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BMR SYMPOSIUM
CANBERRA, 28-29 APRIL 1976
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SOME INSIGHTS INTO OLD AND NEW ZINC MINERALIZATION AT DUGALD RIVER AND SQUIRREL HILLS, AND URANIUM AT MARY KATHLEEN

G.M. DERRICK

Dugald River: Stratigraphic relations between the Dugald River ore zone and the adjacent Knapdale Quartzite are much debated. Recent mapping by BMR and GSQ suggests that the lode occurs in the upper Corella Formation, which is overlain to the west by a constantly west-facing block of Knapdale Quartzite; this in turn is overlain by, and grades into, cupriferous scapolitic metasiltstone and limestone assigned to the White Blow Formation. No faulting is evident along the Knapdale Quartzite/White Blow Formation boundary, but farther west the White Blow Formation is probably faulted against pyrrhotitic limestone of the upper Corella Formation.

At the Lady Clayre mine, 8 km southwest of Dugald River, a thin stromatolite-bearing sequence is faulted against the Knapdale Quartzite. It contains a thin bed of branched columnar stromatolites, overlain by a domed biostromal bed, and is considered to be part of the upper Corella Formation. Domed brecciated quartzitic rocks which flank the Dugald River lode to the east are thought to be a part of this sequence.

The likely presence of stromatolites in the vicinity of the Dugald River lode adds further weight to the suggested correlation of Dugald River with the Deighton Pass sequence, 60 km to the south-southwest. Both sequences are essentially transgressive, and display stromatolitic carbonate zones which grade seawards(?) into Zn-bearing black pyrrhotitic and graphitic shale and limestone deposited in the more rapidly subsiding parts of the depositional basin. In both areas the mineralized beds are overlapped by regressive fluvial arenites, which are succeeded by silt, limestone, and shale of a second cycle of transgression.

Copper mineralization in both areas occurs in fine arenite-siltstone-limestone facies landwards of the Zn-bearing black shales. Base metal may have been derived by erosion of basement areas, but the Renfro model, in which metal-charged terrestrial waters mix with saline and sulphate-enriched seawater, and precipitate metals in the presence of H_2S derived from algae, may be applicable.

The presence of copper in scapolitic siltstone above the Knapdale Quartzite suggests that similar transitional facies in the White Blow Formation at Deighton Pass should be examined for this metal.

Squirrel Hills: In 1971, Amoco Minerals discovered zinc mineralization in the Soldiers Cap Group, southeast of Cloncurry. It occurs in at least four stratabound zones which extend discontinuously for over 50 km along strike. The country rocks are metamorphosed shale, greywacke, siltstone, feldspathic arenite, and basalt of the Llewellyn Creek Formation and Mount Norna Quartzite; they are intruded by granite, aplite, and pegmatite, and are metamorphosed to at least high-amphibolite grade.

The lode horizons contain iron-rich sphalerite in a gangue of garnet "sandstone" and "quartzite", skarn, and gahnite-bearing quartzite, and closely resemble Broken Hill mineralization. Previous comparisons between the Willyama and Cloncurry Complexes based on the supposed similarity of the major Mount Isa and Broken Hill Ag-Pb-Zn deposits have foundered because of a 200 m.y. age difference between the deposits. However, the Soldiers Cap Group Zn mineralization now provides at least circumstantial evidence that the eastern part of the Cloncurry Complex is a continuation of the Broken Hill sequence.

Features common to both Soldiers Cap and Broken Hill mineralization are:

1. Lode horizons contain gahnite and garnet "sandstone/quartzite", skarn, magnetite, and apatite.
2. Upper lode levels are Zn-rich, whereas the lower levels are enriched in Cu and pyrrhotite.
3. Sphalerite is iron-rich.
4. Country rocks are of similar composition. Basalt, shale, siltstone and feldspathic quartzite at Squirrel Hills are compositionally similar to amphibolite, feldspathic gneiss, and quartzite at Broken Hill.
5. Sequences are metamorphosed in the low-pressure intermediate facies series.
6. Ages of the two deposits are similar, between 1650 and 1780 m.y., the older age being closer to the likely age of sedimentation.

Differences between the two areas include lower Pb values and a slightly lower grade of metamorphism at Squirrel Hills, but these features probably reflect a geological continuum in the original depositional basin and depth of burial, respectively.

<u>Mary Kathleen:</u> The Mary Kathleen uranium deposit is contained in west-dipping middle Proterozoic calcareous, dolomitic, and alkali-rich metasediments of the Corella Formation. These rocks have been thermally metamorphosed to pyroxene and hornblende-hornfels grade by the nearby Burstall Granite, and they are intruded by a swarm of rhyolitic and microgranitic dykes associated with this granite.

Early in the metamorphism, diopside, hedenbergite, ferrohastingsite, andesine, wollastonite, and scapolite were formed from calc-magnesian rocks, and fine-grained soda feldspar-bearing scapolite-diopside rock developed from sodic and calcareous shale. The mafic minerals, abundance of scapolite, and evidence of alkali metasomatism indicate a fluid phase enriched in Na, Cl_2, Ca, Fe, and Mg.

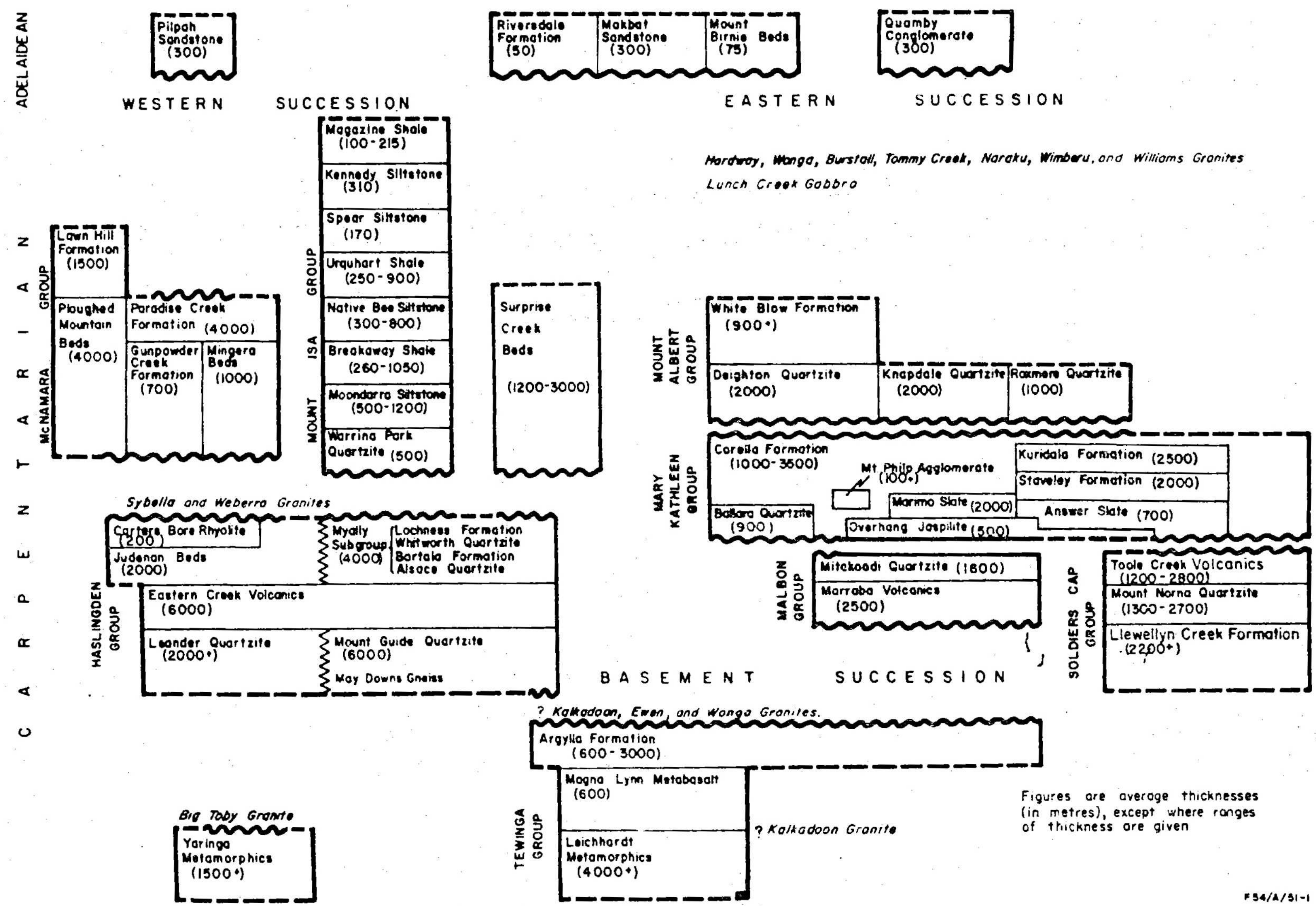
Extensive development of skarn marked the onset of a lower-temperature metamorphic/metasomatic event related to intrusion of the acid dykes. It is marked by the formation of garnet and subsequent crystallization in veins, fractures, and interstices, of albite, epidote, pyrrhotite, chalcopyrite, pyrite, tremolite, prehnite, quartz, calcite, and chabazite. Allanite-uraninite mineralization, which constitutes the Mary Kathleen orebody, followed the formation of garnet, but preceded the crystallization of sulphides and hydrated Ca-Al silicates. Fluids associated with this second metasomatic event were enriched in U, rare earths, Si, Al, Ca, CO_2, H_2O, and Na.

