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Record 1979/2

CRUST AND UPPER MANTLE OF SOUTHEAST AUSTRALIA

Summaries of papers presented at a symposium held in Canberra, February, 1979

compiled by
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FOREWORD

This Record contains summaries of papers, to be presented at a symposium on the crust and upper mantle of southeast Australia (CUMSEA), held in Canberra on 12-14 February 1979. The symposium is sponsored by the Department of Geology, Australian National University; the Bureau of Mineral Resources, Geology and Geophysics; and the Geological Society of Australia.

The CUMSEA symposium aims to bring together, in an interdisciplinary environment, the results of recent and current work on the structure, composition, and tectonic development of the crust and upper mantle in southeast Australia. The secrets of the crust and upper mantle are only slowly being revealed by patient study and hard work. It is not yet practical to drill deep holes down to the upper mantle. So we must work on accessible clues such as the chemical composition of rocks currently close to the surface, and the gravity and magnetic fields as measured near the surface.

The summaries that follow show the extent of the work being carried on in this field. Originally it was planned to duplicate the summaries in the same form as they were received. However, this has not been practical and most contributions, although not changed, have been re-typed.

D. Denham

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PETROCHEMISTRY OF CRUSTAL AND UPPER MANTLE NODULES FROM KIMBERLITE PIPES OF SOUTHEAST AUSTRALIA

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A number of the kimberlite pipes recently discovered in New South Wales and South Australia contain nodules derived from the upper mantle and crust. The mineralogy and chemistry of these nodules has been studied with the aim of gaining insight into the stratigraphy of the crust-upper mantle of southeast Australia, and the effects of anatectic processes such as those envisaged for the generation of the Palaeozoic granites of the region.

A detailed study of the crustal-upper mantle nodules from the El Alamein (Port Augusta, S.A.), Calcuttaroo (Terowie, S.A.), White Cliffs (N.S.W.), and Jugiong (N.S.W.) pipes and sills has revealed a range of rock types that show some degree of overlap as well as individual mineralogical and chemical distinction. When combined with previous studies of the White Cliffs, Delegate and Gloucester (all N.S.W.) areas, it is possible to draw some generalized conclusions about the petrochemistry of the crust and upper mantle of the region.

Garnet clinopyroxenite and two-pyroxene granulite are prominent nodule types from most of the kimberlitic intrusives. Of interest in straddling a reaction zone between plagioclase and garnet-bearing assemblages is the occurrence of garnet-two-pyroxene- granulites from the El Alamein and Jugiong pipes and plagioclase garnet clinopyroxenite from Calcuttaroo, Jugiong and Delegate.

Garnet websterite, spinel websterite and spinel-garnet-websterite are relatively rare rock types at most of these pipes but apparently absent from Calcuttaroo. The South Australian pipes also contain abundant garnet clinopyroxenites with phlogopite and/or amphibole as major to accessory phases. The Calcuttaroo pipes contain numerous clinopyroxene-free nodules characterised by assemblages including garnet, orthopyroxene, plagioclase, phlogopite, amphibole, quartz, kyanite, rutile, sphene, apatite and Fe-Ti oxides.

In general, the nodules are of basaltic major element chemistry but some of the garnet clinopyroxenites and websterites are ultramafic. The clinopyroxene-free nodules from South Australia are distinct and of quartz diorite to granodiorite composition. Mineralogically, some of the garnet clinopyroxenites could be termed eclogites as the clinopyroxene contains up to 35 mole % jadeite and low CaTs components. Garnets are almandine-pyrope rich with low grossular content. Spinels vary from pleonaste to chromian pleonaste, and amphiboles are of hornblende to pargasite in composition. Some of the amphiboles are Cl-rich where coexisting with Cl-rich apatite. A rare accessory U-REE-phosphate mineral is present in one of the cpx-free Calcuttaroo nodules.

Geobarometric and thermometric analyses of the mineral assemblages give a variety of P/T estimates. Pyroxene-plagioclase-garnet assemblages indicate pressures in the range 10-20 kbar, 800-1000^{o}C. Coexisting Fe-Ti oxides indicate equilibration temperatures ranging from ~600 to 900^{o}C close to the quartz-fayalite-magnetite buffer curve, but also ranging up to improbably high temperatures and oxygen fugacities. A full range of samples from top to bottom of the crust is obviously not available, presumably due to the dynamics of kimberlite eruption.

In general, the inclusions from the western pipes (South Australia and western New South Wales) contain more abundant hydrous phases and K-Na-Fe-Al-rich phases than the eastern occurrences. The crust and upper mantle could be regarded as potentially more fertile in terms of the anatectic melt component. However, none of the inclusion types corresponds exactly to the best estimate of parental rock type for the I- and S-type granites of the Tasman Fold Belt. The inclusions indicate a predominantly basaltic crust with isolated portions of more silica-saturated character.

GEOLOGY AND GEOCHEMISTRY OF THE BEGA BATHOLITH

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The Bega Batholith, the largest of the meridionally trending granitoid batholiths of southeast Australia, is a composite body consisting of at least 65 separate granitoid plutons. Field relations indicate the granitoids were intruded between the late Ordovician and late Devonian; limited isotopic dating gives a range of ages between 388 and 396 m.y.

The granitoid plutons range in composition from tonalite through to granite. The most widespread rock type is hornblende-bearing granodiorite. All plutons have sharp contacts with the country rocks and are surrounded by narrow (1 km) contact aureoles. Almost all the granitoids, including some of the felsic varieties, contain hornblende bearing xenoliths of quartz diorite composition. The field, petrographic and chemical data indicate that all the granitoids are derived from an igneous (I-type) source. The granitoids are grouped into 10 separate and distinct comagmatic suites on the basis of petrography and chemistry.

The differences in source composition, as reflected by chemical differences between the granitoid suites, imply a variation in the composition of the lower crust in this region. The size of the suites described, for example the Bemboka Suite (840 km^2), Glenbog Suite (in excess 500 km^2), and the orientation of these suites as a series of meridional strips, some of which run the length of the batholith, indicate that large scale, lateral variation in the composition of the lower crust occurs under this part of southeast Australia.

A DYKE COMPLEX ASSOCIATED WITH THE COOLAC SERPENTINITE

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In the southern extension of the Cowra Trough, the Coolac Serpentinite has been tectonically emplaced as a subvertical sheet along the western flank of a Late Silurian to Early Devonain calcalkaline pluton (the Young Granodiorite). Over most of its length, the Coolac Serpentinite is flanked immediately to the west by disrupted units of metabasalt, metagabbro, cherts, pillow basalts and calcalkaline volcanics. At its northern end, 5 km east of Coolac township, where tectonic disruption of the serpentinite and adjacent mafic rocks is not severe, a unit of sheeted dykes, overlying gabbro and having demonstrable stratigraphic association with the Coolac Serpentinite, has been mapped.

The dyke unit contains several textural varieties of basalt intruded as dykes up to 40 cm wide into screens of gabbro. Greenschist grade metamorphism has strongly altered all but about 10% of basalts. Structural analysis indicates that dyke margins are sub-parallel and show a consistent orientation within individual fault blocks, and that this orientation is roughly perpendicular to the gabbro-ultramafic boundary. There is considerable resemblance to the sheeted dyke members of documented ophiolite sequences and ocean floor models, although the scale of development is roughly 10 times smaller than at Troodos or Newfoundland.

Chondrite normalised Rare Earth patterns derived from spark source mass spectrometric analysis of both altered and fresh basalts are reported. Fresh basalts and some metabasalts show either LREE depletion or chondritic patterns. These patterns indicate an oceanic or island arc tholeiite affiliation. Other metabasalts show moderate LREE enrichment which may be primary but could also be caused by secondary mobilisation of LREE.

The tectonic environment of formation most favoured is a narrow basin in which "incipient" axial or diffuse spreading has taken place, accompanied by mantle upwelling and the addition of relatively unfractionated basic to intermediate magma. Oceanic crust has been produced and the process would have been analogous to Mid Ocean Ridge formation, but operating on a much smaller scale and related in time and space to the onset of calc-alkaline vulcanism and shallow basin sedimentation.

A SIMPLE DIAGRAMMATIC APPROACH TO TECTONIC ANALYSIS

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The geological record commonly contains a very detained, but subtle impression of the interplay of various tectonic processes. Historically, analysis of this record has concentrated mainly on identifying the major tectonic events, but has neglected the wealth of information recorded by the myriad of smaller features. A better resolution of the detailed tectonic history of an area can only come from a careful evaluation of all the geological data. The technique described below represents an attempt to use as much of the available data as possible, and thereby to develop a high resolution technique for tectonic analysis.

The analytical method is largely diagrammatic. For a particular area, a composite stratigraphic column is plotted against a linear time scale. Beside them, various features are depicted by appropriate symbol. These are:

(i) environmental features (such as regressive and transgressive sequences, marine and terrestrial sequences).

(ii) provenance features (such as quartzose, flint clay, lithic and contemporaneous acid volcanic and intermediate to basaltic volcanic sources for sediments).

(iii) contemporary igneous activity (such as granite plutonism, acid volcanism, intermediate to basic volcanism, and

(iv) deformation (thrust, strikeslip and normal faulting and folding). Besides these data are depicted the associated regional palaeogeographic and tectonic events. These include regional uplift, regional subsidence, regional deformation, crustal rifting and acid volcanism, crustal extension and basaltic volcanism, granite plutonism, and sedimentary transport direction. In each of the above groups, other symbols may be added if necessary.

The events depicted are not isolated or random, but occur in sequence which last about 25-50 m.y. Examples are described from a number of localities from the Late Palaeozoic of Eastern New South Wales.

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PETROGENESIS OF AN S-TYPE VOLCANIC - PLUTONIC ASSOCIATION -THE STRATHBOGIE IGNEOUS COMPLEX, CENTRAL VICTORIA.

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Our paper discussed the origin, evolution and emplacement of the magmas responsible for the Late Devonian Strathbogie Igneous Complex. The Violet Town volcanics and the Strathbogie batholith comprise this S-type complex which is one of numerous Palaeozoic plutonic and/or volcanic associations that contain the aluminous phases cordierite and garnet.

Although the Strathbogie batholith is a composite mass with mappable textural and chemical variants, a limited range of bulk compositions (SiO_2 70-75 wt%) is developed, exhibiting regular trends on Harker diagrams. There are several possible mechanisms contributing to this chemical variation:-

(a) progressive partial fusion,

(b) "unmixing" of restite components,

and (c) differentiation by crystal fractionation.

Quantitative calculations suggest that the first mechanisms can have only minor effects. Fractionation of 10-20% of early crystallized biotite and plagioclase from the more mafic granitic magmas would yield compositions close to the silicic variants. In this regard field, petrographic and chemical characteristics of the granites indicate a primary magmatic origin for the bulk of the biotite and plagioclase as well as quartz, K-feldspar, garnet and cordierite.

Estimates of the physicochemical conditions, during magmatic evolution of the granite suggest initial crystallization at 5 to 7 kb with T in excess of 800°C and final magmatic crystallization at 1 kb or less. From crystallization experiments (Clemens and Wall, this volume) temperatures of <875°C and water contents of around 4% are inferred. These emplacement conditions are compatible with the low (P = 0.5 to 1.0kb) pressure contact metamorphic assemblages in the aureole and the high level of intrusion inferred on stratigraphic grounds.

The earliest phase of the Strathbogie Igneous Complex, the Violet Town volcanics is intruded by the Strathbogie granites. The volcanics are thick pyroclastic flows ranging in composition from rhyodacite to rhyolite (67 to 72% SiO_2). These volcanics also contain garnet, cordierite, biotite and orthopyroxene as well as plagioclase, quartz and K-feldspar. Textural criteria suggest a magmatic origin for most of these phases, although minor restite is present. The petrographic features and chemical variation suggest that the rhyolites at the base of the volcanic sequence represent a primary magma while the upper units are differentiates of a second, genetically related, more mafic magma. Fractionating orthopyroxene, biotite and plagioclase have played the major role in producing the variation.

Results of thermometry and barometry using garnet, cordierite, orthopyroxene, biotite, plagioclase and ilmenite, suggest that the mafic phenocryst phases equilibrated up to 4-5 kb and temperatures of 800-850^{o}C with a magma water content of about 3.5wt%.

The chemical and mineralogical similarity of the granite and the volcanics suggest a compositionally similar source region for the magmas. Degree of partial melting, temperature and H_2O content may have been the factors controlling the evolution and emplacement mechanisms of the magmas.

Silicic magmatism was widespread during the Late Devonian in Central and Eastern Victoria. A mass of mafic magma emplaced at the base of the crust could have provided the heat source for anatexis of granulite facies metapelitic and feldspathic gneiss (possible Precambrian in age) in the lower continental crust of south - eastern Australia.

CRYSTALLIZATION AND ORIGIN OF SOME "S-TYPE" GRANITIC MAGMAS

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This paper discusses experimental and thermodynamic studies of the phase relations of peraluminous granitoids and the application of these results in determining the P-T-a_{H_2O} history of the magmas, the nature of and conditions in the magma source regions.

Four compositions were studied experimentally: a garnet-cordierite rhyolite and a garnet-cordierite-hypersthene-biotite rhyodacite from the Marysville Igneous Complex; a garnet-biotite adamellite from Wilsons Promontory and a garnet-cordierite granite from the Strathbogie batholith in Victoria. Crystallization experiments were carried out in internally heated gas apparatus with P = 1-7 kb., T = 700° - 900°C, a_{H_2O} = 0.1 -1.0, $fO_2 \leqslant$ QFM, run times of 100 - 500 hours. Anhydrous starting glasses were seeded with natural cordierite and almandine and in some cases sillimanite and quartz. Water activities were controlled by large excesses of H_2O - CO_2 vapour, melt water contents then being calculated using the approach of Burnham (1974). Run products were examined optically, by X-ray and electron microprobe abalysis.

Essential features of the crystallization relations are summarised in the following diagrams, for the granite composition:-

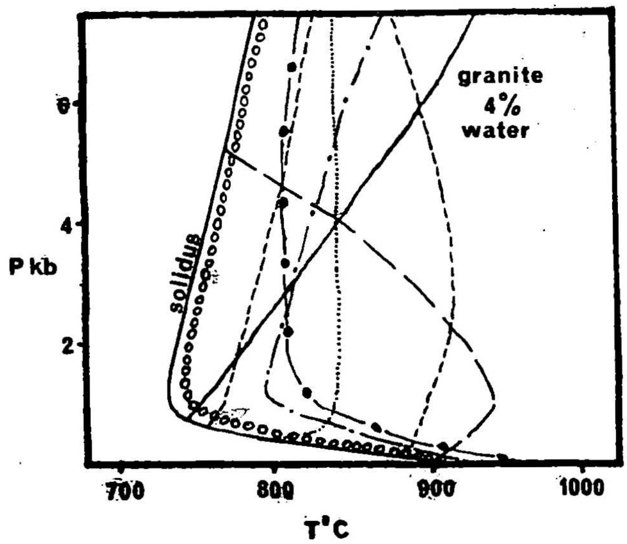

FIG.A $X^{melt}_{H_2O}$ = 4 wt%

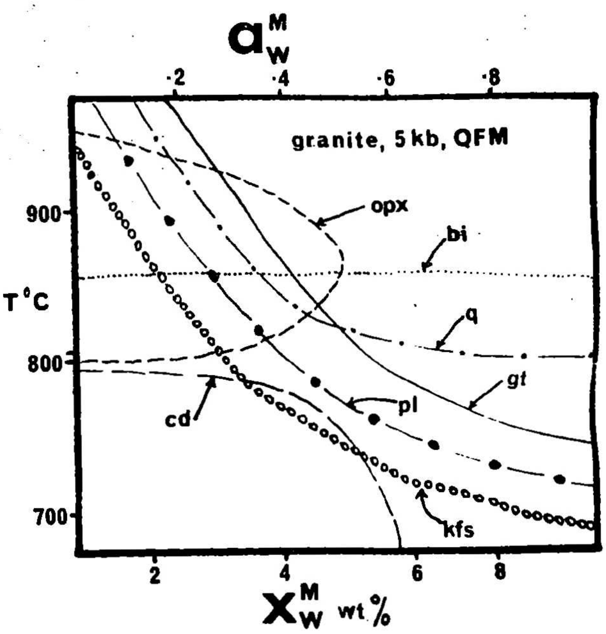

FIG.B for P = 5kb.

For water-undersaturated conditions, in all compositions except the rhyolite, plagioclase exhibits the highest temperature liquidus of the felsic phases for $P < 3 - 4$kb., while quartz assumes this position at higher pressures. K-feldspar liquidi are near the solidi. Cordierite appears near the magma liquidus at $P = 1 - 2$kb. and is unstable at $P > 5$kb. Spessartine-poor almandine garnet grew in all compositions at $P > 1$kb. and became a near-liquidus phase at $P = 4 - 5$kb. Thus cordierite and garnet bear no special significance for estimates of the pressures of magma generation (cf. T. Green, 1976, 1977) and can be regarded as normal crystallization products of peraluminous magmas. Orthopyroxene has a 100°C wide crystallization field (up to 900°C) which narrows somewhat at high pressure. Biotite liquidi have near-vertical dP/dT slopes and occur around 850°C for $X_{H_2O}^{melt} = 2$-10 wt%. Early crystallization of biotite requires $X_{H_2O}^{melt} \gtrsim 3$ wt%. Microprobe analyses of coexisting phases show that X_{Fe} Ilm $>$ Gt $>$ Melt $>$ Opx $>$ Bi $>$ Cd (at 800°C) suggesting that biotite - orthopyroxene fractionation could contribute to high Fe/(Fe+Mg) as shown by the natural rhyolitic magmas. Sillimanite seeds partially or completely dissolved in the melts at all pressures. Melt normative corundum content, in sillimanite-seeded runs, increased with higher temperatures and water contents. While lower than Green's (1976) values, the normative corundum contents of the melts in sillimanite-saturated runs are appreciably higher than for the natural magmas at reasonable T and $X_{H_2O}^{melt}$ values. Difficulties with the microprobe analyses of hydrous glasses make these results somewhat tentative.

Crystallization sequences of the Devonian volcanic and granitic rocks are simulated by the experimentally determined phase relations for magma water contents of 3 - 5% (4% best value) with near-liquidus phases present at $T \lesssim 850^{\circ}$C and initial $P \gtrsim 5$kb. Application of our experimental results to natural magmas requires accurate geothermometry on these materials. For the above inferred magma water contents, magmatic temperatures of 800°C (for $P \gtrsim 5$kb.) would suggest up to 15% restite garnet, biotite, orthopyroxene, plagioclase and quartz; at 850°C very small amounts of these phases would have been present (cf. White and Chappell, 1977). Our geothermometry suggests early magma temperatures of 800° - 850°C for some of the volcanics, although the Wilsons Promontory adamellite could have been lower temperature ($< 800^{\circ}$C) with appreciable restite present.

The inferred magma P - T - X_{H_2O} liquidus relations and water contents place strong constraints on magma source materials and conditions. Muscovite-bearing assemblages cannot have been present in the source region, while biotite-, orthopyroxene- and garnet-bearing source rocks appear most likely. Sillimanite- bearing assemblages probably comprised only minor portions of the source regions in view of the lower normative corundum content of the natural magmas compared to the sillimanite-saturated experimental liquids and the limited stability of biotite (F-poor) with sillimanite and quartz (Phillips and Wall, this volume). On these grounds, Victorian Upper Devonian granitoid magmas were probably produced by partial melting of a terrane dominated by quartzo-feldspathic gneisses, these materials having been derived from some combination of immature sediments and felsic igneous products.

Temperatures of at least 800° - 850°C characterized the source region during magma genesis. Pressures $\gtrsim$ 5kb. may be inferred from the magma liquidus relations and geobarometry on natural phenocryst assemblages. Rare almandine-rutile assemblages in some volcanics suggest pressures of over 7kb. Partial melting hence took place under low- to intermediate-pressure granulite facies conditions. The inferred magma water contents indicate $a_{H_2O} \approx 0.3 - 0.5$ for these P - T conditions, broadly consistent with the presence of biotite - orthopyroxene assemblages in the source rocks. Reactions involving biotite provided the water for the development of the partial melts. These reactions took place under vapour absent conditions. The relatively high-temperature, markedly water-undersaturated magmas produced were able to rise to high crustal levels. Water saturation was attained around 1kb., with ensuing fragmental eruption of the volcanic materials. We have not yet noted unequivocal differences in the granite and volcanic magmas, thus upper crustal tectonic features could strongly influence volcanic versus plutonic emplacement.

GEOLOGY & PETROLOGY OF SOME SOUTH AUSTRALIAN KIMBERLITES

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A group of 42 dykes and 6 diatremes of kimberlite intrude Adelaide Fold Belt rocks 240 km north of Adelaide, just to the east of Terowie.

