY

Depart	:	UNSW (Department of Applied Geology)	8.30
Arrive	:	Sydney Park (STOP 1)	9.00
Depart	:	Sydney Park	9.30
Arrive	:	Prospect Quarry (STOP 2)	10.30
Depart	:	Prospect	11.00
Arrive	:	Mulgoa Clay Pit (STOP 3)	11.30
Depart	:	Mulgoa Clay Pit	12.15
Arrive	:	Londonderry Core Library (STOP 4 and lunch)	1.00
Depart	:	Londonderry Core Library	3.00
Arrive	:	Londonderry Clay Pit (STOP 5)	3.15
Depart	:	Londonderry Clay Pit	3.45
Arrive	:	Londonderry Sand Pit (STOP 6) (Readymix - Farley Pit)	4.00
Depart	:	Londonderry Sand Pit	4.15
Arrive	:	UNSW (Department of Applied Geology)	6.30

Location Sketch

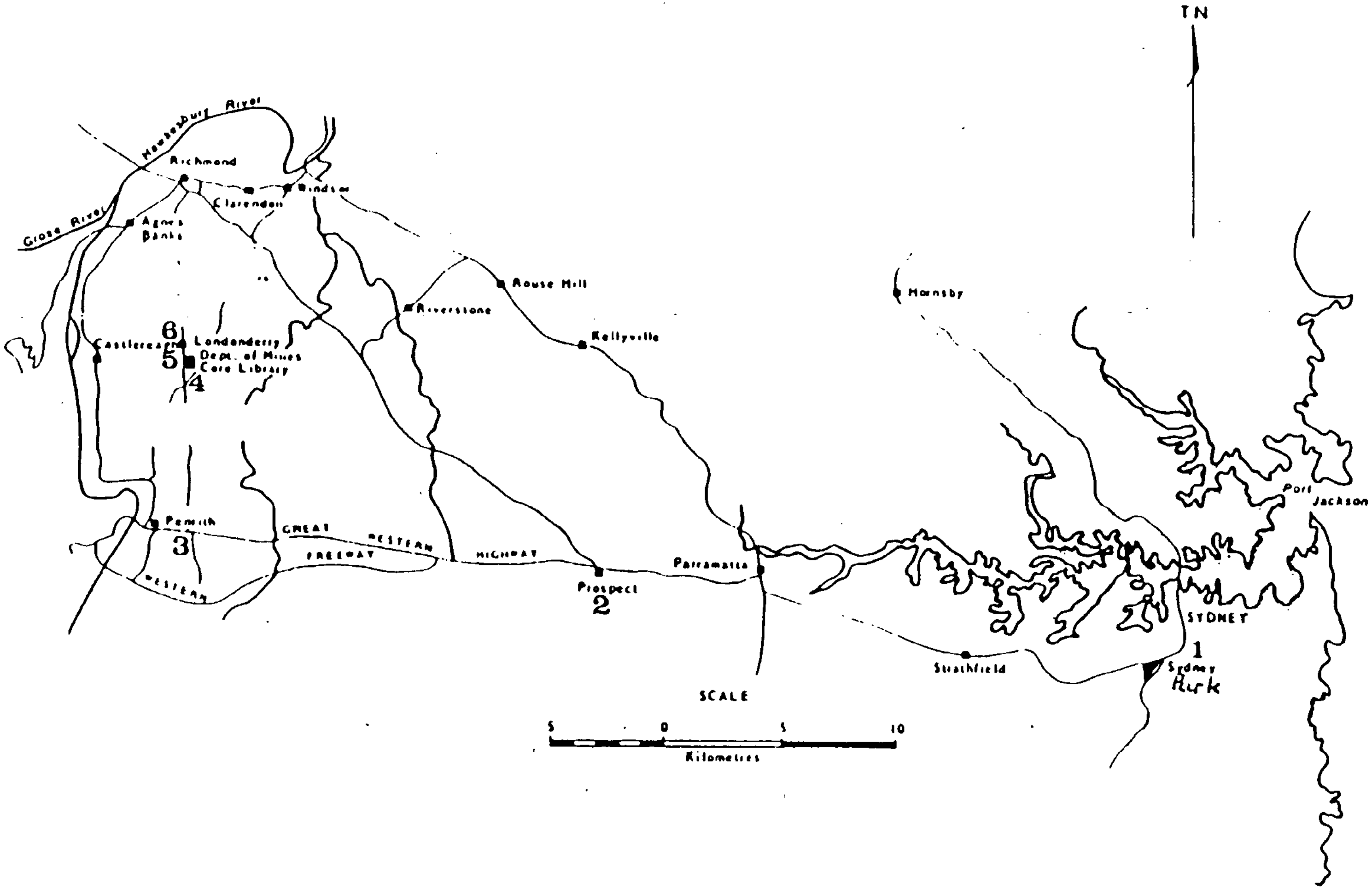


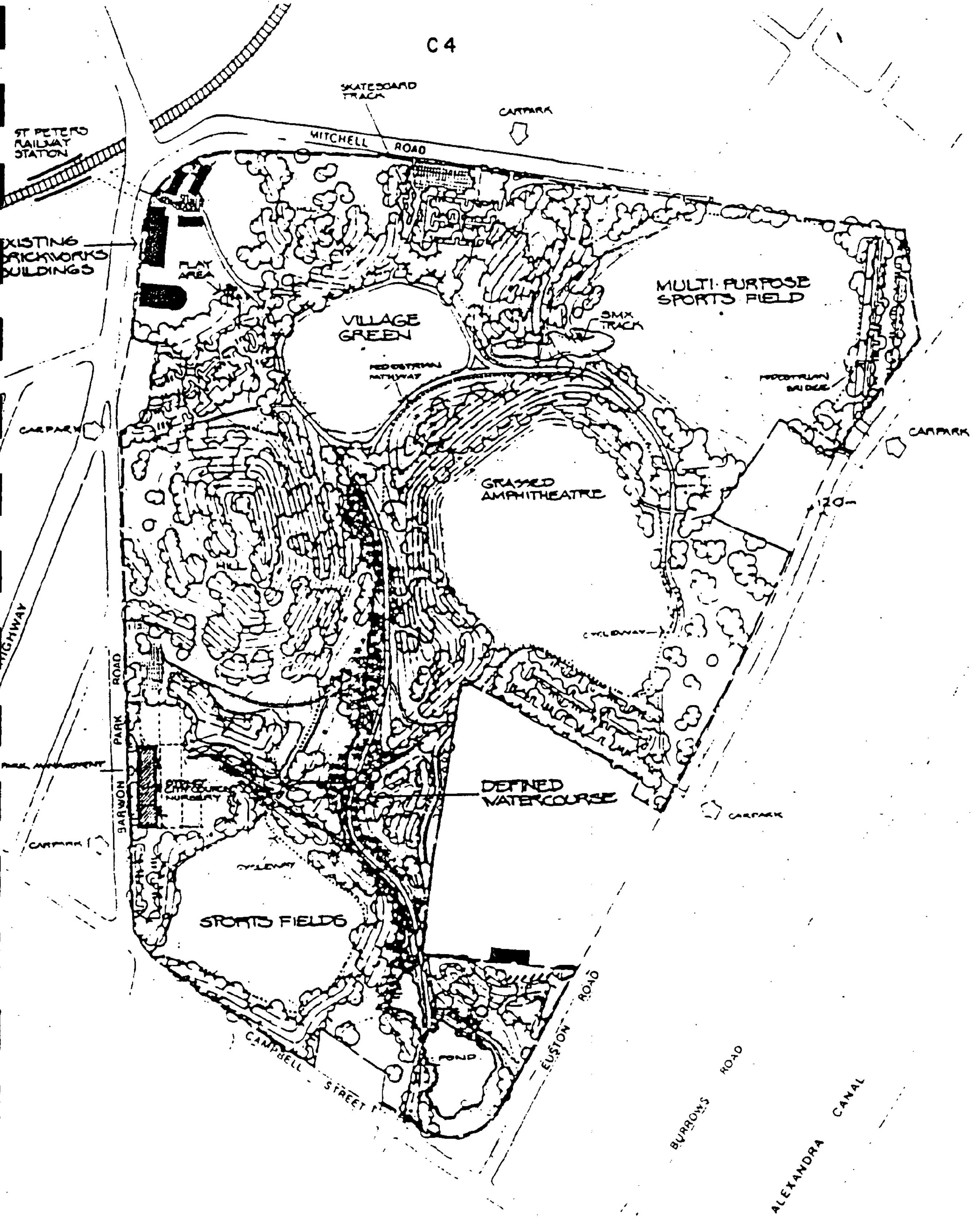
FIG 1

STOP 1: SYDNEY PARK

The Sydney Park, five kilometres southeast of the City Centre is a major Bicentennial Project of the State Government to develop the 34 hectare site of the Austral Brickworks worked-out brickpits. The Sydney brick industry was established on Ashfield Shale at this site in 1848 and the first machine-made brick was produced in 1871.

The St. Peters Brickpits were initially acquired by the State Government for waste disposal purposes. Between 1952 and 1968 the pits were infilled with garbage and industrial waste but since 1968 only "clean wastes" have been used for infilling and by completion in 1988 the site should be restored to a gently sloping profile. The design concept (Figs. 2 and 3) includes restoration of the existing brickworks buildings.

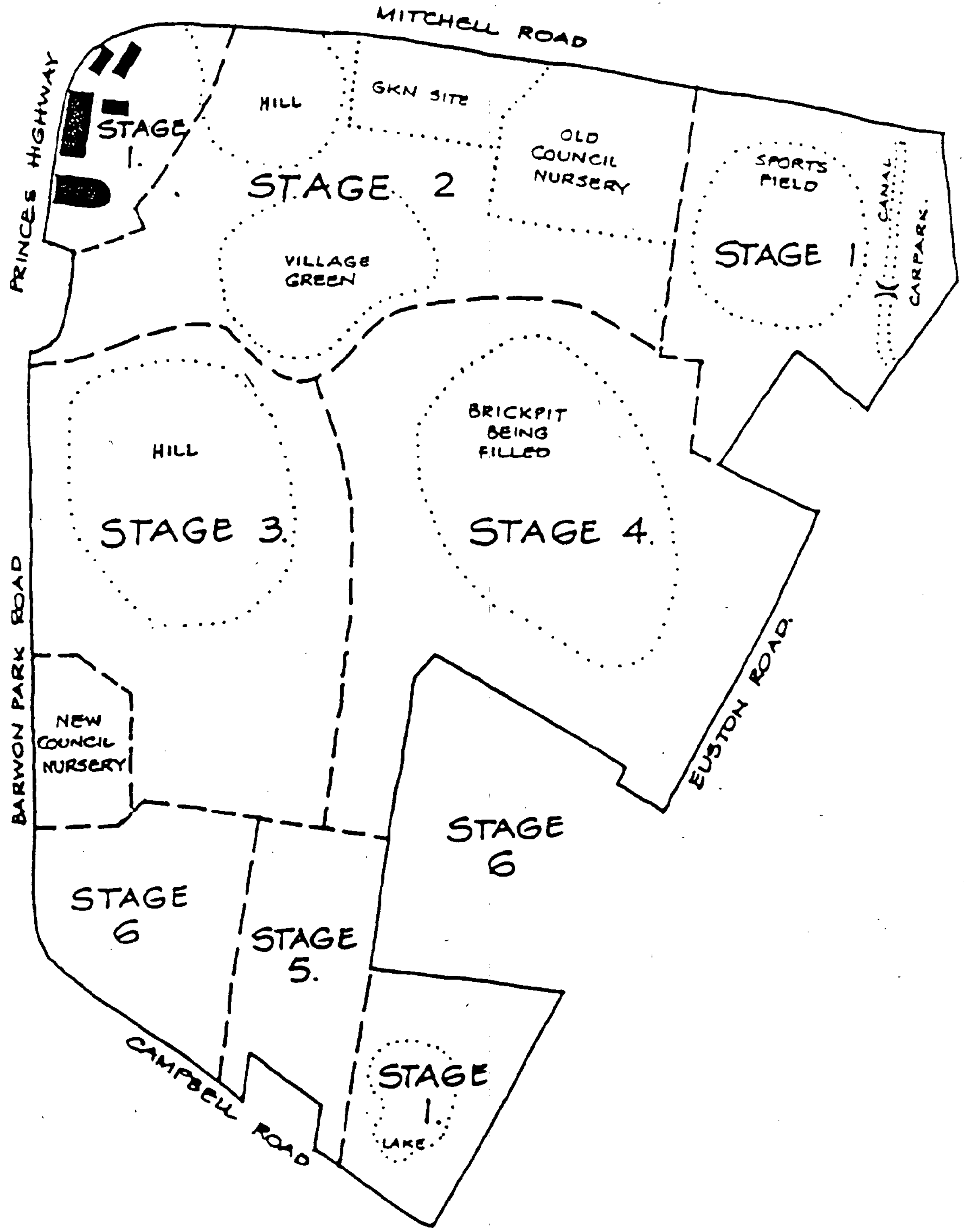
Ashfield Shale (Triassic) typically consists of about 40% quartz, 30% kaolinite, 20% illite and 10% siderite.



DESIGN CONCEPT

SYDNEY PARK

FIG 2



STAGING

SYDNEY PARK

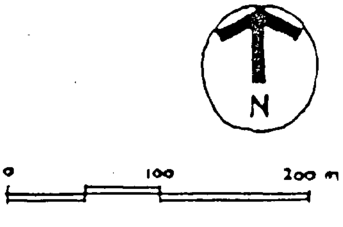


FIG 3

STOP 2: BMI PROSPECT QUARRY (Plate II)

Prospect Quarry is the largest quarry in Sydney and is ideally situated on the western edge of the district. Quarry products are bitumen screenings, road base and fill, coarse aggreate for concrete and other construction materials. Total production exceeds one million tonnes yearly.

The Prospect Intrusion is a dolerite/basalt/picrite igneous body emplaced during the Jurassic into strata of Triassic age. The intrusion is dish-shaped, measures about 2.5km long by 1.2km wide and up to 110m thick and occupies the boundary between the Wianamatta Group (above) and the Hawkesbury Sandstone (below).

A fine-grained chilled margin is of the order of five metres thick and forms the upper and lower intrusion margins.

The igneous rock types consist of varying proportions of olivine, pyroxene, plagioclase and iron minerals and secondary minerals are almost invariably present.

The following zeolite and secondary minerals have been recorded: - analcime, natrolite, pectolite, stilbite, prehnite, calcite, chlorite and clay minerals.

Notes on clay minerals developed in soils at Prospect are presented in the Appendix.

THE PROSPECT INTRUSION

1. FORM AND FIELD RELATIONS

The Prospect Intrusion (Jp) is a large sill-like alkaline dolerite-picrite intrusion. Being more resistant to weathering than the surrounding sedimentary rocks, it has produced the ridge named Prospect Hill. The ridge is elevated some 60 metres above the surrounding countryside and is approximately 1 km x 2 km in plan. Quarrying of the intrusion has proceeded from the central area of the hill.

Intrusion occurred during the Jurassic (radiometric date 160 to 168 million years) at a depth of less than 1 000 m in the lower part of the Wianamatta Group (Ashfield Shale, Minchinbury Sandstone and Lower Bringelly Shale). The sedimentary rocks are Triassic, being deposited some 40 to 70 million before the time of intrusion, formerly covered the central portion of the intrusion, but most of the shale has been removed during quarrying operations. Block faulting occurs around the edges of the intrusion. Vertical displacements of up to 20 metres from the regional levels have been measured in the sedimentary units both below and around the edges of the intrusion.

The intrusion is basin-shaped and up to 120 metres thick. In plan, it is roughly oval, with a small offshoot to the north. It measures approximately 2.5 km. by 1.1 km. and extends to a maximum of 80 metres below the floor of the quarry.

2. ROCK CLASSIFICATION

The three main rock types found in the intrusion are classified according to the percentage of original olivine contained in them.

% Olivine	Rock Type
<10	Dolerite (or alkaline diabase)
10 to 25	Olivine dolerite (or alkaline olivine diabase)
>25	Picrite

Picrite occupies the lower half of the intrusion. Olivine dolerite occurs above the picrite, especially in the central portion of the intrusion and dolerite occurs above the olivine dolerite in the central area and above picrite in the elevated edges of the intrusion.

Typical compositions of the rocks at Prospect are as follows:

Rock Type	% Plagioclase	% Olivine	% Pyroxene	% Secondary Minerals	% Opaques
Basaltic Chilled Margin	5-25	20-30	15-20	20-60	0-5
Dolerite	15-35	0-10	15-30	20-50	0-10
Olivine Dolerite	15-25	10-25	20-30	30-40	0-5
Picrite	10-25	25-40	15-30	30-50	0-5

The intrusion margins cooled very rapidly on contact with the cool sediments, thus producing a very fine grained rock. The resulting fine grained chilled margin is in the order of 5 m thick and envelope the intrusion.

At the intrusion margins, the processes that result in a single magma producing a number of rock types, did not have time to occur. Thus the chilled margin has approximately the same composition as the original magma and therefore approximates the average composition of all rock found in the intrusion.

3. ROCK DESCRIPTIONS

Basalt

The basalt is a very dark grey to black fine grained rock composed of plagioclase, pyroxene (titansalite) and olivine. Other constituents which vary in quantity include biotite, analcime, titanomagnetite, apatite and secondary clays and prehnite. It occurs in the basaltic chilled margin, and small dykes and sills associated with the intrusion.

Dolerite

The dolerite is a medium to coarse grained dark grey rock composed of plagioclase, titansalite, completely altered olivine, titanomagnetite and interstitial analcime. Accessory minerals include alkali feldspar, apatite, biotite, prehnite, sphene and ilmentite. Clay minerals, prehnite and zeolites sometimes constitute up to 50% of the rock.

Picrite

The picrite is a medium grained rock composed of olivine, tiansalite, plagiclase, titanomagnetite and interstitial analcime. The olivine is usually fresh, but contains rims and fractures composed of secondary clay minerals, including saponite. Accessory minerals include ilmentite, biotite, hornblende, apatite, sphene, and chrome spinel. Secondary minerals can occasionally constitute up to 70% of the rock. Fresh specimens of picrite are difficult to find as the saponite in the rock is expansive and the picrite rapidly breaks down on exposure to the atmosphere to a sand sized material.