130 samples of various rock types from within a 6 km-radius of the Mary Kathleen orebody have been analysed for uranium using the neutron activation method. Gabbro, dolerite, and amphibolite east of the Burstall Granite, and well away from the acid dykes, contain 0.9 ppm U, about the world average for basic rocks. However, altered basic rocks of similar age from near the Burstall Granite and acid dykes show a threefold enrichment to an average of 3 ppm. The Burstall Granite is enriched in uranium to 7 ppm average, and the acid dykes to 12 ppm average, compared to the world average of about 4 ppm for such rocks. Calc-silicate and calcareous metasediments contain on average from 2.5 to 4 ppm U, and appear to be slightly enriched (3.5 ppm average) in the vicinity of the acid dykes. Skarn assemblages outside of the orebody contain about 3 ppm away from, and about 7 ppm adjacent to, the acid dykes. A west-dipping glassy quartzite stratigraphically below the orebody, and quartzite clasts within the orebody, contain an average of 1 ppm U.

The uranium at Mary Kathleen may have been derived from the Burstall Granite and its emanations, or by mobilization of U from within the sedimentary pile during metamorphism, or both. The partly mined orebody originally contained about 12 000 tonnes of uranium oxide, an amount which could reasonably have been extracted from metasediments of grade 2 ppm U, and volume 3 000 m x 1 000 m x 600 m, within the metasomatic and mobilizing influence of the acid dykes. However, the uranium-rich nature of the acid dykes, and the persistent uranium enrichment of sediments and basic rocks adjacent to them, indicate that at least some of the uranium probably has a magmatic hydrothermal source.

A composite source for the uranium is postulated. It is suggested that uranium-rich fluids associated with the dykes were further enriched by collecting of uranium from sediments intruded by the dyke swarm. The fluids travelled in a westerly direction away from the Burstall Granite down a falling temperature gradient. These fluids were impeded in most places by a chemically inert barrier of quartzite, but breached this barrier on the eastern side of the Mary Kathleen orebody, and intersected a sequence containing relatively permeable lenses of conglomerate. The ore fluids became concentrated in these lenses, and formed the broadly stratabound orebody.

Similar orebodies could be expected in the vicinity of other permeable zones stratigraphically above quartzite and adjacent to fractures and acid dykes, but such sites appear to have been removed by faulting and erosion. However, fractured areas of the quartzite hanging wall (i.e. the eastern side of the quartzite), in the vicinity of rhyolite dykes, could also be sites of economic uranium mineralization at depth.



Correlation diagram of Proterozoic stratigraphic units in the Mount Isa region.

COPPER PROSPECTS IN THE MT ISA AND WESTMORELAND AREAS

A.G. ROSSITER

Geochemical work by the BMR since 1973 has shown promising indications of copper mineralization at two localities - one near Mt Isa, the other in the Westmoreland area.

The first prospect is 12 km WNW of Mary Kathleen. An ironstone outcrop, discovered in the course of regional geological mapping in 1972, was considered sufficiently interesting for geochemical and geophysical work to be carried out in the area during the following year. The geochemical investigation consisted of a detailed stream-sediment survey followed by soil sampling on a geometric grid. A small copper anomaly occurs in the vicinity of the original ironstone, but a much more promising anomalous zone, also associated with ironstone outcrops, lies some 200 metres to the west. Here a soil anomaly 600 metres long and up to 100 metres wide has been outlined. A peak copper value of 950 ppm in the anomalous zone compares with background levels of less than 60 ppm elsewhere. Ironstone samples contain as much as 0.3 percent copper. No elements apart from copper appear to be significantly enriched in the area. The prospect is situated at the intersection of two faults in calcareous siltstone of the Lower Proterozoic Corella Formation - a very favourable geological environment for copper mineralization.

The second prospect is in the Westmoreland area just west of the Queensland-Northern Territory border, about 400 km NNW of Mt Isa. A stream-sediment anomaly delineated in 1975 during regional sampling of the Seigal 1:100 000 Sheet area was followed up by more detailed stream-sediment work and a reconnaissance soil survey. A soil anomaly exceeding 2 km in diameter has been outlined. The maximum copper value found so far is 1180 ppm - this compares with regional background levels of less than 60 ppm. Copper and tin appear to form a halo around a core rich in lead, lithium, niobium, rubidium, thorium, uranium, and yttrium. Arsenic, beryllium, bismuth, and tungsten are enriched in the area, but the available data do not indicate any zoning of these elements. The anomaly occurs in high-level granite and acid volcanics of Carpentarian age. The geological environment, large apparent size, and elemental zoning of the mineralization suggest that it may be of the 'porphyry' type.

PAY VERSUS NON-PAY KIMBERLITES

JOHN FERGUSON

Of natural diamonds about 88 percent are derived directly from kimberlite, and the remaining 12 percent from detrital deposits. Diamond can be an accessory mineral in kimberlite, having a concentration of less than 1 ppm. World-wide distribution of kimberlites indicates that they are virtually restricted to the older (1500 m.y.) continental cratonic areas, and that the diamondiferous kimberlites are concentrated in the older and thicker nuclei of these stable platforms. Kimberlites range in age from Precambrian to Cretaceous, and possibly even younger; this spread of ages is present in single provinces.

Kimberlite emplacement is confined to areas of anorogenesis, but related to large-scale uplift and distension; in some cases there is an association with major rifting. On the local scale, structures in the upper crust control the localization of the intrusives. Kimberlites most commonly occur in diatreme, dyke, and, rarely, sill forms. The diatremes have conical shapes that result from explosive breakthrough from kimberlite fissure feeders at depths 2 to 3 km below surface.

Kimberlite is an ultramafic alkaline rock recognized more commonly by its associated suite of xenoliths (mostly garnet lherzolite, peridotites, pyroxenites, and eclogites) and xenocrysts (mostly Mg-rich ilmenite, pyrope-rich garnet, chrome-diopside and phlogopite) rather than by the matrix minerals. The latter comprise olivine (Fo_{90}) and lesser amounts of dolomite, calcite, ilmenite, perovskite, rutile, spinels, magnetite, phlogopite, and apatite. Owing to the rapid emplacement of kimberlites, the mineral assemblage has not had time to equilibrate to crustal conditions, thereby maintaining an upper-mantle facies assemblage. Kimberlites probably form at depths ranging from 100 to 250 km, so that the first essential requirement for the presence of diamond would be that they originate at depths below about 150 km - that is, within the diamond stability field for the projected continental geotherm. In that the site of kimberlite generation is thought to be close to the lithosphere-asthenosphere boundary - that is, within the low-velocity zone - it is important, from a prospecting viewpoint, to select target areas for pay kimberlites where the palaeo-low-velocity zone exceeded depths of 150 km $\pm$. A study of the mineral assemblages in some xenoliths allows estimates of equilibration temperatures and pressures to be made. For this P-T estimate it is necessary that the rock equilibrated with the assemblage Ca-rich pyroxene + Ca-poor pyroxene + garnet. The equilibration temperature is estimated from the diopside solvus, and with this knowledge it is possible to estimate the equilibration pressure from the Al_2O_3 content of enstatite. Using this pyroxene geotherm, it has been found that old stable cratonic areas more than 1500 m.y. old provide the necessary conditions for the generation of kimberlites within the diamond stability field. Additional useful mineralogical parameters for determining the favourability of kimberlites for diamonds can be gleaned from the composition of garnets and ilmenites. High Mg and Cr and low Ca contents in garnets and high Mg and Ti contents in ilmenites reflect diamond-facies assemblages. The intergrowth of $diopside_{ss}$ and $magnesite_{ss}$ is an additional indication of an assemblage originating within the diamond facies regime.

ECONOMIC MINERALIZATION ASSOCIATED WITH CARBONATITES

JOHN FERGUSON

Carbonatites are primary igneous rocks containing one or more of the following principal minerals: calcite, magnesiodolomite, ankerite and/or siderite. The most common minor minerals are sodic pyroxenes and amphiboles, apatite, magnetite, biotite, and alkali feldspars, all of which may reach the proportions of major constituents producing associated rock types. Carbonatites are geochemically identified by strong enrichment in one or more of the following elements: Sr, Ba, La, Ce, and Nb, which can occur in independent minerals or else proxy for other elements in the major and accessory mineral assemblages. In common with felspathoidal rocks, carbonatites are also enriched in P, F, Zr, Hf, Ti, and Th.

Carbonatites occur in alkaline igneous provinces as independent or composite plugs, dykes, cone-sheets, rarely concordant intrusions, and as effusives. Most typically they occur as central cores to ultramafic alkaline volcanic rocks, and mark the latest phase of explosive igneous activity. Carbonatites range in age from Precambrian to present-day, and are mostly confined to stable continental platforms associated with areas of major uplift, distension, and rifting. Carbonatites are surrounded by metasomatic aureoles (fenites) characterized by the introduction of alkalis. The chemistry of the fenitised rocks suggests that the metasomatising fluids were originally in equilibrium with silicate magmas.