The dykes vary from 0.05 to 11 metres in width with some traceable along strike for up to 400 metres. The sandy textured serpentine matrix displays flow banding parallel to the strike. Contact with the country rock is very sharp. The dykes contain very few mantle xenoliths and angular country rock inclusions are absent.

The diatremes are small, the largest being 6 hectares in area and contain brecciated kimberlite which has been highly weathered to clays of the montmorillonite group. The country rock in contact with the diatremes has been severely fractured with many angular dislodged pieces being incorporated in the kimberlite. Mantle and lower crustal xenoliths include rounded boulders of earlier formed kimberlite and several types of eclogite. Relict minor structures such as autoliths are very similar to those described from Lesotho kimberlites.

The high ratio of dykes to diatremes suggest that extensive erosion over an extended period of time has taken place. However, no tectonic deformation of the kimberlite bodies has been observed.

Evidence used to class the rocks as kimberlites includes:

(i) their megacryst mineralogy, especially the garnet compositions;
(ii) the mode of occurrence of the intrusions;
(iii) their bulk chemical composition.

Although the rocks are highly weathered, their composition approximates very closely to average kimberlite analyses.

The presence of kimberlite in the Terowie region suggests that the region was a well established craton and under tension at the time of emplacement.

INTERPRETATION OF SUBSURFACE SHAPE OF GRANITES IN THE EASTERN LACHLAN FOLD BELT USING AEROMAGNETIC AND GRAVITY DATA

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Comparison of aeromagnetic and geological maps of the Canberra and Bega 1:250 000 Sheet areas indicates that most of the granites in the area have an associated magnetic anomaly. Susceptibility measurements on hand samples confirm that the granites are magnetic and susceptibility values vary from 0.001 - 0.05 SI Units. The granites have been grouped on chemical criteria into I-types, which are of purely igneous origin, and S-types which have been derived by partial melting of sedimentary rocks (Chappell & White, 1974). The I-type granites are far more prominent than the S-types in the magnetic anomaly map. Two-dimensional magnetic modelling over the I-type granites (Fig. 1) indicates that most have the form of broad elongate domes with shallow dipping sides. However a few have steeply dipping sides, and some of the less magnetic have sides which dip inwards so that the intrusion becomes narrower at depth. A depth to the base of the granites of 3 km below sea level fits the larger wavelength features adequately. It is suggested that the I-type granites were intruded through relatively small feeder pipes and that they spread out laterally in a sill-like manner. Those on the Canberra sheet apparently migrated both laterally and vertically for considerable distances and penetrated sufficiently close to the surface to give rise to extrusive volcanic activity. In contrast most of those on the Bega sheet remained at depth as large bodies and moved only short distances from the source region.

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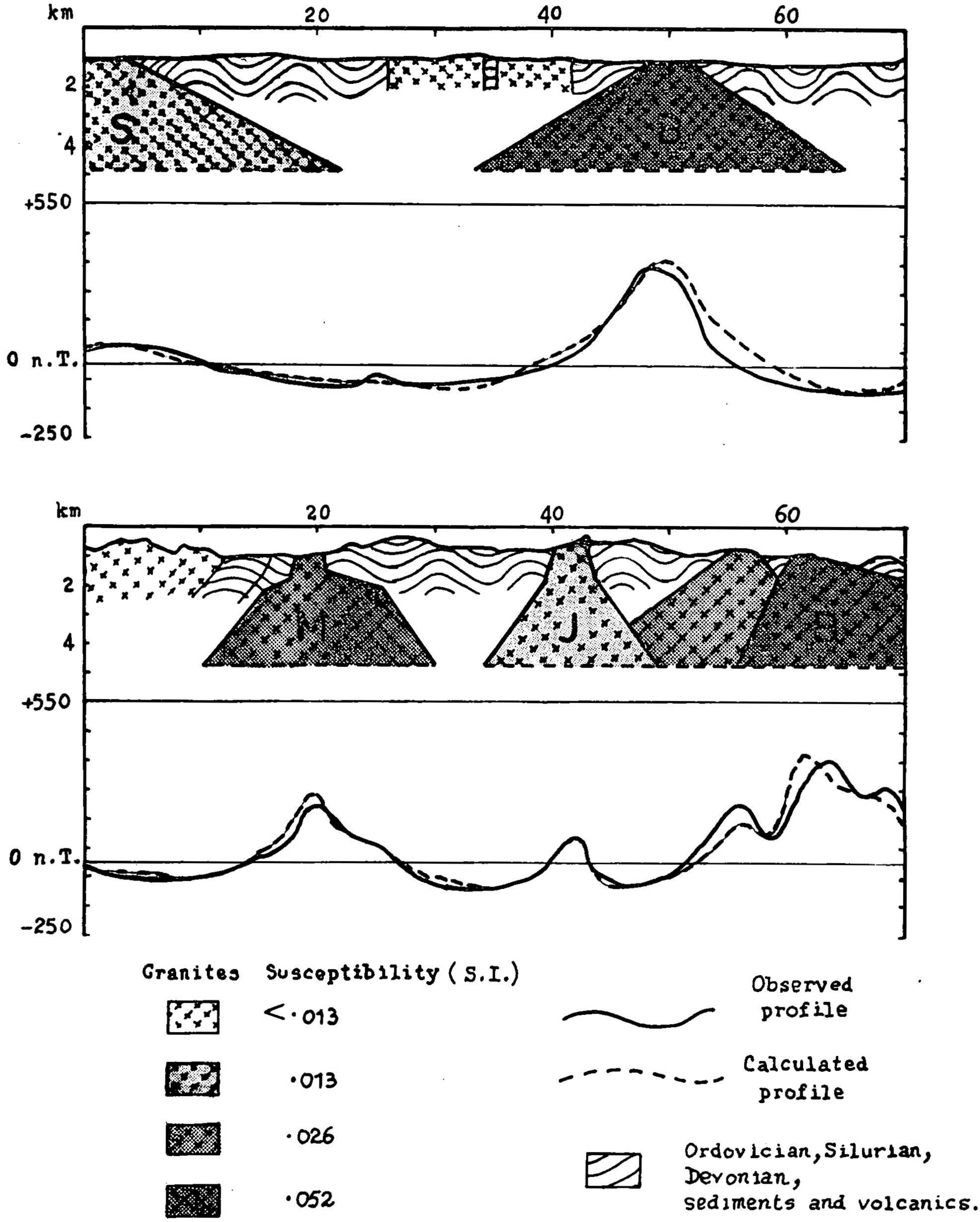

East-west cross-section of granites in the Canberra 1:250 000 Sheet area, illustrating their general dome-like shape. Top section is across Sutton Granite (S) and the northern extension of the Braidwood Granite (B). Bottom section is across the Michelago Complex (M), the Jerangle Complex (J), and the southern part of the Braidwood Granite (B).

GEOCHEMISTRY OF DEVONIAN GRANITOIDS AND ASSOCIATED VOLCANIC ROCKS EAST OF MELBOURNE, VICTORIA

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The results of a study on the geochemistry and mineralogy of two Upper-Devonian igneous complexes, covering a total area in excess of 3.500 km^2 directly east of Melbourne, are discussed. The complexes represent part of the massive igneous activity in the Melbourne Trough culminating after the main phase of deformation of the Tabberabberan Orogeny.

The two igneous complexes consist of several subvolcanic granitoid plutons and two suites of acid volcanic rocks. Traditionally cauldron subsidence has been proposed to explain the structural association of these acid volcanics with the adjacent plutons. The chemical association of both rock types is here discussed using a modified AFM-diagram.

An analysis of the chemical data for whole rock, contained minerals and inclusions show that there are differences in the chemical evolution of the granitoid magma's as well as differences in possible source materials for the formation of the magma's. Mechanical mixing of melt with residual source material and chemical differentiation through fractional crystallization are the two most likely processes to explain the chemical evolution trends of the different magma's.

MODELS FOR EVOLUTION OF THE S.E. AUSTRALIAN CRUST AND RESOLUTION OF THE 'CONTINENTAL OR OCEANIC SUBSTRATE' PARADOX

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The exposed part of the crust in southeast Australia consists entirely of Phanerozoic rocks, some 75% of which are sedimentary and volcanic rocks and their metamorphic derivatives. The substrate on which these rocks were deposited is a matter of inference, and of dispute (Crook & Powell, 1976). Validation of the inferences and resolution of the dispute is essential to an understanding of the origin, evolution and present nature of the southeast Australian crust.

A continental substrate has been proposed or implied by Hills (1956): "pre-Cambrian basement"; Rutland (1973): "reworked Proterozoic basement complex; and White, Williams & Chappell (1976): "continental crust, possibly crystalline shield". An oceanic substrate has been proposed by Crook (1969): "a largely simatic substrate" and (1974): "oceanic crust". Scheibner (1972) showed an oceanic substrate for the region and several ensimatic island arcs, on a series of palinspastic sections of N.S.W.

The evidential bases for these conflicting inferences reveal a remarkable paradox. Granitoid geochemistry and the distribution of S-type granitoids (Chappell & White 1974, 1976; White *et al.*, 1976; White & Chappell, 1977), mantle isochrons (Compston & Chappell, 1976) and the geochemistry of possible protoliths for the S-type granitoids (Wyborn, 1977) clearly imply a Proterozoic sialic source for the granitoids. The source must underlie the exposed Phanerozoic rocks.

The widespread occurrence of rocks characteristic of the oceanic realm, particularly flysch; the increasingly mafic character of the lower parts of many Paleozoic sequences (Crook, 1974), some of which are demonstrably of oceanic tholeiitic affinities (Crawford & Keays, 1976 & in press); and the occurrence of ophiolites and related rocks (Crook & Felton, 1975) equally clearly imply an ensimatic origin for the Paleozoic sediments and volcanics and hence an oceanic substrate.

I propose to review several models for development of the crust of the region, some previously published and some new, in the light of the above evidence, and show how the paradox can be resolved. This will involve the presentation of a new comprehensive model for the origin and evolution of the crust of S.E. Australia (Crook, 1978).

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PERTURBATIONS TO THE GEOTHERMAL FIELD AND GLACIAL RETREAT IN THE SNOWY MOUNTAINS

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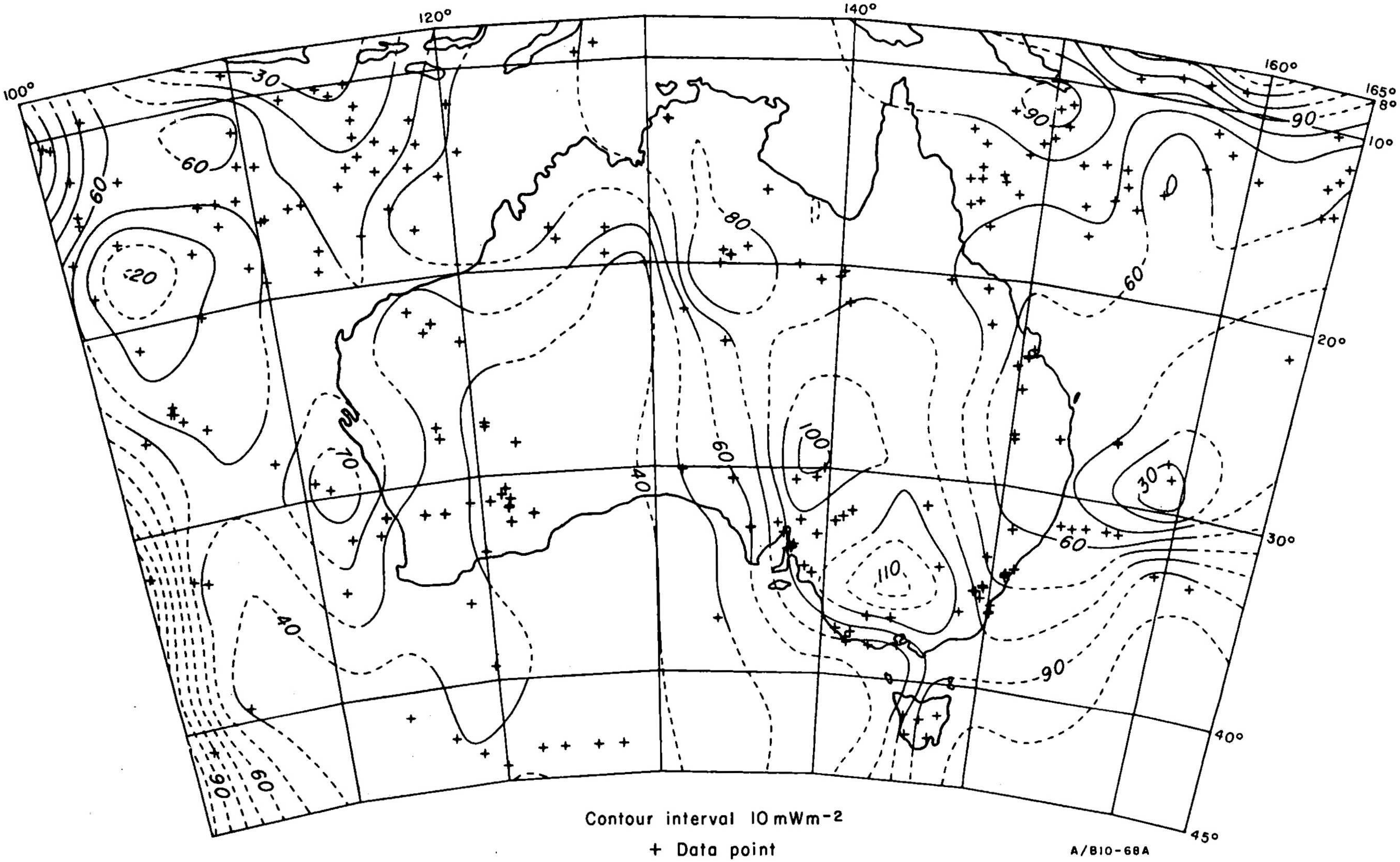
Temperature gradients depend primarily on the concentration and distribution of trace-element radioactivity in the crust and on variations in thermal conductivity. However, thermal perturbations are also caused by mass transfer and these result in regions of anomalous heat flow. Models of crustal formation are constrained therefore by observations of surface heat flow.

Heat flow in the southeast of Australia exceeds the world average (Fig. 1) and regional trends are consistent with continued episodic intrusions migrating to the south. However, none of the heat flow data have been corrected for recent climatic perturbations, consequently crustal models are poorly constrained and the volume of intrusive rocks cannot be well determined.

Surface heating subsequent to Quaternary glaciation in the Snowy Mountains results in decreased near-surface thermal gradients. Heat flow therefore appears to increase with the depth of determination. Some data obtained at depths less than 300 m may require positive corrections of up to 25% depending on the rate of glacier retreat and the amount of warming. Ambiguities can be resolved only if heat flow data are obtained at depths greater than 1000 m.



100°
120°
140°
160°
165°
8°
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30°
40°
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70
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80
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100
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90
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30
60
90
0
Contour interval 10 mWm-2
+ Data point
A/B10-68A

THE MEREDITH ULTRAMAFIC BRECCIA PIPE - VICTORIA'S FIRST KIMBERLITE?

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The Meredith breccia pipe, situated 52 km west of Melbourne, intrudes Ordovician metasediments of the Ballarat Trough. It contains a wide range of rock and mineral inclusions: 1) Abundant angular blocks of Ordovician country rocks. 2) Rounded clasts of fine-grained mafic igneous rock. 3) Ultramafic nodules. 4) Rounded megacrysts of amphibole, phlogopitic mica, pyroxenes, garnet and picro-ilmenite.

The matrix consists largely of nontronitic clay, pseudomorphing olivine and other mafic minerals, and carbonate. Many of the inclusions show similar alteration products. Small prisms of diopsidic augite in the matrix indicate a minimum emplacement temperature of 400-500^{o}C.

Coarse phlogopite from the breccia has yielded a K/Ar age of 163 $\pm$ 4 m.y. If this is the age of pipe emplacement a relationship with the Jurassic volcanic rocks of western Victoria and South Australia is indicated.

The inclusion suite provides information on the nature of the upper mantle beneath Victoria at the time of breccia emplacement. The mineral chemistry and petrology of the ultramafic nodule suite are described in detail.

Ultramafic nodules.

Two main groups of ultramafic nodules are present:

1) Garnet- and spinel-bearing lherzolites with metamorphic textures.
2) Wehrlites and clinopyroxenites with phlogopite and amphibole, displaying igneous cumulate textures.

The lherzolites often contain garnet and spinel which show no evidence of a reaction relationship. Phlogopite is an accessory phase. Variation in the compositions of chrome diopsides, garnets and spinels indicates equilibration of lherzolite assemblages over a range of P-T conditions. In the wehrlites proportions of olivine and aluminous augite are variable. Phlogopite is always abundant. Abundant nodules of amphibole- and phlogopite-bearing clinopyroxenite display well-developed cumulate textures, with augite or occasionally phlogopite the dominant cumulus phase, and kaersutite the major intercumulus phase. Adcumulates of kaersutite and phlogopite also occur. Other ultramafic nodules include dunites and a wehrlite with garnet and picro-ilmenite. These have metamorphic textures.

Megacrysts.

Two probable origins are indicated for the megacryst assemblages- as debris from ultramafic nodules (xenocrystic) and as high pressure liquidus phases of the breccia or similar magmas (magmatic). Relative abundances of megacrysts are olivine (60), phlogopite (14), aluminous chrome diopside (8), kaersutite (6), aluminous augite (4), orthopyroxene (4), chromian spinel (3), pyropic garnet (1) and picro-ilmenite (trace).

The most abundant garnet is flesh-pink pyrope with Mg-numbers of 80-85 and 1.4-2.0% Cr_2O_3. Rare grains have 2.5-5.6% Cr_2O_3. These garnets are interpreted as disaggregated nodule material. Common orange garnets have Mg-numbers of 58-82 and less than 0.2% Cr_2O_3, and they are interpreted as magmatic garnets.

The most abundant spinels are brown picotite which grade into chromite-rich varieties. Mg-numbers range from 60-76, and values of 100Cr/Cr+Al from 10-55. All spinels have less than 1% TiO_2. The spinels are thought to be derived largely from the disintegration of lherzolite nodules, whose spinels show a similar compositional range.

Rare, homogeneous picro-ilmenite grains are up to 1.8 cm in diameter, and contain a maximum of 9.3% MgO. Chromium contents are less than 0.25% Cr_2O_3.

Megacrysts of black Ti-aluminous augite reach 9 cm in diameter. They are frequently intergrown with kaersutite. Their compositions grade into those of smaller dark green megacrysts of chromian-aluminous augite. Kaersutite megacrysts reach 10 cm diameter. Abundant red-brown titaniferous phlogopite occurs in plates up to 3.5 cm in diameter.

Two spinel-diopside pairs from probable garnet-spinel lherzolite nodules have yielded temperatures of 1120^{o}C and 1090^{o}C using the experimental calibration of Mori (1977). A similar estimate for a spinel lherzolite gave 940^{o}C. To date, estimates of pressures of equilibration have been hampered by lack of relict orthopyroxene. However, use of the above temperature estimates with published curves for the spinel lherzolite to garnet lherzolite transition yields pressures within the range 18-2kb. These temperatures and pressures indicate equilibration of spinel-bearing lherzolites on a mantle geotherm slightly steeper than the oceanic average. The presence of garnet lherzolite nodules of deeper origin is almost certain.

Large unzoned aluminous augite, titaniferous phlogopite, and orange pyrope show a range of compositions implying growth under different P-T conditions. These could have been sampled by a rapidly rising magma originating from greater depths so that the magmatic inclusions may not be strictly cognate.

In contrast to most other eastern Australian breccia pipes, the Meredith pipe contains no xenoliths of crustal rock types such as garnet granulites. The presence of garnet-bearing lherzolites, and abundant phlogopite and rare picro-ilmenite megacrysts are more characteristic of kimberlites than of the alkali basalt-nephelinite suite. The assemblage described is at present unique in eastern Australia, and it probably constitutes Victoria's first kimberlite. It shows similarities in age and mineralogy with the Terowie kimberlites of South Australia. Despite the apparent high geothermal gradient associated with its emplacement, the Meredith body comes closer to sampling upper mantle material from potential diamond-bearing regions than any other presently known intrusion in Victoria.

STRESS FIELD IN THE CRUST OF SOUTHEAST AUSTRALIA

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Evidence from earthquake focal mechanisms and overcoring measurements in mines and quarries indicates that the Lachlan Fold Belt is currently in a state of substantial compression.