The last rocks to form in the Prospect intrusion were pegmatite, syenite and aplite. These rocks occur as thick sheets, lenses and thin veins respectively. The pegmatite contains the same minerals as the dolerite. The syenite and aplite are similar in composition, containing both alkali and plagioclase feldspar, unlike the dolerite and pegmatite that contain very little alkali feldspar. Wilshire (1967) considers that the pegmatites were probably formed by dilution of dolerite by volatiles, that the syenites were formed by replacement of pegmatite and that the aplites were formed by secretion of liquid residues into fractures.

During or soon after the formation of the last rock types, hot water vapour containing volatiles appeared in the intrusion. These vapours were under pressure and contained those elements not yet completely utilised in the crystallisation of the primary minerals. This vapour circulated through the intrusion and altered the primary minerals by leaching and exchanging elements. This process is known as deuteric alteration.

All the rocks in the intrusion contain between 20 and 70 percent secondary minerals, most of which formed by deuteric action. The high percentages are due to very little vapour being lost from the intrusion. Olivine and plagioclase were particularly susceptible to alteration, the olivine forming green clays which include expansive saponite, and the plagioclase forming analcime and prehnite. Analcime, green clays, calcite, pectolite and zeolite minerals (in particular, natrolite and stilbite), occur both as newly formed minerals or as alteration products of earlier fokrmed minrals. They occur in the groundmass, as well as in amygdules, cavities and veins, and as joint coatings.

5. FIELD OBSERVATIONS

The following notes may be of assistance when looking for the geological features described:

Orientation

Pine trees have been planted to the east of Prospect Quarry. A crusher is located on the western side of Prospect Quarry and is at RL 80. The quarry floor is at RL 48.

Shale

Shale is generally weathered and can be recognised from a distance by its horizontal bedding. Only small pockets of shale currently remain above the intrusion and most of the brown material in the uppermost faces on the eastern side of the quarry is weathered, igneous rock.

Weathering

A great deal of the higher portions of the intrusion have been removed by erosion. Depths of weathering vary considerably depending on the durability of the rock types involved. Weathered dolerite typically contains spherical boulders of fresh dolerite.

Chilled Margin

Generally occurs at the top of a face since the overlying shale has to be removed before the rock below can be used to produce road building materials. From a distance the chilled margin appears as a dark band occupying the upper quarter of a face. It can also be distinguished by closely spaced parallel joints.

Dolerite

Occurs in the upper faces. A face of dolerite, when viewed at a short distance, can be distinguished from picrite by the sharp rock edges.

Picrite

Most of the bottom face is picrite. The picrite typically has rounded surfaces due to its rather rapid decomposition to sand sized mineral grains on exposure to water. On closer inspection, the rock has a slight greenish tone.

Hornfels

Shale adjacent to the chilled margin has been thermally metamorphosed to hornfels. Since only 0.5 m to 1 m of shale has been affected, the hornfels can only be seen by close inspection.

Deuteric Alteration

Secondary minerals resulting from dueteric alteration can be seen in hand specimens. They are generally dull due to their fine crystal sizes and most are green or white. Picrite breakdown generally occurs through secondary minerals resulting in the dull, greenish appearance of decomposing picrite. Secondary minerals also occur as joint and vug fillings, and in veins.

Aplite

A fine grained, white rock occurring in thin veins a few centimeters thick.

Pegmatite

A mafic pegmatite in Prospect Quarry is much coarser grained that the dolerite. From a distance, it appears as light-coloured sheets about 3 to 4 metres thick. The light colour is due to the presence of zeolite coatings on well developed joint surfaces, and also on occasions due to a relatively high proportion of feldspar and analcime.

Syenite

Has a similar appearance to pegmatite but has a medium grainsize and generally occurs as large pods and lenses rather than as sheets.

Prehnite

An attractive green secondary mineral. Good specimens are as common as fossilised bird's teeth in Prospect intrusion, so don't be disappointed if you don't find any.

Fault Zone

A small fault zone trending 002 degrees (M), and approximately 20 metres wide contains minor sulphide mineralisation. The main minerals are pyrite and marcasite. A variety of iron-oxy-hydroxides have resulted from the weathering of the primary sulphides. This gives the fault zone a distinct yellow-brown colouring. There is only minor displacement along the fault.

6. QUARRY PRODUCTS

Quarrying commenced at Prospect Hill in 1870. However, it was not until the 1920's that operations began on a relatively large scale. More than half of the present quarry has been excavated during the last decade.

The shale overburden is stockpiled to the north of Prospect Quarry and used for brickmaking and bund walls. Recently a large quantity of shale was used to strengthen Prospect reservoir, located adjacent to the western side of the intrusion.

The following products are produced from Prospect Quarry:

Fine Crushed Rock

0.6 million tonnes of fine crushed rock are produced annually. This product is used for the layer below the bitumen surfacing on roads. The product is graded by screening in the crusher plant (P2) so that all sizes below 20 mm are present. This grading ensures that the product will compact well to produce a dense layer that will distribute traffic load over a wide area on the weaker material below a road. Some 40 mm fine crushed rock is also produced. Fine crushed rock contains dolerite, crusher dust from the aggregate crushers and a small amount of shale.

Road Base

0.5 million tones of road base are produced annually. Road base is a graded product similar to fine crushed rock, however, it generally has a maximum particle size of 40 mm and no shale is added. 20 mm and 70 mm road base are also produced. Road base is used for a layer below the fine crushed rock layer where necessary. Road base contains fresh and weathered dolerite and olivine dolerite.

Aggregate

0.2 million tonnes of aggregate are produced annually. The products are single sized (5 mm, 10 mm, 14 mm, 20 mm or 40 mm) and are produced by screening in a separate crusher plant to that used to produce the other products (P3). Aggregate contains only basaltic chilled margin and dolerite. It is used in bituminous road surfaces.

Greystanes Gravel

Greystanes gravel is the quarry term for weathered or partially weathered dolerite. This product is used for rill, reinforced earth works, bridge abutments etc. -20 mm greystanes gravel is also used for unsealed tennis courts, running tracks etc.

Prospect Sand

Decomposed picrite and olivine dolerite which is crushed to -5 mm and then washed to remove the expansive clays is being trialled as a sand substitute. The material has been used in both concrete and bitumen trials and is performing very well.

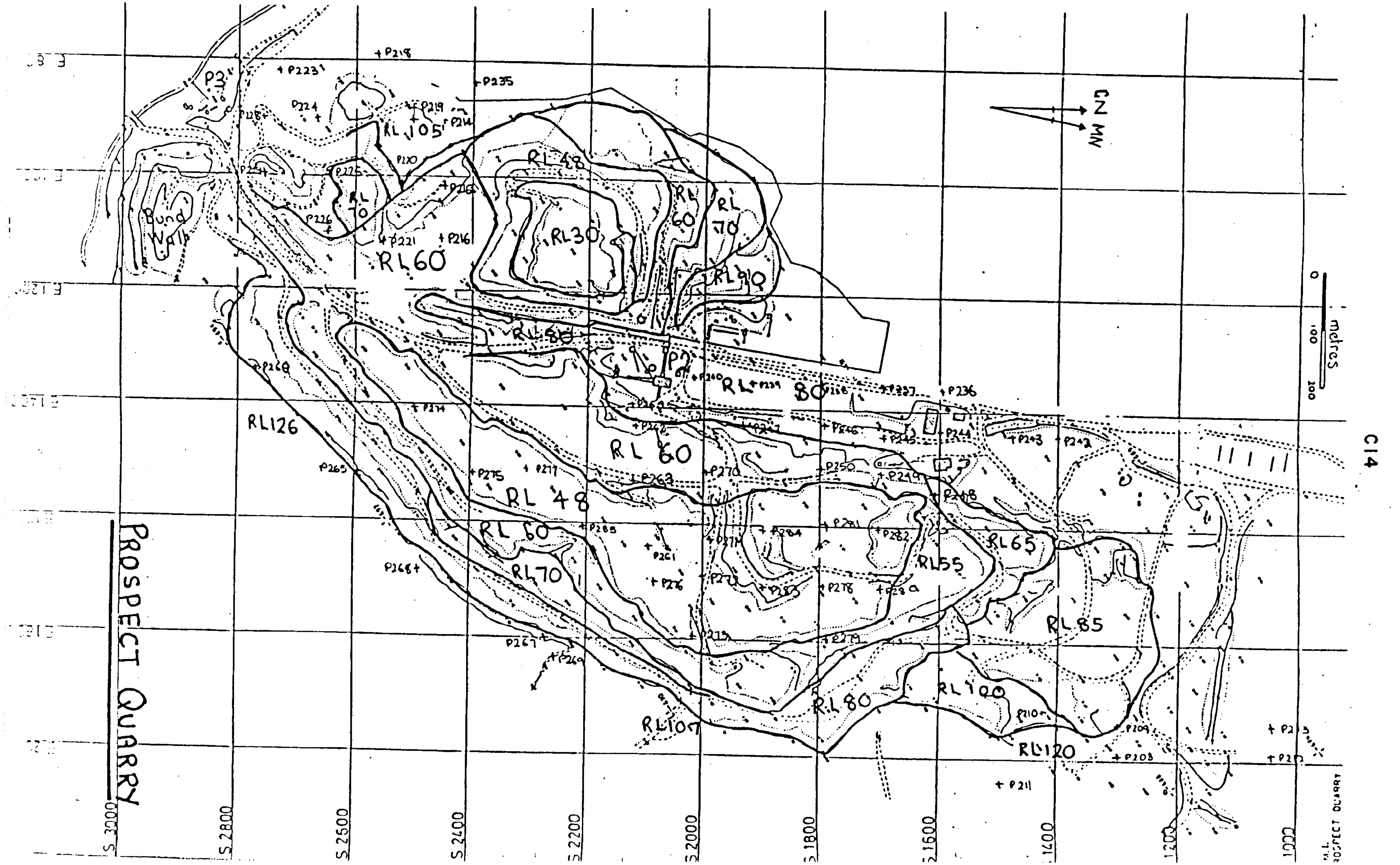
7. QUARRY OPERATIONS

There are two quarries currently operating in the Prospect Intrusion, BMI's Prospect Quarry and Readymix Farley's Styles Quarry.

BMI's operation consists of two crushing plants and associated screen houses, 3 rock drills, 2 front-end loaders, 13 rear end dump trucks, 1 water cart, 1 dozer, 1 general purpose loader, a lime stabilisation plant, a precoating plant and 2 weighbridges.

Rock is blasted using a mixture of ammonium nitrate and diesel oil. It is loaded onto 35 tonne heavy duty trucks and transported to one or two crushing plants depending on the product. Gyratory cone crushers of various sizes are used, the crushers getting progressively smaller as material moves through the plant. The crushed rock is screened and automatically recombined in the correct proportions for a graded product. Remaining oversized material is recirculated through the crushers. The product is loaded from the crusher into trucks and stockpiled or sent out directly for use. the graded-product crusher (P2) is controlled from a central control room by means of a mini computer. Radioactive caesium 137 is used in the equipment that weighs material passing on conveyor belts.

P2 consists of a 42-70 inch gyratory primary crusher, with two secondary and two tertiary crusher. P3 consists of a 48-42 inch primary jaw crusher and five secondary and tertiary crushers.



PROSPECT QUARRY
C14
GN
MN
0
100
200
metres
P3
P2
Bund Wall
RL 105
RL 70
RL 48
RL30
RL 60
RL 70
RL 90
RL 80
RL 60
RL 80
RL126
RL 60
RL 48
RL 60
RL70
RL55
RL65
RL 85
RL 80
RL 100
RL 120
RL 100
P218
P223
P235
P224
P219
P214
P228
P220
P225
P254
P226
P221
P216
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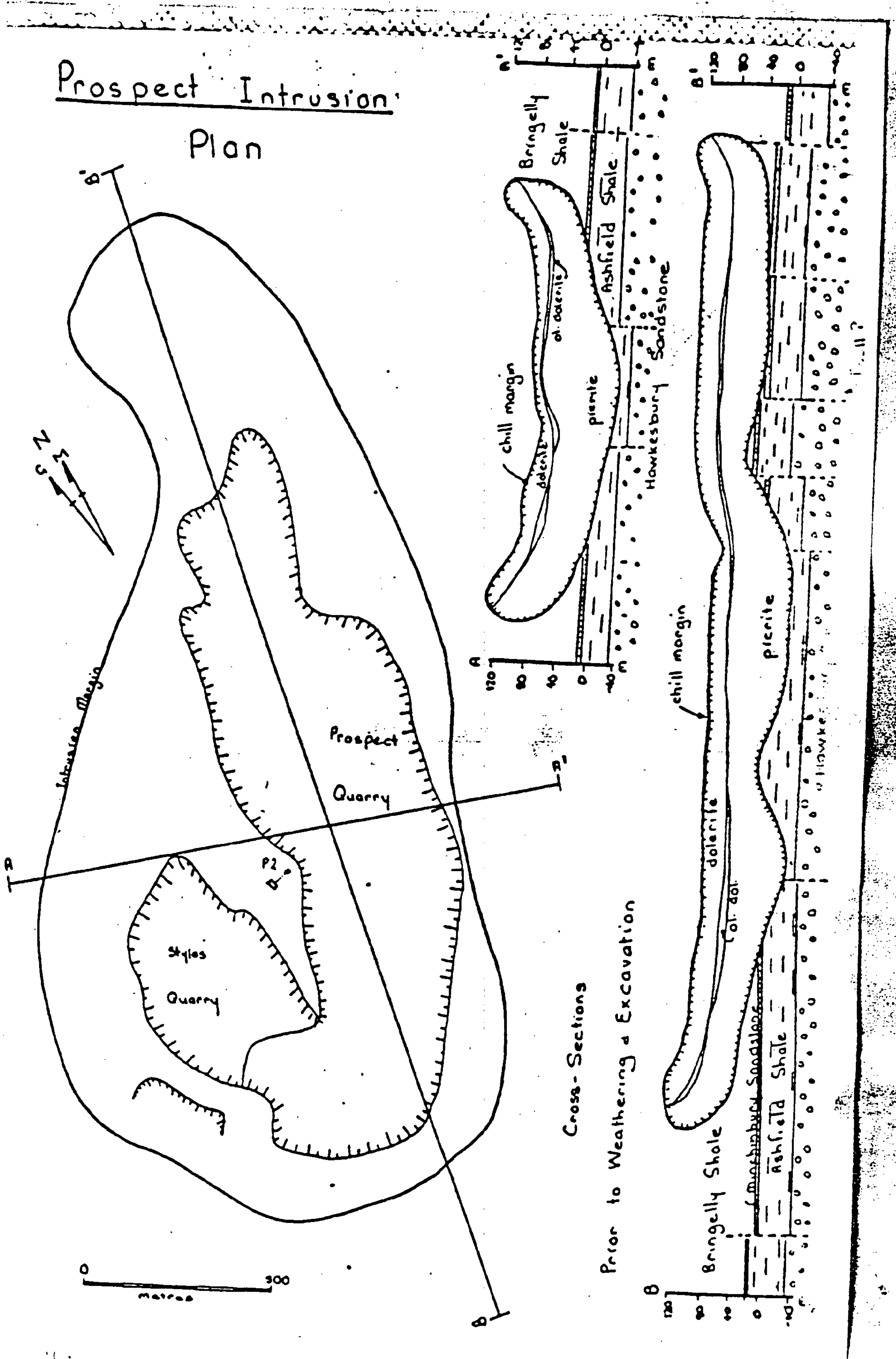
P281
P282
P268
P276
P273
P283
P278
P280
P267
P260
P279
P272
P210
P209
P208
P211
P213
P212
S 3000
S 2800
S 2500
S 2400
S 2200
S 2000
S 1800
S 1600
1400
1200
1000
PROSPECT QUARRY

Prospect Intrusion

Plan



Cross-Sections

Prior to Weathering & Excavation

STOP 3: MULGOA CLAY PIT (Mulgoa Quarries Pty. Ltd.) [Plate 12]

The Bringelly Shale comprises the top part of the Wianamatta Group and is now the chief source of raw material for the production of structural bricks in the Sydney Region. Bringelly Shale of Triassic age typically consists of approximately 40% quartz, 25% kaolinite, 20% illite, 10% illite-smectite mixed-layer clay and 5% siderite.

In the Mulgoa area near Penrith, strata belonging to the Bringelly Shale have been the subject of an intensive investigation by the NSW Department of Mineral Resources to assess the light-firing shale resources available for extraction and to provide a basis for future land-use planning.

Reserves of pale firing clay/shale available to the brickmaking industry in the Sydney Region are limited and the Mulgoa deposit constitutes the largest identified resource of pale firing clay/shale in the region.

A drillhole core from this locality will be displayed at Stop 4.

Notes on clay minerals in a soil developed on Bringelly Shale are presented in the Appendix.

STOP 4: LONDONDERRY CORE LIBRARY

The NSW Department of Mineral Resources provides facilities at Londonderry Centre for storing, examining and sampling drill cores. The collection of drill core currently exceeds 600,000 metres, 45% from coal drilling, 45% metalliferous and 10% from various other drilling programmes. The core is stored in 100,000 individual boxes and is the result of both company and government drilling programmes.

Selected drill cores laid out on the inspection benches are Razorback DDH1, Mulgoa DDH-M7, Coorabin RDH3, Gulgong-Home Rule Corehole MC6, Alliance Quirindi No. 1, Brogheda DDH1 and Merrygoen DH97 and the following notes apply.

DM Razorback DDH1

The Middle Triassic Wianamatta Group is dominantly a shaley formation and is the topmost stratigraphic unit in the Sydney Basin. The thickest section of Wianamatta Group sediments is 304.2 metres intersected in DM Razorback DDH1.

A detailed account of the strata is presented in NSW Geological Survey Bulletin 25 entitled "The Geology and Resource Potential of the Wianamatta Group" by C. Herbert (1979).

Stratigraphy is summarised in Fig. 4 and copies of the detailed log are available separately.