The economic minerals most commonly exploited in carbonatites are apatite, pyrochlore, rare earth minerals, fluorspar, and barite. By-products of these commercial operations include vermiculite and minerals containing iron, titanium, zirconium, uranium, thorium, and strontium. Copper enrichment in carbonatites is regarded as atypical, despite the large-scale mining of copper at the Palabora carbonatite complex, Transvaal. In order to understand the role of sulphides in carbonatites it is necessary to look at their petrogenesis. As noted, carbonatites are associated in space and time with other alkaline rocks, and are typically found in closest association with the ultramafic alkaline varieties which include kimberlites. Textural evidence within such rock-suites suggests that the carbonatites developed by a process of unmixing or immiscibility with these magmas. Experimental work demonstrates that silicate magmas can dissolve large proportions of CO_2 at mantle pressures. Once this carbonated magma is brought into low-pressure crustal regimes, the CO_2 enters into a carbonate phase giving rise to carbonatites. The silicate-carbonate fractionation results in the partitioning of the sulphide-rich assemblage into the volatile-rich carbonatitic magma. Providing that this magma is not violently erupted to surface, with attendant loss of the volatile phase, the sulphide assemblage is retained in the carbonatite or in the sheltered and fenitised wall-rocks.

GEOCHEMISTRY AND PETROGRAPHY OF ROCKS FROM AROUND THE WOODLAWN Cu-Pb-Zn ORE BODY, SOUTHEASTERN NEW SOUTH WALES

I.B. LAMBERT

Baas Becking Geobiological Research Laboratory

The Woodlawn ore body, which is being developed by Jododex Australia Pty Ltd, is near Tarago, about 45km northeast of Canberra. It consists of massive Cu-Pb-Zn sulphide lenses plus stringer and disseminated mineralization.

Chemical, X-ray diffraction and microscopic studies have been carried out on approximately two hundred and fifty representative samples from diamond drill cores at various distances up to several kilometres from the ore body.

These investigations have substantiated the general geological picture evolved during complementary studies by Jododex, the NSW Geological Survey and CSIRO Division of Mineralogy, and further elucidated details of rock distributions, alteration minerals and geochemical anomalies in the Woodlawn area.

The two main rock types in the vicinity of the ore are the felsic volcanics, which are dominant to the south and the west of the ore, and the fine-grained sedimentary rocks, which are most abundant in the immediate vicinity of the ore body and to the north. The sedimentary rocks seem to be mainly derived from the acid volcanics. Dolerite intrusions are common to the north.

There is an extensive aureole of silicification, chloritization, sericitization and stringer mineralization around the ore body, in which felspars and primary ferromagnesian minerals are virtually absent (except in some dolerite intrusions). The main chemical changes within the hydrothermally altered rocks include addition of Si, Mg, Fe, (Mn), Al, (K), Ag, Cd, Zn, Pb, (Bi), Cu, S, (Sn) and depletion of Na and Ca, with the elements in brackets showing less systematic trends.

The aureole of chemical and mineralogical anomalies can be divided into several distinct zones.

Zone I occurs in the immediate vicinity of the massive ore. It represents the most intense alteration and may include precipitates from the metal-rich ore-forming solution. It is characterized by abundant stringer mineralization, chlorite schists and cherts, together with altered volcanic and sedimentary rocks. The rock chemistry is dominated by high Mg and Fe values with low SiO_2 in the cherts; the altered volcanics and sediments are chemically intermediate between these extremes. Ca and Na contents of all rocks are very low, as evidenced by the absence of plagioclase, and K is somewhat depleted.

Zone II surrounds Zone I. It is a relatively extensive zone of less intense hydrothermal alteration, characterized by less common stringer and disseminated mineralization and a virtual absence of felspars (except in some basic rocks). There is widespread silicification of the felsic volcanics, whilst Mg contents are significantly higher than in unaltered felsic volcanics and sediments, and tend to increase towards the ore body.

Na and Ca are much depleted, but K contents are fairly normal and reflect the abundance of sericitic muscovite.

Zone III, which comprises the volcanic pile to the south of the ore body evidently was not permeated ubiquitously by hydrothermal solutions. It contains patchy development of chlorite-rich rocks and stringer to disseminated base metal and pyrite mineralization. Elsewhere the felsic volcanics tend to be silicified, but they generally contain albitic felspar. The chemical features of the rocks in this zone are therefore highly variable.

Outside these zones there is some silicification of the felsic volcanics and other mild chemical changes which can be ascribed largely to deuteric alteration and low grade metamorphism, rather than to mineralization.

We consider that sea water descended into the volcanic pile and was heated and chemically modified to a minor degree as it circulated and ascended to the surface, where it gave rise to Zone II alteration by reaction with the volcanics and sediments. Ore formation and Zone I alteration could have occurred relatively rapidly following mixing of this circulating sea water with highly metalliferous solutions. The latter would be analogous to those which form porphyry copper deposits and could have been generated during sub-volcanic magma fractionation and/or by extensive rock leaching at moderate to high temperatures. Explosive volcanic activity offers a feasible means of "tapping" the metalliferous solution and enabling rapid ascent of the resultant mixed solution.

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THE RESPONSE OF GEOPHYSICAL PROSPECTING METHODS TO THE WOODLAWN OREBODY

I.G. HONE

The Bureau of Mineral Resources has conducted test surveys over the Woodlawn orebody with transient electromagnetic, magnetic induced polarization and a variety of down-hole geophysical methods. The purpose of this work was to investigate the response of the more recently introduced electrical prospecting methods to the Woodlawn orebody. Interpretation of the data recorded was greatly assisted by geological information provided by company mapping and drilling.

A semi-regional transient electromagnetic survey was made with the Russian MPPO-1 equipment and, although affected by cultural noise, the results show a strong anomaly over the deposit. Detailed analyses of the results indicate the attitude of the orebody and its shallow depth.

The magnetic induced polarization survey was carried out using recently developed Scintrex equipment. Anomalies were recorded over the orebody, black pyritic shales and weakly mineralized dolerites. It was difficult to separate these anomalies on the basis of polarization response alone, but the ore zone was clearly resolved by a zone of high conductance.

The down-hole surveys employed resistance, resistivity, induced polarization, self-potential, gamma ray and electromagnetic methods. All down-hole surveys provided information on the physical properties of the ore and host rocks. Most methods can be used to assist geological correlation between holes. The resistivity and resistance logs indicate a large contrast in resistivity between the conducting massive sulphides and the resistive country rocks. The self-potential method proved the most successful in indicating the presence of remote mineralization. The down-hole electromagnetic surveys were made with a Turam-type system and recorded anomalous field strength and phase readings when the probe was in or less than 10 metres from the orebody.

The survey results show that the Woodlawn orebody has an extremely high conductivity and that prospecting methods based on conductivity, conductance, or self-potential measurements, clearly respond to the orebody. Of the surface methods used by the Bureau of Mineral Resources the transient electromagnetic method proved the most cost-effective for semi-regional exploration in this environment. The down hole surveys indicate that the self-potential method is an effective tool for detecting mineralization away from the hole.

GEOPHYSICAL SURVEY OVER HEAVY MINERAL DEPOSITS, JERUSALEM CREEK NSW

N. SAMPATH

Between May and November 1975, the Bureau of Mineral Resources carried out airborne and ground geophysical surveys over heavy mineral sand deposits in the Jerusalem Creek area, NSW. The surveys were the first stages of an investigation into the geophysical response of heavy mineral deposits and the role of geophysical methods in heavy mineral sand exploration.

The heavy mineral sand deposits at Jerusalem Creek are of the beach ridge type and occur in several forms and grades. Rutile, zircon and ilmenite are the major constituents of the heavy minerals.

The geophysical methods employed in the surveys were magnetic, radiometric and induced polarization. These methods were selected because of expected contrasts in the magnetic, radioactivity and induced polarization characteristics of heavy mineral and quartz sands.

The airborne magnetic and gamma-ray spectrometer surveys covered an area of approximately 200 square kilometres of coastal plain centred on Jerusalem Creek. No aeromagnetic anomalies were observed over heavy mineral deposits; however the airborne gamma-ray spectrometer data shows some correlation with the beach ridge system. The most distinct radioactivity anomalies correlate with man-made dumps and excavated areas.

On the ground, magnetic, radiometric and magnetic, and electrical induced polarization surveys were carried out over the high-grade Evans West deposit. This deposit was chosen as the site for ground surveys because the detailed geology provided by the extensive development drilling could be used to assist interpretation of the geophysical results. To further assist interpretation of the geophysical surveys, beach sand samples were collected for laboratory measurement of physical properties.

The magnetic induced polarization (MIP) results clearly delineate the orebody but a limited electrical induced polarization (EIP) survey of the deposit was not so successful. EIP traverses over dumps containing different heavy mineral fractions showed that ilmenite was the source of the induced polarization anomalies produced by the heavy mineral sand, a finding supported by subsequent laboratory studies. No magnetic anomalies were observed over the heavy mineral deposit and this result is consistent with laboratory measurements which show a very small susceptibility contrast between heavy mineral sand and quartz sand. Measurements made in the laboratory and in mine workings show that the heavy mineral deposits were distinctly radioactive; however, due to the blanketing effects of overburden, no radioactivity anomalies were recorded over the unmined area.

The ground surveys show that the MIP method could be usefully employed as a prospecting tool for high grade heavy mineral deposits. Ground magnetic and radiometric methods seem unsuitable for deposits of the Jerusalem Creek type due to the low suscept ibility of the heavy minerals and the blanketing effects of overburden.