Reliable earthquake focal mechanisms are available from three recent earthquakes: Picton (NSW) in 1973, and Bowning (NSW) and Balliang (Vic.) in 1977. Each of these mechanisms indicates that the faulting associated with the earthquakes was caused by compressive stress, with the axes of compression being close to horizontal and, on average, close to east-west. This evidence is supported by reliable overcoring measurements made underground in mines, such as Cobar, and close to the surface in quarry floors and rock outcrops.

During 1978 sites at Ardlethan, Berrigan, Tocumwal, Milton and Moruya (all in NSW) were tested in shallow drillholes using USBM borehole deformation and CSIRO hollow inclusion gauges. The tests were made in competent rock ($E \sim 50$ GPa) at depths ranging from 3-9 m. At each site the stress measured was compressive.

Near the coast at Milton and Moruya the axes of maximum compression were north-south, but at all the other sites the maximum stress was close to east-west. Stress magnitudes ranged from 5 to 20 MPa with the highest values being obtained from Tocumwal and Berrigan. Surface indications of high stress were also seen at these sites, with uplift and cracking evident in a quarry floor, and uplift of an exfoliated slab near one of the sites.

FE-RICH GARNET CLINOPYROXENITES FROM THE KAYRUNNERA KIMBERLITIC DIATREME

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Recent studies of inclusions from the Kayrunnera kimberlitic diatreme in N.W. New South Wales recognised two types of basic inclusions (Edwards et.al., 1978). The Type I inclusions were found to comprise assemblages of clinopyroxene + rutile $\pm$ plagioclase $\pm$ quartz $\pm$ K-feldspar $\pm$ scapolite $\pm$ sphene $\pm$ apatite. The Type II inclusions contain assemblages of clinopyroxene + garnet + kyanite + quartz $\pm$ plagioclase $\pm$ K-feldspar and are lower in Ti, total Fe, higher in Al and have a higher Mg/Mg + ΣFe ratio than the Type I inclusions. These rocks were estimated to have equilibrated at 850^{o}C - 900^{o}C and 18-23 kb. Altered phlogopite bearing lherzolite inclusions contain co-existing garnet and spinel. These are estimated to have equilibrated at between 18 and 25 kb at temperatures of not more than 900^{o}C.

The low Mg/Mg + ΣFe ratio of the garnet clinopyroxenites and the absence of enrichment in K and P suggest that the Type I inclusions represent the product of an Fe-rich mantle source rock and not the product of mantle fractionation processes. In order to test this hypothesis 28 Type I inclusions were analysed for major and trace elements. Details of these analyses will be presented and the possibility that these rocks represent the melting products of a phlogopite rich mantle source will be assessed.

PETROLOGY NEAR THE CRUST-MANTLE BOUNDARY BENEATH COLORADO-WYOMING

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A large number of nodular xenoliths has been recovered from kimberlite pipes, of Devonian age, in the Front Range of Colorado-Wyoming. These xenoliths belong to 5 suites -- eclogites, websterites, peridotites, granulites, and megacrysts. Although nodules are believed to have come from depths as great as the depth of generation of the kimberlite, about 200 km, many nodules of the first four suites appear to have been plucked from the kimberlite walls within about 30 km of the crust-mantle boundary.

Although there is no reason to doubt that the crust-mantle boundary (at about 50 km) represents a chemical change from granulites to peridotites, phase transitions must occur within or immediately below the lower crust. These include the granulite-eclogite, spinel-garnet websterite, and spinel-garnet peridotite transitions. Examples have been found of rocks within the first two transitions -- cpx + gar + plag $\pm$ rutile granulites and a spinel-garnet olivine websterite. The latter rock contains sufficient olivine to be termed a lherzolite, but chemically is distinct from residual peridotites thought to constitute the bulk of the upper mantle. Like other websterites and associated garnet clinopyroxenites, it is unusually sodic (2.0% Na_2O in clinopyroxene) while poor in titania and chrome (0.15% TiO_2 and 1.3% Cr_2O_3 in garnet). The nodule is believed to have equilibrated at about 850^{o}C and 21 kb, placing the spinel-garnet peridotite boundary (at least among the websterite group) at about 70 km. It may be noted that this depth is nearly the same as estimated by Ferguson, Ellis, and England (1977) from a similar nodule in a pipe in New South Wales, but the Colorado paleotemperature is much cooler.

The garnet-spinel clinopyroxenite-websterite-lherzolite suite, a little-recognized part of the subcontinental upper mantle section, is believed to represent metamorphosed cumulates and to lie in pockets within a lherzolitic-harzburgitic mantle. Indeed, irregular websteritic bands have been found within lherzolite nodules. Paleotemperatures suggest that the bulk of the lherzolites associated with the suite lie below the websterites, perhaps reflecting substantial olivine-two pyroxene-garnet precipitation at greater depths than clinopyroxene-garnet fractionation.

S-TYPE GRANITE GENESIS AND EMPLACEMENT IN N-E VICTORIA AND ITS IMPLICATIONS

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Chemical data from extensive gneissic granitoids of the Omeo region in north-eastern Victoria suggests an origin from partial melting of the felsic components of the metamorphosed Ordovician quartzose flysch sequence. Because of the chemical character of the Ordovician metasediments the range of melt compositions derived from this source is severely restricted. Removal of considerable amounts of near minimum melt liquid (derived largely from volumetrically significant psammitic bands) to high crustal levels to form relatively residue free S-type granites, enriched the source region in less mobile melt-saturated former psammopelitic and pelitic material. This residue ultimately crystallized to form highly melanocratic gneissic "granodiorites" containing abundant xenocrysts of high grade metamorphic minerals such as cordierite, sillimanite, and garnet. Structural analysis of the fabric elements of both the plutonic and country rock in the Omeo region show that the highly contaminated and migmatitic granitoids possesses all the structural elements of the surrounding regional metamorphic envelope. This suggests partial melting to have been largely post tectonic and that the pre-existing structural elements inherited during ultrametamorphism have been preserved almost in situ.

Chemical data from S-type granitoids from the Murrumbidgee, Berridale, and Kosciusko Batholiths differ markedly from that recorded in the Omeo region. Melt compositions from these plutons cover a considerable chemical range and two distinct xenolith lineages can be recognised. The chemistry of the melts from these batholiths appears incompatible with an origin involving the partial melting of the Ordovician sediment pile in these regions. The source material for these melts appears to be lower in Al_2O_3 and K_2O but higher in CaO than that for the Omeo S-type granitoids. A study of melt and residue chemistries suggests that psammitic material of composition A below approximates the parent chemistry for the melts in the south-eastern New South Wales S-type batholiths and psammites of composition B the parent material in the Omeo region. For comparison analyses C of a typical psammite from the Omeo region is also presented. Minimum melt chemistries for both regions approximate analysis D.

	A	B	C	D
SiO_2	65.86	74.59	74.69	73.95
TiO_2	0.62	0.60	0.61	0.08
Al_2O_3	14.91	12.23	11.65	14.39
Fe_2O_3	0.96	0.63	0.78	0.37
FeO	4.36	3.27	2.86	0.47
MnO	0.09	0.05	0.03	0.02
MgO	2.64	1.53	1.63	0.35
CaO	3.74	1.06	0.96	0.58
Na_2O	1.95	1.68	1.87	2.55
K_2O	3.07	3.22	2.56	5.29
P_2O_5	0.14	0.19	0.17	0.12
H_2O	1.39	1.10	1.37	0.93
	99.73	100.15	99.18	99.10

THE DISTRIBUTION OF MEDIUM AND HIGH-GRADE METAMORPHIC ROCKS IN THE WAGGA-OMEO METAMORPHIC BELT

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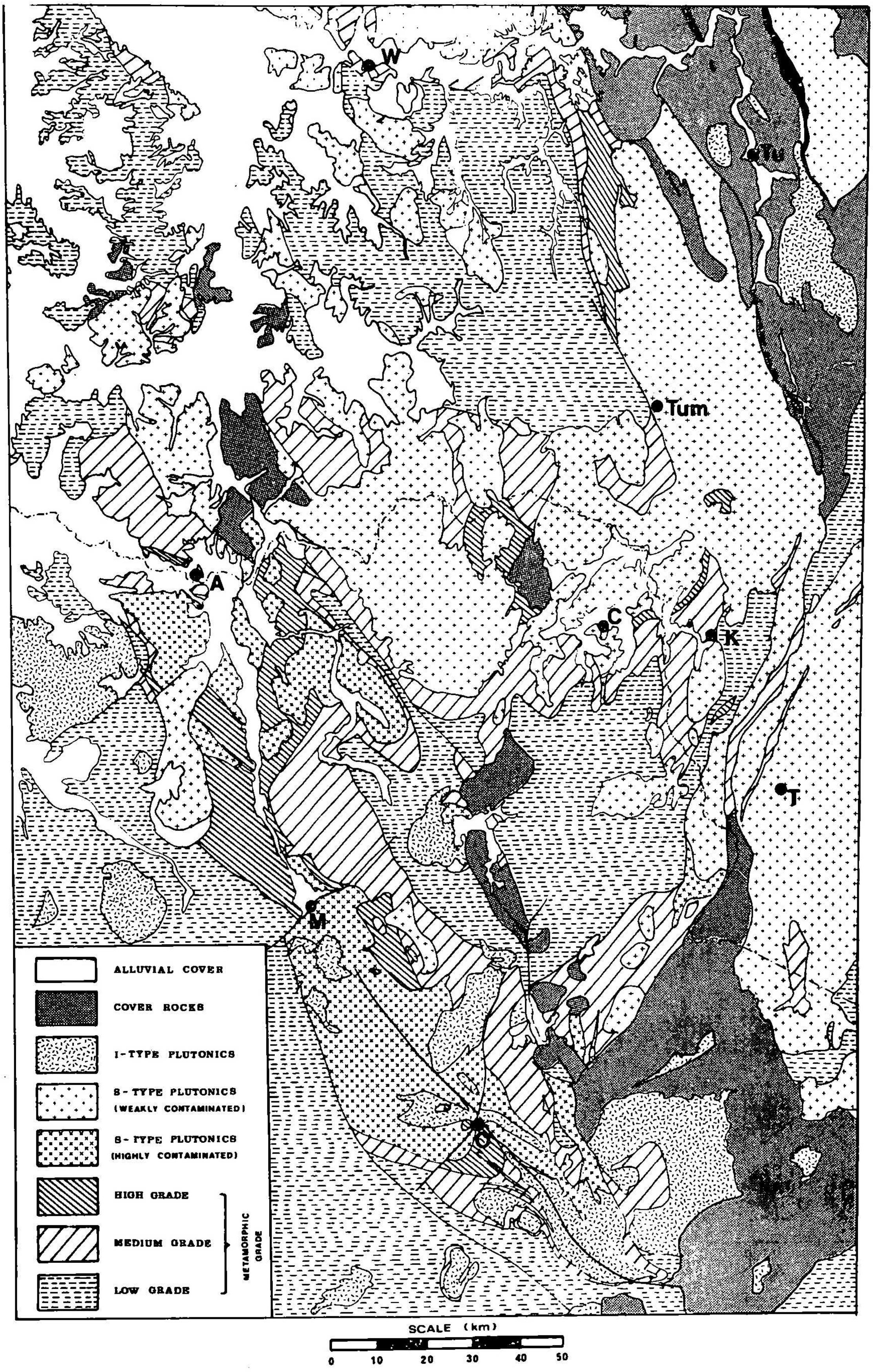
The area of exposed medium and high grade regionally metamorphosed rocks in the Lachlan Fold Belt can be subdivided into two coeval metamorphic zonal series with respect to the first appearance of either potassium feldspar or sillimanite in metapelitic assemblages.

Series A is characterised by a high grade zone containing the assemblage sillimanite + muscovite. The corresponding zone of series B metapelites contains Andalusite + potassium feldspar. The distribution of the two series reflects a slight pressure gradient across the region. P-T conditions at the peak of metamorphism may have approximated 4 kb P_{H_2O}, and $650^{\circ}C$, in the core of the complex with a geothermal gradient of about $40^{\circ}C/km$.

A metamorphic zonal map for the Wagga-Omeo Metamorphic Belt is presented showing the distribution of three zones based on the incoming of cordierite and sillimanite in metapelitic assemblages. The zonal scheme adopted is independant of the two metamorphic zonal series described above.

THE DISTRIBUTION OF MEDIUM AND HIGH-GRADE METAMORPHIC ROCKS IN THE WAGGA-OMEO METAMORPHIC BELT



TRANSFORM FAULTS ASSOCIATED WITH THE ANTARCTIC AND TASMAN SEA RIDGES AND THEIR RELATIONSHIP TO CONTINENTAL FRACTURES AND KIMBERLITIC ACTIVITY IN SOUTHEAST AUSTRALIA

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Recent discoveries have established the existence of fourteen areas where kimberlitic rocks occur in southeastern Australia, in the States of New South Wales, Victoria, Tasmania and South Australia (Ferguson & Sheraton, 1977; Stracke & others, 1977). One or more intrusives are found in each area, the maximum being twenty-seven. Rb-Sr dating on whole-rock samples and on phlogopite separates have established Permian and Jurassic ages for kimberlitic occurrences in northwestern New South Wales and South Australia, respectively. Field relations indicate that all the occurrences postdate the Proterozoic, and that some are as young as Tertiary.

In an attempt to relate the kimberlites and their associated rock types to a structural framework a number of features were investigated: on and offshore structures, igneous activity, earthquake activity, general tectonics, gravity, and magnetics. Of the features investigated on and offshore structures and earthquakes appear to be the most pertinent. Two prominent belts of earthquake activity are apparent, one striking north to northwest through the Flinders Ranges of South Australia and extending to the northwest margin of the continent; the second belt trends north through Tasmania, across Bass Strait into Victoria, and then northeastwards into New South Wales, and continues offshore in southeastern Queensland. Cleary & Simpson (1971) have postulated that these two zones of earthquake activity correspond to projected continental extensions of oceanic transform faults originating from the Antarctic Ridge. The South Australian kimberlitic occurrences all lie on the continental projection of the oceanic fracture-zone arising from present-day spreading associated with the Antarctic Ridge. This feature is in accord with the hypothesis developed by Wilson (1965) that lines of weakness in old continental crust determine sites for the development of transform faults; Ringis (1975) has found that this concept applies for the south-eastern Australian margin. On the eastern seaboard, the southern spreading ridge is also thought to be responsible for the projected continental fracture zone which lies coincident with a broad belt of Cainozoic igneous activity, and is also approximately the edge of Cainozoic epeirogenic uplift and the Cainozoic mean-line of hot-spot migration. All the kimberlitic occurrences near the eastern seaboard of Australia fall within this broad zone of activity. Their location also appears to have been governed by fracture patterns developed initially during pre-breakup times, which later became the sites of continental extensions of transform faulting during the Tasman Sea opening; this spreading commenced 80 m.y. ago, and aborted 60 m.y. ago. A number of the kimberlites on the eastern seaboard of Australia are located at the intersections of the projected continental transforms stemming from the two spreading centres.

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SEISMIC STRUCTURE OF SOUTHEASTERN AUSTRALIA AND CONSTRAINTS OF CRUSTAL EVOLUTION

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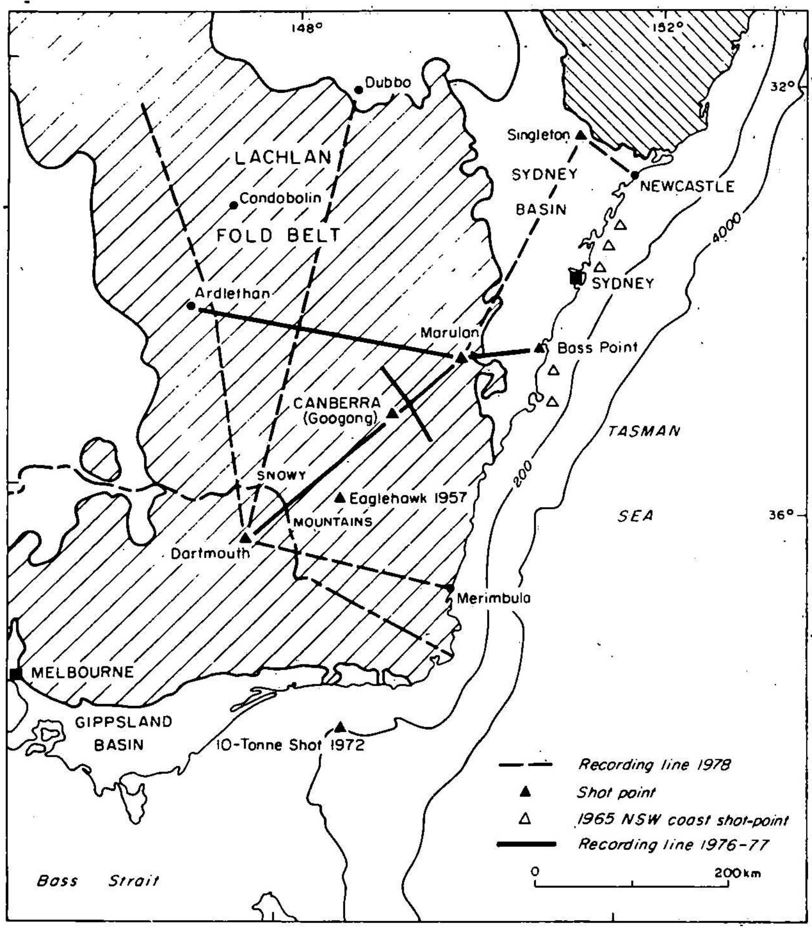
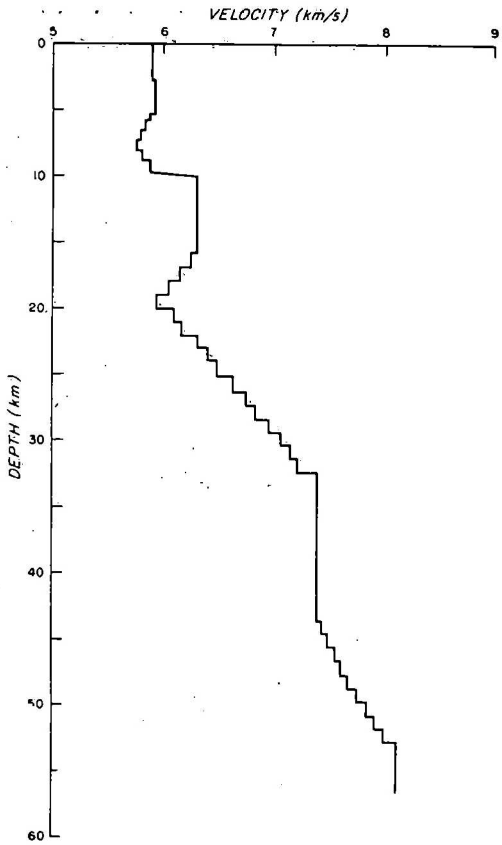
A number of descriptions of the Palaeozoic evolution of the Lachlan Fold Belt in southeastern Australia use plate tectonic concepts with analogues in the present-day western Pacific margins. The substrate of the Belt has been variously postulated as being "continental", "oceanic", and combinations of the two.

During the last ten years detailed seismic interpretations of the crust in continental areas have become available. In Europe, seismic recording on long profiles has been used; in USSR, deep seismic sounding methods have been used; in North America, vertical seismic sounding through crystalline basement, using techniques developed for oil exploration, has been used. These investigations show that early models of "continental" crustal structure were simplistic. The concept of a layered, homogeneous crust is no longer acceptable when both lateral and vertical variations in continental structures have been detected.