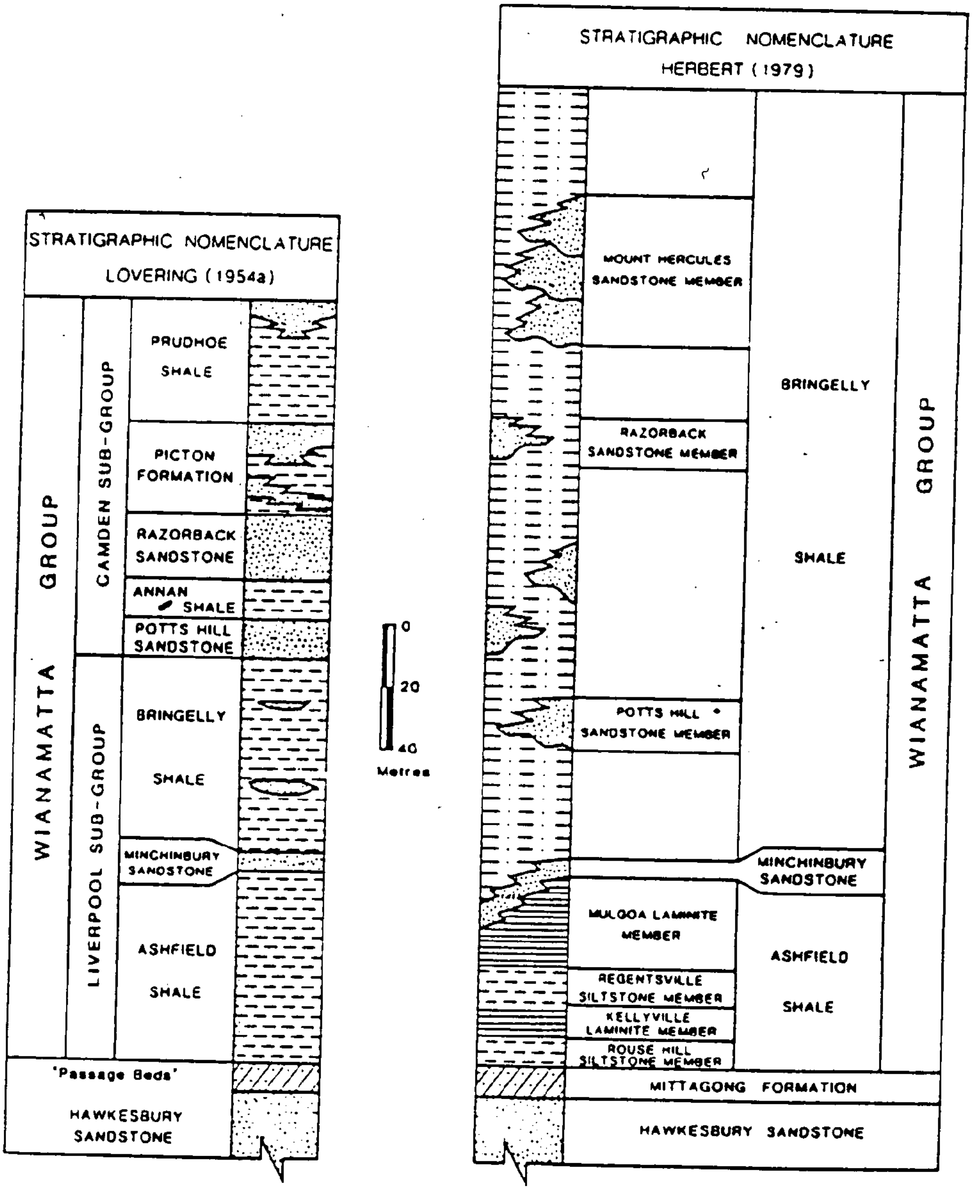

STRATIGRAPHIC NOMENCLATURE
LOVERING (1954a)
WIANAMATTA GROUP
CAMDEN SUB-GROUP
LIVERPOOL SUB-GROUP
PRUDHOE SHALE
PICTON FORMATION
RAZORBACK SANDSTONE
ANNAN SHALE
POTTS HILL SANDSTONE
BRINGELLY SHALE
MINCHINBURY SANDSTONE
ASHFIELD SHALE
'Passage Beds'
HAWKESBURY SANDSTONE
0
20
40
Metres
STRATIGRAPHIC NOMENCLATURE
HERBERT (1979)
WIANAMATTA GROUP
BRINGELLY SHALE
MOUNT HERCULES SANDSTONE MEMBER
RAZORBACK SANDSTONE MEMBER
POTTS HILL * SANDSTONE MEMBER
MINCHINBURY SANDSTONE
ASHFIELD SHALE
MULGOA LAMINITE MEMBER
REGENTSVILLE SILTSTONE MEMBER
KELLYVILLE LAMINITE MEMBER
ROUSE HILL SILTSTONE MEMBER
MITTAGONG FORMATION
HAWKESBURY SANDSTONE

FIG 4

DM Mulgoa DDH M7

In 1981, a drilling programme undertaken by the NSW Geological Survey at Mulgoa resulted in the identification of the largest known resource of light-firing clay/shale in the Sydney region.

Drillhole DM Mulgoa DDH-M7 contains excellent examples of the entire stratigraphic sequence seen at Stop 3. Copies of the detailed log are available separately.

DM Coorabin RDH3

Transported kaolin of Tertiary age in the Oaklands Sub-basin part of the Murray Basin is used for refractories, pottery and whiteware ceramics.

Coorabin RDH3 was drilled in the vicinity of the main clay workings during a coal drilling programme and provides a typical section through the clay-rich strata. The bore summary is presented in Fig. 5.

Gulgong - Home Rule Corehole, MC6

The Gulgong - Home Rule district near Mudgee is possibly the chief source of ceramic ball clay, refractory bond clay and white filler clay in NSW.

Discontinuous lenses of white and grey ball clay are developed within a sequence of grit, sand and carbonaceous clay of Cainozoic (Pliocene-Pleistocene) age and overlying the Gulgong Granite, a plutonic intrusion of Carboniferous age. The clay deposits formed within discontinuous basins along major palaeodrainage systems.

The Gulgong Clay Province is currently the subject of several major exploration and

C20

N.S.W. Dept of Mines – Coal Section   BORE SUMMARY   Page 1 of 1

Hole sizes, depths: 5¼ ins – 302'8"
Casing sizes, depths: 6" Surface Casing to a depth of 4 ft
Casing extracted: Whole length
Plugs, depths: Bore plugged with cement.
Non-cored intervals:

Geophysical logs and depths:
GAMMA; NEUTRON; H.R DENSITY, H.R. DENS. DETAIL, S.P, RESISTIVITY; TEMPERATURE.

BORE NAME D.M. COORABIN R.D.H. 3

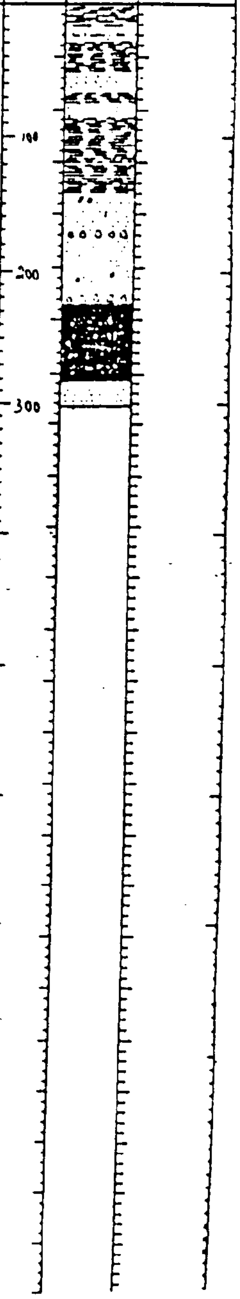
Bore Filing Systems – References

Dept of Mines M'film Nos

1:50,000 Sheet OAKLANDS 8126 - IVN (TM, ~~other~~)
GR DA 274633. Bore No. 8

CHEMICAL ANALYSES AND OTHER SEAM TESTS CONDUCTED

SEAM NAME OR OTHER IDENTIFICATION	L Detailed G Geophysical log R Radiometric	A Analysed P Proximate U Ultimate	K Gray King C CSN	Pl Plastometry D Dilatometry	R Reflectance M Macerals	S Sulphur P Phosphorus Cl Chlorine	G Sp Gr E Sp En (CV)	H HG Index F Fus. Points	W Washability	Mi Min Matter A Ash Anal		Stratigraphic Units		DEPTH Feet Metres	GRAPHIC LOG	REMARKS (Seam identification, stratigraphy etc.)



BORE NAME: D.M Coorabin R.D.H 3
COLLAR LEVEL: 420 ft. DATUM: A.S.L.
TOTAL DEPTH: 302'8"
LOG AND LEVEL: Approximate, surveyed (strike out one)
DATE COMMENCED: 8 · 11 · 1973 COMPLETED: 10 · 11 · 1973
SUNK BY: W.L. SIDES & SON PTY. LTD. (Melbourne)
FOR: DEPARTMENT of MINES
STANDING WATER LEVEL:
REF. FILE OR INFORMATION SOURCE: M73/7611

LOCATION:
A COUNTY URANA PARISH CLEAR HILL
PORTION: On Road Res. W of Por. 45
B 1/50,000 SHEET (T.M., ~~other~~) OAKLANDS 8126 - IVN
GR DA 274633.

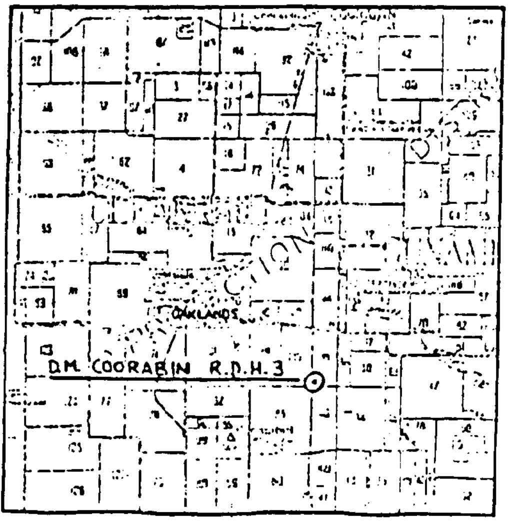


FIG 5

development projects and the Gulgong - Home Rule Corehole MC6 from the Parish of Stubbo provides an example of a section through a typical deposit.

Depth (metres)		Description
from	to	
0	5.6	Sand, silt, sandy clay (no core)
5.6	7.5	White clay
7.5	8.0	Grey clay, iron staining
8.0	8.5	Grey sandy clay
8.5	9.0	Altered basalt

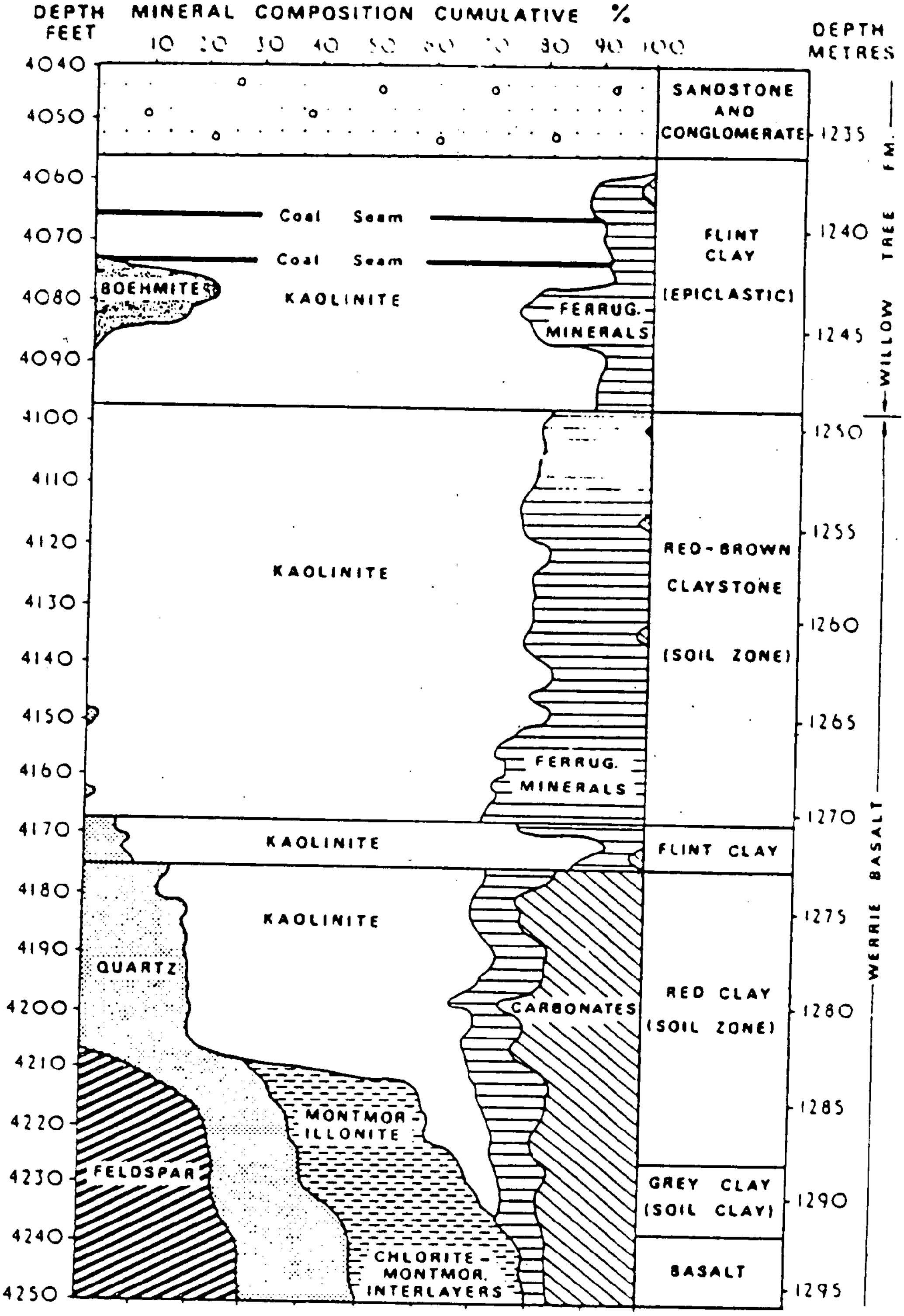
The dominant clay mineral is kaolinite (usually disordered) and quartz is the most abundant non-clay mineral.

Alliance Quirindi No. 1 Bore

Kaolinite clayrocks (flint clay) and fossil laterite of Early Permian age in the core of the Alliance Petroleum Quirindi No. 1 Bore.

The Quirindi Bore commenced in Jurassic strata about 30km to the west of Quirindi and penetrated a conformable sequence of Mesozoic and Permian strata to a depth of 1275 metres, terminating in the Werrie Basalts approximately 45 metres below the base of the Willow Tree Formation (Greta Coal Measures equivalents).

The Werrie Basalts at the base are characteristic of occurrences elsewhere in that they are considerably altered by hydrothermal activity and comprise, in addition to labradorite, abundant chlorite, calcite, chalcedonic quartz and hematite. Much of the chlorite is interlayered with montmorillonite.



Section of the lower part of the Quirindi Bore showing the mineral composition of the various zones.

FIG 6

The basalts pass up into a grey clay zone (see Fig. 6) succeeded by red clay containing abundant white blebs of carbonates. Although the basaltic textures are preserved throughout the grey and red clay zones, the mineralogy grades from an assemblage rich in felspar, chlorite, carbonates and quartz to one in which kaolinite is the only aluminosilicate mineral present.

Overlying the red clay zone is about two metres of kaolinite clayrock. A marked change in mineral composition is apparent in this interval with kaolinite being rather more abundant and the quartz, hematite and carbonate contents somewhat diminished.

The kaolinite clayrocks are succeeded by nearly 21 metres of red-brown claystone that lacks a clastic structure but rather resembles the red and grey claystones lower in the sequence in that the basaltic texture is retained intact. Apparently this red-brown claystone represents a basaltic flow altered _in situ_.

The kaolinite clayrocks above the red-brown claystone have a thickness of more than 12 metres and are fairly coarse-grained. The clasts, some of which exceed 4mm in diameter, generally have pseudomorphs of volcanic textures although fragments composed of oriented kaolinite microlites are evident. Kaolinite which for the mostpart has a disordered structure is the dominant mineral and is associated with hematite near the base but higher in the sequence the iron is in the form of siderite. Boehmite, present as granular aggregates and also as vermicular crystals is a prominant constituent between the 1242 and 1245 metre levels. Two thin coaly bands occur toward the top of the zone.

Quartz-lithic sandstones overlie the kaolinite clayrocks.

Similar sequences of lateritic soils and kaolinite clayrocks are developed on the Werrie Basalts in the Boggabri and Wingen areas.

DM Brogheda DDH1

In the Permian Newcastle and upper part of the Singleton Coal Measures bentonitic clays, tuffaceous beds and bentonitic claystones are not uncommon.

DM Brogheda DDH1 is one of many bores drilled by the Department of Mineral Resources in the Denman-Scone area (Hunter Valley) as part of a project to assess the suitability and reserves of coal available for a possible future coal-to-oil conversion plant.

The bore also provides several examples of the tuffaceous beds in the coal measures. The results of evaluations of these beds as commercial bentonites are tabled below:

[illegible]	[illegible]	[illegible]	[illegible]	EXCHANGEABLE CATIONS [illegible]				CATION EXCHANGE CAPACITY [illegible]	[illegible]	LIQUID LIMIT	[illegible]	[illegible]	ELECT-RICAL CONDUCT-IVITY [illegible]	pH	MINERALOGICAL COMPOSITION X-RAY DIFFRACTION				
				[illegible]	[illegible]	[illegible]	[illegible]								SMECTITE	KAOLINITE	QUARTZ	OTHER MINERALS IDENTI-FIED	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	TRACE	TRACE		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	TRACE	TRACE		[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	LOW	LOW		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	LOW	LOW		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	TRACE	TRACE		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	TRACE	TRACE		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	TRACE	TRACE		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	LOW	TRACE		[illegible]

A detailed account of the bentonite clays is presented in NSW Geological Survey, Mineral Resources No. 45 entitled "Bentonite and Fullers Earth in New South Wales" by G. G. Holmes.

Graphic log is presented in Fig. 7 and copies of the detailed log are available separately.

