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Record 1972/56

NOTES TO ACCOMPANY THE METALLOGENIC MAP OF AUSTRALIA

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INTRODUCTION

Metallogenic Maps depict concentrations of deposits of metals within their geological framework.

Thus they go beyond the more familiar mineral deposits map which shows the geographic distribution of mineral deposits, possibly with indications of their size, state of exploitation, and other factors of value to economic geography.

The exact nature of the legend for a metallogenic map is governed by the relationships assumed to exist between the concentrations of metals and their settings: map design can be used to emphasize the more important facts and symbols created to incorporate several parameters into a single symbol. Metallogenic maps are not simple and easily read documents, but are complex representations of complex relationships and so should convey a great deal of information.

In 1956 at the 20th Session of the International Geological Congress in Mexico, the Commission for the Geological Map of the World set up a Sub-Commission for the Metallogenic Map of the World. After study of available maps showing mineral deposits, this sub-commission recommended that although countries should continue experimentation towards suitable presentation of data, an Editorial Committee for the Metallogenic Map of Europe should be set up; this committee would work towards firstly a legend and secondly a Metallogenic Map of Europe. The committee was fortunate in so far as the compilation of the Tectonic Map of Europe at this time was well advanced. In 1964 a legend reflecting the basic philosophy for the Metallogenic Map of Europe was prepared and compilation begun. The first two sheets of the Metallogenic Map at a scale of 1:2 500 000 were published in 1969.

Australia was represented on the sub-commission from 1960 onwards. The presentation of the legend for the map of Europe paved the way for the Australian compilation. A suitable area was selected for a pilot compilation early in 1965 and the main study began in 1966.

A suitable geographical base map of Australia at 1:5 000 000 was available and a geological map on this base was in the final stages of publication. The second edition of the Mineral Deposits Sheet of the Atlas of Australian Resources (Scale 1:6 000 000) was published during 1965. In that year the Tectonic Map Committee of the Geological Society of Australia began work on a Tectonic Map of Australia and the philosophies and preparation of that and the Metallogenic Map were developed together.

When compilation started three major reference works on mineral deposits in Australia were available: The Geology of Australian Ore Deposits, First Edition (1953)[1], edited by A.B. Edwards; Second Edition (1965)[2], edited by J. McAndrew; and Australian Mineral Industry; The Mineral Deposits (1965), edited by I.R. McLeod[3]. Each contained overall summaries of the ore deposits of Australia, the first two regionally and by individual deposits, and the last by commodity; and so served as a broad base of information. As a metallogenic study requires detailed information, about two years were spent in assembling as much data as could be gleaned from the literature. The relationships between tectonic framework and distribution of metal deposits were then examined so that provinces could be recognized and outlined. Since this process is subjective it is clear that the finished map represents only one possible interpretation - different interpretations or additional information not available at the time of compilation could produce different maps.

ACKNOWLEDGEMENTS

The maps and this account are entirely based on the material of previous workers and therefore their indirect contributions have been paramount to the finished work. The co-operation of the Tectonic Map

[1] 5th Empire Mercury and Metalliferous Congress.

[2] 8th Commonwealth Mines and Metalliferous Congress.

[3] Bureau of Mineral Resources, Bulletin 72.

Committee of the Geological Society is gratefully acknowledged, and in particular that of my fellow members of the Territories Subcommittee, Dr M.J. Rickard and Messrs H.F. Doutch and K.A. Plumb, without which my knowledge of the Australian tectonic framework would have been embarrassingly slight. My thanks are expressed to the members of State Surveys and Mines Departments, in particular Dr J.L. Daniels of Western Australia, Mr B.P. Thomson of South Australia, Mr L. McClatchie and Dr E. Scheibner of New South Wales, and Messrs J.H. Brooks, P. Ellis, and K.R. Levingston of Queensland, who helped so willingly during 'fact finding missions' to their various organizations, and to people from industry who offered advice during compilation. The patient helpfulness of my supervisors, I.R. McLeod and Dr G.E. Wilford, has made the task considerably more agreeable over the years of the project. The clarity of the map is entirely due to R.A. Swoboda, whose patience and cartographic skill has transformed a conflicting mass of complex data into a legible whole.