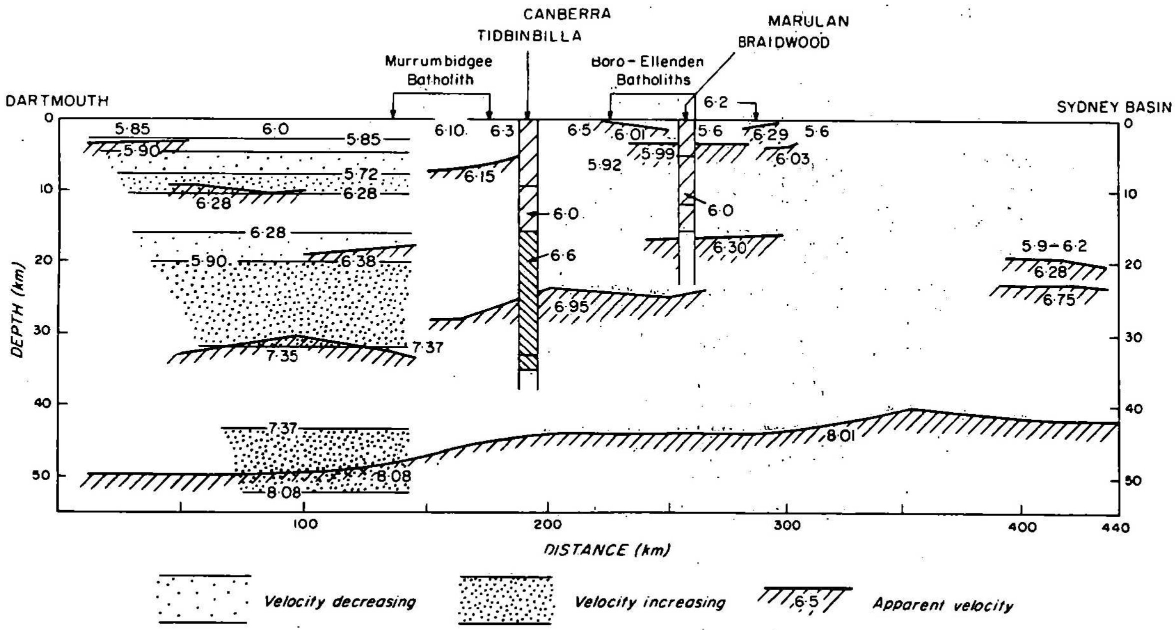
Since 1978, seismic investigations by BMR in the Lachlan Fold Belt (Fig. 1) have shown that its crustal structure is complex. Velocity changes are transitional rather than discontinuous, and crustal thickness exceeds 50 km in places. Velocity-depth profiles include a low-velocity zone in the upper crust, and another in the middle crust (Figs. 2 and 3). The considerable crustal thickness under the Lachlan Fold Belt is in marked contrast to the crustal thicknesses of 30-36 km under present-day western Pacific island arcs. An Andean-type evolutionary model may therefore be more appropriate for Palaeozoic southeastern Australia.



LACHLAN SEISMIC TRAVERSES



VELOCITY— DEPTH MODEL
FROM DARTMOUTH SHOTS TOWARDS MARULAN



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S AND I TYPE-IGNEOUS ACTIVITY IN THE NORTHERN PART OF LACHLAN FOLD BELT

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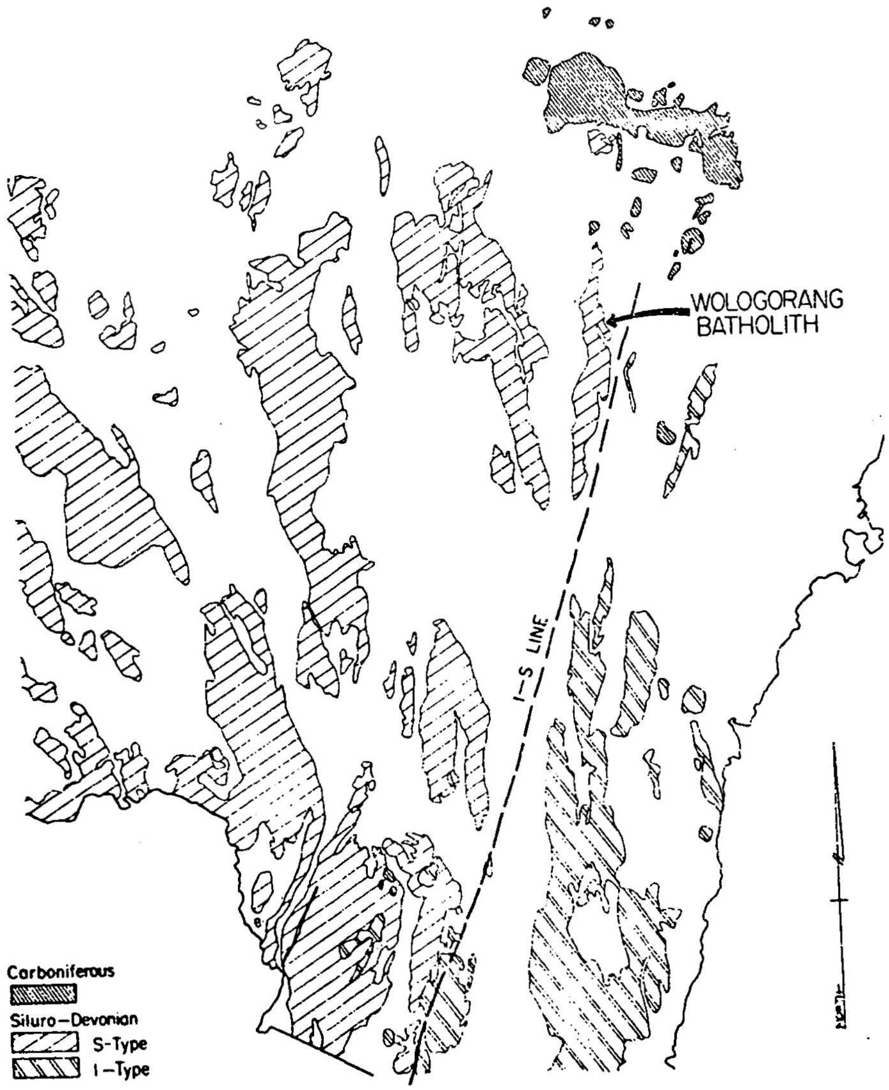
New data for the Wologorang Batholith which outcrops north-west of Goulburn indicate that it has S-type characteristics and is similar in age to the major S-type batholiths in the southern part of the Lachlan Fold Belt. The Wologorang granites are predominantly biotite leucogranites which have a strong post-magmatic (metamorphic) northsouth foliation. The biotites are alumina-rich and are commonly recrystallized. A bulk-rock Rb/Sr isochron based on samples defines an age of 404 $\pm$ 10 m.y. with an $^{87}Sr/^{86}Sr$ initial ratio of 0.7110 $\pm$ .0013 (M.S.W.D. = 2.79). However biotites separated from samples with the least deformed primary biotite yield Carboniferous ages similar to Evernden and Richards' biotite K/Ar dates indicating that the effects of the Carboniferous deformation/metamorphism in the northern part of the Lachlan Fold Belt extended at least as far south as Goulburn. The presence of biotites that record the intrusive age reported for many S-type granites further south do, however, indicate that the Carboniferous event was largely confined to the north. The age of the bulk rock with the highest Rb/Sr ratio is relatively insensitive to changes in calculated initial ratio and we therefore believe that the bulk-rock isochron gives the intrusive age.

These data indicate that the I-S line of Siluro-Devonian granites defined in the southern part of the Lachlan Fold Belt extends in a NNE direction at least as far north as the Wologorang Batholith. On petrographic grounds we suspect that part of the Davies Creek Granite which outcrops just south of the Bathurst Batholith is also a leucrocratic S-type granite. The Devonian I-type Marulen Batholith just to the east of Wologorang suggests, but does not prove, that the Wologorang Batholith is the most easterly S-type granite. To the north of the Bathurst granite the rocks exposed are sediments of similar age to the granites further south, so the I-S line can be inferred only on the basis of the interbedded volcanics. The general position indicated by the I-type Merrions Tuff is to the west of the line indicated by the intrusion.

Although the I-S line is a clear and meridionally continuous feature of the Siluro-Devonian granites, the subsequent Carboniferous plutonism that occurred throughout much of the northeastern part of the Lachlan Fold Belt does not record this dichotomy of source rocks. Although the Carboniferous granites occur on both sides of the proposed northern extension of the I-S line all are apparently I-type. This change from S-type to later I-type plutonism has also been noted in the New England Batholith. This change in source-rock type could be a function of one or more of the following factors. (1) Thrusting of the upper crustal rocks over different lower crustal rocks between the two intrusive events (2) depletion of the S-type source region in low melt fraction and heat producing radioactive elements during the first intrusive episode (3) isostatic uplift of the S-type source rocks out of the melting level during the unroofing of the first series of granites and (4) emplacement of new I-type source rocks that provided the later granites during or after the first S-type plutonism.



MICROSTRUCTURAL EVIDENCE FOR THE ORIGIN OF XENOLITHS IN AN I-TYPE PLUTON OF THE NEW ENGLAND BATHOLITH.

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In this study microstructural criteria are applied to evaluate the restite model of xenoliths in the Walcha Road Adamellite, a large I-type pluton of the Moonbi Suite (O'Neil *et al.* 1977) of the New England Batholith. We support conclusions of Chappell (1978) that the xenoliths are not derived from the quartz-rich metasedimentary country rocks and that the xenoliths are mineralogically and geochemically related to the pluton. Using igneous nomenclature the xenoliths range from micro-granodiorites and adamellites that are only slightly more mafic than the host to hornblende micro-"syenites" that are much more mafic than the host. All the xenoliths are massive and finer-grained than the host, although most contain larger phenocrysts of plagioclase ± quartz ± hornblende.

At least four mechanisms could generate xenoliths in granites. These mechanisms and the predicted microstructures of the resultant xenoliths are discussed below. In each case modification of the xenolith to minerals stable in the melt (e.g. Nockolds, 1933) and associated grain-shape changes could obscure evidence of the ultimate origin.

(a) Cumulates of phenocrystal ± refractory material that have been disrupted and carried up by the intruding magma would be expected to be coarse-grained and consist of polyhedral crystals, elongate or platy crystals being aligned. The intercumulus liquid might crystallize to give interstitial mineral grains. Slow cooling of these cumulates could result in modification towards a granoblastic microstructure as shown by Vernon (1971), which obscures but does not usually obliterate the cumulate microstructure.

(b) Restite material that has not been melted might be expected to resemble relatively coarse-grained, high-grade (upper amphibolite to granulite facies) regional metamorphic rock. If a melt fraction has been removed, the restite material might be expected to have microstructures similar to the cumulates of model (a). Flood *et al.* (1977) considered that (a) and (b) might, in this case, be microstructurally indistinguishable.

(c) Marginal parts of the pluton, especially the upper margin, would be expected to be granitic in mineral assemblage and finer-grained than the more central parts of the pluton. As well as the upper parts of the pluton it is possible that a pluton might be intruded into volcanic or a shallow intrusion of the same magmatic episode, which would also be much finer-grained and might well be more mafic than the granite magma (Flood et al., in prep.). These would have igneous microstructures. However, if the xenoliths are from small intrusions, some xenoliths of the adjacent metasedimentary rocks should also be present.

(d) Accidental xenoliths, which have reacted with the magma to form a mineral assemblage the same as that of granite (e.g. Nockolds, 1933) might be expected to preserve any large-scale layering, and, if quartz-rich metasediments were involved, these should be mineralogically stable and thus be preserved. Igneous xenoliths of accidental origin might well be microstructurally and mineralogically similar to the observed xenoliths but, if these were from discrete small intrusions, some xenoliths of the adjacent metasedimentary rocks again should be present.

The restite model is not in accord with the fine grain-size, the porphyritic igneous microstructure, the granodioritic composition of many of the larger xenoliths, or the complex normal and oscillatory zoning of the plagioclase phenocrysts. The cumulate origin also does not explain the fine grain-size, the massive fabric, the granodioritic composition, or the extremely K-feldspar-rich xenolith compositions. No evidence is seen that supports a mechanism involving the modification of metasedimentary material. Although the pluton does not have chilled margins at the present level of exposure, the porphyritic igneous microstructure of the less mafic xenoliths and their chemical and modal similarity to the host support mechanism (c). However, the absence of associated metasediments implies either that only the inner parts of a chilled margin were reincorporated, or that at the level of xenolith incorporation the country rock consisted only of volcanic rocks and shallow intrusive rocks associated with the pluton.

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THE PETROLOGY, COMPOSITION AND LAYERING OF THE LAYER 3 ROCKS ASSOCIATED WITH THE COOLAC OPHIOLITE SUITE

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In the vicinity of Cootamundra, Gundagai and Tumut, in southern New South Wales, a suite of rocks is exposed which appear to be ophiolitic in nature and thus may represent a section through the Early Palaeozoic oceanic lithosphere. The suite consists of several alpine-type serpentinite bodies in association with a sequence of layered ultramafic and mafic plutonics, mafic volcanics and fine-grained sediments.

This discussion is concerned with the layered plutonic portion of the suite. These rocks are particularly well developed adjacent to the northern end of the major serpentinite body - the Coolac Serpentinite Belt. Here they crop out over an area of approximately 15 km^2. The name 'North Mooney Complex' has been applied to them in this area.

The complex, which is almost entirely unserpentinized, consists of a series of diopside-rich rock types ranging in composition from dunite, wehrlite and clinopyroxenite to hornblende- and quartz-bearing gabbro, and finally to minor diorite, trondhjemite and albitite, together with several pegmatitic phases.

The essential points to be made are:-

(1) Recognition of two distinct divisions of the plutonic rocks, based on structural and textural evidence.
They comprise:

(a) a predominantly ultramafic layered sequence exhibiting magmatic accumulation features including cumulus textures, and post-cumulus overgrowth and space filling, together with mineral - and size-graded layers and spectacular cyclic units. The latter vary upward from olivine cumulate (dunite) to hornblende gabbro.

(b) a massive, structureless gabbroic zone which overlies and/or intrudes the layered rocks and contains the minor felsic derivatives.

(2) Establishment of a characteristic chemistry which is high in MgO and CaO and very low in K_2O, P_2O_5 and Rb. The mafic members show some Fe enrichment, whilst Na_2O is enriched only in the minor felsic derivatives.

(3) Correlation of the rocks with observed features of well-developed continental ophiolite complexes and with presend-day models of the oceanic lithosphere. This leads to an interpretation of the position of the rocks which correlates with oceanic layer 3, and the complex underlying 'transition' zone or possible crust-mantle interface between the main layers of the oceanic lithosphere.

SEISMICITY AND THE TECTONIC STRUCTURE OF VICTORIA

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The Seismology Centre at Preston Institute of Technology has been operating a network of seismographs within Victoria since the beginning of 1976. At present this includes six smoked paper analog instruments, with a timing resolution of ± 0.02 seconds, and five locally developed triggered digital systems. The peak frequency response is in the 5 to 20 Hz range. Timing accuracy is such that all good arrivals can be read to better than ± 0.1 seconds. A typical displacement gain is about 400,000 at 10Hz.

Most of the seismographs are in arrays about two dams under construction. This gives a very poor distribution of instruments within the state, most being close to an east-west line.

Considerable effort has been spent in developing earthquake location procedures. All events are located interactively on a minicomputer, using a variety of methods under the control of the operator. This always concludes with a non-linear least squares location. Particular attention has been paid to depth determination. For earthquakes at appropriate distances, wide angle P and S reflections from the Moho and other interfaces are used to give depths. For more distant earthquakes, depth control is given by the use of both direct and refracted wave phases.

A variety of crustal models with 2 or 3 layers are used for locations. These have been determined from both blast and earthquake records. Current models have horizontal interfaces at about 4, 16 and 33 kilometres, but a new model with variable crustal thickness is being developed.

For a typical location, three phases (P, S and one other) may be used from each of five or more seismographs. The standard deviation of time residuals is normally less than 0.2 seconds. The 95% uncertainty ellipsoid usually shows a location accurate to between 1 and 4 kilometres in each direction.

Earthquakes are being located in Victoria at a rate of about 150 per year, with magnitudes from below 0.0. It is aimed to locate all events with magnitude greater than ML = 1.0 within 100 kilometres of Melbourne.

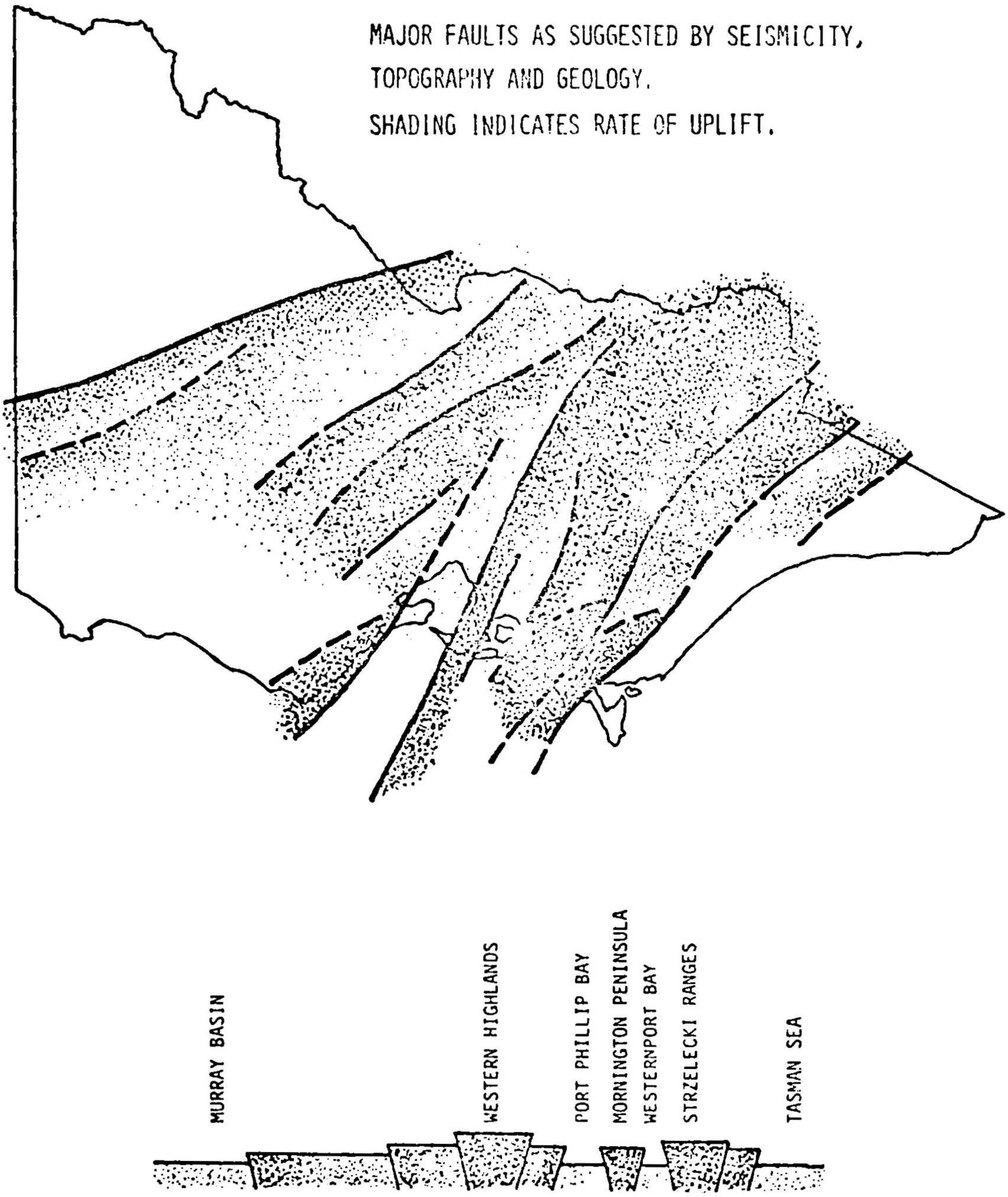
All earthquakes located to date lie within the crust, most with depths less than 20 kilometres. Epicentres are unevenly distributed about Melbourne, with a slightly higher concentration to the east. There are areas of high activity in the Gippsland hills and south of the Otway Ranges. A belt of epicentres extends west from Echuca to the South Australian border.

A detailed study of the earthquake distribution in three dimensions, together with topographic and geological evidence, has suggested a theory for the current tectonic activity in Victoria.

Most earthquakes occur either under the upthrown block of a mapped fault, or under highland areas. Earthquake depths tend to increase with horizontal distance from the surface outcrop of the fault. This suggests large scale reverse faulting. The faults dip at about 45^{o} to the base of the crust. Faults are spaced at distances of the order of crustal thickness, giving a fairly uniform distribution of epicentres.

The orientation of the faults indicates that Victoria is being compressed from south-east to north-west. This is supported by strain measurements, and focal mechanisms of large earthquakes.

Many of the large scale faults have surface expression of a series of smaller en echelon faults. This could possibly be attributed to a secondary rotation within the stress field. North-south Palaeozoic, and east-west Mesozoic faulting influence some surface outcrops.