THE USE OF GRAVITY TO INVESTIGATE THE GEOMETRY OF THE RUM JUNGLE GRANITIC COMPLEXES

J.A. MAJOR

In 1974 a gravity survey was made on and around the Rum Jungle and Waterhouse granitic complexes, about seventy kilometres south of Darwin. The principal aim of this work was to determine the size and shape of the granitic bodies.

The investigations indicate that some of the rocks in the complexes have the same density as the surrounding metasediments. Other rocks in the complexes have lower density. This finding is, in general, consistent with the geology as mapped.

The geometry and density of the granitic complexes were investigated by matching observed gravity profiles with theoretical profiles calculated for models having a uniform density contrast with the surrounding rocks. Mass deficiency calculations were also made to estimate the volume of low density material in the complexes. For both studies, rock densities used were determined from measurements on drill core samples. Results show that the volume of low density material determined from the calculations is consistent with the volume determined by modelling.

Simple modelling indicates that the density discontinuity between the light rocks and the surrounding denser rocks extends no deeper than four kilometres. The most realistic geological interpretation of this model is that the low density material forms a basement at about four kilometres depth which rises to the surface within the complexes. This interpretation agrees with the theory put forward by other workers in the area, that the Archaean rocks were intruded by a low density Middle Proterozoic granite.

Sediments in the trough between the Rum Jungle Complex and Waterhouse Complex appear to reach a depth of 2.5 kilometres. Sediments in the embayment area deepen to the west and contain dense rocks, possibly amphibolite or massive dolomite.

In areas where there is a marked density contrast between the complexes and metasediments, estimates can be made of the contact inclination. These estimates show that the contact invariably slopes outwards from the complexes, a finding which agrees with current geological concepts regarding the emplacement of granite bodies.

THE CAHILL FORMATION - HOST TO URANIUM DEPOSITS, ALLIGATOR RIVERS AREA, NORTHERN TERRITORY

R.S. NEEDHAM

The Alligator Rivers Uranium Field of the Northern Territory has proven reserves of about 335,000 tonnes of uranium oxide which is worth about $16,000 million, calculated at likely contract prices for delivery of yellowcake in the early 1980's. The area is amongst the world's greatest uranium fields, and promises to become one of the great mining districts in Australia.

The uranium is contained in the Cahill Formation, a Lower Proterozoic unit confined to the northeastern part of the Pine Creek Geosyncline. It is a time and facies equivalent of the Koolpin and Golden Dyke Formations, which are host to uranium deposits elsewhere in the geosyncline. Lower Proterozoic units of the uranium field are poorly exposed. Clues which led to recognition of the Cahill Formation and its relationship to mineralization were: similar host rock geology of the ore deposits, air-photo trend patterns, scattered but characteristic exposures of silicified carbonate which are confined to the formation, aeromagnetic patterns, and finally the results of drill traverses across the formation in unmineralized areas.

The formation comprises a carbonate-carbonaceous-pelitic lower unit and a more psammitic upper unit, both containing amphibolite-grade schist as the major rock type. The major uranium deposits and prospects are located in the lower carbonate-carbonaceous unit which is correlated with the host rocks of the major ore bodies. The uranium is probably syngenetic, having originally been precipitated under reducing conditions in lagoonal environments adjacent to an ancient granitic land mass. Concentration took place during extensive regional metamorphism and deformation 1800 m.y. ago.

Folding and metamorphism are more intense in the northeast of the area, where the rocks have been granitizied and are transitional into a migmatite complex, which is the focus of the 1800 m.y. event. The southwestern margin of the complex is marked by a large overfold, where metasedimentary rock types more resistant to partial melting enable approximate extensions of Cahill Formation in a migmatite terrain to be mapped.

Conventional airborne radiometric techniques are of little use in areas of overburden. Track-etch and emanometer methods are being used in the area, but pattern drilling may soon become the predominant exploration method. Careful selection of areas will be fundamental to successful exploration, and will be based on the distribution pattern and stratigraphy of the Cahill Formation.

A MINERALOGICAL AND STABLE ISOTOPE INVESTIGATION OF ORE GENESIS IN THE GOLDEN DYKE FORMATION

T. DONNELLY AND W.M.B. ROBERTS

The Golden Dyke Formation is part of the Lower Proterozoic Goodparla Group of sediments. The Formation has been mined principally for gold and uranium, and the isotope study is an attempt to corroborate conclusions based on mineralogical and geological evidence on the genesis of mineral deposits within the Golden Dyke Formation.

Stables isotopes of sulphur, carbon, and oxygen from the the Goodparla sediments and from mineral deposits in the Golden Dyke Formation were used in the investigation. Results were obtained which suggested low temperatures, connate fluids, and sulphur derived from both igneous and organic sources were responsible for ore deposition.

When compared with the geological evidence the results show close agreement.

PRECAMBRIAN PALAEOMAGNETISM OF AUSTRALIA

J.W.G. GIDDINGS

Plate tectonics, unlike any other theory of global tectonic processes, has met with unqualified success in providing an explanation of observations from many different branches of the earth sciences. The applicability of the theory to the Phanerozoic history of the earth is becoming well established. The problem that arises, and one which is currently controversial, is whether plate theory is a viable theory of tectonic processes in the Precambrian. Solution of the problem will not only provide a proper framework within which to interpret the origin of Precambrian orogenic zones, but will also contribute to our understanding of the early evolution of the earth and, in view of the relationship between metallogenesis and plate tectonics, will have a bearing on the selection of areas of potential mineralization. The talk describes Precambrian palaeomagnetic results now available for Australia and demonstrates how they may be used to solve the problem of whether or not plate tectonics was operative in the Precambrian.

There are two opposed schools of thought on the origin of the various Precambrian orogenic zones or mobile belts. On the one hand there are those that support the applicability of the plate tectonic regime back to about 3000 m.y., arguing that a mobile belt is the culmination of an episode of ocean basin closure between blocks of continental material which were once widely separated (plate tectonic model). On the other hand there are those who favour an ensialic origin for the belts, arguing that they were generated in situ between crustal blocks that have remained contiguous (single continent model). The two viewpoints are based on geological criteria which are clearly not unique. Ultimate acceptance of one or other of the models will depend on a quantitative demonstration of the one obvious difference between the two models - the amount of relative motion involved between adjacent crustal blocks.

Palaeomagnetism, by virtue of its ability to detect relative motion, is the only research tool potentially able to discriminate between the two models. Thus, if we consider a block of continental crust and measure the directions of remanent magnetization of the outcropping rock units, then the corresponding pole positions may be joined in chronological order to produce an apparent polar wander path - an expression of the motion of the continental block with respect to the rotation axis of the Earth. If an expanse of continental crust comprises a number of crustal blocks separated by orogenic zones then, in terms of the plate tectonic model, the crustal blocks will once have been widely dispersed. The apparent polar wander path for the "continent" will therefore initially comprise a number of unrelated apparent polar wander paths, one for each of the crustal blocks. Subsequent suturing of the blocks will result in the coalescing of the individual paths into a common path. It is evident that the alternative, single continent model will manifest itself as a single apparent polar wander path (allowing for jostling and small separations of the blocks not detectable palaeomagnetically).

Australia provides a suitable testing ground for the two models. Geologically, the Australian Platform comprises a welded assemblage of Precambrian crustal blocks separated by a network of younger mobile belts. 29 palaeomagnetic poles from 9 crustal blocks are now available for analysis. They comprise:

(i) 16 poles from isotopically dated (Rb-Sr method) Precambrian formations belonging to 8 crustal blocks, 9 of the poles relating to the Yilgarn Block. The poles range in age from 2500 m.y. to the latest Precambrian.

(ii) 10 poles from certain haematite orebodies developed in the banded iron formations of the Yilgarn, Gawler and Pilbara Blocks and the Hamersley Basin. Geological criteria enable broad age limits to be assigned to these poles.

(iii) 3 poles for which maximum ages are known.

Consideration of the data shows that the dated poles lie chronologically in sequence along a single apparent polar wander path. The orebody poles also fall on this path in positions which do not violate the geological constraints on their ages. The path can therefore be used to provide closer limits on the ages of ore formation. An average rate of apparent polar wander of 0.3^{o}/m.y. calculated from the path is the same as that found from Precambrian and Phanerozoic paths of other continents. Palaeoclimatic implications of the common path are its prediction of:

(i) Tropical palaeolatitudes for northern Australia during much of the Carpentarian (1800 m.y. - 1400 m.y.) at a time when there was widespread accumulation there of carbonates, including stromatolitic reefs - sediment types used as palaeoclimatic indicators of tropical conditions.

(ii) Polar latitudes for Australia at two distinct periods in the Late Precambrian within the age range 1150 m.y. - 620 m.y. This finding correlates with the abundant geological evidence for two distinct, widespread glaciations about this time.

Precambrian palaeomagnetic data for Australia thus favour the single continent model in which the mobile belts result from in situ development between essentially contiguous cratons. However, opening and closing of small intercratonic ocean basins (of the order 1500 km) cannot be ruled out in view of the experimental errors inherent in the palaeomagnetic and isotopic dating techniques. It must be stressed, though, that before an unequivocal statement can be made regarding the nature of the mobile belts much work remains to be done in Australia to refine the apparent polar wander path. It is noted, however, that the conclusion reached from the Australian palaeomagnetic data is supported by similar work in Africa and North America for which considerably greater numbers of palaeomagnetic results are available for analysis.