Dm Brogheda DDH 1

BGH01

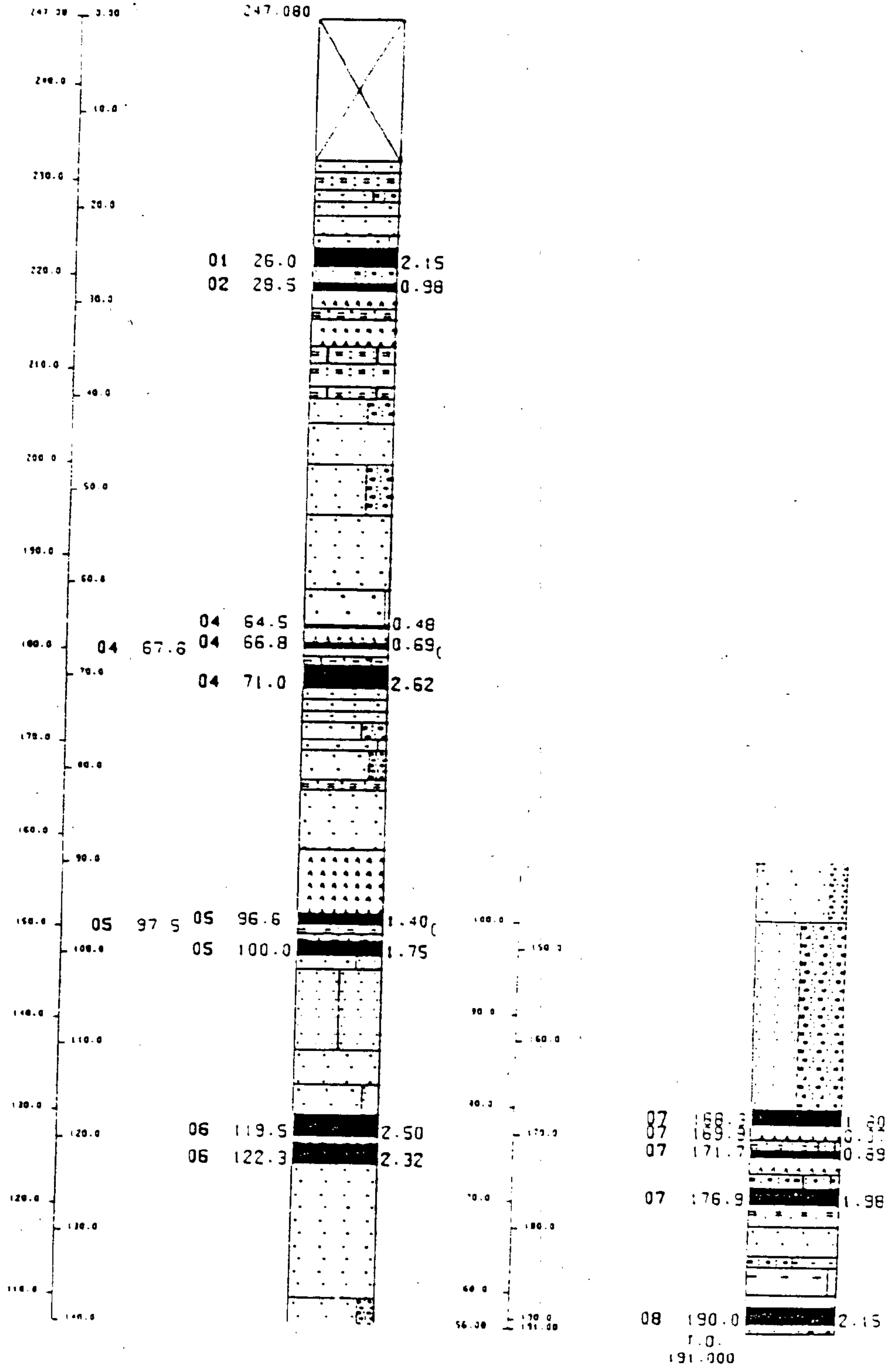


FIG 7

Merrygoen DH97

The Jurassic Ukebung Creek Claystone contains beds of flint clay used in the manufacture of refractories. The Merrygoen Flint Clay Deposit near Dunedoo is the major producer of flint clay in NSW and drillhole DH97 contains thin beds of Merrygoen type clay. The drillhole is neither typical nor ideal and is presented on the basis of its being the best available at the time. Log sheet with ten chemical analyses is presented in Fig. 8.

A detailed description of Merrygoen Flint Clay is given by M. L. Higgins and F. C. Loughnan (1973) in Proc. Australas. Inst. Min. Metall., 246, 33-40.

PROPERTY AND/OR DEPOSIT NAME: Sell's

DRILL HOLE NO: D.H. 97

FROM	TO	INT	SAMPLE NO.	DESCRIPTION	CHEMICAL ANALYSIS								
					IL	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O
0	26'0	26'0		Augered - shale, etc.									
26'0	30'8	4'8		Sandstone - banded (only lower 8" retained									
30'8	31'5	0'9		Shale - banded									
31'5	32'6	1'1		2nd Grade, non pellet, develops small pellets, slightly carbonaceous									
32'6	33'8	1'2	1	2nd Grade, coarser pellet, coaly, slightly silty	26.9	60.3	4.2	32.2	2.3	40	25	10	.40
33'8	35'9	2'1		2nd Grade/siltstone									
35'9	36'1	0'4		2nd Grade, fine pellet, poor, silty									
36'1	37'10	1'9	2	2nd Grade, coarser pellet, poor, silty	18.5	61.2	4.5	31.0	1.7	45	.10	05	.10
37'10	38'7	0'9	3	1st Grade, coarse pellet	14.6	60.5	.4	30.4	1.4	35	.05	05	<.05
38'7	39'0	0'5		Coal and special claystone									
39'0	40'0	1'0		2nd Grade, weathered, coaly									
40'0	42'8	2'8	4	2nd Grade, fair to good, coaly some pyrite present	25.0	58.9	.7	36.0	2.8	.20	.15	.05	.40
42'8	44'0	1'4	5	2nd Grade, fair to good, paler	11.0	64.5	1.1	30.5	1.8	.25	.25	.05	1.20
44'0	45'0	1'0		Siltstone, some banded									
45'0	45'10	0'10	6	2nd Grade, fair to medium	12.9	63.7	.6	31.9	2.1	.25	.15	<05	.80
45'10	46'1	0'3		2nd Grade, banded, silty									
46'1	46'5	0'4		1st Grade, coarse pellet									
46'5	47'5	1'0		2nd Grade, fair to poor									
47'5	48'2	0'9	7	2nd Grade, medium, iron pellet	12.5	63.7	9	31.7	1.6	25	.45	05	1.05
48'2	48'6	0'4		2nd Grade, poor, silty									
48'6	48'11	0'5		2nd Grade, good									
48'11	50'0	1'1		2nd Grade, coaly and silty									
50'0	52'3	2'3		2nd Grade, slightly coaly, fair									
52'3	54'9	2'6		2nd Grade, coarser, sandy									
54'9	55'5	0'8	8	1st Grade	13.5	5.75	.5	40.7	1.0	.25	.05	.05	.10
55'5	56'1	0'8	9	2nd Grade, coarse pellet, sandy	14.1	62.7	.9	34.6	1.4	.30	05	.10	.30
56'1	56'11	0'10	10	1st Grade, coarse pellet, slightly coaly	15.3	60.3	.6	36.3	1.7	15	<05	<.05	.25
56'11	60'0	3'1		2nd Grade, coaly and silty bands									

FIG 8

STOP 5: LONDONDERRY CLAY PIT (PGH) (Plate 13)

The Tertiary plastic clay unit designated the Londonderry Clay, ranges up to ten metres thick and overlies the basal Tertiary Rickaby Creek Gravel. The clay is used as a raw material in the manufacture of pipes and tiles.

Preserved in the clay is a lateritic profile consisting of a hardened ironstone at the top (1 - 2 metres thick) passing gradually down into a dense mottled clay zone. This zone consists of yellow, red, brown and orange clay with white and grey phases. In places, a pallid zone has been preserved in the form of a white or cream coloured clay, commonly very siliceous in composition.

Throughout the entire clay unit, sand is found in patches and aggregates with silt, wholly or partly cemented by iron oxide and forming relatively coherent masses. In addition, lateritic pisolites and nodules are abundant. The plasticity and moisture content of the clay unit are variable. Generally the clay is relatively impervious.

It is probable that the clay was originally an overbank deposit of silt laid down during periods of flooding along the Nepean River subsequent to migration of the stream course towards its present position. Under the conditions imposed by lateritisation, the silt has been transformed to clay and the underlying gravel has been severely leached.

The clay consists of varying proportions of quartz and kaolinite which are the dominant minerals with smaller amount of smectite, illite, mixed layered clays and goethite.

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The clay consists of varying proportions of quartz and kaolinite which are the dominant minerals with smaller amount of smectite, illite, mixed layered clays and goethite.

STOP 6: LONDONDERRY SAND PIT (Readymix-Farley) [Plate 14]

The Londonderry Clay is overlain by a sand unit up to eight metres in thickness. Known as the Agnes Banks Sand, this is a clean, white, quartz sand near the surface, grading down into a yellow brown sand containing a higher proportion of clay-sized material and iron oxides. Generally, the sands are medium grained and composed of sub-rounded quartz grains with varying proportions of limonite-coated quartz grains and clay sized particles. A typical analysis of the more widespread yellow sand would be 91% quartz, 4% kaolinite, 2% felspar and 3% limonite. The clay content increases with depth and in some places, white clay with 33% kaolinite occurs immediately overlying the Londonderry Clay.

The boundary between the Londonderry Clay and the overlying sand is sharp and in isolated areas is marked by a thin layer of small, well-rounded quartz pebbles. Overall, the sand has been strongly leached and sedimentary structures destroyed. Weathering processes have caused the decomposition of the clay minerals in places to produce gibbsite.

The origin of the sand is controversial. Some workers contend that the east-west trending, linear sand bodies are sand dunes and these indicate a predominantly aeolian origin. Others have suggested that the sand is predominantly fluvial and the body or sand sheet has undergone subsequent redistribution by dominantly westerly winds and weathering processes.

Quarry products include washed sands mainly used for concrete. Water from the Nepean River is used for the washing process. The tailings disposal area consists of several connected dams. The amount of tailings accumulated is approximately 0.5 million tonnes (dry basis) and the rate of generation of tailings is approximately 5,000 tonnes (dry basis) per month. When the dams are filled, the tailings in them are allowed to dry. Trees and vegetation are then planted in the dams. Clay testing reports are presented in Figs. 9 and 10.

The sand washing plants in the Sydney area generate tailings at a rate of more than 400,000 tonnes per annum and a major programme of testing of the tailings has been undertaken by the NSW Department of Mineral Resources (Chemical Laboratory Report No. 82/2 by J. Wong).

Notes on the clay minerals associated with the soil profile in the sand dunes at Agnes Banks are presented in the Appendix.

N.S.W. DEPARTMENT OF MINERAL RESOURCES - CHEMICAL LABORATORY

CLAY TESTING REPORT

Sample No.: L80/2149 Description: Sand washing tailings

Location: Farley and Lewers, Londonderry.
Surface of tailings dam, 10 m from the discharge.

Moisture Content: 43%
(as received)

Mineralogical Composition

- Quartz - high
- Halloysite/Kaolinite - high
- Mica - low
- Feldspar - low
- Anatase - trace
- Goethite - trace
- Smectite - trace

Chemical Analysis
(air dry basis)

	%
SiO_2	64.4
Al_2O_3	19.5
Fe_2O_3 (Total)	4.15
MgO	0.34
CaO	0.02
Na_2O	0.12
K_2O	1.53
TiO_2	0.68
P_2O_5	0.04
MnO	0.02
SO_3	<0.1

Particle Size Analysis
(% by weight)

+75 um	20
-20 um	72
-10 um	65
-5 um	56
-2 um	47
-1 um	41

Water Soluble Salts: 0.

pH
(1:5, sample:water): 5.

Plasticity Limits

Plastic Limit:	27
Liquid Limit:	62
Plasticity Index:	35

Drying Characteristics

Linear drying shrinkage:	8 %
Water loss :	37 %
Dry green strength :	high
Tendency to crack :	no

Working Properties

Very plastic, soft.

Firing Characteristics

Temp. °C	Shrinkage %	Water Absorption %	Colour (B.S. 381C:1964)	Hardness
950	0	22	Salmon Pink	moderate
1000	0	22	Salmon Pink	moderate
1050	3	18	Salmon Pink	moderate
1100	3	17	Salmon Pink	moderate
1200	7	9	Terra Cotta	hard
1300	8	4	Light Stone	v. hard
1400				

Loss on ignition (110°C-1000°C): 8.6%

FIG 9

N.S.W. DEPARTMENT OF MINERAL RESOURCES - CHEMICAL LABORATORY

CLAY TESTING REPORT

Sample No.: L80/2151 Description: Sand washing tailings

Location: Farley and Lewers, Londonderry.
Surface of a partially dry dam.

Moisture Content: 36% (as received)

Mineralogical Composition

Quartz - high
Halloysite/Kaolinite - high
Mica - low
Feldspar - trace
Goethite - trace
Smectite - trace

Chemical Analysis (air dry basis)

	%
SiO_2	62.2
Al_2O_3	20.3
Fe_2O_3 (Total)	3.48
MgO	0.39
CaO	0.02
Na_2O	0.12
K_2O	1.63
TiO_2	0.73
P_2O_5	0.04
MnO	0.02
SO_3	<0.01

Particle Size Analysis (% by weight)

+75 um	9
-20 um	83
-10 um	72
-5 um	64
-2 um	55
-1 um	48

Water Soluble Salts: 0.04

pH
(1:5, sample:water): 4.8

Plasticity Limits

Plastic Limit:	27
Liquid Limit:	61
Plasticity Index:	34

Drying Characteristics

Linear drying shrinkage:	9 %
Water loss :	39 %
Dry green strength :	high
Tendency to crack :	no

Working Properties

Very plastic, soft.

Firing Characteristics

Temp. °C	Shrinkage %	Water Absorption %	Colour (B.S. 381C:1964)	Hardness
950	1	23	Salmon Pink	moderate
1000	1	23	Salmon Pink	moderate
1050	4	17	Salmon Pink	moderate
1100	4	17	Salmon Pink	moderate
1200	8	6	Terra Cotta	hard
1300	10	0	Light Stone	v. hard
1400				

Loss on ignition (110°C-1000°C): 10%

FIG 10

APPENDIX

Notes on the Clay Minerals Associated with the Soil Profiles

NOTES ON CLAY MINERALS DEVELOPED IN SOILS ON ALKALINE OLIVINE DIABASE at Prospect NSW. Profile 73 is a Prairie soil belonging to Reservoir Clay series and is the mid-slope member of the catena. Layer depths are 731 0-10cm; 733 20-30cm; 735 57-80cm.

LAYER 731 (35% <2 um, A horizon). This layer contains a smectite swelling, when glycerated, to 1.75nm from 1.49nm Mg a.d. and collapsing to 1nm , Mg 300C. Potassium saturated and air dry the spacing is 1.3nm. A small amount of chlorite is present as shown by the small reflection at 1.45nm glycerated and at 300C. The chloritised mineral is thermally stable and the low angle tail to the 1nm reflection at 550C implies a chlorite/mica interstratification at that temperature. This suggests that the smectite is in fact interstratified with chlorite to a small extent. No certain identification of kaolinite can be made.

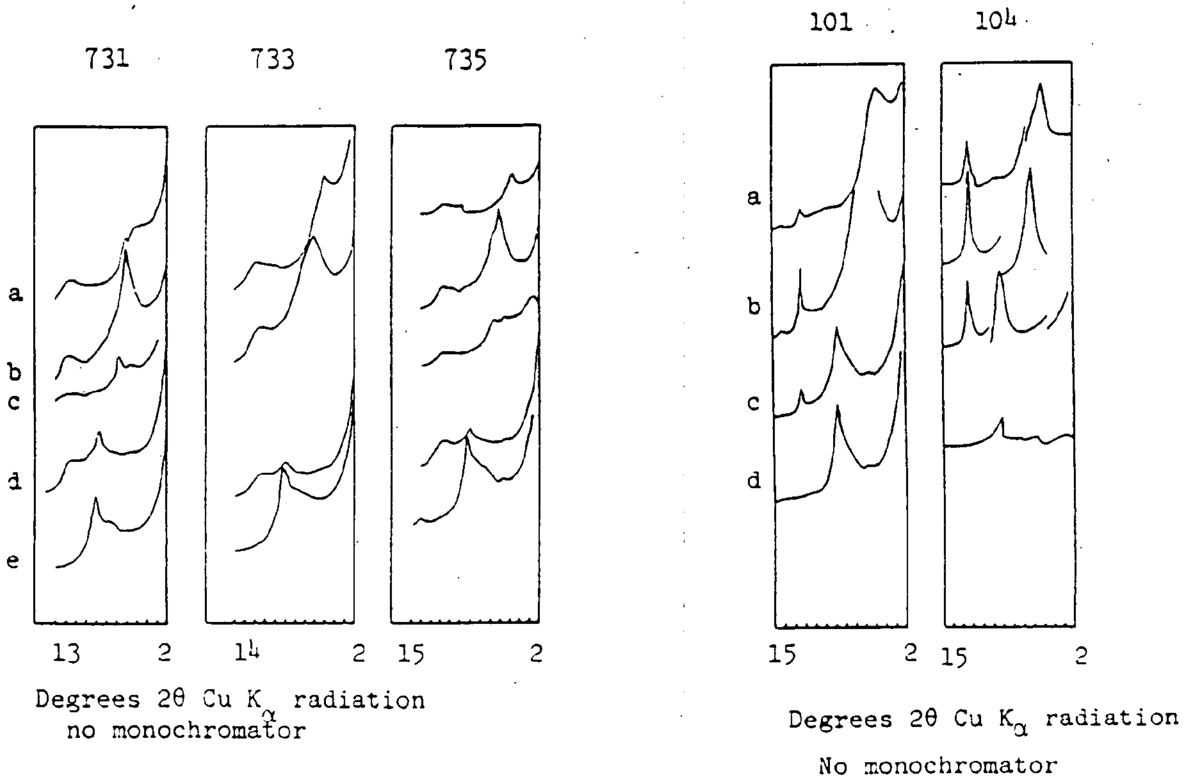
LAYER 733 (B_1 horizon). The clay mineralogy is generally similar to 731 but there is evidence of some more chlorite being present because the low angle tail to the 1nm reflection is enhanced.

LAYER 735 (B_2 horizon). This layer has a similar mineralogy to 733 and 735 bu more chlorite is present and some persists as a separate phase at 550C. Enhancement of the reflection on heating from 300C to 550C suggests a geological origin.

Profile 10 is a Black Meadow Soil of the Greystanes series and occurs at the bottom of the slope and is therefore the lowest member of the catena developed on the basic igneous rock. The profile contains free calcium carbonate below 40cm. Layer depths are 101 0-10cm; 104 90-140cm.

LAYER 101 (59% <2 um, A horizon). The clay fraction is dominated by smectite with a small amount of chlorite which persists to 550C. The low angle tail to the 1nm reflection suggests some mica/chlorite interstratification at high temperatures and implies the smectite probably is interstratified with a some chlorite. A small amount of kaolinite is also present.