MAJOR FAULTS AS SUGGESTED BY SEISMICITY,
TOPOGRAPHY AND GEOLOGY.
SHADING INDICATES RATE OF UPLIFT.
MURRAY BASIN
WESTERN HIGHLANDS
PORT PHILLIP BAY
MORNINGTON PENINSULA
WESTERNPORT BAY
STRZELECKI RANGES
TASMAN SEA

A GRAVITY INVESTIGATION OF THE STRUCTURAL FORMS OF GRANITOIDS IN THE NEW ENGLAND OROGEN

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Over 120 plutons in the New England Orogen have been grouped into 6 suites defined by field relationships and petrology and by isotopic dates. It has been suggested by Harrington and Korsch that the suites are products of the subduction of plates carrying continental and semi-continental crust, at the following times:

Valla Plutonic Suite	210 - ?181 Ma	Late Triassic and Jurassic
Stanthorpe Plutonic Suite	225 - 222	Mid and early Late Triassic
New England Batholith	253 - 230	Late Permian to early Mid Triassic
Hillgrove Plutonic Suite	?300 - ?270	Late Carb. and Early Permian ? reintruded in Permian
Bundarra Plutonic Suite	?320 - ?270	Late Carb. and Early Permian
Mt. View Range Granodiorite (of ? 'Knuttung Plutonic Suite')	336	'Mid' Carboniferous

Several groups of workers have contributed to the building of genetic hypotheses via field, petrographical and isotopic studies but less attention has been given to pluton geometry in 3D and to mechanisms of intrusion.

Nearly all of the intrusions are regionally discordant to the steeply-dipping and multiply-deformed country rocks. Most of the plutons are epizonal but some of those in the Hillgrove Plutonic Suite include migmatites and gneissic rocks. Some of the latter seem to have formed at the same time as the Bundarra Plutonic Suite but to have been reintruded later. The plutons of the New England Batholith (or Suite) and their correlatives in Queensland form a strongly curved magmatic arc; and Korsch has shown that some of the plutons were probably diapirs surrounded by sediment-filled rim synclines. Detailed gravity surveys have shown that some large plutons 20 to 30 km in diameter are not 'bottomless' and do not flare outwards at depth, but extend only to depths of about 4 km. Others extend to 10 km. Theoretical considerations suggest that small density contrasts between the rising plutons and the country rocks would favour the development of lateral intrusions with 'pancake' and 'mushroom' forms, whereas bigger contrasts would favour the development of plug-like forms. That is the case so far. In other workds, models are emerging that allow 3D shapes to be related to density contrasts (and probably viscosity contrasts) between the plutons and the intruded rocks (which have more complex geometries). The plateau region of New England is about 1 km high and is in isostatic equilibrium assuming an Airey-type crust.

STRUCTURAL HISTORY & TECTONICS OF THE NEW ENGLAND-YARROL OROGEN

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The following matters will be discussed:-

(1) The thick greywacke sequences in Zone B of the New England Orogen, east of the Peel Fault have been very difficult to handle because of multiple deformations, multiple episodes of plutonism and scarcities of marker beds and fossils. Gradually the sediments have been divided into "associations" and these have now been grouped into four "layers" which can be correlated with units west of the Peel Fault in the Tamworth Belt. There were four corresponding deformations (D1 to D4), four plutonic suites, and four tectonic periods (TP1 to TP4) between the Devonian and the early Mid Triassic.

(2) Part of the orogen, termed Zone C, was removed to Lord Howe Rise when the Tasman Sea opened in the Late Cretaceous and is not exposed, but part of its northwestern continuation is exposed in the Moreton Basin and Yarrol Orogen where four more tectonic periods (TP5 to TP8) can be recognised in the Mesozoic. The New England-Yarrol Orogen is therefore a Palaeozoic and Mesozoic feature which continued to evolve until the early Late Cretaceous, long after the 'Hunter-Bowen Orogeny'.

(3) It has been assumed that the orogen developed under the control of one or more eastward-facing arc systems but we suggest that the Gwydir and Kuttung arc systems (TP1 and TP2) could have been westward-facing and that they formed far to the north and were moved southwards towards the Lachlan Orogen in the Late Carboniferous. The movement seems to have included 500 km of strike-slip on the Mooki Fault (an Australian "San Andreas Fault"?). The Sydney, Gunnedah and Bowen basins developed above the fault in the Early Permian.

(4) The Gympie (-Brook Street) arc system of TP3 formed in the Early Permian in the Yarrol Orogen and Zone C. West of it in New England and Queensland a major east-facing magmatic arc of plutons and volcanics formed in TP4 (Late Permian to early Mid Triassic). Similar arcs formed successively in TP5 to TP8 until the Tasman Sea opened.

(5) The opening was followed in TP9 by the eruption of basaltic volcanics which are arranged in 5 arc systems, not previously recognised. These are similar to Cenozoic basaltic arcs in Europe between Spain and Poland north and west of the Alps, and they raise difficult tectonic problems.

System U:Upper M:Middle L:Lower	Stratigraphic units in Zone A (Gunnedah Basin and Tamworth Belt), Surat Basin, and Sydney Basin	Stratigraphic units in Zone B (Tablelands Complex), Clarence depression and southeast Queensland	Deformations	Isotope Ages in yrs x 10^6	Plutonic Rocks and Isotope Ages in yrs x 10^6	Tectonic Periods and Epochs	Leading Tectonic Events
Cainozoic	Sediments Basaltic volcanics	Sediments Basaltic volcanics	Epeirogenesis with local steep dips	0 65 80	Cainozoic, basic, mainly concealed in craton & inferred from gravity anomalies	9C 9B 9A TP 9	Basaltic central volcanoes Basaltic lava fields on craton Opening of Coral Sea (60-53 Ma), Tasman Sea (80-60 Ma) and formation E. Australia eymatogen
Cretaceous U		Sediments (Cape Conway) Whitsunday Volcanics & Proserpine Volcanics	D8		Cretaceous suite(s) 110, 115, (?125±)	TP 8 Whitsunday	Acidic & intermediate volcanism, central Queensland coastal region Bowen to Gladstone, and in D.S.D.P. hole in Zone C (Lord Howe Rise)
Cretaceous L	Rolling Downs Group 'Blythesdale Group'	Burrum Coal Measures Maryborough Formation Grahams Creek Formation (volcs.)	D7	138	Jurassic-Cretaceous suite 133-142 (?125±)	TP 7 Maryborough	Volcanism & plutonism followed by filling of upper part of Maryborough Basin
Jurassic	Pilliga Sandstone Purlawaugh Formation Garrawilla Lavas	Walloon Coal Measures Bundamba Group North Arm Volcanics (Moreton Basin)	D6	200	Upper Triassic suite 205-215	TP 6 Moreton	Volcanism & plutonism followed by filling of Moreton & Surat basins & lower part of Maryborough Basin
Triassic U	?Mild deformation, movements on major faults & non-deposition in part of Surat Basin	Ipswich Coal Measures Brisbane Tuff & correlatives (Ipswich Basin)	D5	215	Stanthorpe Suite 216-230	TP 5 Stanthorpe	Volcanism & plutonism followed by filling of Ipswich & Tarong basins
Triassic M, L Permian U	Napperby Beds Digby Beds Black Jack C.M. Gladstone Fm. Porcupine Fm. — Wianamatta Gp. Hawkesbury Ss. Narrabeen Gp. 'Upper C.M.' & 'Upper Marine'	Toogoolawah Group (Esk Trough) Dummy Creek Association (Wildash Gp., Drake & Emmaville volcanics) — Brooweena Fm., & part of Gympie Gp.	D4	230 240	New England Batholith 230-253	TP 4 Hunter-Bowen	Major magmatic arc, New England Batholith, other plutons, & volcanics, filling of Esk Trough; upper parts of filling of Sydney & Bowen basins
Permian L	Willow Tree C.M. Werrie Basalt Temi Group — 'Lower C.M.' & 'Lower Marine'	Ashford Coal Measures Coffs Harbour Assoc. Silverwood Assoc. Nambucca Assoc. — Part of Gympie-Biggenden Province	D3	255	Hillgrove Suite(s) ?270-300	TP 3 Gympie	Gympie arc system; mosaic of small plates in Anaiwan marginal sea; volcanism and diamictites; Hillgrove plutons; lower parts of filling of Sydney & Bowen basins
Carboniferous U, L	Currabubula Fm. Merlewood Fm. 'Kuttung Group' Namoi Mudstone Tulcumba Sandstone *Onus Creek Unconformity* Tangaratta Formation Mandowa Mudstone Keepit Conglomerate	Beenleigh Association Sandon Association	D2	300 328 345	Bundarra Suite (Zone B) ?270-?320 Plutonic boulders derived from ?Kuttung Volcanic arc, & ?Gwydir volcanic arc (Zone A) Mt View Range Granodiorite in Zone A (336) & Roma 'granite'	2D 2C 2B 2A TP 2 Kuttung	Kuttung volcanic arc system Intrusion of Bundarra batholith Rise of Campbell High Sedimentation in Tamworth Belt (?back-arc basin), and Sandon clastic wedge built into ocean
Devonian U, M, L Silurian Ordovician Cambrian	*Baetive Unconformity* Baldwin Formation Tamworth Group Cambrian & Ordovician limestone blocks	Woolomin Association & part of Thanes Creek Slate Ordovician, Silurian (and Devonian) blocks and fault slivers	D1	395	Boulders in Keepit Conglomerate, ?derived from Gwydir volcanic arc, ages unknown. Mt Morgan Tonalite & correlatives	1C 1B 1A TP 1 Gwydir(-Calliope)	Gwydir arc system; ?back-arc basin in Tamworth Belt, deeper basin to east with Woolomin sediments & volcs.

MODELS OF THE UPPER MANTLE BASED ON ULTRAMAFIC AND GABBROIC XENOLITH SUITES FROM THE VOLCANICS OF VICTORIA.

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Ultramafic and gabbroic xenoliths are abundant in alkaline igneous rocks of the Mesozoic, Lower Tertiary (Older Volcanic) and Quaternary volcanic episodes in Victoria. They are found in basalts, pyroclastics and intrusives from over sixty widely distributed localities, of which about forty are Newer Volcanic eruption centres.

Recent extensive collecting of xenolith suites from the Newer Volcanics has yielded important material showing relationships between many different phases. From these observations, models of rock relationships in the Upper Mantle are suggested.

Victorian deep-seated xenolith types can be broadly grouped into:-
Metaperidotites (representing refractory Upper Mantle).
Metapyroxenites (altered U. Mantle lenticles).
Ultramafic Cumulates (unmetamorphosed deep magma differentiates)
Granulites and Gabbros (Lr. Curst, granulite grade metamorphics)
Intrusives (non-cumulate magma differentiates, U. Mantle to Crust)

The predominant metaperidotite xenoliths are enstatite - Cr diopside - spinel lherzolite. The lack of garnet indicates depths of origin between Moho and about seventy km. Variable fusion of the lherzolite during magma-generating episodes is reflected in the wide range of peridotite compositions. These show progressive Mg-depletion and Fe-enrichment, which is further complicated by shearing and migmatisation. Under wet conditions associated with migmatisation, kaersutite peridotites developed locally beneath the Camperdown Area.

Garnet-bearing metapyroxenites are recorded from the Older Volcanic at Phillip Island and Cape Patterson; and from the Newer Volcanics at seven eruption centres, of which the Bullenmerri and Gnotuk maars are the most important. Garnet pyroxenite developed within the larger magma lenticles trapped in the Upper Mantle peridotites. A progressive sequence from spinel lherzolite to garnet pyroxenite is developed in which spinel and orthopyroxene are replaced by high-pyrope garnet.

The observed relationships between members of the Metaperidotite and Metapyroxenite Groups and the subsequent Cumulate and Intrusive Groups can be explained by diapyric magma ascent, confined to the Mantle. During crystallisation there was differentiation into various ultramafic cumulates and dioritic residual liquid. The latter was injected along fissures to form diorites and hornblendites. Alteration of wall rocks often resulted in the appearance of interstitial amphiboles. The deep-seated nature of some members of the Intrusive Group is exemplified by xenoliths from Anakie Yowang, showing inclusions of lherzolite in a coarse garnet diorite and other xenoliths of pyroxenite and peridotite intensively veined by hornblendite.

Xenoliths of the Granulite-gabbro Group are abundant at the Anakies and Mount Franklin, but these do not show any relationships to other xenolith groups. These are interpreted as being accidental Lower Crustal material, unrelated to the vulcanism. Rare microsyenite and minette xenoliths from Anakie Yowang may be accidental pre-Tertiary rocks. Two examples found show inclusions of microsyenite enclosed in diorite.

MELTING OF BIOTITE AND HORNBLENDE IN THE CRUST

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Crystallization of the hydrous minerals biotite and hornblende from a magma can exert a major control over many trace element abundances and the abundance of H_2O in the residual magma (melting of those minerals will play a similar role during partial melting). We present here a general quantitative model for melting of hydrous minerals in terms of H_2O activity, and discuss qualitative effects of fluorine on their stability.

Neglecting fluorine for the moment, the stability of a hydrous mineral in the melting range will depend mainly on the reaction stoichiometry and the activity of H_2O (a-H_2O). The latter is a function of total pressure (P) and the H_2O content of the melt.

Under most conditions of bulk composition, P, and T biotite and hornblende melt incongruently. For example, in a hydrous basaltic magma in the 2-10 kbar range and melting reaction of hornblende is approximately:

$$\text{Hornblende} = \text{Augite} + 3\ \text{Liquid}$$

where the moles of liquid are calculated on an 8 oxygen basis. Such a reaction can be generalized as follows:

$$1A(OH)_2 = bB + CH_2O(\text{fluid}) + m\ \text{Liquid}.nH_2O$$

where $A(OH)_2$ represents a mica or hornblende which melts to yield b moles of anhydrous crystals (B), c moles of H_2O in the fluid, and a melt containing m moles of silicate and n moles of H_2O. Sufficient thermodynamic data are available to allow calculation of hydrous mineral melting temperatures as a function of H_2O activity. Isobaric calculations indicate that at P greater than 2 to 4 kbar, hornblende melting T initially increases with decreasing a-H_2O, passes through a maximum, and then falls rapidly to subsolidus T. The T maximum occurs in the range 3-4 wt% H_2O in the melt, and the intersection of the solidus and the hornblende melting curve occurs in the range 1-3 wt% H_2O in the melt. Consequently the presence of hornblende at super solidus T in the lower crust requires at least 1 and more probably 2-3 wt% H_2O in the magma.

Addition of fluorine to a hydrous mineral-melt system stabilizes the mineral to higher T and lower H_2O activity. Thus the above conclusions are invalid for hornblendes containing more than about 10 mole % F/(F + OH).

Fewer data are available for biotite melting, but our experiments on andesite and granodiorite compositions suggest that biotite requires roughly the same amount of H_2O in magmas as does hornblende. However, biotite stability is also highly sensitive to the K_2O content of the magma.

PALAEOGEOGRAPHIC AND TECTONIC CONTRASTS ACROSS THE I-S LINE AT COOMA, S.E. AUSTRALIA

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A north-south line about 8 km west of Cooma, the Bobundra Line, separates areas in which Ordovician and Lower Silurian sediments show markedly different stratigraphy and sedimentary structure. This line is represented on the ground by a probable east-dipping thrust with several kilometres displacement. A series of thrusts of similar orientation lie to the west of this line, and, locally, immediately to the east of it. Further to the east similar thrusting is not observed.

The fold pattern shows a contrast across this line: though gradational on a local scale, it is distinct on a regional scale. Folds to the east are commonly tight or isoclinal and axial-plane foliation is generally developed. To the west, except in the vicinity of the Cooma Metamorphic Complex, folds are more open, bedding-axial plane angles are commonly 20° to 30° or more and axial-plane structure is rarely discernible. Quantitative strain studies have been carried out by several methods and the results show a correlation with the fold tightness.

The main folding west of the Bobundra Line occurred prior to the emplacement of the Cootralantra Granodiorite, dated at 420 Ma. (Williams *et al.*, 1975). Further tightening of the folds produced at this time and local refolding occurred in the vicinity of the Cooma Complex at about 410 to 405 Ma. The strata east of the line underwent the main part of their deformation after the intrusion of the Micaligo/Koolambah pluton, dated indirectly at post 403 Ma. and intruded probably after the main folding to the west.

It appears unlikely that major cover-basement décollement has occurred in the area. If this is the case, considerations of present crustal thickness (White et al., 1974), exposed stratigraphic thickness and crustal strain provide constraints on the crustal structure. The existence of a sialic layer of significant thickness before deformation as a basement to the sediments east of the Bobundra Line is precluded. The existence of such a sialic layer to the west is not precluded but limits can be placed on its pre-deformation thickness: thicknesses typical of Precambrian shields are not possible.

All the above observations suggest a fundamental tectonic break associated with the Bobundra Line and are best explained by the presence of significant sialic basement to the Ordovician - Lower Silurian sequences underlying the area to the west of the line but not the area to the east. The Bobundra Line corresponds closely in position and orientation to the I-S line of White et al. (1976). These authors interpreted the I-S line as representing the eastern limit of 'a very thick block of continental crust, possibly crystalline shield'.

The basement west of the line is considered here to have been a thin, probably deformed, metasedimentary sequence deposited in the Late Precambrian on oceanic floor and underplated by igneous material suitable to act as a source for the I-type granitoids of the area. Less likely, it may have been greatly distended shield.

If major décollement has occurred, e.g. in association with the thrusts, the basement in the west may have had a typical shield structure.

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GROSS CRUSTAL STRUCTURE AND LONG PERIOD P WAVES.

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Crustal thickness and average velocity can be determined by fitting the spectral ratio of the vertical and horizontal radial components of teleseismic long period P waves to the theoretical spectral ratio of feasible crustal models. The vertical and horizontal radial transfer functions are calculated by the Haskell-Thomson matrix formulation pointwise in the frequency domain by calculating the transmission coefficient of a given layered system for each of a sequence of input frequencies at the base. The character of the spectral ratios is affected mainly by the total crustal thickness and average velocity. Knowledge of these parameters is particularly valuable in combination with complementary data from deep crustal reflections at near vertical incidence. Simulation shows that the spectral ratios are relatively insensitive to phase velocity and thin low velocity surface layers. Comparison tests using data from the SRO installation at Narrogin (West Australian Shield) and the ASRO/HGLP installation at Charters Towers (Queensland continental margin) reveal that the mean crustal thickness at both Narrogin and Charters Towers is about 39 $\pm$ 4 km and the mean crustal P wave velocity is about 6.6 km/sec. These values are consistent with independently derived models of "normal" continental crust. The simplicity of implementation and interpretation of the spectral ratio method makes it potentially useful for gross crustal structure determination using long period P recorded by portable seismometer packages sited in remote areas.

SUB-ALUMINOUS VOLCANIC ROCKS OF THE SILURIAN AND DEVONIAN OF EASTERN VICTORIA.

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Recent field and petrological studies by Monash University students have shown shown that the three major groups of middle Palaeozoic volcanic rocks of Eastern Victoria - the dominantly Silurian Mitta Mitta Volcanics, the Lower Devonian Snowy River Volcanics and the Upper Devonian volcanics of the Avon River Group - are more diverse in both structure and lithology than previously recognised. In particular, the main belt of the Mitta Mitta Volcanics centred on the Darmouth Dam may be subdivided into at least three areas on the basis of lithology and probably age:

a) A southern succession of massive dacitic ash flow units underlying the shallow marine sediments of the Wombat Creek Group. These volcanics are of probable Lower to Middle Silurian age.

b) In the Larsen's Creek area - a diverse group of andesitic to rhyodacitic fragmental volcanics which contain phenocrysts of hypersthene, augite and hornblende, associated with coarse clastic sediments.

c) In the Mount Benambra area - at least two major rhyodacitic to rhyolitic ash flow units separated by basaltic lava flows, and a previously unrecognised belt of clastic sediments. Petrographic similarities between the ash flows and those of the Jemba Rhyolite may indicate a Lower Devonian age.

Basaltic lavas associated with the dominant acid-intermediate ash flow volcanics of the three groups range from probable quartz tholeiites with relict phenocrysts of diopsidic augite to weakly alkaline types with titan-augite associated with plagioclase in spectacular ophitic textures. In some sequences, particularly the Avon River Group at Snowy Bluff, basaltic lava piles reach thickness of up to 400 m.

In all cases, volcanic activity was of bimodal rhyolitic to rhyodacitic/basaltic to andesitic type. Magma mixing may have produced the more intermediate types. Volcanic deposits and terrestrial to shallow marine sediments appear to have accumulated in fault-bounded troughs typical of post-orogenic basin - and - range provinces such as those of the Heroynian areas of central Europe in Upper Carboniferous to Lower Permian and the western U.S.A. in Upper Tertiary to Recent times.

The abundance of acid volcanic rocks indicates that magma sources within a thick continental crustal section were available throughout the Silurian and Devonian. The dominance of sub-aluminous ("I-type") volcanics suggests that these magma sources were originally mafic to intermediate igneous rocks or immature sediments or both. Melting within the crust was probably triggered by the uprise of mafic magmas from the upper mantle. Geochemical study of representative samples from these bimodal volcanic groups should provide data on the evolution of the crust and mantle beneath the Lachlan mobile belt during the Silurian and Devonian, and lead to a better understanding of the driving forces behind processes of igneous activity, tectonism and sedimentation.