CORRELATION OF PRECAMBRIAN ROCKS

M.R. WALTER

Rational mineral exploration programs require a sound geological framework, the basis for which is the correlation of rock bodies. More direct uses of correlation in exploration depend on the fact that some types of ore deposits are temporally restricted - few banded iron formations are younger than 1800 m.y. old and few major lead-zinc ore deposits are older than that. Intercontinental correlation can be used with pre-drift assemblies of continental plates to locate segments of mineralized belts disrupted during drifting.

The present status of 6 methods of correlation will be very briefly reviewed. These are: 1. Correlation of distinctive rock types (e.g. tillites, iron formations); 2. radiometric dating of sediments; 3. palaeomagnetic pole positions; 4. palaeomagnetic reversal patterns; 5. use of microfossils; 6. use of stromatolites. This review is based on papers and discussion at a recent international conference in Moscow.

The correlation of distinctive rock types is a time-honoured process and in the Precambrian involves especially the use of banded iron formations and glaciogenic rocks. The thick, extensive iron formations are Early Proterozoic, apparently clustering in age at about 2.0 b.y. Iron formations are common in the Archaean, but these are associated with volcanics and greywackes, whereas the Proterozoic examples accompany extensive dolomites and limestones. However, there are also occasional younger banded iron formations. Glaciogenic rocks fall into two groups, Early Proterozoic and latest Proterozoic. In Australia there were two latest Proterozoic glacial episodes which are probably approximately synchronous across the continent.

Rb-Sr and K-Ar dating of glauconite can provide reliable results if numerous determinations are made, but isolated datings are of little or no value since the results are frequently spurious. Rb-Sr whole-rock isochron dating of fine-grained detrital rocks is successfully used here in Australia. Again, isolated dating may be of little value since detrital micas and felspars may be mixed with diagenetic minerals in a system that was never isotopically homogenised. In some cases at least it is possible to separate out the diagenetic micas and date only these. This method has been used successfully on North African Precambrian sediments.

The use of palaeomagnetic pole positions for correlation will be discussed in this Symposium by Dr Giddings. It is apparent that once a polar wander curve is well established, when a pole position is determined for a rock body it can be plotted on the curve and dated in relation to other units. However, the establishment of such a curve depends on the use of other dating methods, and there are difficulties such as determining just what event in a rock's history is recorded by the magnetism.

The use of palaeomagnetic reversal patterns for correlation in the Precambrian is much the same as matching the magnetic "stripes" on the sea floor. Patterns of reversals can be detected in sedimentary rocks using extremely sensitive magnetometers. This method has been used in a crude form for about a decade, and recent instrumental advances have broadened its applicability. It is presently being applied in Australia and North America.

Precambrian microfossils are not rare, contrary to what was once thought, and are commonly found in black shales and fine-grained cherts. In the USSR they have been used in biostratigraphy for some years. Within the Proterozoic this is a very promising method, although much basic research remains to be done. Significant recent discoveries include that of a fossil microbiota in the Nabberu Basin (W.A.) iron formation that is indistinguishable from that in the Gunflint and Biwabik Iron Formations of North America. It has also recently been demonstrated that there are biostratigraphically useful sudden size increases in several groups of microfossils at about 1.4 and 1.0 b.y. ago.

Stromatolites have been used in Precambrian biostratigraphy for only the past 17 years, so this method is still in its infancy. It is now apparent that the form and fabric of stromatolites is controlled by both biological and physical factors. While this means that it is particularly difficult to interpret these features, it also means that stromatolites are useful in both biostratigraphy and palaeoenvironmental analyses. Stromatolites are being used to group sedimentary rocks into broad units, with time spans averaging 300 m.y., and finer subdivisions also seem possible.

Stromatolites are indisputably powerful tools for precise intrabasinal correlation. With careful observation in the field and a minimum of laboratory investigation a wealth of information can be gained for making local correlations.

MINERAL PROSPECTS OF THE ARUNTA BLOCK

A.J. STEWART

The Arunta Block is the mass of Precambrian basement rocks situated between Alice Springs and Barrow Creek in the southern part of the Northern Territory. To date, the total value of all mineral products, at present-day prices, is about $10m, half of it from sales of mica. The remainder came chiefly from copper and gold, and small amounts of tin, tungsten, tantalum, silver, lead, zinc, and bismuth. The figure of $10m represents an average yield of about $270 per km^2 from the exposed Arunta Block, a figure which is orders of magnitude below those for many other parts of Australia. The main reasons for the failure to realize the region's full potential are the low level of prospecting, the distance from outlets, its small population, and, until 1970, the lack of geological knowledge of the area. Since 1970, BMR has mapped about two-thirds of the Arunta Block, recognized a stratigraphic sequence in the metamorphic rocks, and outlined the geological history. All known data on mineral occurrences have been collected and collated, and a metallogenic history outlined. A program of isotopic dating is also currently in progress, and first results have already been published.

The Arunta Block comprises Early Proterozoic (or older) sedimentary and volcanic rocks which were complexly deformed and metamorphosed 1800-1700 m.y. ago. The metamorphic rocks are grouped into three divisions separated by unconformities; the first division comprises two subdivisions separated by another major stratigraphic break. The metamorphic facies in all three divisions ranges up to granulite. Rocks in the three divisions show a gradation from dominantly volcanic types and subordinate sediments in division I, through pelites, dirty sandstones, and subordinate volcanics in division II, to quartzite, pelite, and carbonate in division III. All three divisions are intruded by granite, and a diorite-tonalite-granite complex is also present. Most of the granites date around 1700 m.y., but intermittent granitic intrusion continued to about 1000 m.y. ago. Other important igneous rocks in the Arunta Block are a differentiated basic complex with kimberlitic affinities, and a carbonatite body; both these intrusions are close to a deep crustal fracture, the Woolanga Lineament, in the eastern part of the Block.

Mineral occurrences in the Arunta Block can be grouped into five types, based on origin. Further, the distribution of the various types defines two zones in the Arunta Block, northern and southern.

1. Stratabound (Oonagalabi type). These are small to medium-size copper-lead-zinc-(bismuth) deposits lying along the stratigraphic break in division I of the metamorphic rocks, in the southern Arunta zone. Sulphide minerals are present in three adjacent rock-types which are present at almost every occurrence: (i) magnesium-rich rocks, containing abundant cordierite, anthopyllite, phlogopite, and enstatite, as well as sapphirine; (ii) forsterite marble; and (iii) quartz-magnetite rock. This type of deposit may be a metamorphosed soil or an early part of a metamorphosed evaporite sequence, but neither hypothesis explains all features of the deposits.

2. Igneous. (a) Acid. Granitic pegmatites occur in both zones of the Arunta Block. They contain copper, lead, tin, tantalum, and tungsten in the northern zone, and lead, beryllium, thorium, uranium and rare earth elements in the southern zone. The Jinka Granite is the source of tungsten and molybdenum which were metasomatically introduced into nearby calc-silicate country rock.

(b) Basic. Small amounts of copper minerals occur along faults and joints in many orthoamphibolite bodies in the southern Arunta zone.

(c) Ultrabasic. Chromium occurs in two small exposures of serpentinite in the southern zone.

3. Metamorphic. Abundant coarse mica occurs in cross-cutting pegmatites in the Harts Range in the eastern part of the southern Arunta zone; the pegmatites are metamorphic segregations that were 'sweated out' of metapelitic gneisses of division II. Gold occurs in pyrite in quartz or quartz-carbonate veins in the southeast of the Block; the lodes formed during greenschist facies metamorphism of the Arunta basement and unconformably overlying Heavitree Quartzite during the Late Palaeozoic.

4. Deposits formed by weathering. Small areas of laterite on carbonate rocks of the third metamorphic division contain up to 60 percent manganese. Uranium, as carnotite and pitchblende, occurs in Late Palaeozoic sandstone and Quaternary calcrete overlying the Arunta Block, and is thought to be derived from granites in the Arunta Block.

5. Deposits of unknown origin. Fluorite and fluorite-barite veins cut several granite masses in the northern Arunta zone. Some of the veins that cut the Jinka Granite also cut Late Proterozoic sediments which unconformably overlie the Granite.

The copper occurrences are the most numerous in the Arunta Block, but most are small and uneconomic. There is no evidence for large stratabound deposits of the Oonagalabi type, although drilling results at Oonagalabi itself have never been released. The pegmatite coppers are rich, but very small; one is being worked by a small mining company, operated by aboriginals. The orthoamphibolite coppers appear to be little more than concentrations of background copper localized during metamorphism and faulting. The dioritic complex may be worth prospecting as a possible porphyry copper; two small copper-bearing calcite veins cut orthoamphibolite which is intruded by the dioritic rocks, but copper minerals are not known in the dioritic rocks themselves.

The tungsten pegmatite occurrences are small, but one is rich enough to support a small syndicate operation. The metasomatic tungsten-molybdenum deposit is also being worked by a small syndicate. The other mineralized pegmatites are all too small to warrant exploiting for metals; some are used as sources of gemstones and mineral specimens.