LAYER 104 (77% <2 um, B horizon). This deeper layer shows less evidence of chloritisation and much more kaolinite is present than in 101.



Diffraction patterns Cu K radiation. Treatments for 73 profile are a) Mg glycerated; b) Mg air dry; c) K air dry; d) Mg 300C; e) Mg 550C. Treatments for profile 10 are a) Mg glycerated; b) Mg air dry; c) K 300C; d) Mg 550C.

NOTES ON CLAY MINERALS DEVELOPED IN SOILS ON ALKALINE OLIVINE DIABASE at Prospect NSW.

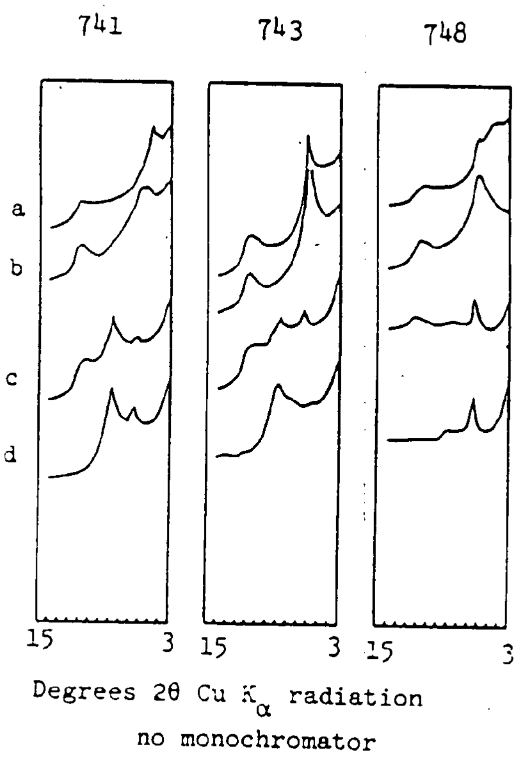
Profile 74 is a Reddish Chocolate Soil belonging to the Prospect Clay series. It is the uppermost member of the catena developed on the basic Prospect intrusion. Layer depths are 741 0-10cm; 743 20-3-cm; 748 80-90cm.

LAYER 741 (39% <2 um, A horizon). The 1.51nm reflection (Mg a.d.) with a second order reflection at 0.75nm close to the kaolinite reflection suggests smectite and this is confirmed by the glycerated sample which swells to 1.84nm. When heated to Mg300C a small amount of chlorite (1.4nm) becomes apparent. The shift of the kaolinite spacing on heating suggests a kaolinite/smectite interstratification. The collapse of the chlorite to 1.33nm at 550C shows that it is very thermally stable.

LAYER 743 (48% <2um, B horizon). The 1.45nm in Mg A.D did not change on glyceration suggesting a vermiculite or a chlorite. Heating to 330C caused some collapse of the chlorite to 1.36nm and another mineral possibly the vermiculite to 1nm. The broad low angle shoulder to the kaolinite reflection at 300C suggest some interstratification with smectite. Heating to 550C results in a mica/ chlorite interstratification due to collapse of some of the chlorite interlayers. Layer 746, 50-70cm, has a similar mineralogical composition.

LAYER 748 (24% <2 um, B_2 C horizon) contains a smectite swelling to 1.85nm when glycerated and a chlorite collapsing to 1.33nm at 300C. A small amount of kaolinite is present and may be interstratified with smectite. The partially collapsed chlorite (1.36nm) is thermally stable and persists in the 500C treatment.

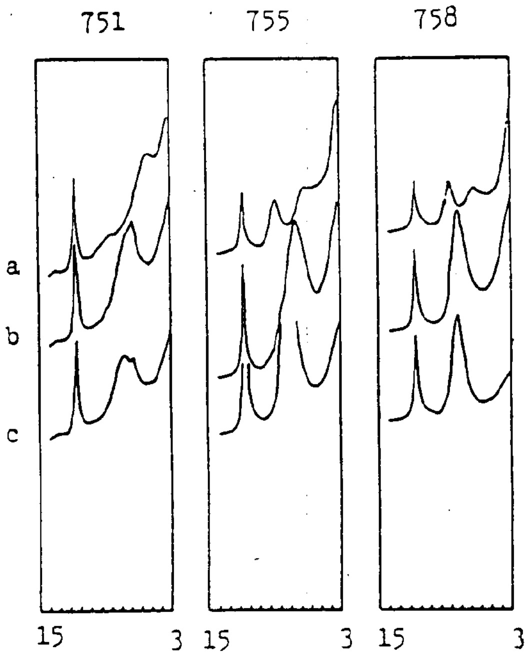
The weathering sequence in this profile seems to be a destruction of the smectite towards the surface as well as loss of the chlorite. The chlorite was dissolved by 2M HCl (30 minutes) as was the smectite suggesting that the smectite was high in iron. The chlorite was unaffected by treatment with dilute hot sodium carbonate. The 1.36nm chlorite spacing is sometimes associated with interlayers rich in iron.



Diffraction patterns of <2 um clay. The treatments are: a) Mg glycerated; b) Mg air dry; c) Mg 300C; d) Mg 550C. Cu K radiation, monochromator not fitted.

NOTES ON CLAY MINERALS DEVELOPED IN SOILS ON BRINGELLY SHALE at Prospect NSW.

Profile 75 is a Red Podsolic Soil of the Cumberland Clay Loam series and is developed on shale about 0.5 km north of the basic igneous intrusion. The profile contains kaolinite as the dominant clay mineral with a smectite/mica interstratified mineral and a small amount of separate phase smectite in Layer 751 (0-10cm). In Layer 755 the interstratified smectite/mica is present in greater amount and contains more mica. In Layer 758 (150-180cm) the interstratification is dominated by mica and a small amount of vermiculite may be present. Comparison of the mineralogy of profile 110A with 75 shows the way in which the kind and degree of interstratification of mica and smectite varies in the County of Cumberland.



Cu Kα radiation
no monochromator

Diffraction patterns of Profile 75, treatments are a) Mg glycerated; b) Mg air dry; c) K air dry.

NOTES ON CLAY MINERALS IN A SOIL DEVELOPED ON BRINGELLY SHALE at University of Sydney Farms, Cobbity NSW.

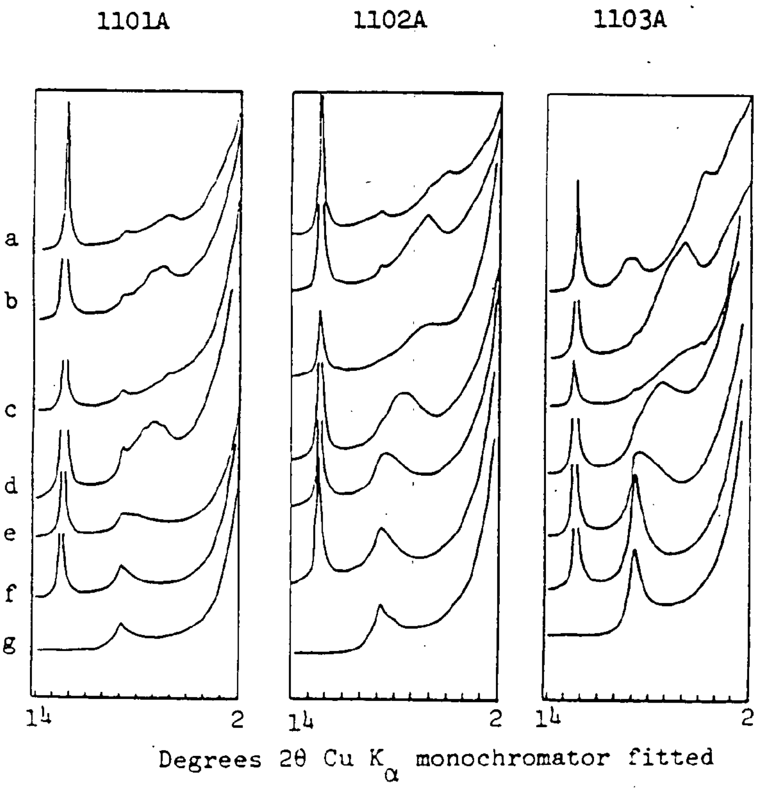
Profile 110A is Red Podsolic Soil belonging to the Cumberland Clay Loam series. Layer depths are 1101A 0-15cm; 1102A 15-45cm; 1103A 45-65cm; weathered shale was encountered at 65cm.

LAYER 1101A (19% <2 um, A horizon). Dominant clay mineral is a kaolinite (d=0.712nm in all treatments and disappears at 550C). Random powder shows kaolinite is extensively b-axis disordered. Reflections at 1.0nm are due to a small amount of illite. The reflection at 1.37nm Mga.d. suggests a mica/smectite interstratified mineral and the presence of swelling lamellae is confirmed by glyceration and by the absence of a reflection at 1.37nm in the K wet treatment. The small residual reflection at 1.43nm in both of the above treatments suggest the presence of chloritised smectite. The low angle shoulder to the 1.0nm reflection in K 110C confirms the presence of chlorite which now appears to be interstratified with the collapsed smectite and mica. The 1.43nm reflections noted above may therefore imply that there is tendency for the chlorite to segregate from the mica/smectite/chlorite interstratification. The chlorite interlayers are presumably aluminous and are thermally unstable being mostly destroyed by 330C with any residual layers being decomposed by 550C.

LAYER 1102A (50% <2 um, B_1 horizon). Mineralogy is similar to layer 1101A but there is less segregation of the chloritic mineral in the mica/smectite/chlorite interstratification. The shape of the 1.09 nm reflection at K 110C implies that there is more chloritised material in the clay in this layer than in the surface soil. As for the surface soil, most of the interlayers are destroyed by heating at 300C, but there is some further collapse at 550C.

LAYER 1103A (10% < 2um, B_2 horizon). This layer seems to contain a smectite mineral (1.48 nm Mg a.d. which swells to 1.84 nm when glycerated; it has a 1.25 nm spacing K a.d. The K 110C treatment shows that there is some chloritised layers present, most of which are destoyed by heating to 300C. This suggests that the interstratified mineral is a smectite/chlorite in which the chlorite is a minor constituent. The K wet diffraction pattern shows that there is very little illite in this layer. b-axis disordered kaolinite is a major constitutent of this layer.

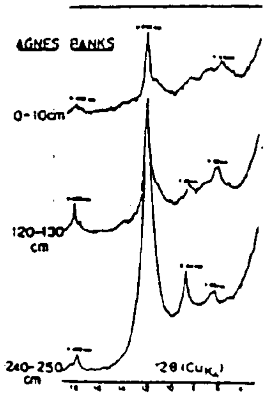
The data suggests that the smectite weathers out towards the surface of the profile and may accumulate aluminous interlayers. The greater concentration of illite in the A horizon may reflect a greater resisitance to weathering then the smectite. The kaolinite is largely inherited from the Bringelly shale and persists throughout the profile which is undergoing acid weathering.

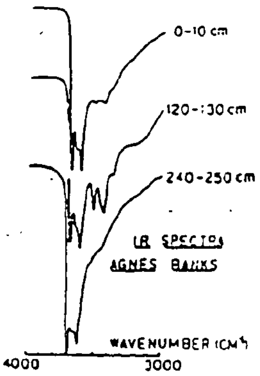


Diffraction patterns of < 2um clay. The treatments are: a) Mg Glycerated; b) Mg air dry; c) K wet; d) K air dry; e) K 110C; f) K 300C; g) K 550C. Cu Kα radiation, monochromator fitted.

NOTES ON THE CLAY MINERALS IN THE SAND DUNES AT AGNES BANKS

The Agnes Banks profile was collected from the pits remaining after extraction of the sand for commercial purposes. The soil profile is a Podsol and the data below show that the small amount of clay in the profile is dominated by a kaolinite which random powders show to be extensively b-axis disordered. Gibbsite occurs throughout the profile but is most strongly concentrated at 120-130cm. The gibbsite may develop from the very intensive leaching of the sands by rainfall through dissolution of the kaolinite. The infrared spectra confirm the presence of the gibbsite as well as the kaolinite. This profile was inspected by V.C. Farmer and contains the very fragile concretions which he has shown contain imogolite in other dunes on the NSW coast . Farmer has concluded that formation of imogolite is a very important aspect of podsolization.





11 diffraction patterns of the Agnes Banks layers are Mg air dry. Clay mineral notes by B.G. Davey, University of Sydney.

APPENDIX D

FIELD NOTES FOR 2 DAY POST-CONFERENCE EXCURSION TO HUNTER VALLEY N.S.W.

11-12 DECEMBER 1986

ITINERARY

DAY ONE - THURSDAY, 11 DECEMBER 1986

Depart	:	UNSW (Department of Applied Geology)	8.30
Arrive	:	Swansea (STOP 1 and Morning Coffee)	11.00
Depart	:	Swansea	12.00
Arrive	:	Hunter Valley Winery (Lunch)	1.00
Depart	:	Hunter Valley Winery	2.30
Arrive	:	Liddell (STOP 2)	3.00
Depart	:	Liddell	3.30
Arrive	:	Cressfield (STOP 3)	4.30
Depart	:	Cressfield	5.30
Arrive	-	Scone (Airlie House Motel)	6.00

DAY TWO - FRIDAY 12 DECEMBER 1986

Depart	:	Scone	8.30
Arrive	:	Burning Mountain and Quarry No. 7 (STOP 4)	9.30
Depart	:	Burning Mountain	10.30
Arrive	:	Mullite Mountain and Quarry No. 1 (STOP 5)	10.45
Depart	:	Mullite Mountain	11.30
Arrive	:	Roadside Stop (Picnic Lunch)	1.00
Depart	:	Roadside Stop	1.30
Arrive	:	Seaham Zeolite Locality (STOP 6)	2.30
Depart	:	Seaham Zeolite Locality	3.00
Arrive	:	UNSW (Department of Applied Geology)	6.30

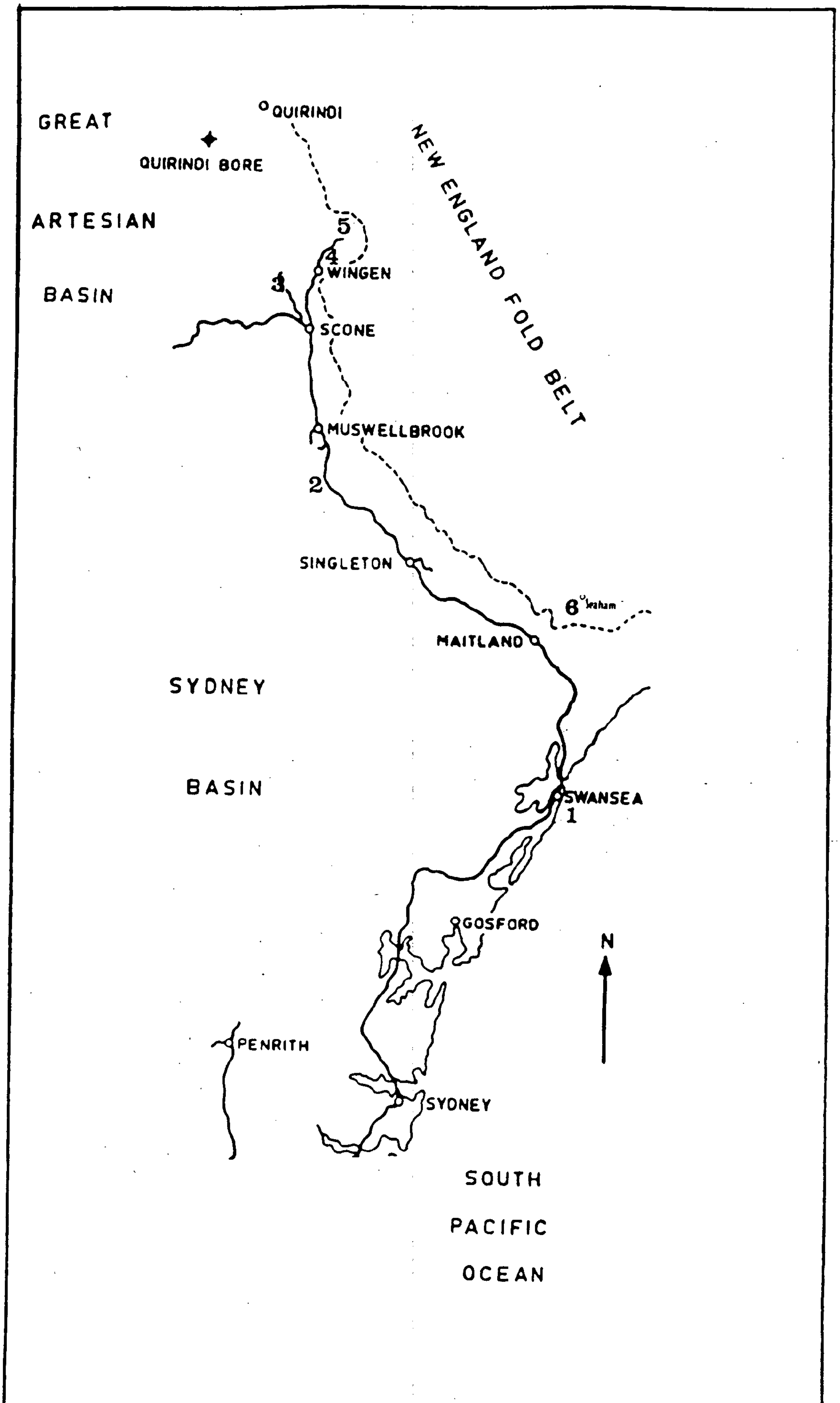

GREAT
ARTESIAN
BASIN
QUIRINDI
QUIRINDI BORE
NEW ENGLAND FOLD BELT
5
4
WINGEN
3
SCONE
MUSWELLBROOK
2
SINGLETON
6
Seaham
MAITLAND
SYDNEY
BASIN
SWANSEA
1
GOSFORD
N
PENRITH
SYDNEY
SOUTH
PACIFIC
OCEAN

FIG 1

STOP 1: SWANSEA, PILOT STATION (Plate 15)

Analcite chert and mixed layered minerals in the Reid's Mistake Formation of the Newcastle Coal Measures.