THERMAL MODELS AND LACHLAN FOLD BELT TECTONICS

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Model studies show that increases in temperature in the upper mantle above the level of isostatic compensation cause elevation of the surface and if the crust is susceptible to metamorphism, metamorphic contraction may overtake elevation and subsidence results. A second subsidence phase occurs with cooling. The uplift and subsidence curves have been computed for 20 and 35 km crusts with 5 and 10 km thick basal basic layers respectively. The upper crust is assumed to be susceptible to metamorphism.

Models have been produced for 1) heating and cooling at the base of the lithosphere and 2) heating by a hot column of material introduced immediately below the crust a) with cooling commencing at the time of emplacement and b) with cooling after thermal equilibrium with the crust has been reached.

Of these models it is only in the last that the generation of magmas by crustal fusion is possible. Metamorphism reaches a maximum in the models of group 2 in 10 to 20 my depending on crustal thickness, although half of the metamorphic subsidence occurs in less than 20% of that time. Ignoring the isostatic effects of erosion, water loading and sediment loading, model 2a gives a maximum of 600 to 800 m of subsidence below the initial datum, and model 2b gives 1400 to 1600 m of subsidence after metamorphism and about 100 my of cooling. In model 1 there is no significant metamorphism in 20 km crust and so, simple thermal uplift and subsidence of about 1000 m takes place during the thermal cycle. In the 35 km crust model subsidence of about 300 m below the datum takes place over nearly 100 my in the heating phase. On cooling, the final level is about 1000 m below the datum and is reached after over 100 my.

In order to try to apply these models to South Eastern Australia, three time-space plots of the geology have been prepared. They reveal sequences of depositional, volcanic, plutonic and tectonic events that can be interpreted as thermal cycles. They comprise 1) a heating phase of a) uplift followed by b) a marine transgressive sequence, mostly with volcanics (acid) and then 2) a cooling phase of sedimentation without vulcanism. A wide applicability of model 2b is suggested. Where repeated cycles occur subsidence associated with the vulcanism is more likely to represent upward transfer of material in the column than metamorphic subsidence. Cycles commenced in the Early Cambrian (?), Early Silurian, basal Early Devonian and Early Carboniferous (north east part only).

Although the foundation on which the progressively cratonised accumulation was built is not visible, stratigraphy and model studies suggest initially thinner crust under the Wagga metamorphic belt than under the southern highlands. This generally supports the suggestion of an Ordovician island-arc and marginal sea in the region. The Silurian-Devonian events are generally in accord with type 2b models. The original crust under the Melbourne Trough could have been thicker than that to the west and east and was possibly in part an arc peripheral to a Cambrian-Early Ordovician western Victorian marginal sea. The crust under the trough behaved like a 2a model with an Early Cambrian initiating event. The subsequent mid-Devonian event had little if any metamorphic subsidence associated with it.

In contrast with the grand orogenies resulting from collisions, tectonic episodes are restricted in their distribution and can possibly be attributed to crustal reorganisation ("auto-orogenesis") associated with the generation and rise of granitic magma. This would simplify the tectonic history by essentially removing the Benambran (and Quidongan), Bowning and perhaps the Tabberabberan Orogenies as major unexplained compressive events with crustal thickening. In this scheme however, if compressive events occurred then mushy regions would be the ones in which most deformation would occur, or if the lithosphere were under continuous compressive stress, the shortening would take place in any region that became softened.

Although the thermal event scheme (if valid) does not explain the tectonics of the Lachlan Fold Belt, since no reason for the events is apparent, it does provide a potential unifying framework for much of the geological evolution of the foldbelt.

THE LOWER CRUST BENEATH THE SOUTHERN RIO GRANDE RIFT: EVIDENCE FROM XENOLITHS AT KILBOURNE HOLE MAAR

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Mafic and silicic rocks of granulite facies grade dominate the crustal xenolith population at Kilbourne Hole Maar. No rocks of similar grade have been documented in outcrop nor in wells drilled to basement in the region. Mineral equilibria involving garnet, orthopyroxene, clinopyroxene and feldspars were attained at temperatures between 750°C and 1000°C and at corresponding depths of 18 to 30 kilometres. Although the rocks are equilibrium assemblages with respect to major and minor elements, textural equilibrium is variable. Cathode luminescence studies of feldspars in both mafic and silicic rocks have revealed unusual mixing textures which have been "quenched" by the volcanic sampling process. The textures are observed most frequently in garnet-bearing, peraluminous xenoliths, which are interpreted to be residues after partial melting and extraction of S-type granitic magmas. These textures, along with heat flow and seismic refraction data from the region support the conclusion that the P and T recorded by the mineral equilibria in these rocks reflect the ambient geothermal beneath the southern Rio Grande Rift.

REGIONAL METAMORPHISM OF A SEDIMENT-RICH SEQUENCE UNDER CONDITIONS OF A HIGH GEOTHERMAL GRADIENT: THE WILLYAMA COMPLEX, BROKEN HILL.

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The Willyama Complex is a low-intermediate pressure terrane comprising pelites and psammopelites, with lesser felsic and mafic gneisses and calcsilicates. Four metamorphic zones have been mapped on the basis of pelitic and mafic assemblages, with the highest grade Two Pyroxene Zone accounting for the SE half of the Willyama Block:

Andalusite-Muscovite Zone
Sillimanite-Muscovite Zone
Sillimanite-K feldspar Zone
Two Pyroxene Zone

The three mapped isograds (Andalusite-Sillimanite, Sillimanite-K.feldspar, Two Pyroxene) are diffuse in detail and their placement is hindered by metastable persistence of andalusite, retrogression and bulk rock compositional control, respectively. Granitic segregations (commonly syn-metamorphic melts) are common above the Sillimanite-K.feldspar Isograd.

Prograde metamorphic pressures are tightly constrained by silicate barometers (Opx-Gt-Plag, Cord-Gt-Sill) and vary from 3-4kb in the lower grade regions to 6kb near Little Broken Hill. Temperature varies from 550^{o}C in the Andalusite-Muscovite Zone up to 750-800^{o}C, based on dehydration and melting relations in pelites.

This detailed knowledge of P-T conditions allows an evaluation of water activity in the high grade metasediments and mafic gneisses. Biotite-sillimanite breakdown reactions in pelites suggest aH_2O values during prograde metamorphism from 0.3 to 0.6 depending on T, in the Two Pyroxene Zone, with similar though less definite values in mafic gneisses determined from hornblende breakdown. This contrasts with inferred aH_2O estimates of 0.8 to 1.0

in the lower Sillimanite-K.feldspar Zone. Biotite dehydration and partial melting reactions in the metasediments at high grades appear to act as a regional aH_2O buffer. There is no strong evidence for variation in aH_2O on a mesoscopic scale, but on a regional scale aH_2O decreases slightly towards the highest pressure areas in the SE.

The Willyama supercrustal sequence developed in a rift situation with sedimentation and volcanism being closely followed by related low pressure-high temperature ($40^{\circ}C/km$) regional metamorphism.

DEEP CRUSTAL SEISMIC REFLECTIONS AT GUNDARY PLAINS, NSW

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In May 1978, deep crustal seismic reflections were recorded from six shots at Gundary Plains, 15 km south of Goulburn, NSW. The area lies on the Dartmouth-Marulan deep-crustal refraction survey line (see Finlayson, this Record).

The reflections were recorded on two cross-traverses with a maximum shot-to-geophone offset of 6 km. Three shots were fired for each traverse; the average charge size was 370 kg in 20 holes at 10-20 m depth. Sixteen geophones in line 5 m apart were used for each recording channel, and 48 channels for each shot were digitally recorded.

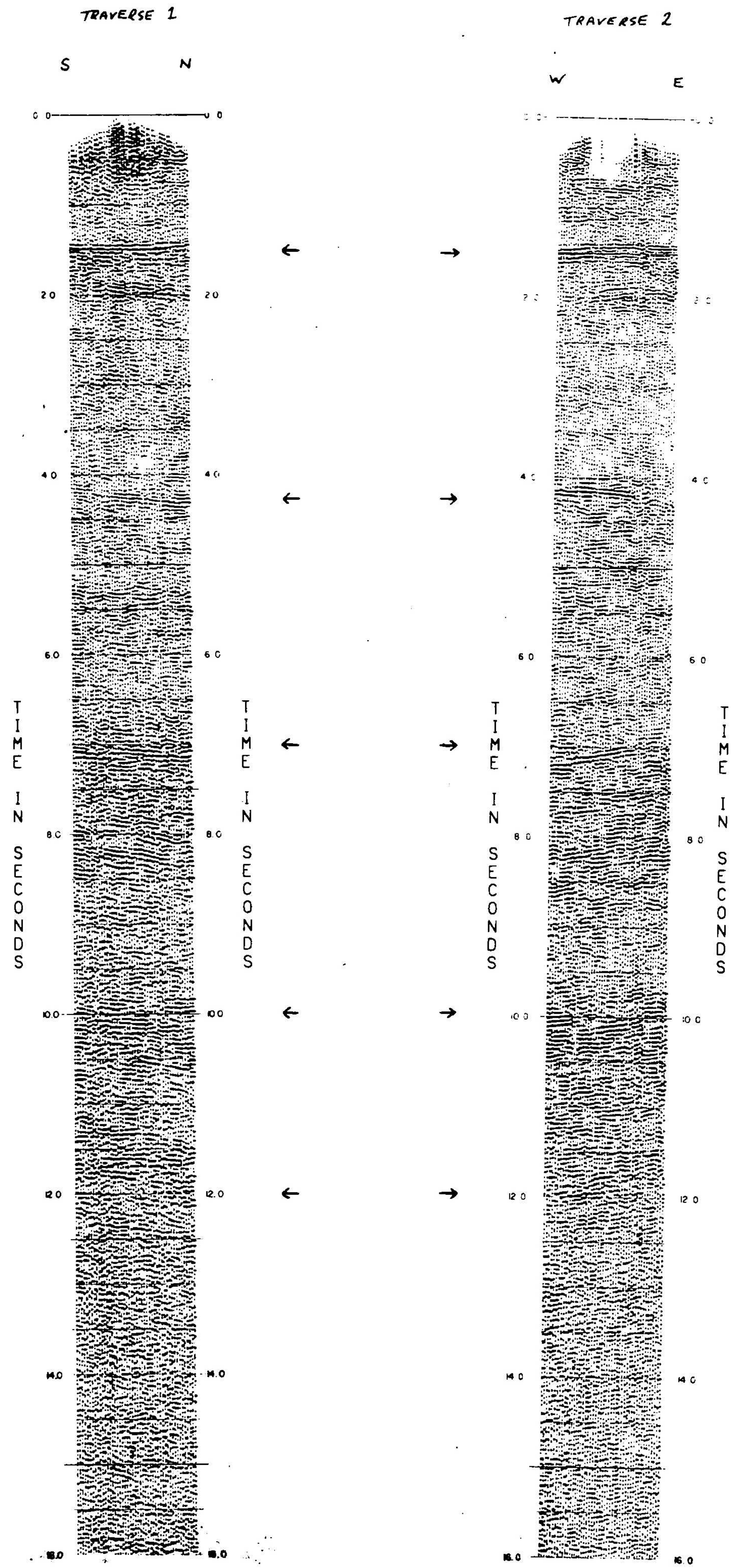
The data processing consisted of applying static corrections, and summing the records into a three-fold stack for each traverse. Stacking velocities were computed from a constant velocity stack analysis, and a time-variant filter was applied to the stacked sections.

Fairly good reflections were recorded down to 12 seconds, the results are summarised below:

Reflection Time (s)	Depth (km)	Dip and Dip direction	Average Velocity km/s	Interval Velocity km/s	Associated refraction km/s
1.5	4.5	2/242	6.0	6.0	5.8
4.2	13.5	12/047	6.4	6.7	6.2
7.0	23.5	20/291	6.7	7.2	6.3
10.0	34.1	16/289	6.8	7.0	LVZ
12.0	41.4	16.290	6.9	7.4	7.4

GUNDARY PLAINS 1978

DEEP CRUSTAL REFLECTIONS



The interval velocities derived from the reflection data are higher than refraction velocities; this has yet to be explained.

Comparison of the reflections at Gundary Plains with those recorded at Tidbinbilla and Braidwood in 1969 (Taylor & others) indicates that the three sets of data fit reasonably well into a regional picture. The crustal thickness at Gundary Plains is similar to that at Tidbinbilla, but about 6 km thicker than at Braidwood. Gravity evidence shows a gradual crustal thickening from Braidwood to Gundary Plains to Tidbinbilla. One reason may be that the granite at Tidbinbilla contributes to the Bouguer anomaly difference between there and Gundary Plains; other explanations may be mis-correlation of seismic reflections between the two localities, or different velocity functions at the two localities.

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THE STRUCTURE OF THE LOWER CRUST FROM EXPLOSION SEISMOLOGY

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This studies of the earth's crust and uppermost mantle by explosion seismology during the past 20 years have revealed detailed information on the structure of the lower crust and crust-mantle boundary. At regional examples from Europe and North America it will be shown that similar characteristics of the observed data can be related with comparable tectonic units as for example graben areas, fold belts or stable shield areas.

In Europe the Alps are characterized by a thick crust (45-55 km) and gradational Moho, whereas for Hercynian Europe a thin crust (30 km) and sharp Moho are characteristic. In many cases the velocity-depth structure is more or less uniform and a lower crust cannot be separated. In some areas however, an intermediate boundary within the crust can clearly be defined. Especially on profiles crossing Tertiary volcanic areas or graben areas as, e.g., the Rhinegraben, this intermediate boundary becomes dominating while the transition from lower crust to uppermost mantle is gradational.

The crustal thickness of North America is on average more than 40 km, and the crust-mantle boundary is in general a 5-10 km thick transition zone. Exceptions are the Coast Ranges of California, the Basin and Range province and possibly the Mississippi embayment. In the west also a zonal division from N to S is evident: In the Cascade Mountains, the Columbia Plateaus, and the middle Rocky Mountains the lower crust is well expressed with velocities between 6.4 and 7.0 km/s. Towards the south the thickness of the the lower crust decreases rapidly: in the southern Sierra Nevada and southern Rocky Mountains upper crustal material reaches to great depths (30-35 km) and lower crustal material seems to be almost absent beneath the southern Basin and Range province. The structure of the adjacent stable part of the North American continent (Great Plains and Appalachians) is characterized by a thick crust, broad transition zones between upper and lower crust and at the crust-mantle boundary, and relatively high velocities.

CRUSTAL THICKNESS IN THE SOUTHERN PART OF THE LACHLAN OROGEN -DEDUCED FROM VOLCANO - AND PLUTON - SPACING GEOMETRY

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Recent studies have demonstrated relationships between the spacing of volcanos and the thickness of the crust or lithosphere in oceanic and continental regimes. Spacing is controlled by lithospheric load (depth) and viscosity contrast and should therefore be related to depth of magma generation. In southern New South Wales granites occur in two zones - a western zone of S-type and an eastern zone of I-type (Chappell & White, 1976); since these are thought to be generated from sialic continental crust and dioritic subcrust respectively, the spacing geometry of these plutons should be different. The histograms A and B show similar peaks however in the 5 - 10 km range; it appears that pluton spacing is controlled by a 10 km thick brittle upper crustal layer. Longer modes may be provided by the size and spacing of batholiths and pluton clusters; I-type plutons tend to be 50 km long, spaced 22 km apart, and S-types are longer (75 to 100 km) and more closely spaced (16.5 km). This may indicate that S-type magma generates at 16 km and I-type at 22 km.

The Victorian plutons are more discrete post-tectonic bodies. Ordovician, Silurian to Early Devonian plutons reflect these 16 km and 24 km modes and an additional one at 35 km. This suggests that at the commencement of Transitional (cratonic) conditions the Lachlan orogen had a 35 km-thick crust. Pluton lengths may indicate that the crust or lithosphere boundary was at 75 km thinning to 50 km eastwards.

Major Silurian volcanic centres also show some spacing regularities (Kemezys, 1978) (Fig. C) but these have much longer modes at 80 km and 110 km. Since these are of dacitic to andesite composition they are probably of crustal origin and their spacing indicates an unusually thick 80 km crust. A tentative crustal section of the Lachlan orogen is sketched in Fig. 1.

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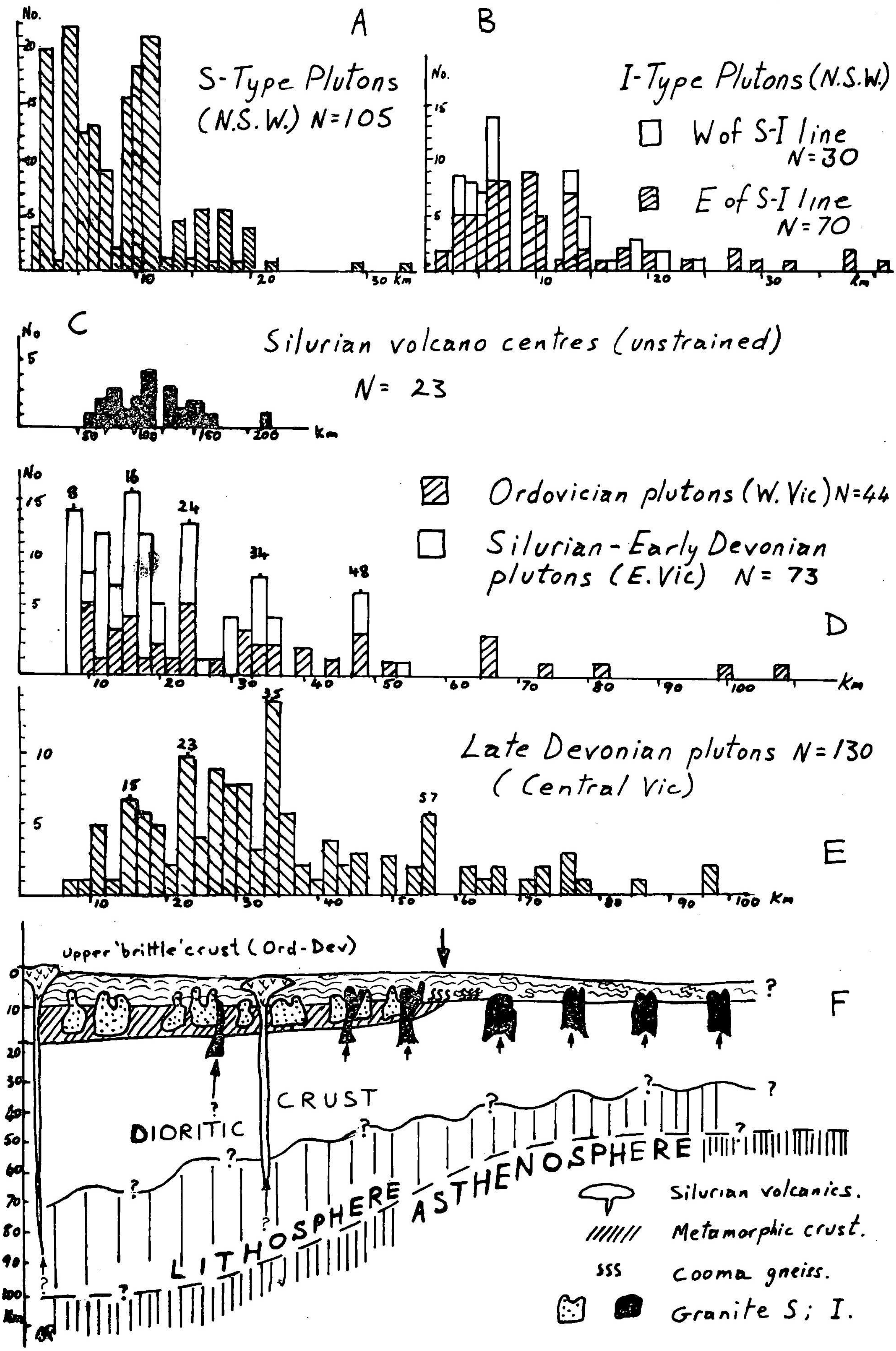

A
B
S-Type Plutons (N.S.W.) N=105
I-Type Plutons (N.S.W.)
W of S-I line N=30
E of S-I line N=70
C
Silurian volcano centres (unstrained) N= 23
Ordovician plutons (W. Vic) N=44
Silurian - Early Devonian plutons (E. Vic) N= 73
D
Late Devonian plutons N=130 (Central Vic)
E
Upper 'brittle' crust (Ord-Dev)
F
CRUST
DIORITIC
LITHOSPHERE
ASTHENOSPHERE
Silurian volcanics.
Metamorphic crust.
sss Cooma gneiss.
Granite S; I.