The gold deposits in the southeast Arunta are (or were) rich, but small; the easily worked near-surface ore has been extracted, and the remaining unoxidized ore is not economic. Large amounts of mica still exist in the Harts Range, but cannot compete with imported material.

The fluorite-barite veins in the Jinka Granite have been prospected and evaluated, but are subeconomic at present prices. The uranium occurrences are still being evaluated, but in any case they face strong competition from the large deposits in other parts of the Northern Territory.

The location of the kimberlitic intrusion and carbonatite body, both of mantle origin, along the Woolanga Lineament suggests the possibility that diamond-bearing kimberlites and rare-earth-bearing carbonatites may be present elsewhere along the Lineament, concealed beneath superficial Cainozoic sediments.

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PLATES AND VOLCANOES IN PAPUA NEW GUINEA

R.W. JOHNSON

Present-day tectonism and volcanism in Papua New Guinea are governed by the relative movements of two minor plates caught between the larger, converging, Pacific and Indo-Australian plates. Johnson & Molnar (1972) and Curtis (1973) considered that three minor plates may be present, and argued from the premise that instantaneous poles of rotation for all the plate boundaries were a long way (90°) from Papua New Guinea. Krause (1973), on the other hand, favoured the existence of two minor plates, and argued that some poles of rotation may be within, or close to, Papua New Guinea.

Fourteen volcanoes in Papua New Guinea have erupted this century, and ten of these are found at the seismically highly active southern margin of the South Bismarck plate. This plate margin is therefore a critical one for volcanologists, and the volcanology group at BMR has, on the basis of field and petrological studies, attempted to establish a broad tectonic framework to account for the volcanism.

The south Bismarck Sea volcanoes coincide with two convergent plate boundaries: (1) a western arc off the north coast of mainland Papua New Guinea extends from the Schouten Islands to the western end of New Britain, and is associated with the Indo-Australian/South Bismarck plate boundary; (2) an eastern arc, overlying the northward-dipping New Britain Benioff zone, is associated with the boundary between the Solomon Sea and South Bismarck plates.

The compositions of rocks from the western arc change along the volcanic chain. Because the present-day pole of rotation for the Indo-Australian/South Bismarck plate boundary could be in the northwestern part of mainland Papua New Guinea, and because rate of plate convergence probably governs the thermal regime under any one part of the arc, it is postulated that primary mantle-derived magmas are produced under unique sets of conditions under different parts of the western arc, giving rise to contrasting magma compositions at different volcanoes along the arc. The compositions of volcanic rocks in the eastern arc change progressively northwards with increasing depth to the underlying Benioff zone. The unusual distribution pattern of the eastern arc volcanoes may be due to the thermal influence of a thrust slice beneath west New Britain, and to the proximity of instantaneous poles of rotation in, or near, the Gulf of Papua.

These and related studies in other volcanic areas in Papua New Guinea lead to the following general conclusions:

(1) Most plate boundaries in Papua New Guinea are <u>zones</u> of deformation, and the only boundaries that can be represented by a single line are those defined by the axis of the submarine trench south of New Britain and west of Bougainville Island. In particular, the Ramu and Markham valleys on mainland Papua New Guinea are considered to represent a collision zone between a Tertiary island-arc and the northern margin of the Australian continent, and the presence of the western arc volcanoes cannot be reconciled

with the models that interpret the axes of the Ramu and Markham valleys as a present-day plate boundary.

(2) Models which assume that the present-day poles of rotation are a long way from Papua New Guinea are probably less realistic than those (e.g., Krause, 1973) which regard them as nearby. This applies particularly to the boundaries at the southern margin of the South Bismarck plate.

(3) Evidence for the present-day existence of a third minor plate north of the South Bismarck plate is not compelling. Plate boundaries may have existed in the zone north of Manus Island and north and east of New Ireland and Bougainville Island, but there is little seismicity and, like the Ramu and Markham valleys, the zone is probably best regarded as a possible site of former plate boundaries.

Information on former plate boundaries is critical to an understanding of early Cainozoic magmatism and metallogenesis in Papua New Guinea. Mineralization of the Cu-Au-Mo type is associated with Tertiary island-arc type igneous rocks in several parts of Papua New Guinea, and there is now a need for extending the present studies on contemporary plate boundaries and active volcanism to older igneous formations and their associated tectonic regimes.

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THE MEDIAN TECTONIC LINE IN NEW GUINEA - A CONTINENT-ISLAND ARC COLLISION SUTURE

R.J. RYBURN

The term Median Tectonic Line was first used in Japan for the major fault separating two contrasting metamorphic terrains of late Mesozoic age - the high-pressure low-temperature Sanbagawa belt and the low-pressure high-temperature Ryoke belt. Similar paired metamorphic belts have since been recognized in many of the young orogenic belts bordering the Pacific Ocean (and elsewhere), notably in California, New Zealand, and Sulawesi. In most areas the high-pressure belt lies on the oceanward side of a contemporaneous low-pressure belt, from which it is separated by a 'median tectonic line'. The high-pressure belt is characterized by sporadic occurrences of blueschist containing lawsonite, glaucophane, aragonite, and omphacite, by the abundance of dismembered ophiolites, and by the absence of intrusives coeval with the metamorphism. The low-pressure belt contains metamorphic minerals characteristic of a medium to high geothermal gradient (andalusite, sillimanite, cordierite), and abundant calc-alkaline intrusives and volcanics.

Paired metamorphic belts can be explained in terms of the plate tectonic model for convergent plate boundaries. Subduction of oceanic lithosphere results in a marked depression of the isotherms in the subducted slab conditions suitable for blueschist-facies metamorphism. Thus the high-pressure belt is made up of sediments and fragments of oceanic crust that have been subducted and subsequently uplifted. The low-pressure high-temperature belt corresponds to eroded parts of the volcanic arc overlying the subduction zone, where magmatism has resulted in a high geothermal gradient. It is important to note that the 'median tectonic line' is usually a vertical fault produced by isostatic uplift of the subducted material after subduction has ceased, and usually lies nearer the volcanic arc than the underthrust. In some circumstances, however, the underthrust is preserved beneath relatively intact ophiolite sequences at the leading edge of the over-riding plate. These sequences represent oceanic crust and upper mantle forming a basement to the volcanic arc, and are commonly tilted towards the arc by buoyant upsurge of the underlying subducted material.

Knowledge of New Guinea geology has reached a stage that allows tentative recognition of an early to mid-Tertiary median tectonic line and paired metamorphic belts. Unlike most other examples, the high-pressure low-temperature terrain lies on the continental side of the low-pressure belt. Blueschist-facies rocks, mostly metamorphosed ophiolites (gabbros and volcanics), are known from the northern fall of the central ranges in Irian Jaya, from southern tributaries of the Sepik River, and from south of the Papuan Ultramafic Belt. Low-grade metasediments and dismembered ophiolites are also common in the high-pressure belt. In the low-pressure belt, or North New Guinea Arc, volcanics and intrusives of Eocene to Oligocene age are widespread. Owing to the shallow depth of erosion, low-pressure high-temperature metamorphics are not widely exposed, but are present in the Sepik Valley. The age of metamorphism in both belts appears to be Oligocene, the same as in New Caledonia. Northward-dipping intact ophiolite sequences, probably basement to the North New Guinea Arc, include the Papuan Ultramafic Belt, the Marum Complex, and several smaller bodies in the south Sepik area.

The North New Guinea Arc is interpreted as an eastward extension of the Indonesian arc system that was impacted by the northern margin of the Australian continent in about the late Oligocene. Throughout the early Tertiary, oceanic crust north of the continent was consumed in a northward-dipping subduction zone beneath the North New Guinea Arc. Thus the median tectonic line in New Guinea is thought to approximate to the collision zone. The presence of late Tertiary intrusives in the central ranges of New Guinea, and two small occurrences of blueschist on the north coast of Irian Jaya, suggest that 'flipping' may have taken place during the collision, followed by southward subduction in the late Tertiary.

The model proposed here has some implications for the location of mineral deposits in New Guinea. Apart from the porphyry-copper potential of the North New Guinea Arc, and lateritic nickel associated with the ultramafic bodies near the median tectonic line, the blueschists and other metaophiolites are a favourable environment for cupriferous bedded pyrite lenses similar to those in the Sanbagawa belt in Japan. Jade may yet be found in the high-pressure belt, as chloromelanitite, a close relative of jade, occurs in the south Sepik blueschists.

BEACH RIDGES, SEA-LEVEL CHANGES AND HEAVY MINERALS - SOME PRELIMINARY RESULTS

P.J. COOK

Many relative changes of sea level have taken place during the Quaternary, mainly in response to fluctuations in the volumes of ice in the Arctic and Antarctic. During "still-stands" of sea level there is extensive mechanical working and reworking of strandline deposits which in places results in heavy mineral deposits. The current state of knowledge suggests that the richest heavy mineral deposits are associated with high sea level stands, and that the longer the still-stand, the richer those deposits are likely to be. Therefore if a precise sea level curve can be established it should be possible to forecast the periods in which heavy mineral deposits are most likely to have formed. Consequently as an aid to the exploration of these deposits, BMR is not only compiling information on known deposits but is also examining beach ridge sequences onshore and offshore in order to help define a sea level curve with greater precision.