The Newcastle Coal Measures, located at the top of the Permian in the north-central sector of the basin, have a maximum thickness of about 460m and comprise, in addition to coal and carbonaceous shale, polymictic conglomerate, lithic sandstone and siltstone, claystone and abundant tuffaceous rocks. Four seams, namely the Wallarah, Great Northern, Victoria Tunnel and Borehole have been major producers of coal. The stratigraphic subdivision of the Newcastle Coal Measures is given in Fig. 2.

The Reid's Mistake Formation lies between the Upper and Lower Pilot Seams, approximately 110m below the base of the Triassic and consists mostly of tuff and transported volcanic debris. At the pilot station near Swansea, the bulk of the formation is made up of interbedded claystones and dense, hard cherts, the latter consisting of devitrified tuffaceous material.

The claystones are composed of quartz and mixed-layered montmorillonite-illite minerals with or without minor amounts of felspar. The mixed-layered clays, which have both regular and random stackings (see Fig. 3) are rather common throughout the Late Permian coal measures, particularly in the northern part of the basin.

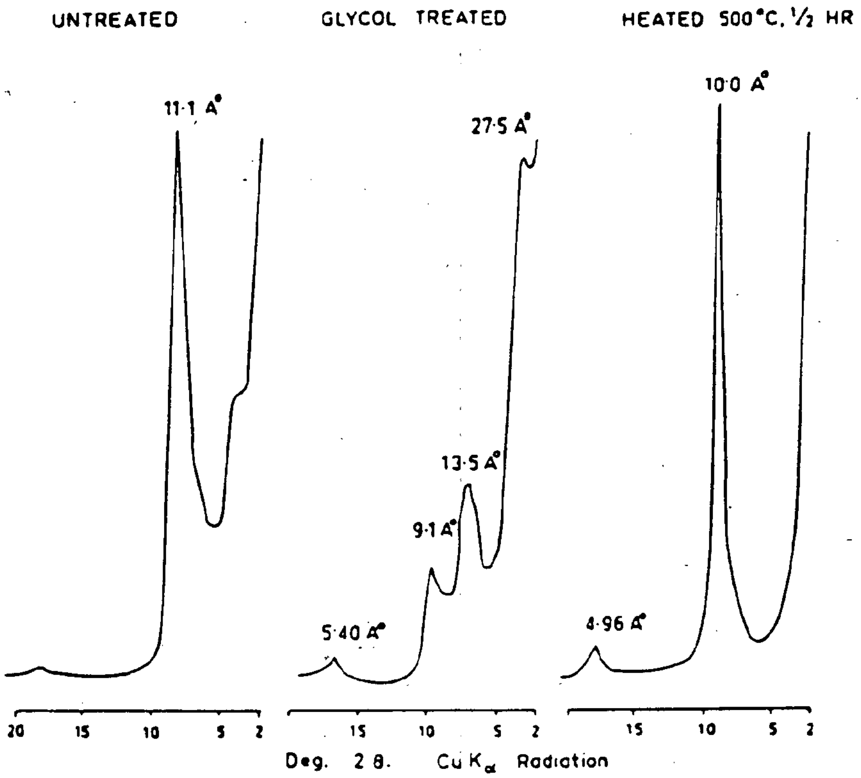
The cherts consist of abundant shards pseudomorphed by chalcedony and/or analcite, the latter varying in content up to 90% with small amounts of mixed layered clay minerals and felspar. Since the mixed layered clay minerals are readily converted to analcite in the presence of sodium hydroxide, it is believed that the deposits represent glassy volcanic debris that accumulated in a highly alkaline floodplain environment.

For further reading see paper entitled "The Reid's Mistake Formation at Swansea Head, New South Wales" by F. C. Loughnan and A. S. Ray (1979) and published in Jour. Geol. Soc. Aust., 25 : 473-481.

Subdivisions of the Newcastle Coal Measures

Moon Island Beach Sub Group	Wallarah Seam
	Catherine Hill Bay Fm.
	Great Northern Seam
	Eleebana Fm.
	Fassifern Seam
Boolaroo Sub Group	Croudace Bay Fm
	Upper Pilot Seam
	Reid's Mistake Fm.
	Lower Pilot Seam
	Warners Bay Fm.
	Hartley Hill Seam
	Mt. Hutton Fm.
Cardiff Sub Group	Australasian Seam
	Tickhole Fm.
	Montrose Fm.
	Kahibah Fm.
	Wave Hill Seam
	Highfields Fm
	Fern Valley Seam
	Kotara Fm.
Lambton Sub Group	Victoria Tunnel Seam
	Shepherds Hill Fm.
	Nobby's Seam
	Bar Beach Fm.
	Dudley Seam
	Bogey Hole Fm.
	Yard Seam
	Tighe's Hill Fm.
	Borehole Seam

FIG 2



X-ray data for the mixed layer clay mineral associated with analcite.

FIG 3

STOP 2: NEW ENGLAND HIGHWAY, LIDDELL POWER STATION

Erratics in the uppermost beds of the Marine Maitland Group.

Much has been written concerning the late Palaeozoic glaciation in Australia, particularly its bearing on the reconstruction of Gondwanaland. Most workers are in little doubt that during the closing stages of the Carboniferous, glacial conditions prevailed over at least part of New South Wales. But, in the Permian, evidence is far from conclusive and is virtually restricted to occurrences of erratics in the marine strata of the Dalwood and Maitland Groups and their stratigraphic equivalents.

Mostly, the erratics are of local derivation and therefore could be attributed to mud flows. However, in places, blocks weighing up to several tonnes and obviously of a distant source, occur in these rocks and accounting for their origin is difficult unless resort is made to glacial activity. Generally, they are believed to have resulted from ice-rafting. On the other hand, the widespread development of flint clays and palaeolaterites in the non-marine rocks of both the Early and Late Permian rather indicates that warm and probably tropical conditions prevailed. Possibly the Permian was a period of marked climatic fluctuations.

STOP 3: CRESSFIELD BENTONITE DEPOSIT (Plates 16 & 17)

The Cressfield Bentonite Deposit is the major source of supply in NSW of bentonite for use in foundry sands and for pelletising iron ore.

The bentonite bearing strata comprise the topmost Permian coal measures of the Murulla Beds (Singleton Coal Measures equivalents). Coarse Triassic sedimentary rocks equivalent to the Narrabeen Group, overlie the bentonite bearing strata whereas the underlying sequence is the Bickham Formation.

The eight commercial bentonite seams at Cressfield vary in thickness from 0.5 metres to over 3.0 metres and consist of nearly pure montmorillonite which has both Ca^{2+} and Mg^{2+} on the exchange positions. The minor impurities detected within the bentonite include kaolinite, quartz, felspar, fresh biotite, anatase, barite, calcite and celestine.

A typical section through the Cressfield Bentonite Deposit is presented in Fig. 4.

Similar to many other bentonite occurrences, the Cressfield bentonite probably formed by subaqueous alteration of volcanic ash. Unlike the Na-bentonites of Wyoming, USA which were formed in a marine environment, the Cressfield bentonite environment of formation was terrestrial - possibly a shallow fresh water coal swamp.

A. Soil, coarse conglomerate and clay overburden 8.0m

B. Bentonite seam T2 1.0m, Pale whitish yellow, massive

C. Interseam sediments 0.3m, carbonaceous shale

D. Bentonite seam T1 2.9m, pale whitish yellow-green, massive

E. Interseam sediments 5.5m, carbonaceous shales, coal and clay

F. Bentonite seam P3 0.6m, pale green, massive

G. Interseam sediments 1.0m, carbonaceous shales, clay and sandstone

H. Bentonite seam P2 1.0m, pale green, massive

I. Interseam sediments 0.5m, carbonaceous shale

J. Bentonite seam P1, 0.9m, grey-green, massive

K. Interseam sediments, 4.5m, carbonaceous shale, clay, coal and sandstone

L. Bentonite seam I, 0.7m, grey-green, massive

M. Interseam sediments, 3.5m, carbonaceous shale, shale and sandstone

N. Bentonite seam L2, 0.8m, green and grey-green, massive

O. Interseam sediments, 0.8m, carbonaceous shale

P. Bentonite seam L1, 2.2m, grey-green, massive

Q. Subseam sediments, carbonaceous shales, lithic sandstone and conglomerate

FIG 4

STOP 4: BURNING MOUNTAIN AND QUARRY NO. 7 (Plates 18 & 19)

Burning coal seams within the Koogah Formation have metamorphosed the enclosing rocks in many places. The distribution of burnt zones is depicted in Fig. 5.

Mount Wingen or "Burning Mountain" as it is commonly termed is a geological phenomenon that features dramatic thermal activity. The site, discovered in 1828 was originally thought to be an active volcano and consequently attracted considerable attention. Many of the pioneering geologists, including Sir Thomas Mitchell, visited Burning Mountain and scientific investigation revealed that the thermal activity is in fact due to the subsurface combustion of a seam of coal. Recently the site has been developed as a tourist attraction.

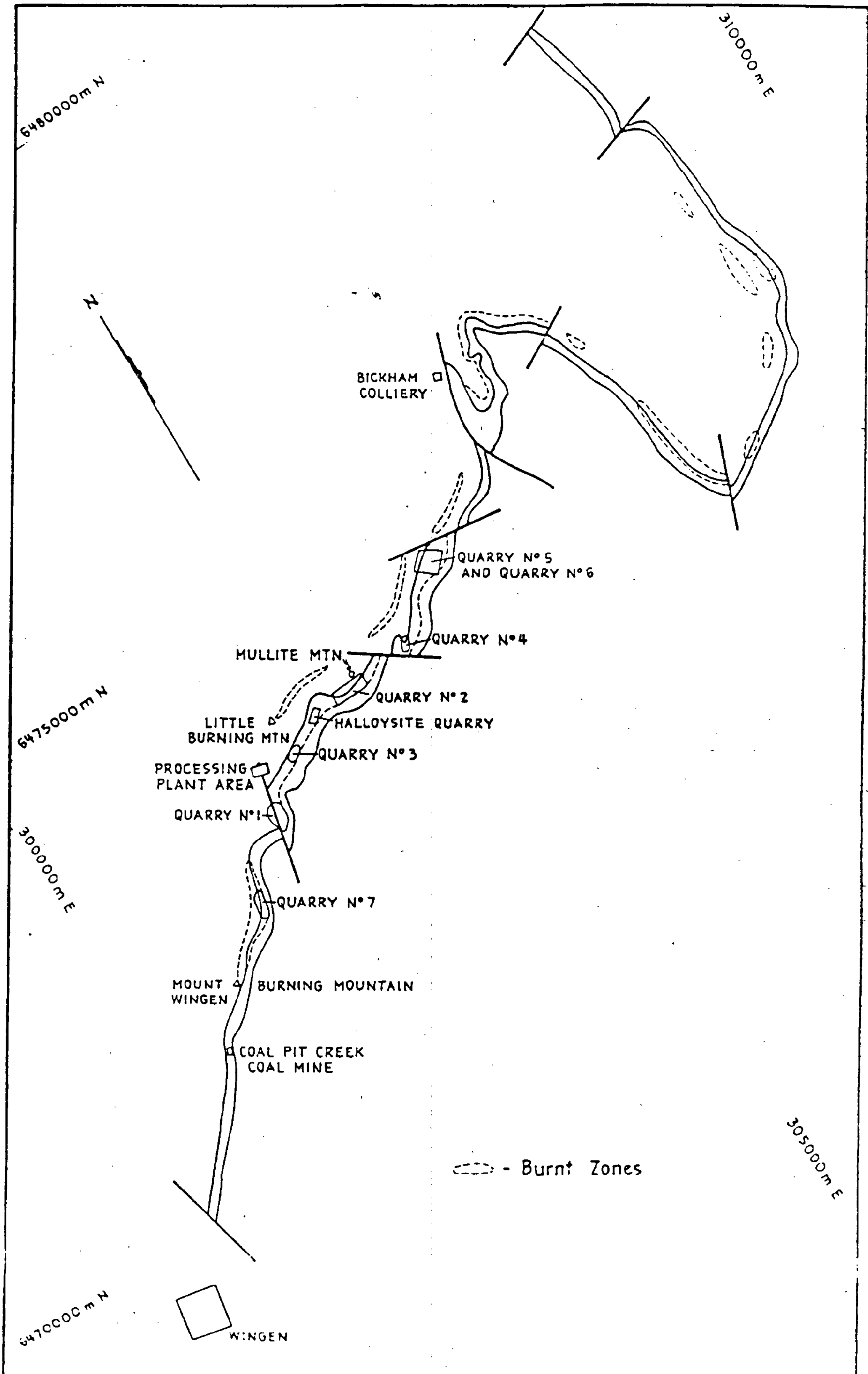
Geologically, the burning coal seam lies close to the boundary between the Upper and Lower subdivisions of the Koogah Formation. At Burning Mountain, strata strike northeast and dip at 26° northwestwards and the coal seam consists of impure bituminous coal.

The calculated rate of advance of the fire at Burning Mountain is about one metre per year southwestwards. Possible causes of ignition include lightning, aboriginal camp fires and igneous intrusions however the suggestion that ignition of the seam resulted from heat generated by oxidation of pyrite has gained widest acceptance.

The fumeral activity at the present combustion site at Burning Mountain comprises emission of heat and gases and deposition of exhalative minerals around the vents. Gases include sulphur dioxide, carbon dioxide and water vapour and the principal mineral phases are sulphur and gypsum.

Beds of kaolinite clayrock juxtaposed with burnt out coal seams have been altered by combustion metamorphism to mullitite (a rock composed predominantly of mullite and subordinate cristobalite and with or without tridymite). The mullitite is generally pale in colour, hard and dense and contains relict sedimentary textures. It is believed to have formed under temperature conditions between 1000°C and 1750°C and is currently exploited for chamotte, a refractory raw material.

Further from the burning coal seams, progressively lower temperature conditions prevailed and combustion metamorphism at less than 950°C altered kaolinite to metakaolin, a X-ray amorphous form.



ZONES OF COMBUSTION METAMORPHISM

FIG 5

Much of the metakaolin has subsequently been rehydroxylated by groundwater to yield halloysite and this reaction is continuing at the present time. Halloysitite, the rock formed by this reaction, is currently exploited as an industrial granular absorbent and as a nucleating agent in the manufacture of ammonium nitrate prills.

Halloysite also infills contraction fractures in the halloysitite rocks and hematite segregates occupy the burnt zones. Combustion metamorphism has also produced buchites at a few localities.

Quarry No. 7 presents a section through the metamorphosed strata and features a particularly colourful array of halloysitites.

STOP 5: MULLITE MOUNTAIN AND QUARRY NO. 1

Quarry No.1 not visited. Quarry No.3 visited instead.(Plate 20)

Quarry No. 1 contains a section through unaltered kaolinite clayrocks of the Lower Koogah Formation. The kaolinite clayrocks are typically dark grey to pale grey and brownish grey in colour, massive and variably carbonaceous, stratified and textured.

Virtually all the clasts in the kaolinite clayrocks have undistorted residual volcanic textures and, since the formation immediately overlies basalts more than two kilometres thick, there can be little doubt as to the source of the kaolinite.

The essential minerals, kaolinite (disordered-ordered) as well as anatase, gibbsite and boehmite formed in the sourceland as a result of prolonged penetrative chemical weathering. Kaolinite debris was transported to a site of accumulation wherein the kaolinite clayrock acquired sedimentary fabrics, accessory constituents (eg. carbon) and pedogenic (eg. gorceixite) and diagenetic (eg. siderite) minerals. The strata may be interpreted as the mid-to distal-fan accumulations of alluvial fans.

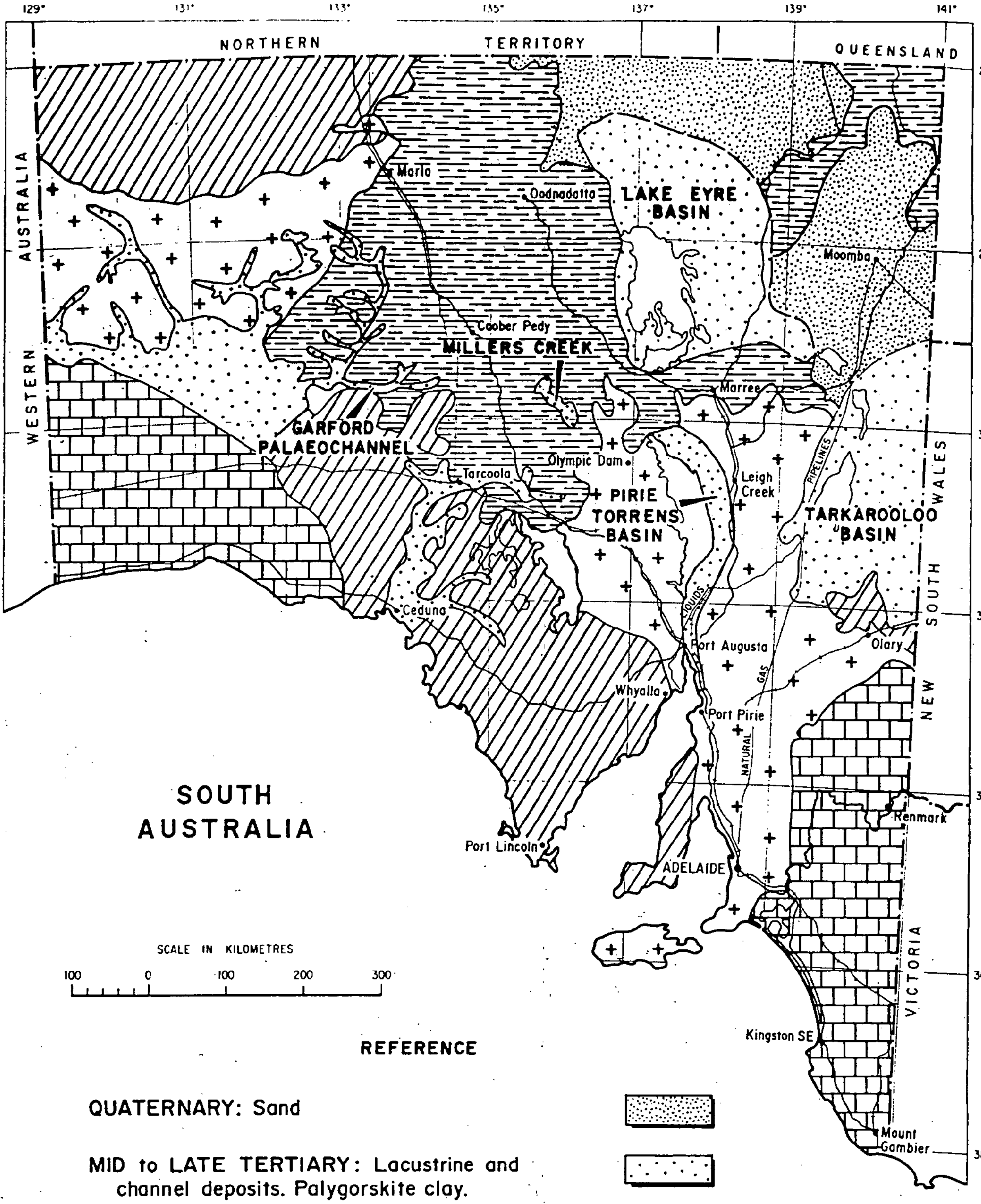
Stop 5 includes a visit to an operating pit and various aspecs of the mining operations will be demonstrated. The mullite rock or chamotte as it is commonly termed, is an extremely volume-stable refractory aggregate. Chamotte is usually prepared industrially by high temperature calcination of aluminosilicate raw material and as far as can be determined this locality is the only place in the world where mining of mullitite is carried out.