THE LEGEND

The Metallogenic Map of Europe was originally mooted as the pilot study for the world map. The proposed legend was published in 1964, after some discussion of alternative proposals for presentation; it has been modified in detail during compilation of the final map. Our legend was modified from this early European legend as problems were encountered, so that the legend for the Australian map suits the local conditions and the scale of 1:5 000 000, which was used instead of the European scale of 1:2 500 000. Some of the alterations were prompted by the work of the Tectonic Map Committee of the Geological Society of Australia, the aim being co-ordination of the philosophy of the Metallogenic Map with that of the Tectonic Map - an aspect regarded as highly desirable by overseas workers.

The Legend for the Metallogenic Map of Europe

The legend for the Metallogenic Map of Europe is based on the concept that since metallogenic events are related to tectonic events they are best depicted in a tectonic framework. Two major divisions of the framework were recognized - orogenic domains and platforms, with the orogenic domains distinguished according to age. The European concept of platform emphasized the basement more than the cover rocks, so all platformal regions are depicted by the one colour, with overprints indicating age of sedimentation.

The time-honoured factors that are regarded as affecting ore deposition, such as rock type, vulcanicity, time-relation of intrusions to tectonism, chemical nature of igneous activity, structure, and metamorphism were incorporated in the legend to amplify the tectonic framework; some additional factors important in exploration, such as geochemical and geophysical anomalies, lateritization, palaeogeographic conditions, and palaeosoils were also included.

The genetic classification scheme for ore deposits in the European map is a modified version of Lindgren's classification. Europeans use the broad class exogene for deposits formed at the earth's surface and endogene for deposits formed within bodies of rock; but these terms have different meanings in Australian literature and have not been used in the Australian map. Deposits were divided into two size categories. Major deposits were to be those that contained before exploitation more than 0.05% of known world reserves plus past production of a metal; no lower limit for the small deposits shown was given.

The metal contents of deposits, and the chemical compounds in which they occur (sulphide, silicate, carbonate, etc.) further classify the deposits; the metals are placed into naturally occurring groups. The European legend included some non-metallic commodities which, except for phosphorus, are not included in the Australian legend.

The Legend for the Metallogenic Map of Australia

During compilation of the Tectonic and Metallogenic Maps, legends suited to Australian geology were evolved, modified, and redefined.

Tectonic Domains (Time-Tectonic Units)

In the Tectonic Map of Australia (1971) the units delineated as tectonic domains have been recognized and classified by consideration of certain diagnostic characteristics of tectonic style such as deformation, igneous activity, sedimentary facies, and metamorphism. Three types of tectonic domains are thus recognized:

Orogenic Domains (including metamorphic complexes), which are pre-cratonic developments involving flysch-like sequences in extensive linear troughs, abundant and varied volcanic and plutonic rocks, and intense deformation and widespread metamorphism.

Transitional Domains, which are late to post-orogenic developments associated with cratonization that are intermediate in time and style between orogenesis and cratonic tectonism. They are characterized by downwarps and cauldron subsidence, molasse-like sedimentation, abundant volcanic and plutonic rocks, moderate deformation, and rare metamorphism. Some domains in this category are represented only by post-orogenic granites.

Cratonic Domains (Platform Covers), which involve mild tectonism with the spread of platform cover, mild deformation of basement and cover (including the development of narrow mobile zones). They are characterized by widespread, generally thin, shallow water and continental sediments, rare small plutons, and basaltic sheets.

A formally named Orogenic Province is a group of broadly contemporaneous orogenic domains of similar tectonic history and style that, together with associated transitional domains, form the youngest basement to an immediately succeeding Platform Cover.