Work by BMR on beach ridges in the Gulf of Carpentaria (Smart), and Broad Sound (Cook, Polach) supports the idea that sea level stabilized at about 6000 years BP. Offshore work on the north NSW and south Queensland coast (Jones) has shown that there are a number of features associated with Quaternary shorelines, the most prominent of which are at depths of about 20-30 m (late Holocene), 40-50 m, 77-85 m, 105-120 m and 160-180 m. The 20-30 m feature has been sampled by drilling (Planet), but to date none of the deeper submerged features have been sampled. Uranium-series dating of coral material from the Newcastle and Evans Head areas (Marshall, Thom) has now proved that the Inner Barrier formed during the last interglacial period when sea level was somewhat higher than the present-day level.

The best developed onshore beach ridge sequence in Australia is that in southeast South Australia. A co-operative program by BMR (Cook, Colwell), the S.A. Dept of Mines (Lindsay, Firman) and Flinders University (von der Borch, Schwebel) is currently being undertaken in this region in the hope of using it to establish a sea level curve for a continental coast. The drilling program to date has made it possible to establish fairly precisely the Quaternary coastal sequence in this region although absolute ages are not available at the present time. Because of its well-developed beach ridge sequence the area has attracted a number of exploration companies looking for heavy mineral deposits. Results obtained from our drilling program indicate that, in general, heavy minerals are not abundant. The greatest heavy mineral concentrations (up to 1.2% total heavies) are found not in the beach ridges but in a non-outcropping marine sand unit which underlies the eastern half of the region and any future exploration effort should probably be directed at this unit.

HABITAT OF PETROLEUM AS RELATED TO MATURATION INDICES

GIPPSLAND BASIN, VICTORIA

S. OZIMIC

It is generally accepted that the source of hydrocarbons in the Gippsland Basin is the organic matter dispersed in sediments of the Late Cretaceous to Early Tertiary Latrobe Group. Comparison of the composition and the degree of maturation of the sediments of the Strzelecki, Latrobe and the Seaspray Groups reveal that only the Latrobe Group sediments satisfy the requirements necessary for the generation of the hydrocarbons encountered in the basin.

The source rocks of the Latrobe Group have been buried deeply enough and for a sufficient length of time for the diagenetic formation of hydrocarbons from exinitic constituents (spores, pollen, cuticle, resin and algae). Present day temperatures (up to 160°C) are assumed to approximate the maximum palaeo-temperatures.

The composition of the hydrocarbons from the Gippsland Basin (dry gas, condensate, oil and gas with a high content of CO_2) indicates a range of different sources and the nature of migration.

The source of gas with a high CO_2 content (e.g. the Marlin - Deep reservoir contains 21% CO_2) is speculative. It may be related to volcanic activity (contact metamorphism) which could have liberated CO_2 through heating calcareous and/or coaly material, or to bacterial action in the early stage of the diagenesis of the Latrobe Group sediments. Dry gas in the Golden Beach No. 1A reservoir is probably biogenic in origin.

The results of coal rank analyses from different offshore wells (68-81% carbon) indicate an oil and wet gas province. This appears to be consistent with the observed liquid/gas ratios of the hydrocarbon accumulations. Moisture content and calorific values of coals of the Latrobe Group from the offshore wells show a direct relationship to depth of burial and the type of associated hydrocarbons.

Temperature gradients (1.5-2.5°C/100m) observed in the individual offshore wells vary considerably.

Present-day distribution of the hydrocarbons throughout the basin is a function of the nature of folding (non-compressional), time of migration (late Eocene and Oligocene) and the sealing off of the Latrobe Group sediments, by the transgressive, calcareous and shaly sediments of the Lakes Entrance Formation.

STRUCTURAL EVOLUTION OF THE GREAT AUSTRALIAN BIGHT BASIN

J.B. WILLCOX

A regional interpretation of BMR seismic profiles along the southern margin of Australia between 120° and 141°E, indicates that 200 to 500 m of sediment underlies the continental shelf in most places, and the western Eyre Terrace. The section is continuous with the Upper Cretaceous and Tertiary section of the Eucla Basin. A much thicker section in the Great Australian Bight Basin, that is, under the Ceduna Terrace and eastern Eyre Terrace, and under the continental rise south of the Terraces, is subdivided by unconformities. By analogy with the well-documented section in the Otway Basin, and by comparison of the structural style with that suggested in Falvey's (APEA, 1974) model for the formation of continental margins, the section is considered to comprise four units: a Lower Cretaceous fluviatile - lacustrine unit (Otway Group equivalent); an Upper Cretaceous and lower Paleocene, mainly fluviatile-deltaic unit (Sherbrook Group equivalent); an upper Paleocene and Eocene shallow marine clastic unit (Wangerrip and Nirranda Group equivalents); and an Oligocene to Recent prograded carbonate shelf unit (Heytesbury Group equivalent). These rocks overlie Precambrian crystalline and sedimentary basement. The main difference between this interpretation and the one presented by Bouef & Doust (APEA, 1975), is that the 'break-up unconformity' is believed to be higher in the section and the post-break-up Tertiary section is about 600 m instead of 3 km thick. In the Bremer Basin and western part of the Otway Basin the Upper Cretaceous/lower Paleocene unit is largely absent. The total thickness of the sedimentary section is at least 2 km in the Bremer Basin, 6 km in the Great Australian Bight Basin, and 6 km in the Otway Basin.

Beneath the extensive continental rise, south of the Eyre and Ceduna Terraces, similar unconformities occur and 2-3 km of Great Australian Bight Basin sediments appear to be present. Oceanic basement, characterized by numerous diffractions and by seafloor spreading anomaly number 22 (upper Paleocene), appears to be in contact with faulted Cretaceous rocks at the foot of the continental rise. On some profiles the oceanic basement is overlain by sediments which are possibly of Cretaceous age and this throws some doubt on the identification of anomaly 22. Although continental crust appears to form the continental rise, the gravity data suggest that it is only 10-15 km thick.

The Lower Cretaceous and basement rocks are sliced by extensive normal faults which trend parallel to the continental margin. The zone of faulting underlies the continental slope in the Bremer Basin, the continental rise south of the Eyre Terrace, the Ceduna Terrace, and occurs throughout the seaward portion of the Otway Basin. In general, the fault-blocks are downthrown southward and tilted northward and beneath the Ceduna Terrace form an elongated structural basin. The Upper Cretaceous and lower Paleocene sediments which fill this basin are faulted at the margins only, probably by rejuvenation of the Lower Cretaceous faults.

The earliest geological event deduced in the interpretation is the erosion of basement probably during the Permo-Carboniferous ice age. In the early Mesozoic, fault-bounded troughs probably formed near the edge of the present continental shelf (e.g. Polda Trough) and south of the Eyre

Terrace. During the Early Cretaceous, fluviatile and lacustrine sediments were deposited south of the basement which now underlies the continental shelf and western Eyre Terrace. Towards the end of the Early Cretaceous an arch formed along the foot of the present continental rise and the tension which resulted was relieved by normal faulting and formation of an incipient rift. By the early part of the Late Cretaceous a structural rift-valley basin had formed. This was followed by marine transgression, which probably spread eastwards across the area, but appears to have been of short duration. Fluviatile and deltaic sediments were deposited in the subsiding rift-valley basin during most of the Late Cretaceous and early Paleocene. The readjustment of fault-blocks near the basin margins in the mid-Late Cretaceous caused a minor unconformity. In the upper Paleocene, commencement of seafloor spreading led to subsidence of the southern fault-blocks and formation of the southern margin. A marine incursion resulted in deposition of shallow marine clastic sediments in the late Paleocene and Eocene. By the Oligocene, the source of detritus had been largely eroded down, and the northward drift of Australia into a warmer latitude possibly caused an abrupt change to carbonate sedimentation. As the margin continued to subside, a shelf of prograded carbonate sands built southwards and pelagic carbonates were deposited on the continental rise.

GALILEE BASIN SEISMIC SURVEY 1975

P.L. HARRISON & J.A. BAUER

The Bureau of Mineral Resources made a seismic survey in the western part of the Galilee Basin in central Queensland during July to November 1975. The location of the BMR traverses and previous company lines is shown on Fig. 1. The main aim of the survey was to obtain basic information on the extent and thickness of the western part of the basin which is entirely concelaed beneath the Eromanga Basin.

The Galilee Basin formed by periodic downwarping during Late Carboniferous, Permian and Triassic times and received mainly terrestrial sediments comprising sandstones and siltstones with thick coal sequences in the Lower and Upper Permian. The western part of the Galilee Basin consists of the Lovelle Depression, a northeast-trending trough of Permian and Triassic sediments up to 700 m thick, west of the Cork Fault. The margins of the Lovelle Depression were poorly known from scattered petroleum wells, water-bores and limited seismic traverses.

Economic interest in the Galilee Basin sediments results from the possible presence of oil, gas or coal. Hydrocarbon shows have been recorded from the Permian sediments of the Galilee Basin. The two most significant shows were from Lake Galilee No. 1 well and Koburra No. 1 well, both of which lie within the Koburra Trough to the east. Minor shows have been recorded from numerous other wells, including Lovelle Downs No. 1 in the Lovelle Depression where oil fluorescence was noted in the cuttings. Possible source and reservoir rocks are known to exist within the Galilee Basin sediments. Possible structural traps were formed by draping over basement highs, and stratigraphic traps may be present. By analogy with the Permian sequences of the Cooper Basin and Bowen Basins, the Galilee Basin could contain commercial quantities of hydrocarbons.