The typical representative energy required to calcine kaolinite clayrock is about 7000 MJ per net tonne of chamotte with burning temperatures in the range from 1400°C to 1600°C and an Al_2O_3 content of 45 per cent on a calcined basis. The energy requirement is approximately equivalent to the consumption of two tonnes of coal per net tonne of chamotte. Not surprisingly, the commercial sector has shown considerable interest in mullitite as a natural chamotte due to its inbuilt energy component.

STOP 6: SEAHAM ZEOLITE LOCALITY, EAGLETON QUARRY (Plate 21)

At Eagleton, about eight kilometres north of Raymond Terrace, steeply dipping, pink to reddish pink, fine-grained, tuffaceous siltstones are exposed in a disused road-base quarry. These tuffaceous siltstones form part of the Carboniferous Grahamstone Lake Formation and they contain zones enriched in clinoptilolite.

Samples collected and tested by the NSW Department of Mineral Resources have returned ammonium exchange capacities (AEC's) of between 37 and 140 m.e.q./100g. and contain between 35% and 84% (by weight) clinoptilolite.



REFERENCE

QUATERNARY: Sand ▒

MID to LATE TERTIARY: Lacustrine and channel deposits. Palygorskite clay. ░

TERTIARY: Marine deposits ▦

CRETACEOUS: Sandstone and montmorillionite shale ☰

ADELAIDEAN and PALAEOZOIC: Sediments, metasediments and granite. + +

ARCHAEAN to PROTEROZOIC: Crystalline basement ▨

FIG. I

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COMPILED		
L. Barnes	LR C.D.O.	11·6·87 DATE
DRAWN		
E. Calabio	SCALE 1:7,000,000	
DATE	PLAN NUMBER	
Mar. '87	S 19153	
CHECKED		

PALYGORSKITE IN SOUTH AUSTRALIA
REGIONAL GEOLOGY

4339

4339

CHEMICAL ANALYSES

	Georgia U.S.A.	Lake Nerramyne W.A.	Lake Frome Embayment	Garford (Clay rich)	Palaeochannel (Dolomite rich)
SiO_2	55·03	59·0	45·04	57·8	14·2
Al_2O_3	10·24	13·4	6·42	8·45	2·72
Fe_2O_3	3·53	5·34	6·03	4·34	1·02
MgO	10·49	8·25	8·64	5·10	16·5
CaO	-	0·96	0·82	-	21·2
Na_2O	–		5·99	4·36	2·34
K_2O	0·47	2·12	0·99	2·30	0·37
LOI	19·86	9·73	16·8	16·7	41·8
CO_2			1·15	0·31	31·5
Water Absorbency %		100	65	40	100

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

PALYGORSKITE IN SOUTH AUSTRALIA

COMPARATIVE CHEMICAL ANALYSES

COMPILED L. Barnes

DRAWN E. Calabio

DATE Mar.'87

CHECKED

SCALE

C.D.O. 11·6·87 DATE

PLAN NUMBER S 19154

FIG. 2

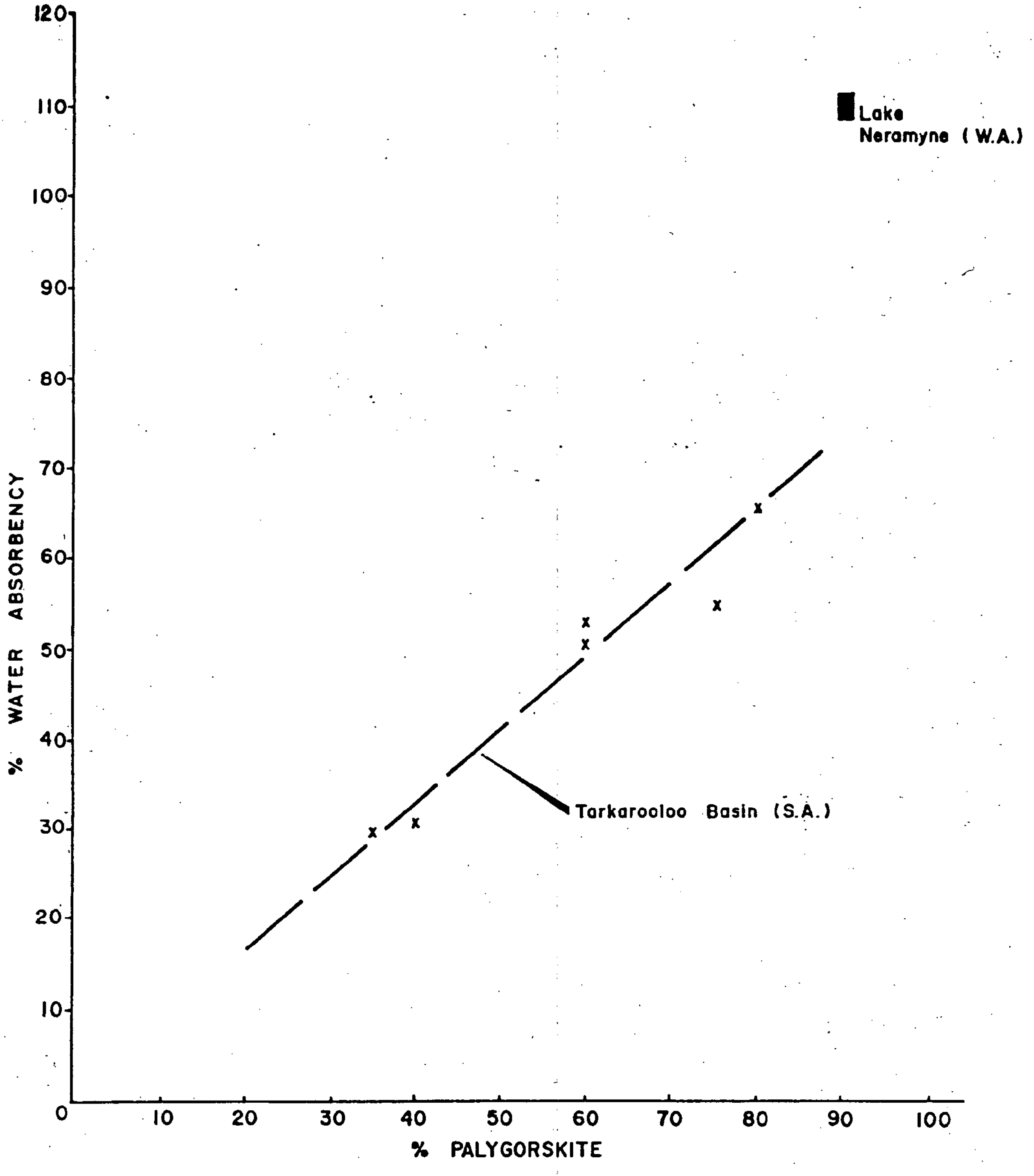


FIG. 3

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

PALYGORSKITE IN SOUTH AUSTRALIA
TARKAROOLOO BASIN
WATER ABSORBENCY VS PALYGORSKITE CONTENT

COMPILED L Barnes	C.D.O. DATE 11·6·87
DRAWN E. Calablo	SCALE
DATE Mar. '87	PLAN NUMBER S 19155
CHECKED	

4339

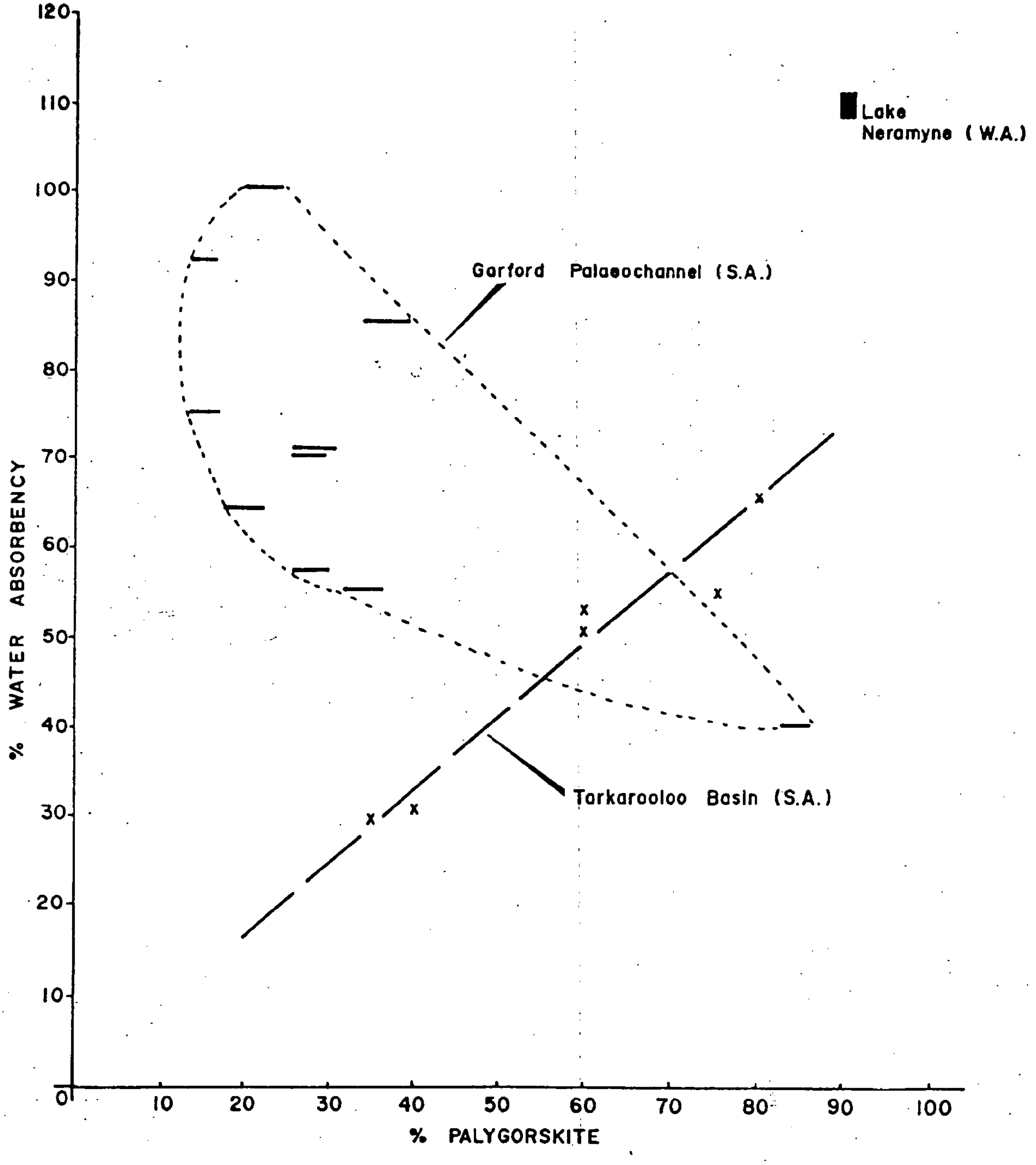


FIG. 4

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

PALYGORSKITE IN SOUTH AUSTRALIA
GARFORD PALAEOCHANNEL
WATER ABSORBENCY VS PALYGORSKITE CONTENT

COMPILED L. Barnes
DRAWN E. Calabio
DATE Mar. '87
CHECKED
C.D.O. DATE 11-6-87
SCALE
PLAN NUMBER S 19156

PLATE 1. LAKE MILLYERA, TARKAROOLOO BASIN, CURNAMONA. General view westwards across lake. Namba Formation crops out in low, dolomite capped escarpment on northwestern lake edge. Flinders Ranges in background.
OCTOBER 1977. SLIDE NO. 3188

PLATE 2. LAKE MILLYERA, TARKAROOLOO BASIN, CURNAMONA. Namba Formation in cliff section on northwestern shore of lake. Dolomite caps grey and green smectite and palygorskite clay.
OCTOBER 1977. SLIDE NO. 35797

PLATE 3. LAKE MILLYERA, TARKAROOLOO BASIN, CURNAMONA. Palygorskite bed, Namba Formation. Upper green-brown palygorskite layer beneath white dolomite bed. OCTOBER 1977. SLIDE NO. 31812

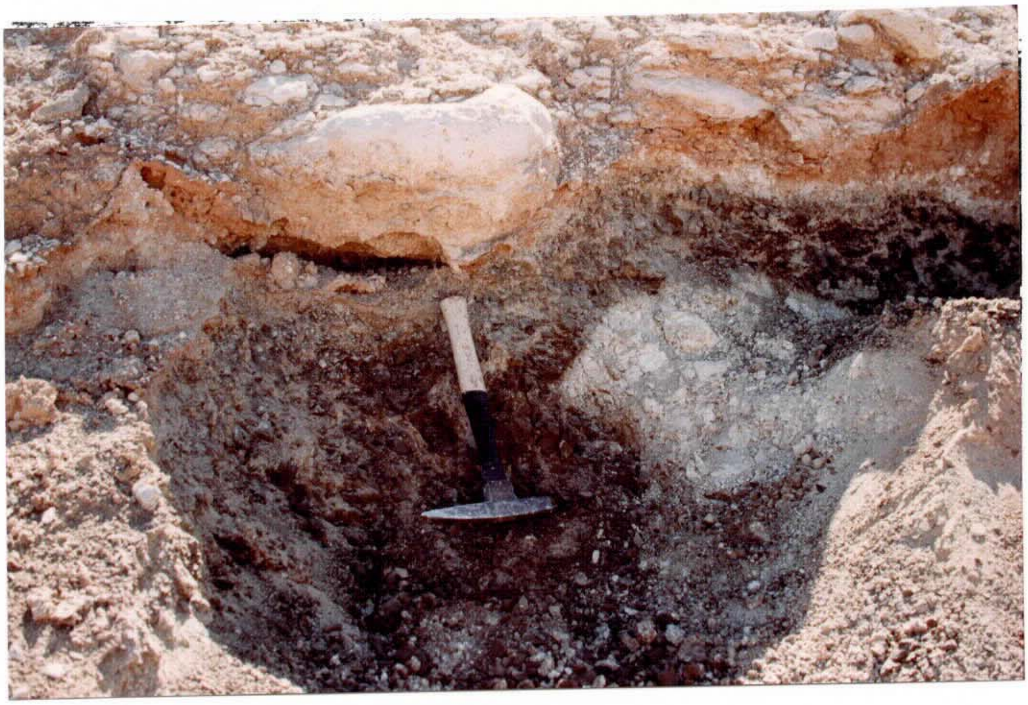


PLATE 4. LAKE MILLYERA, TARKAROOLOO BASIN, CURNAMONA. Palygorskite with dolomite Namba Formation. Palygorskitic clay layer beneath massive dolomite showing white dolomitic mottle within clay layer. OCTOBER 1977. SLIDE NO. 31813

PLATE 5. JUBILEE LAKE - GARFORD PALAEOCHANNEL, COOBER PEDY. View southeast across lake. White palygorskitic dolomite of Garford Formation crops out in low cliffs on southern lake shore, and is at shallow depth, beneath Holocene clay and salt crust throughout lake.
NOVEMBER 1986. SLIDE NO. 35798

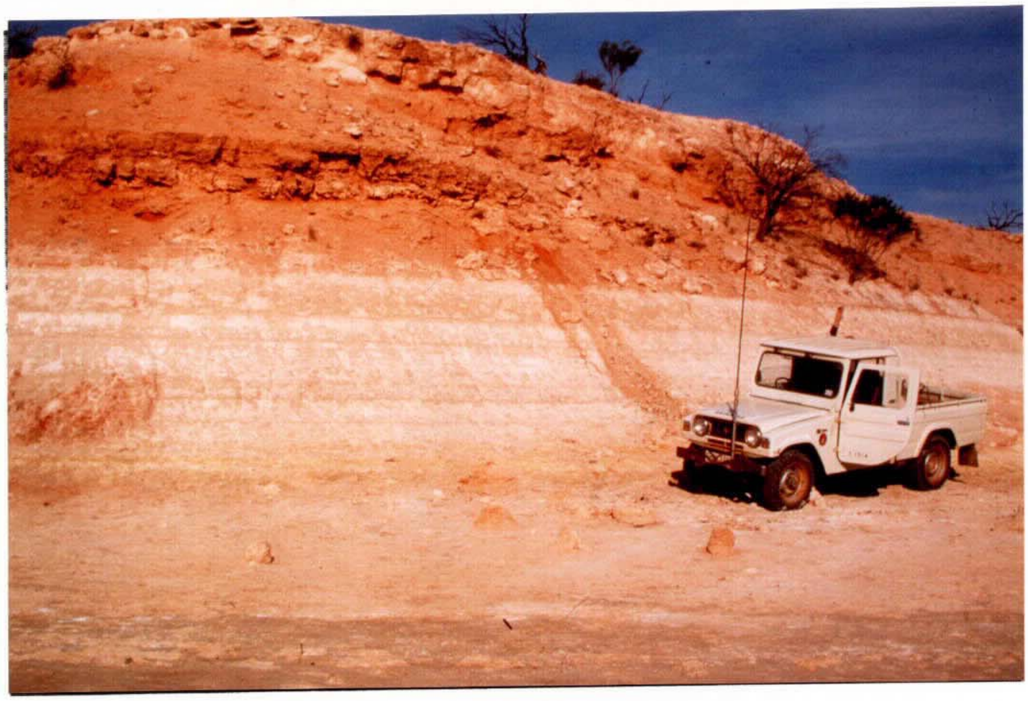


PLATE 6. PB LAKE - GARFORD PALAEOCHANNEL, COOBER PEDY. Massive gypsum bands and red brown silty sand (Quaternary) overlying off-white dolomitic clay and grey-green clay of Garford Formation.
JUNE 1982. SLIDE NO. 24439.