A formally named Platform Cover is a group of sedimentary basins whose developments are similar and broadly contemporaneous. Its deposits overlie the immediately preceding Orogenic Province and associated transitional domains and spread across older Orogenic Provinces and Platform Covers.

This framework has been modified for the Metallogenic Map in that transitional domains are considered with the immediately preceding orogenic domain, hence an Orogenic Province as discussed in the text consists of both the orogenic and transitional domains which form youngest basement to an immediately succeeding Platform Cover.

Five Orogenic Provinces are recognized on the Tectonic Map, but only four Platform Covers: the youngest, New Guinea, Orogenic Province having no cover as yet. There are also six orogenic domains which cannot be assigned to any Orogenic Province using the classification outlined above because the relationship between Platform Covers and these orogenic domains does not indicate the immediate succession in time and space implied by the definition of Orogenic Province.

In the notes that follow, additional terms will be used in the sense indicated:

Shield as a general term is used to indicate both orogenic domain and transitional domain as a geographical entity exposed at the surface. The term belt is used for an elongate shield and block for a roughly equidimensional shield.

A platform consists of undeformed cover resting on deformed basement. The undeformed rocks are referred to as platform cover. (The formally named unit is indicated by the use of capitals.)

A craton is used to refer to an entity of both shield(s) and platform(s) which behave as a stable tectonic entity at a given period of time.

Several different cratons can be recognized, depending on the period of geological time under discussion.

The sedimentary basins that have by tradition been referred to as geosynclines, in particular the Davenport and Adelaide, are distinguished in the text by inverted commas from narrow mobile troughs such as the Lachlan.