THE GEOTHERM AND THE BEGINNING OF ANATEXIS IN EARLY PALAEOZOIC WAGGA BELT METASEDIMENTS

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The temperature T_1 at the base of a sedimentary pile of thickness Z is calculated from the equation below.

$$T_1 = T_o + \frac{(Qo)}{k} Z - \tfrac{1}{2} \frac{(E^1)}{k} Z^2$$

where T_o = temperature at the top of the pile
Q_o = surface heat flow
k = thermal conductivity of sediment
E^1 = total heat productivity from radioactive decay

Uranium, thorium and potassium abundances and density estimates for a three layer crustal model have been used to calculate geotherms which may have applied during the Early Silurian anatectic event. Geotherms with surface heat flows between 2.0 and 3.0 HFU delineate the area of P-T space indicated by examination of mineral assemblages in low and medium grade metasediments.

Several data suggest a geotherm with a surface heat flow of 2.5 HFU.

1. Many granites in the Wagga-Omeo Belt are muscovite-bearing and hence were produced at pressures exceeding 3.7kb.
2. Pressures and temperatures in excess of 5kb and 730^{o}C have been calculated from distribution co-efficients between the cores of garnet and cordierite pairs in granites from Tallangatta in Victoria.

3. The empirical geobarometer of Sassi & Scolari (1974) applied to white micas in low grade metasediments places the Wagga Belt in a low pressure facies series.

Therefore, assuming no crustal thickening, anatexis probably did not begin until a sedimentary depth in excess of 13 km was attained.

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POSSIBLE PROTEROZOIC CRUST BENEATH S.E. AUSTRALIA.

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Evidence concerning the crust and mantle beneath S.E. Australia is provided by both basement and cover rocks of the Delamerian fold belt and adjacent craton. The main question is whether a continental margin was produced by rifting and drifting and if so in what location and at what time. Resolution of this problem is dependent on the interpretation of more local tectonic features and in particular on the role ascribed to large-scale horizontal displacement between tectonic elements.

It has been argued that a continental margin was produced by rifting and drifting in the Cambrian (Veevers and McElhinny, 1976) and that the Lower Palaeozoic rocks of Victoria and New South Wales were deposited in an ensimatic environment.

There is some evidence both in South Australia and in the Mt. Isa region that an active continental margin lay to the east of the present Precambrian shield in the Middle Proterozoic. Any arc-trench complexes associated with this margin, therefore, either lie beneath the Tasman province or have been rifted and drifted away.

A new tectonic regime was established after the cessation of tectonic activity in the Mt. Isa belt and before the deposition of blanket quartzites at the base of the Torrensian. The period between 1400Ma and 1000Ma was a major period of taphogenic and orogenic reworking of the Proterozoic craton. Dolerite dyke and sill emplacement was widespread in the period and the mafic and ultramafic layered intrusions of the Giles complex were emplaced towards the end of the Musgrave orogenic activity. It seems possible therefore that new continental margins and a new configuration of plates were established at this time.

World wide the unconformity at the base of Late Proterozoic sequences marks a profound break in tectonic evolution, corresponding to the beginning of a new chelogenic cycle. The sequences are rather similar on both E and W of the Pacific and on the margins (e.g. in Scotland and Scandinavia) of fold belts now usually interpreted in terms of the Wilson cycle. However, there is little indication from available palaeomagnetic evidence that the Proterozoic Australian continent was in collision with, or later separated from, another continental mass on its easternside (e.g. Morel and Irving 1978).

The Adelaide geosyncline is at least partly intracratonic but it is highly asymmetric both in sedimentation and in basement mobility. It is inappropriate to describe it as an aulacogen in the current restricted sense. The mega-shear pattern initiated during the Middle Proterozoic was reactivated during Adelaidean deposition, especially in the Sturtian, and controls both sedimentation and the subsequent fold pattern. Hypotheses of orocline development subsequent to Adelaidean deposition can be rejected; and hypotheses of large-scale strike-slip movements on major faults also lack plausibility (Rutland and Murrell, 1975).

Application of concepts developed for Phanerozoic rifting (e.g. Veevers and Cotterill, 1978) suggest that the Adelaide geosyncline could have developed as the most westerly intra-arch basin in a multiple rifted arch system. Later phases of deposition could then correspond to deposition in a broad inter-arch and subsequent rim basin. The most easterly intra-arch basin would have been the site of a new ocean which subsequently developed an active margin, evidence for which is provided by metamorphism and plutonism beginning in Late Precambrian times. The model receives some support from the pattern of fold belts and the timing of sedimentation and deformation in both S.E. Australia and Antarctica. Alternatively the tectonic pattern may be interpreted in terms of a broad belt of tectonic activity behind a developing active continental margin, without a preceding period of continental break-up and dispersal. This would imply a much older palaeo-Pacific ocean.

Both models allow the development of basins floored by oceanic crust within the area of Proterozoic crust. The morphotectonic character of Palaeozoic basins in S.E. Australia suggests however that they are most probably underlain by thin Proterozoic crust. If so the lateral continental accretion of S.E. Australia must be regarded as largely Proterozoic rather than Phanerozoic.

Rejuvenation of the whole Phanerozoic chelogen during the Cenozoic is a remarkable feature with profound implications for mantle evolution.

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REFRACTION PROFILES IN S.E. AUSTRALIA CONDUCTED BY R.S.E.S. 1974 - A PRELIMINARY REPORT

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During the period of Professor A.L. Hales directorship of the Research School of Earth Sciences (A.N.U., Canberra), 1974-1978, three refraction profiles were undertaken in the Southeast Australia region. Where possible, these profiles were reversed using normal production blasts of commercial mining operations as controlled sources. Two types of continuous recording seismic tape recorders were used: A.N.U. designed six-track (single vertical component seismometer) and U.T.D. designed fourteen-track (three component seismometers) recorders. Brief details of the profiles are as follows:

(1) South Marulan-Muswellbrook region (designated SYB profile); 280 km long; 27 line sites at 10 km spacing; 12 shot monitor sites; duration 22.10.74-17.11.74.

(2) Dartmouth Dam - Moss Vale (designated DNE profile): 330 km long; 34 line sites at 10 km spacing; 13 shot monitor sites; duration 7.2.76-20.5.76.

(3) East-west profile from Kioloa to Hay (designated PSD profile). This profile for the study of P and S delays associated with earthquakes to the east of Australia (e.g. Fiji-Tonga region); 650 km long; 14 line sites at 50 km spacing; duration 27.5.76-11.8.76.

A map and full details of these profiles will be available at the symposium. The cooperation of Professor Hales' seismology group and the assistance of the R.S.E.S. technical staff during these profiles is gratefully acknowledged.

"RELATIONSHIP OF TRANSFORM FAULTS IN THE TASMAN SEA TO CRUSTAL FRACTURES IN N.S.W."*

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During an initial ("first look") geologic evaluation of LANDSAT-1 images (in 1972-73) it was observed that several major curving lineaments occur in the eastern part of New South Wales. The lineaments in the coastal region strike nearly east to west and curve in a southerly direction inland. It was discovered that with these lineaments were associated Mesozoic cratonic igneous bodies and it was concluded that they were crustal, perhaps even lithospheric fractures.

Ringis (1973) pointed out that on the projection of Tasman Sea transform faults (fracture zones) in the coastal areas in New South Wales cratonic igneous bodies occur. These intrusions are identical to those mentioned above and hence there was at least a geometric relationship between continental crustal fractures and oceanic transform faults.

The Mesozoic age of intrusions dates the crustal fractures as being older than the transform faults which are of Late Cretaceous to Early Tertiary age. From this follows that firstly continental fracturing occurred and during subsequent sea-floor spreading the continental weakened fractured zones localized the transform faults.

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AUSTRALIAN PALAEOZOIC APPARENT POLAR WANDER PATHS: IMPLICATIONS FOR THE TECTONIC EVOLUTION OF SOUTHEASTERN AUSTRALIA

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A reappraisal of Palaeozoic palaeomagnetic data from Australia is given. Certain results from southeastern Australia have previously been interpreted as anomalous (e.g. McElhinny, 1973, p. 229) and a hypothetical geological model has been proposed (Embleton, et al., 1974) to reconcile these with other palaeomagnetic results from rock units elsewhere in Australia. This model, implying a plate collision towards the end of the Devonian in southeastern Australia, maybe unnecessarily complicated if other explanations of the palaeomagnetic data are considered. One alternative that has recently been proposed (Schmidt and Morris, 1977) utilises the polarity ambiguity of palaeomagnetic data from pre-Devonian rock formations. Thus the poles conventionally accepted as being the anti-poles of the Lower Palaeozoic rocks are used and a simple, continuous apparent polar wander path (APWP) can be constructed, thus avoiding a complicated geological model.

New palaeomagnetic data, from Palaeozoic rock formations from southeastern Australia, are discussed in relation to these models. To solve the ambiguity in the interpretation of the palaeomagnetic data, more information is required from late Lower Palaeozoic rocks units.

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CRUSTAL STRUCTURE IN SOUTH AUSTRALIA USING QUARRY BLASTS

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Explosions at three large open cut mines (Leigh Creek, Iron Baron and to a lesser extent Kanmantoo) were used as sources of seismic energy in recording along three linear profiles along and approximately transverse to the axis of the Adeliade geosyncline in South Australia.

Records at approximately 120 sites were obtained out to distances of the order of 350 km with Kinemetrics PS1A portable seismigraphs using smoked paper and a recording speed of 4 mm/s. Times of blasting were determined from records at some of the permanent stations of the University of Adelaide Seismograph Network. Station spacing was nominally 5 km but at large distances from the source this increased to the order of 10 km.

The simplest model of the crust consistent with the observed travel times consists of two essentially homogeneous layers overlying the mantle. The average P wave velocities in the upper and lower crustal layers are 5.95 km/s and 6.46 km/s with the boundary between the layers at approximately 18 km. Although such a discontinuity has been found in other parts of Australia, none of the earlier studies in South Australia found evidence for such a discontinuity. The P wave velocity in the upper mantle is 7.97 km/s and the mean thickness of the crust is 39 km. Both the intermediate and Moho discontinuities vary by up to 5 km from their mean depths. Shear waves have velocities of 3.43 and 4.45 km/s in the upper crustal layer and the upper mantle respectively.

UPPER MANTLE-LOWER CRUSTAL XENOLITHS FROM THE TASMANIAN VOLCANIC PROVINCE

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Xenoliths of high to moderate pressure origin in the Tertiary volcanic rocks of Tasmania include a wide range of metaperidotites, metapyroxenites, cumulate peridotites and pyroxenites, granulites and gabbros and represent samples of underlying upper mantle and lower crustal rocks.

The metaperidotites are widely distributed over fifty localities and are abundant in some hosts (up to 1000 per sq. m at Don Heads). Most are spinel lherzolites containing olivine (Mg_{88-91}), but are associated with harzburgites at some places (Scottsdale). Rare peridotites are more iron-rich (Wattle Hill), with olivine Mg_{86-87}, include garnet (Bow Hills) or show cumulate features (King Island).

Pyroxenites are recorded from over fifteen localities and are mostly websterites, with rare garnet websterite (Bow Hills, Table Cape), mica websterite (Table Cape), subcalcic websterite (Jericho) and olivine websterite and olivine clinopyroxenite (E. Andover). The websterites contain Al bronzite-estatite (Mg_{74-88}) with endiopside ($Mg_{52}Ca_{39}Fe_9$), Al diopside ($Mg_{41-48}Ca_{47-51}Fe_{5-9}$), Al salite-augite ($Mg_{40-51}Ca_{34-47}Fe_{10-15}$), or subcalcic augite ($Mg_{59}Ca_{25}Fe_{16}$), $\pm$ pyrope ($Mg_{62-79}Fe_{17-25}Ca_{2-13}$), titan phlogopite ($Mg_{80}Fe_{11}Ti_9$), olivine ($Mg_{79}$) pleonaste ($Mg_{57-74}$) or apatite. Websterites with inclusions of mica in Al bronzite (Scottsdale, W. Campania) may represent cumulates and are associated with gabbros containing similar pyroxenes and labradorite (Ca_{50-59}).

Gabbroic and granulitic xenoliths include two pyroxene assemblages, either mafic types with Al bronzite (Mg_{77-80}), Al diopside ($Mg_{41-44}Ca_{50-51}Fe_{6-8}$) and calcic plagioclase (Ca_{60-92}), $\pm$ Cr pleonaste ($Mg_{50}Fe_{32}Cr_{18}$) or layered types with hypersthene (Mg_{57-63}), salite ($Mg_{36-40}Ca_{45-47}Fe_{13-19}$), labradorite ($Ca_{55-65}$), $\pm$ ilmenite or ulvospinel. One pyroxene gabbros contain salite-augite ($Mg_{40-48}Ca_{36-46}Fe_{14-17}$) and plagioclase ($Ca_{46-53}$). Other types include olivine (Mg_{79}) or hydrous phases (titan phlogopite and titan pargasite) or are essentially anorthosite, with labradorite (Ca_{51-64}) and magnetite.

Varied xenolithic assemblages at Bow Hills (lherzolite, garnet lherzolite, websterite, garnet websterite), E. Andover (lherzolite, websterite, olivine websterite, olivine augitite, mafic gabbro, olivine gabbro, anorthosite), Scottsdale (lherzolite, harzburgite, mica-bearing websterite, gabbro) and Table Cape (lherzolite, websterite, garnet websterite, mica websterite, gabbro, granulite) indicate some of the petrological complexity of the underlying upper mantle and lower crust. Some of the granulitic xenoliths from Tasmania resemble types described from Victoria, New South Wales and found by the writer in Queensland and suggest a widespread granulitic lower crust below E. Australia.

Megacrysts of Al augite - salite - diopside, Al bronzite, pargasitic kaersutite, olivine, ulvospinel, pleonaste, oligoclase - K oligoclase, andesine-labradorite, sanidine, and K albite, and possibly corundum and zircon are associated with the xenolithic suites and may derive from pegmatitic phases crystallized in the upper mantle-lower crust region. Xenoliths of sanidinite (Scottsdale) and layered nepheline syenite (N. Lake Sorell) are found in undersaturated alkaline hosts, but depth of origin is uncertain.

Plots of co-existing ortho and clino pyroxenes in the xenoliths fall along a more pronounced Mg trend (lherzolite, some websterite, garnet websterite, mica websterite), a slight Mg trend (cumulate websterite, mafic gabbros, granulites) and a constant Mg trend (layered gabbros and granulites). These trends may reflect approximate depths of origin of the xenolithic suites, the deepest showing the greatest Mg trend.

The Tasmanian xenoliths suggest a gabbroic to anorthositic and granulitic lower crust underlain by a predominantly spinel lherzolite upper mantle, grading down into or interfingering with garnet lherzolite, probably at depths exceeding 70 km. The lherzolitic upper mantle incorporates metapyroxenites and garnet pyroxenites and with the lower crust is intersected with cumulate and pegmatitic phases precipitated from basaltic melts.

GEOCHRONOLOGY AND THERMAL HISTORY OF THE COOMA GRANODIORITE

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The Cooma Granodiorite has an outcrop area of approximately $20km^2$ and is surrounded by a regional metamorphic aureole decreasing in grade (migmatitic K-feldspar-cordierite-andalusite-sillimanite gneisses through to a chlorite zone) outwards from the granodiorite. The metamorphic aureole which is an order of magnitude larger than the granodiorite proper, has been suggested to be of the low-pressure andalusite-sillimanite type.

Pidgeon & Compston (1965) analysed both minerals and total rocks from the Cooma Granodiorite and the associated metamorphic zones by the Rb-Sr technique. Analysis of their data gave an age for the Cooma Granodiorite of 406 $\pm$ 12 m.y. and a high initial $^{87}Sr/^{86}Sr$ ratio of 0.7179 $\pm$ 0.005. They found indentical ages for the high-grade metamorphics (migmatite, sillimanite and andalusite zones), and also found high initial ratios which however, were rather variable. From these data they concluded that the granodiorite represented a near in situ melt of the metasedimentary pile, and that the high-grade metamorphics may be associated with the emplacement of the granodiorite. Pidgeon & Compston (1965) found significantly higher apparent ages and low initial ratios for the greenschist-facies rocks (biotite and chlorite zones). They concluded that these higher ages may indicate the original age of deposition or the age of a regional metamorphism which preceded the high-grade metamorphism. However, they surmised that the low-grade rocks were a suitable source material for the partial melting event resulting in the formation of the Cooma Granodiorite.

K-Ar measurements have been made on hornblende separated from amphibolite (occurring as a large xenolithic mass within the granodiorite), and muscovite, biotite and K-feldspar separates from the granodiorite. Ages of 409.6±5.8, 401.3±3.6, 398.8+2.5 and 387±3.9 m.y. were obtained for these minerals respectively, which decrease in the same order as their estimated blocking temperatures (550°, 375°, 250° and 175°C, respectively). Rb-Sr total rock-plagioclase-orthoclase, muscovite and biotite measurements gave ages of 410.0±19.0, 408.2±5.7 and 399.8±3.1 m.y. respectively, which similarly decreases with their estimated blocking temperatures (650-700°, 500° and 280°C, respectively). A slow cooling history for this body can be inferred from these data (in the order of 20 m.y. to cool from about 650° to ~ 175°C). A cooling rate of approximately 15°C per million years is obtained if a linear cooling model is assumed.

An empirical cooling curve has been obtained for the Cooma Metamorphic Complex by combining the estimated blocking temperature of each system with the mineral ages (cf. Harrison et al., 1978). The resultant is an initially concave curve changing character to a convex curve for the bulk of the cooling duration. The concave segment is indicative of an initial thermal contrast between the host rock and the Cooma Granodiorite (~ 200°C) caused by diapirism of the magma. The convex segment is characteristic of slow cooling resulting from regional uplift.

The slow cooling model for Cooma and the nature of the cooling curve suggest that a point source of heat was responsible for the partial melting event. One possibility is that the source of heat may be from a much larger and more mafic body beneath Cooma with the Cooma Complex developed immediately above it from the sedimentary roof rocks.

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GEOCHEMICAL EVIDENCE FOR UPPER MANTLE INHOMOGENEITY BENEATH SOUTH-EASTERN AUSTRALIA

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The Cainozoic alkali basaltic rocks from the Southern Highlands and Sydney-Kiama provinces, New South Wales, range from nephelinites through basanites, basanitoids, alkali olivine basalts, hawaiites and nepheline hawaiites including some potassic types with K_2O : Na_2O > 0.5. Geochemical parameters such as Mg number (100 Mg/(Mg+Fe^{2+})), high Ni and Cr values and oxygen fugacity (estimated on the basis of co-precipitation oxide phases), together with the common occurrence of mantle-derived inclusions, indicate that many of the magmas represent primary or primitive liquids of direct high-pressure origin. These magmas resulted in isolated flows, necks, dykes and sills, with individual flows rarely exceeding a few metres in thickness and generally less than 0.5 sq. km in extent. Most of the basaltic rocks are also geochemically distinctive and are interpreted as representing separate but related dpisodes of partial melting. Rare eruptive centres result in localised sequences of basaltic flows. Successive flows commonly show textural and compositional characteristics consistent with low pressure fractionation processes, quite distinct from possible high pressure differentiation trends.

Most of the basaltic rocks showing primitive geochemical characteristics also contain Cr-diopside series and Al-augite series xenoliths. Megacrysts of high-pressure origin are abundant in several flows and include clinopyroxene, orthopyroxene, kaersutite, anorthoclase, olivine, ilmenite, titanomagnetite, spinels, zircon and apatite. Some megacrysts are compositionally identical to analogous phases in Al-augite series xenoliths in the same host rock. In rare flows, textural criteria such as multiple overgrowths on Cr-diopside series xenoliths provide evidence of a cognate origin for clinopyroxene megacrysts inferred to have been precipitated at high pressures. The abundance of such clinopyroxene grains in these flows (up to 20% of the mode) suggests that clinopyroxene fractionation could be dominant in some basaltic systems at high pressures. Such fractionation could yield nepheline hawaiite from nepheline basanite and alkali olivine basalt compositions.

Trace element data from "primitive" magma compositions show highly variable abundances of compatible (e.g. Ni 100-900 ppm, Cr 90-650 ppm) and incompatible (e.g. Zr 170-450 ppm) elements. The high Ni and Cr abundances in some rocks are paralleled by similarly high values reported for some kimberlitic compositions from eastern Australia. The geochemical characteristics must reflect the mantle source or subsequent fractionation processes. The latter effects are excluded or minimised in the basaltic magmas which are inferred to be primary. Cr/Ni ratios of possible primary compositions range from 0.6 to 1.8. Cr/Ni ratios of different melting models suggest that magmas with lower Cr/Ni ratios may result from <10% partial melting of clinopyroxene-rich lherzolite while those with high ratios are consistent with < 10% partial melting of olivine-rich (< 50%) lherzolite.