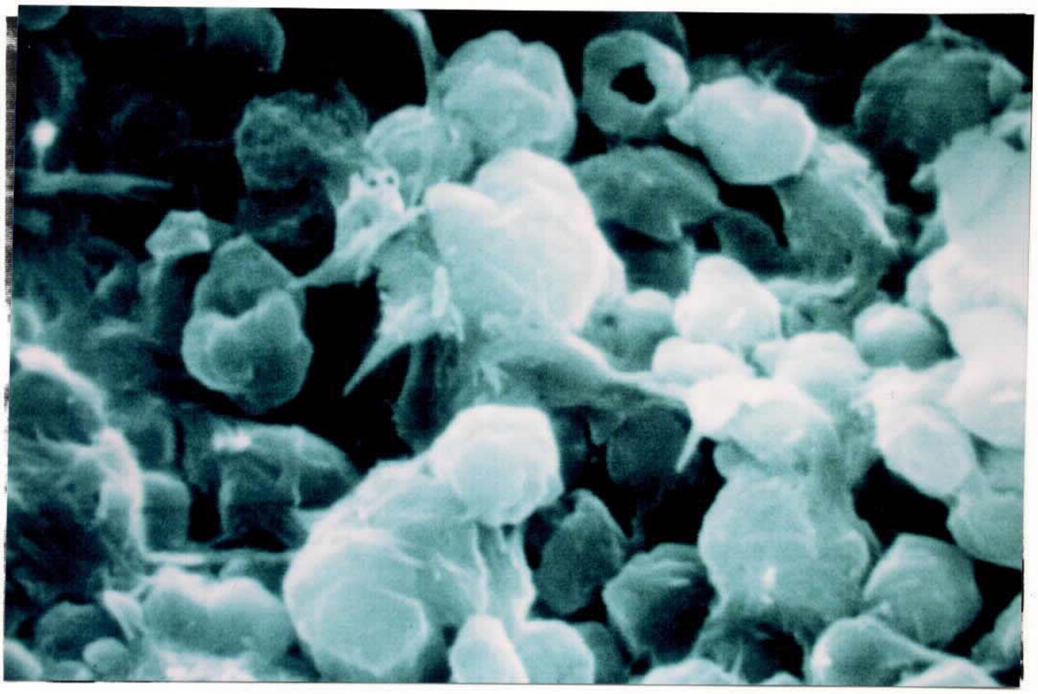


PLATE 7. GARFORD FORMATION - GARFORD PALAEOCHANNEL, COOBER PEDY. SEM Photomicrograph of white palygorskitic dolomite showing acicular palygorskite overgrowths on anhedral-subhedral dolomite grains. Field of view 4 microns across.
SLIDE NO. 35799

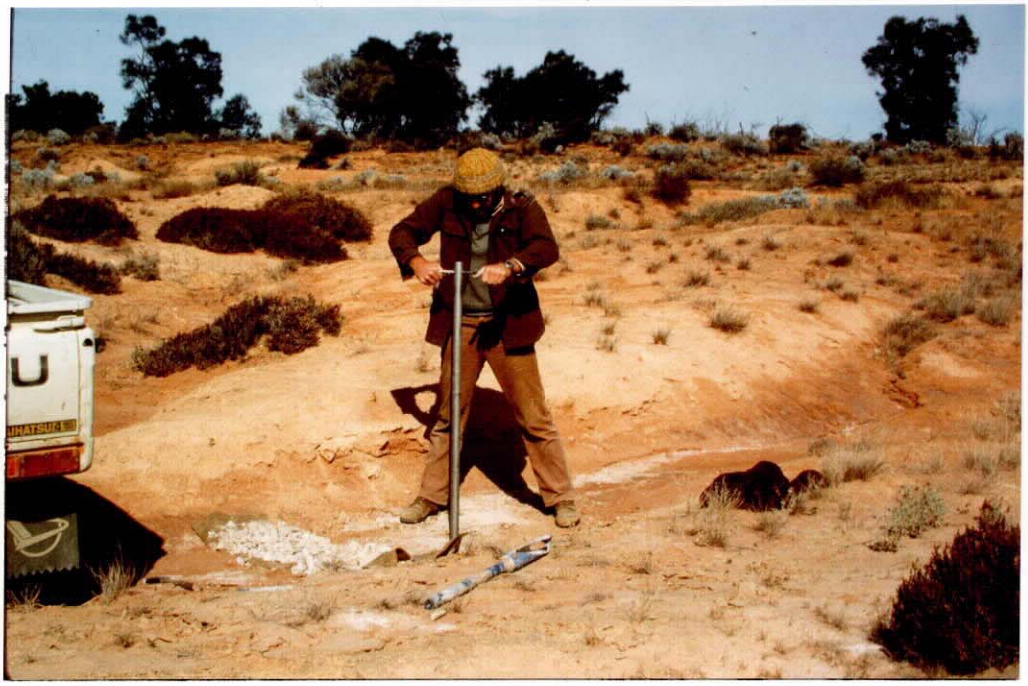


PLATE 8. HAND AUGERING - GARFORD FORMATION, COOBER PEDY. Obtaining samples for absorbancy testing.
JUNE 1982. SLIDE NO. 24440.

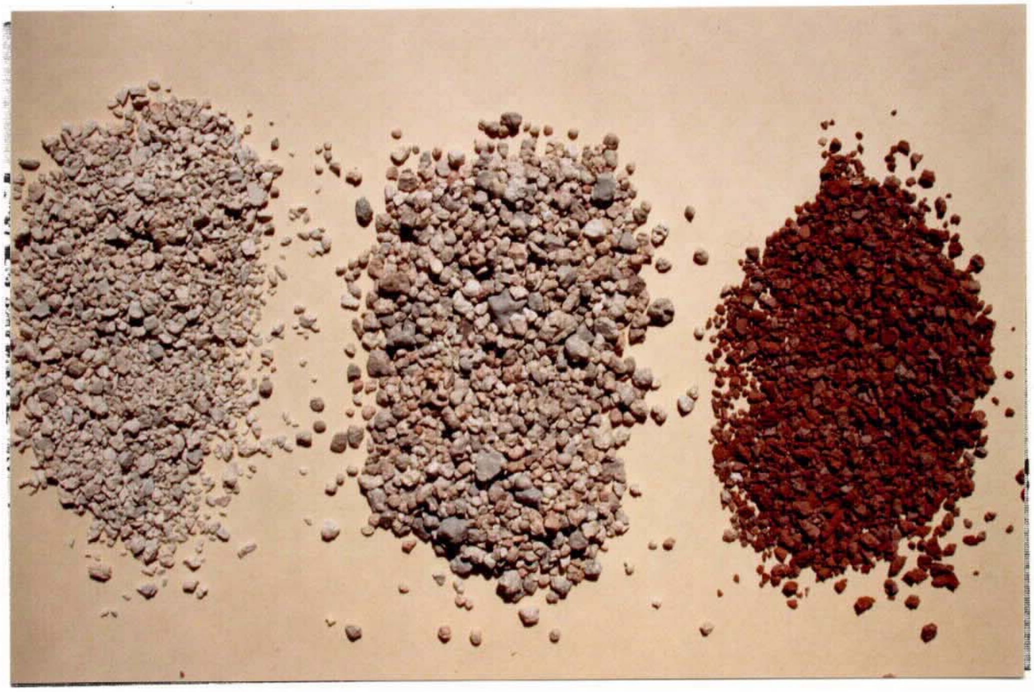


PLATE 9. PALYGORSKITE CLAY - CALCINED SAMPLES.
Left - Commercial pet litter - Woolworths brand, absorbent cat litter.
Centre - White palygorskite dolomite from PB lake, Garford Palaeochannel, calcined at about 650°C.
Right - Green palygorskite clay from Lake Millyera, Tarkarooloo Basin, calcined at about 650°C.
SLIDE NO. 35800

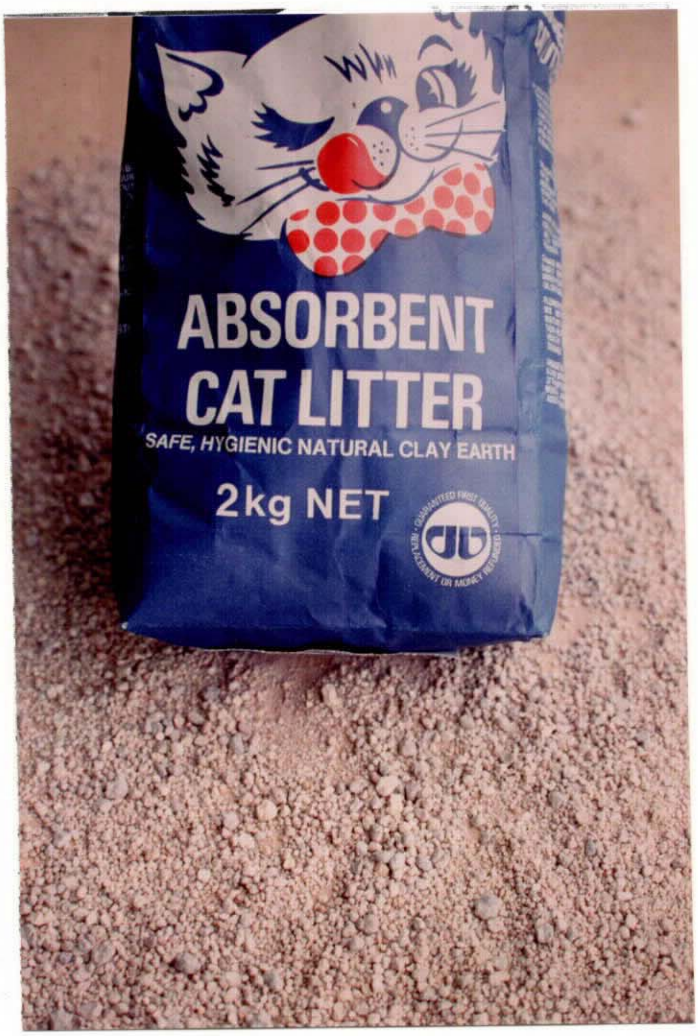


PLATE 10. PALYGORSKITE CLAY.
Commercial pet litter.
SLIDE NO. 325801

PLATE 11. PROSPECT QUARRY, PROSPECT, N.S.W.
General view south, Crusher P2 in centre mid-distance. Left wall and area near crusher are chilled margin and dolerite suitable for high quality aggregate; central part of quarry olivine dolerite and picrite suitable only for crushed rock and fill.
DECEMBER, 1986. SLIDE NOS. 35802-35803

PLATE 12. MULGOA CLAY PIT, PENRITH, N.S.W. Recently opened pit in pale firing, carbonaceous Bringelly Shale, part of Wianamatta Group, of Middle Triassic age. Mulgoa deposit is largest identified pale firing clay/shale resource in Sydney region.
DECEMBER, 1986. SLIDE NO. 35804

PLATE 13. LONDONDERRY CLAY PIT, LONDONDERRY, N.S.W. Sandy, silty, iron mottled, partly plastic Londonderry Clay of Tertiary age used in small quantities for brick and tile manufacture.
DECEMBER, 1986. SLIDE NO. 35805

PLATE 14. LONDONDERRY SAND PIT, LONDONDERRY, N.S.W. Readymix-Farley sand pit showing area cleared of vegetation ready for mining. Agnes Bank Sand of (?)Tertiary age comprises clean, white, medium grained sand grading down into yellow, clayey sand. Sand is washed to produce construction sands.
DECEMBER, 1986. SLIDE NO. 35806

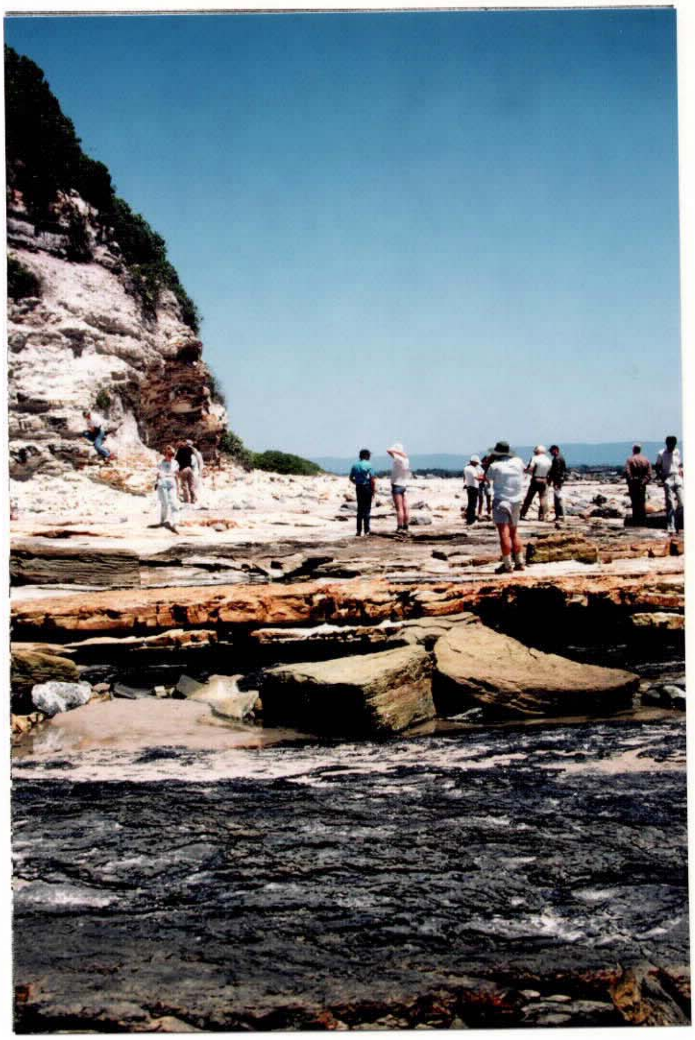


PLATE 15. SWANSEA ZEOLITE LOCALITY, SWANSEA, N.S.W. Cliff section showing interbedded claystone and dense, analcite bearing (up to 90%) cherts in Rieds Mistake Formation, part of Newcastle Coal Measures of Permian age. This coal seam crops out in wave cut platform in foreground.
DECEMBER 1986. SLIDE NO. 35807

PLATE 16. CRESSFIELD BENTONITE, Hunter Valley N.S.W. Bentonite seams L1 and L2. Strata comprise uppermost coal measures of Murulla Beds of Permian age. Bentonite seam L1 exposed in base of quarry overlain by interseam carbonaceous shale and bentonite seam L2. DECEMBER 1986. SLIDE NO. 35808

PLATE 17. CRESSFIELD BENTONITE DEPOSIT, northern Hunter Valley, N.S.W. General view north. Excavator is mining bentonite seam I (0.7 m thick). DECEMBER, 1986. SLIDE NO. 35809

PLATE 18. BURNING MOUNTAIN, northern Hunter Valley, N.S.W. View northeasterly along strike showing present area of subsurface combustion of a coal seam. Natural chamotte quarries to northeast in previously burnt strata.
DECEMBER, 1986. SLIDE NO. 35810

PLATE 19. WINGEN CHAMOTTE QUARRIES, Burning Mountain, northern Hunter Valley, N.S.W. Quarry No. 7 - halloysite quarry, view north. Burning of coal seam (right of photo) calcined kaolin flint clay to metakaolin, which has been rehydroxylated by ground water to halloysite. Used for low grade industrial absorbent.
DECEMBER 1986. SLIDE NO. 35811

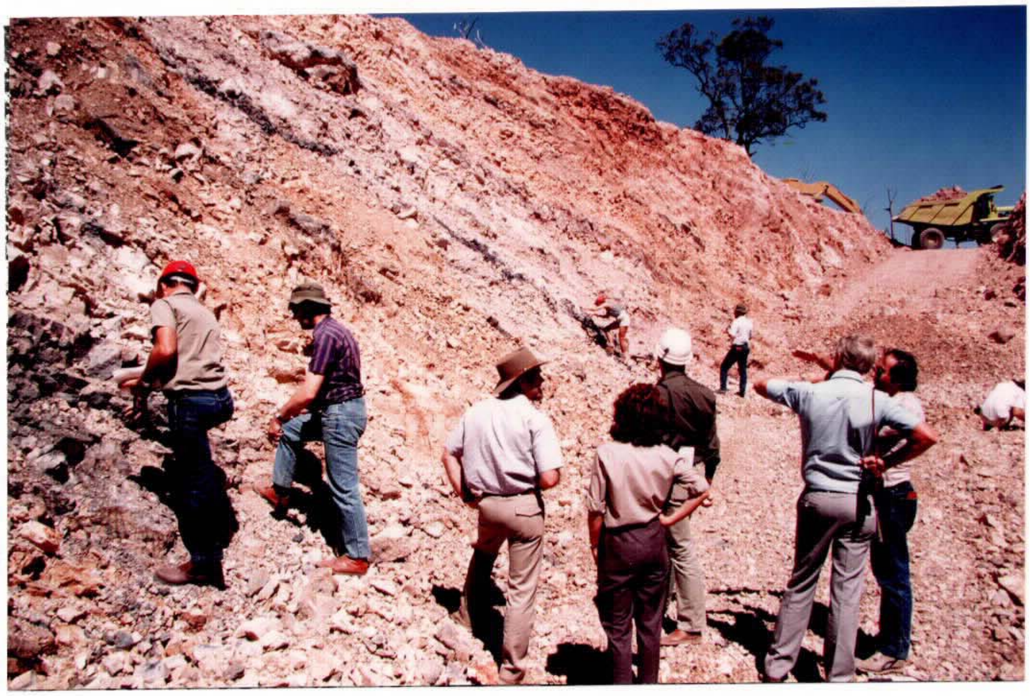


PLATE 20. WINGEN CHAMOTTE QUARRIES, Burning Mountain, northern Hunter Valley, N.S.W. Quarry No. 3 - view west. Overburden removal in progress. White interbeds (centre left) are mullitite rock exploited as volume stable refractory aggregate.
DECEMBER, 1986. SLIDE NO. 35812

PLATE 21 SEAHAM ZEOLITE LOCALITY, EAGLETON, N.S.W. Steeply dipping tuffaceous siltstone of Grahamstone Lake Formation of Carboniferous age. Pink interbeds contain up to 85% (by weight) clinoptilolite zeolite. DECEMBER 1986. SLIDE NO. 35813