Geophysical exploration commenced in the Lovelle Depression with regional gravity and aeromagnetic surveys by the BMR and private companies during 1956-63. In the Mackunda and Winton 1:250 000 Sheet areas, both the gravity and magnetic data indicated the presence of a major northeast-trending fault - the Cork Fault - but the interpreted directions of downthrow conflicted. Seismic work during 1964-71 confirmed the presence of the Cork Fault; it indicated a downthrow to the west of about 300 m and suggested that a trough of sediments 2000 m thick, including at least 600 m of pre-Jurassic sediments, existed on the downthrown side of the fault. Lovelle Downs No. 1 well, which was subsequently drilled on the downthrown side of the fault, confirmed the seismic interpretation and intersected 630 m of Permo-Triassic rocks. It was postulated, by following the seismic lines southwards, that a substantial, though thinner, Permo-Triassic section existed 100 km southwest of the well.

The extent of the southerly part of the Lovelle Depression was known only from the presence of Galilee Basin sediments on seismic lines to the west and south of Lovelle Downs No. 1 well and by the absence of these sediments in Ooroonoo No. 1 well to the south and in Mayneside No. 1 well to the southeast. The Holberton Structure, a prominent surface feature, was thought to be a southerly continuation of the Cork Fault and to mark the southeastern margin of the basin.

Regional gravity and magnetic interpretation have not generally been useful in defining the sedimentary thickness because the gravity anomalies appear to reflect basement density variations and the magnetic anomalies to reflect basement lithological variations.

Both the gravity and magnetic anomalies clearly show the sub-surface extent of the Precambrian metamorphics of the Cloncurry Fold Belt and suggest that the Cork Fault corresponds to the southeastern edge of the Belt. The fault was reactivated during Permian to Tertiary times, with downthrow to the west and controlled the development of a sedimentary sequence on the downthrown side.

The main objective was to further define the extent and thickness of Galilee Basin sediments in the Lovelle Depression.

An additional objective was to verify the presence of a possible sedimentary sequence about 5000 m thick beneath the Eromanga Basin sequence which was indicated on a single seismic line south of Ooroonoo No. 1 well.

The seismic survey obtained 310 km of continuous single-coverage reflection recording and 18 km of six-fold CDP recording. Two expanded spreads were recorded to obtain vertical velocity information.

The area was generally a good one in which to record seismic reflections and small geophone and shot-hole patterns were found sufficient to attenuate coherent shot-noise. Record quality was generally fair.

Company sections near Lovelle Downs No. 1 well were examined and four strong reflections were selected for mapping. They were identified in the well section as:

Horizon	A	Near base of Toolebuc Formation (Cretaceous)
"	B	Near top of Hooray Sandstone (Lower Cretaceous/ Upper Jurassic)
"	C	Near top of Permian
"	D	Basement

The top of the Triassic at the well did not correspond to a significant reflection so that this horizon could not be mapped throughout the area.

These reflections were followed on company lines south of the well and along the BMR traverses.

The identification of the reflections south of the well is tentative because of variable reflection quality. The first two reflections were strong and generally easy to follow whereas the other two reflections were variable in character and sometimes difficult to pick.

Preliminary interpretation indicates that Galilee Basin sediments in the Lovelle Depression are more extensive than previously realized. The first complete northwesterly seismic cross-section over the Lovelle Depression was obtained; this cross-section shows that the sediments thin gradually towards the western margin, and that the eastern margin probably lies east of the Holberton Structure, the previously inferred margin. The maximum thickness of the Permian sediments was about 500 m in the southeast.

Results of this survey, together with review of a company line south of Ooroonoo No. 1 well, indicate Permian sediments are about 200 m thick 70 km south of the well and that the well may have been drilled on a local basement high.

The southern margin of the Lovelle Depression is therefore not yet defined. However a direct link with the Cooper Basin is unlikely because a seismic line in the northwestern part of the Cooper Basin indicates complete thinning of the Permian and Triassic sediments of the Cooper Basin about 100 km south of the presently known extent of the Lovelle Depression. A large unexplored area however remains between the Lovelle Depression and the northwestern Cooper Basin.

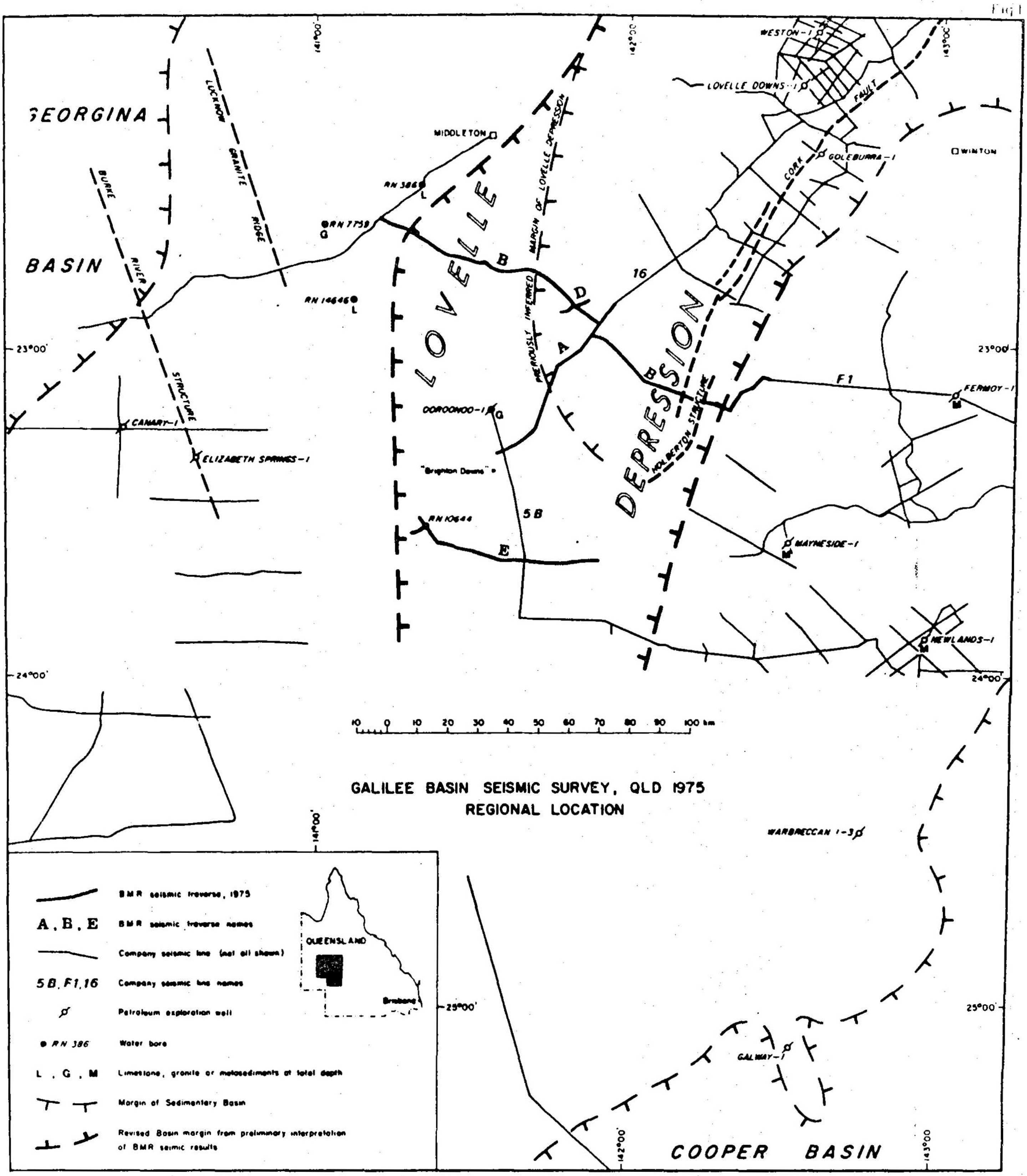
Two major faults were mapped. The Holberton Structure, previously known from geological mapping, corresponds to a major fault in the sub-surface with up to 300 m of downthrow to the west. Another major fault appears to be a southerly continuation of the Cork Fault.

The survey also discovered a basement high having an amplitude of 300 m at basement level; depth to the top of the high is 1400 m. The structure has apparent axial lengths of 7 km and 3 km, and is inferred to trend approximately northwest, parallel to the regional basement trends inferred from the gravity and magnetic anomalies.

The presence of a sedimentary (or possibly metamorphic) sequence up to 7500 m thick beneath the Permian sediments near Mount Windsor was confirmed. The sequence is known only from seismic work and could be one of several older sequences which exploration wells and water-bores have intersected in the area (Proterozoic sediments to the west, metasediments to the east and Palaeozoic carbonates of the Georgina Basin to the northwest).

Further seismic work is required to better define the margins of the Lovelle Depression especially in the unexplored area between the Galilee and Cooper Basins where the thickness of the Permian sediments is unknown. Follow-up work is required to demonstrate whether the basement high found during the survey is a closed structure. More detailed seismic coverage is required where regional coverage indicates a reasonably thick Permian section to determine whether other similar basement highs may be present in the Lovelle Depression.

Fig 1



GALILEE BASIN SEISMIC SURVEY, QLD 1975
REGIONAL LOCATION

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