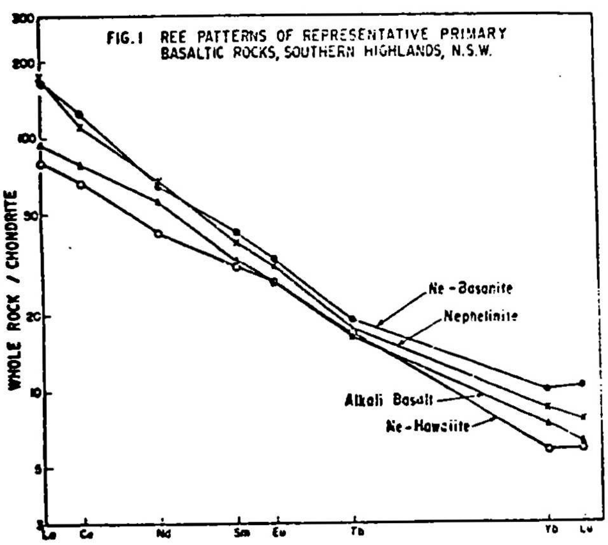
Rare earth element (REE) abundances are high and chondrite-normalised patterns show steep light REE enrichment (Fig. 1). La is generally 100 to 200 x chondrites and La/Yb ratios for primary liquids range from 10 to 25. Degrees of partial melting required, were calculated using a pyrolite model source and assuming that P_2O_5 and K_2O are completely partitioned into the melt. Nepheline basanites require approximately 5-7% melting; potassic basanites, alkali basalts and nepheline hawaiites require 8-11% partial melting. Using known distribution coefficients for REE in mantle minerals, calculations for batch melting conditions indicate that the initial mantle source is LREE enriched.

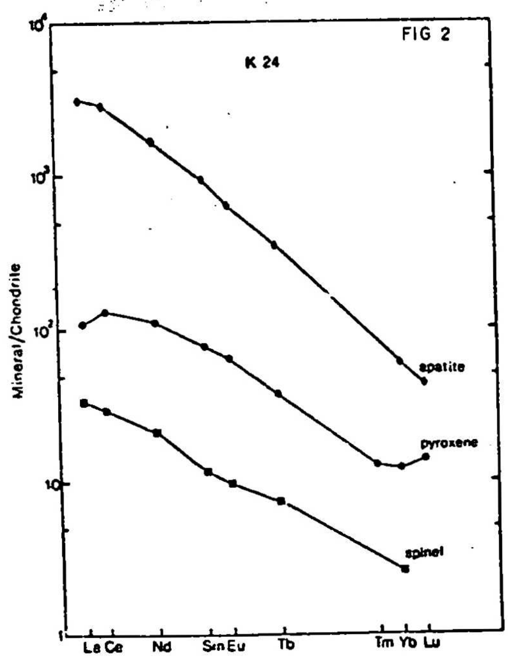
Some dykes, flows, and sills contain a suite of amphibole/apatite-rich xenoliths which are interpreted as representing mantle crystallisation of fractionated kimberlitic xenoliths. The chondrite-normalised REE abundances of separated minerals (including apatite, clinopyroxene, amphibole mica and spinel) are high with general LREE-enriched patterns especially for apatite (Fig. 2). The fluid which crystallised these amphibole/apatite xenoliths would be an ideal source for LREE metasomatism of upper mantle material and may account for REE patterns of primary magmas in alkaline provinces. Textural evidence for mantle metasomatism is the veining and partial replacement of original Cr-diopside and Al-augite series xenoliths by amphibole/apatite suite minerals.

The occurrence of the amphibole/apatite xenoliths is direct evidence of metasomatic activity and inhomogeneity in the upper mantle beneath eastern Australia. Indirect evidence is provided by geochemical data such as the trace element variability of inferred magma compositions from the Southern Highlands and Kiama regions. Intrinsic magma differences must therefore reflect the latest equilibration conditions within a geochemically inhomogeneous upper-mantle which is nevertheless strongly buffered with respect to $f(O_2)$ close to the FMQ buffer system.

FIG. 1: REE patterns for some primary basaltic rock types from the southern Highlands, N.S.W.

FIG. 2: REE element patterns for apatite, clinopyroxene and spinel from an amphibole/apatite suite xenolith.





THE TIMING OF THE LATE MESOZOIC-CAINOZOIC UPLIFT OF THE SOUTHEASTERN AUSTRALIAN HIGHLANDS

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The uplift history of the southeastern highlands is determined using middle to late Cainozoic river beds; these are preserved as river gravels overlain by basaltic lavas. Along major rivers in the highlands old river beds have a reasonably constant slope; this slope is about the same as that of the present river bed, and about the same as a line joining the summits along the valley margin. The approximately parallel relation suggests that the beds of most major rivers remained at a constant height and slope while the highland was uplifted. The relative heights of the river beds of different ages are consistent with uplift at a constant rate during the last 45 m.y. The present level of the pre-uplift river beds is thought to be just above the present valley margins, so if there was only one uplift and if that was at a constant rate then uplift started about 90 m.y. ago.

The total amount of uplift is given by the inferred amount of total river downcutting. Within the highland this is generally about 0.6 km north of Goulburn and 0.8 to 1.3 km south of Goulburn. The area with over 0.5 km total uplift is almost coincident with the area of late Cainozoic uplift, defined as the region with no thick alluvial deposits in river valleys; this suggests that the pattern has not changed much with time.

The highland is within an area of east-west compressive stress. This stress is consistent with the present-day upper crustal deformation of thrust faulting and possibly some folding. The faulting and folding could cause uplift by crustal shortening or by arching of the crust. However, the highland shows little evidence for crustal shortening during the Cainozoic, and gravity and seismic refraction evidence suggest that the crust is not arched but is in isostatic equilibrium, the highland mass being supported by the buoyant effect of crustal thickening. It seems likely therefore that the uplift is driven by crustal underplating, and that the faulting and folding is the surface deformation resulting from the upward movement of the highland.

Wellman, P., in press - On the Cainozoic uplift of the southeastern Australian highland. Journal of the Geological Society of Australia.

GRAVITY EVIDENCE FOR THE DEPTH AND REGIONALITY OF ISOSTATIC COMPENSATION OF TOPOGRAPHY

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The strength of the crust and the mechanism of isostatic compensation of variations of crustal load are important constraints on geological models of present crustal structure and tectonics. These constraints are also pertinent to earlier sedimentation and deformation.

Isostatic compensation of Australian topography was investigated by calculating isostatic corrections for a set of isostatic models. These models were a) for the Airy hypothesis with standard sea-level crusts of 30, 40, 50, 60 and 150 km; b) for a proportion of the Airy compensation at 30 km and with the remainder at 150 km, the proportion at 30 km being 100%, 95%, 90% and 80%; c) for the Vening Meinesz hypothesis with the radius of regionality of 116.2, 174.3 and 232.4 km; and d) all the above calculations carried out with and without the effect of unconsolidated sediment - the sediment thickness assumed being that of the 1971 Tectonic map with a sediment/basement density contrast of 0.47 t m^{-3}.

The best models were assumed to be those where there was no correlation of isostatic anomaly and altitude, and the variance of the isostatic anomalies about their mean was lowest. The best model for the whole or parts of the Eastern Highland was found to be the Airy hypothesis with a standard sea level crust 40 to 50 km thick and no allowance for the effect of sediment. In western Queensland the best model was the Airy hypothesis with a standard sea-level crust between 60 and 150 km thick, while in central South Australia the best model was for no compensation. For all these models the thickness of the inferred sea level crust is greater than the value obtained from seismic data; this is thought to result from a positive correlation between surface altitude and mean crustal density that remains even when unconsolidated sediments are allowed for. This study supports the earlier results, which show that in eastern Australia isostatic compensation is local and is mainly at or near the base of the crust.

AN UNDERPLATING MODEL FOR THE FORMATION OF THE LOWER CRUST

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Inclusions in breccia pipes, the composition of certain granitoids and possibly P-wave velocities suggest that at least parts of the lower crust of southeastern Australia consists of mafic rock. It is suggested that this is produced by underplating.

The idea of underplating of the crust by more mafic materials derived from the mantle was first proposed to explain thick Precambrian crust that had remained undeformed for 2500 m.y. and the major layered intrusions of the Precambrian. The Lewisian gneisses and granulites of Scotland have also been explained as deformed and modified rock of dioritic composition derived by sub-crustal accretion.

Using geochemical and isotopic data and the restite model to project back to sourke rock compositions, it can be shown that certain granitoids are derived from lower crustal source rocks that have never been through weathering processes. The purely igneous source of these granitoids (I-types) must be of intermediate composition; their origin is attributed to underplating.

Previous underplating models have involved accumulation of "dry" magmas presumably generated from the mantle. It is here suggested that the underplated material is dioritic magma produced by the vapour absent melting of amphibole in a down going slab. Because of the negative slope of the amphibole break-down curve at high pressures (20 kb) the magmas so produced move back into the amphibole stability field. The crust and or lithosphere is amphibolitized at depths close to 60 km in the vicinity of the slab; this corresponds to the depths of crust and or anomolous mantle beneath orogenic belts. Vapour absent melting of amphibolite at lower pressures gives melts that will only move back into the amphibole stability field if cooling occurs as the magma rises. These processes give underplated crust of dioritic composition and some amphibolization of pre-existing lower crust.

Vapour absent partial melting at this amphibolized lower crust perhaps geologically much later, gives I-type granitoids and a mafic lower crustal granulite residue. This is again relatively low pressure melting and hence the magmas may move to the surface.

DELEGATE BRECCIA PIPE : LATEST DATA AND INTERPRETATIONS

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More data have been collected on the inclusions in the Mesozoic Delegate breccia pipe of Southeastern N.S.W. and some re-interpretations made as part of a study of the geology of the Numbla 1:100 000 sheet.

Excavation of a dump from an old prospecting pit yielded 120 kg of new inclusions considered to represent the proportions of various types in the pipe. By weight, 30% are peridotites, 57% are two pyroxene granulites and most of the others are pyroxenites; garnet pyroxenites amount to only 3.5%.

The peridotites are all spinel-bearing, though some are comparable in chemical composition with garnet harzburgites and lherzolites from Kimberlites. The peridotites are considered to be derived from the uppermost part of the mantle or from a region in the mantle where the spinel field is expanded because of a high geothermal gradient.

Garnet pyroxenites (fassaite ecologites) with or without plagioclase and/or sulphur-rich scapolite have a basaltic composition with normative nepheline. However, certain trace element abundances (e.g. low Nb) differ from those of alkali basalts and indicate that these pyroxenites are either recrystallized precipitates from an alkali basalt melt or represent residues of more fertile pyroxenites from which alkali magma, such as nephelinite, has been extracted. Temperatures and pressures of equilibration of these, as well as spinel peridotites using various published data are near 1050^{o}C and 15 kb. This also indicates a high thermal gradient. Temperature estimates for a garnet-spinel-scapolite websterite are lower (near 850^{o}). This means that the pipe has probably sampled a range of pyroxenites at various levels in the upper mantle.

Clinopyroxene + orthopyroxene + platioclase $\pm$ scapolite granulites have equilibration temperatures somewhere between 700^{o} and 950^{o}C. If these are lower crustal rocks as previously suggested, then these temperatures are again consistent with a high thermal gradient in the Mesozoic. The higher Al and Ca and lower Na and K in these granulites compared with tholeiitic basalts are consistent with them being early accumulates from basic magmas. However, they could also be residues of a more felsic rock from which SiO_2 and alkalies have been removed in a melt phase. The rare "charnockite" recorded from Delegate may be close to the original felsic rock composition.

It is concluded that the geothermal gradient in southeastern Australia was high in the Mesozoic as well as at present, that the lower crust corresponds to the granulites in chemical composition and mineralogy and that the granulites may represent residue from an earlier partial melting event that produced the granitoids now seen in the upper crust.

STRUCTURAL STUDIES IN THE MALLACOOTA BEDS, VICTORIA

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Two major tectonic folding phases have deformed the Ordovician turbidite sequence known as the Mallacoota Beds. This sequence comprises alternating sandstones, shales and subordinate cherts, all of which contain a wide range of primary sedimentary structures and complex syn-sedimentary folding. The tectonic folds are extremely variable in style and distinction between them is based on overprinting relationships and younging criteria. Large tight to isoclinal first generation folds are recognised (F_1) and have been refolded about major second generation structures (F_2). On a regional scale F_1 and F_2 folds are approximately co-axial, with southerly plunges, although in outcrop they may diverge by up to 90^{o}. The folds are characterized by a variety of cleavage types.

ELECTRICAL CONDUCTIVITY OF THE UPPER MANTLE FROM GEOMAGNETIC ARRAY STUDIES IN AUSTRALIA

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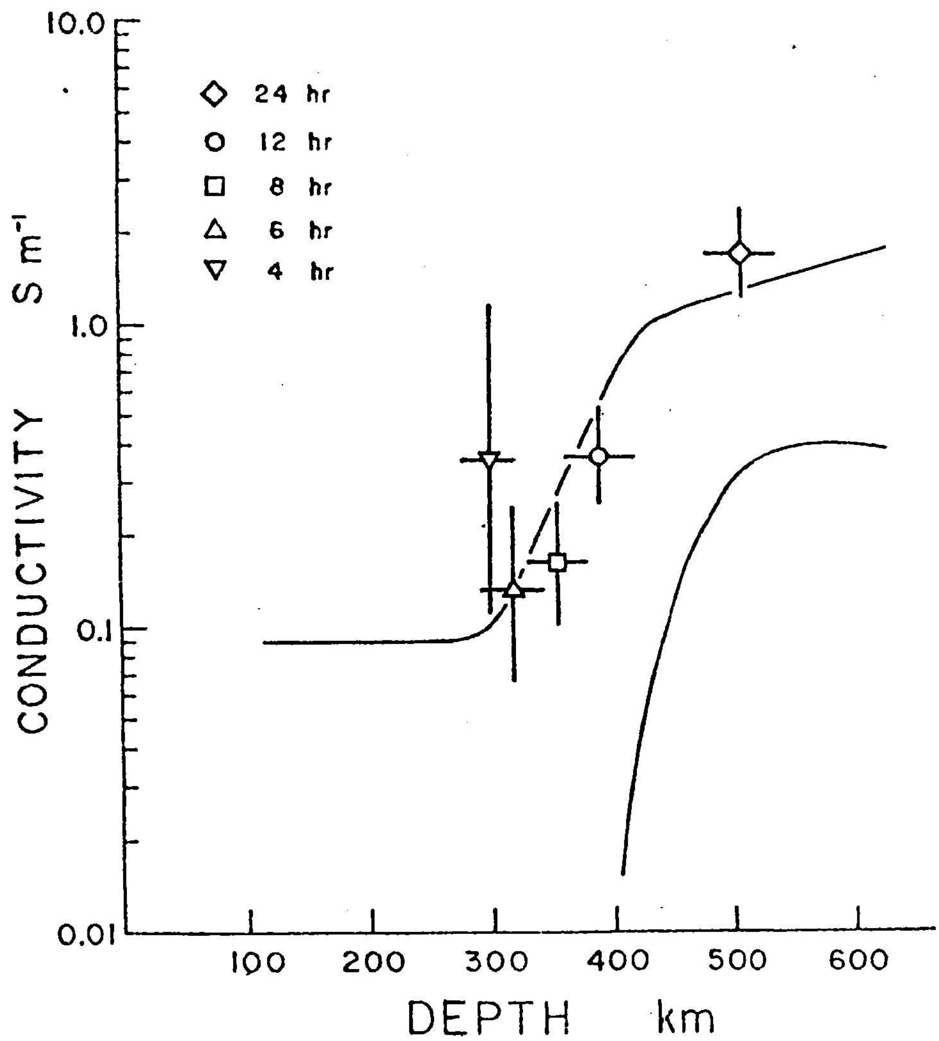
Magnetometer array studies have been carried out by ANU over southeastern, southern and central Australia using sets of 21 to 25 Gough-Reitzel portable magnetic variometers. The basis of these operations is to use natural time variations of the geomagnetic field arising from ionospheric currents external to the earth, to study electromagnetic induction within the earth. Three components of the transient magnetic fields are measured and inter-related in order to determine the response of the electrically conductive earth to externally applied source fields.

The array studies have delineated major conductivity "anomalies" in southern Victoria, central South Australia and southwestern Queensland as well as the expected conductivity contrasts along deep-water seacoasts. Removed from these anomalies in northwestern Victoria and southern Northern Territory the fields are laterally uniform indicating that conductivity varies with depth only. By relating the vertical component of these uniform magnetic fields to the sum of the gradients of the horizontal components, the layered conductivity structure can be deduced.

The figure below shows the conductivity - depth profile calculated from the vertical component and the horizontal gradients of two successive quiet daily variations in central Australia. The conductivities and depths were found using a simple "depth to a substitute conductive half-space" model at the major harmonics of the daily variation.

The points are consistent with the general principle that electromagnetic fields of lower frequency penetrate deeper into the earth. They also lie satisfactorily close to the profiles found by global analysis, confirming on a local scale these more general results. The high conductivity at approximately 300 km depth, while similar to a result from the Hawaiian Islands, must remain tentative until more data is analysed and more elaborate inversions have been made.

At the time of this writing, the data from northwestern Victoria is being similarly analysed. Preliminary results are of the same order of magnitude as the results from central Australia. The conductivity-depth profiles are also being inverted to give the apparent temperature versus depth for these two areas.



Conductivity versus depth for the major harmonics of two quiet daily variations in central Australia. Line profiles represent upper and lower limits of a "best-fitting" global model.

THE MINERALOGICAL AND CHEMICAL RELATIONSHIPS OF SILURO-DEVONIAN VOLCANICS AND GRANITOIDS IN THE CANBERRA REGION

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A study of Middle Silurian to Early Devonian felsic volcanics from the Canberra 1:250 000 Sheet area has revealed that, like the granitoids in the Lachlan Fold Belt, they consist of S and I-types, with a meridional I-S line passing east of Canberra. S-type volcanics are older than I-type volcanics in any one area, and where relations can be established with granitoids the volcanics are always older than the granitoids.

Despite chemical alteration in the volcanics (mainly albitisation caused by low-grade burial metamorphism) there is good correlation between the chemistry of the volcanics and adjacent granitoids, and a number of suites of I-type volcanics can be distinguished.

The simplest way to distinguish between S and I-type volcanics is by their mafic phenocryst content. Although both types contain biotite and orthopyroxene phenocrysts, S-types also contain cordierite and/or garnet, in some cases with sillimanite inclusions, and I-types also contain clinopyroxene phenocrysts. Primary amphibole is rare in I-type volcanics, but uralitisation of pyroxene is widespread. Compared to the granitoids then, the volcanics contain a more anhydrous mafic mineral assemblage.

Applying the restite model to these volcanics the following conclusions regarding crustal anatexis in the southern Lachlan Fold Belt can be drawn.

1. Anatexis to produce the volcanics left an anhydrous (granulite-facies) residuum.

2. The granitoid magmas cannot have been produced by a later melting event than that which produced the volcanic magmas, as the source area was already granulite.

3. S-type granitoids must have already been in a magmatic state in the Middle Silurian, as S-type volcanism was abundant at that time. Hence the granitoids must have taken at least 10 m.y. to intrude and cool to their strontium isotopic ages.

4. Granitoids cannot be related to any of the Benambran, Quidongan, Bowning, or Tabberaberan 'Orogenies'.

GEOCHEMICAL EVIDENCE FOR THE EXISTENCE OF A PRE-ORDOVICIAN SEDIMENTARY LAYER IN SOUTH-EASTERN AUSTRALIA

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Silurian S-type granitoids constitute a major component of the exposed Palaeozoic rock types of the Lachlan Fold Belt. Chemical data indicate that the widespread Ordovician and Early Silurian quartz-rich sediments are too poor in calcium, sodium, lead and strontium to be the source of these S-type granitoids. Such deficiencies have been noted before and it has been suggested that mafic volcanic material has been an additional component of the source region. However, cognate xenoliths indicate that the sedimentary pile from which the granitoids were derived contained very little mafic volcanic material. Further, a study of one of the most comprehensive Ordovician mafic volcanic sections shows that although the mafic volcanics can supply calcium, sodium and strontium, they are too poor in aluminium, barium, rubidium, zirionium, yttrium and lead.

It is thought that the source is mineralogically similar to the Ordovician sediments but that it contains more plagioclase ($>20\%$) and hence more calcium, sodium, strontium and lead. Compositionally similar rocks to the postulated source region can be found in the Cambrian Kanmantoo Group in South Australia and the Precambrian Robertson Bay Group in Antactica.