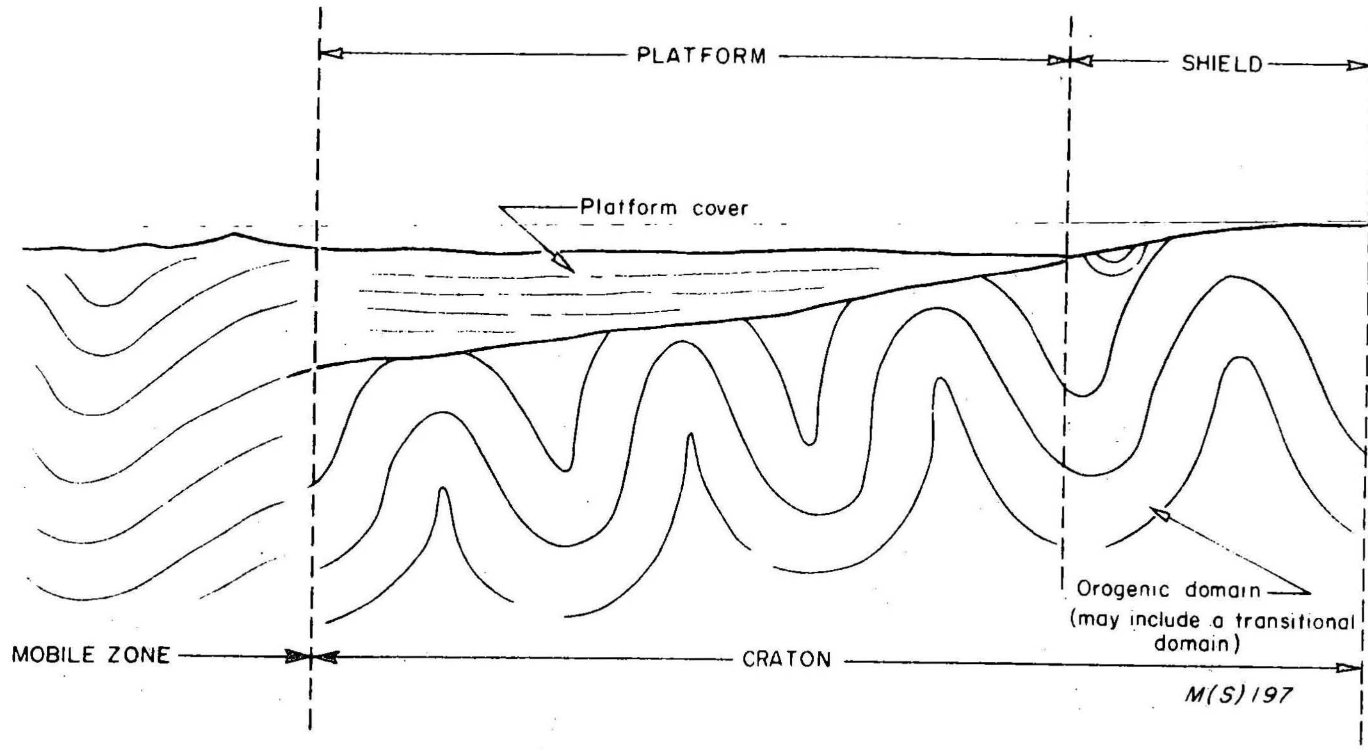

FIG 1 Schematic relationship among tectonic units showing terminology used in the text

Time Terms

The Tectonic Map Committee has adopted a time terminology based on the division of geological time into time spans with tectonic significance. Although orogenies and igneous intrusions occupy relatively short spans within geological time, on regional and Australia-wide bases they have a time distribution with recognizable maxima which were assumed to have tectonic significance. Intervals were therefore chosen so that these maxima could be suitably divided one from another into tectonically useful time units. The number system shown on the face of the map symbolizes these divisions of time, and also permits the presentation of additional data on the type of event involved.

The terminology for Phanerozoic time units is based on the Australian Stratigraphic Code, 4th Edition, 1964 (Geological Society of Australia).

The Precambrian time units, in particular Nullaginian, Carpentarian, and Adelaidean, are used in the sense of Dunn, Plumb & Roberts (1966).

Metallogenesis

Any metallogenic map is based on the assumption of relationships between the geological framework and the location of ore deposits. The generalizations govern the categories used in the legend; specific relationships are delineated on the face of the map.

The heavy dependence placed on the available literature (no fresh field studies were undertaken during the preparation of the map) means in turn a heavy dependence on the opinions of geologists over a long period of time during which 'fashions' in metallogenesis have altered radically. The vast majority of Australian ore deposits were describedduring a period when all ore deposits were assumed to be hydrothermal, even if the supposed granite source was far removed or invisible. On the other hand most regional studies belong to the more recent era of 'syngeneticism', and opinion today seems to be swinging towards emphasis on tectonic mobilization. This involves migration of ions along a pressure-temperature gradient to where conditions suitable for accumulation were set up - the ions (in particular copper, lead, zinc and sulphide) having been trapped during formation of the geosynclinal pile. Modern theories involving palaeogeographic conditions for sedimentation, groundwater movement, and leaching under stable land surfaces, are now being applied to studies of the origin of many ore deposits; the resulting conclusions, combined with a more detailed knowledge of the geology of mineralized areas, may result in the changing of many province boundaries shown on this map.

Whatever the controlling factors nominated for ore deposits, it is still feasible to describe them in a tectonic framework. The tectonic framework used for the Tectonic Map of Australia is admirably suited to the description of metallogenesis; in particular the groupings of the igneous rocks fit very well with the environments proposed for ore genesis.

Genetic Classification

In any genetic classification, grouping must be somewhat arbitrary. Every probable combination of pressure and temperature conditions feasible within the crust (and at the earth's surface) very probably played an important role in the formation of some orebody somewhere - in much the same way as the various metamorphic facies are now recognized as spanning the same entire range.

It has been assumed that where the terms 'mesothermal' and the like have been used in the literature they correspond broadly to the values put on them by Lindgren in 1911. The classification scheme is intended to correspond without precise values to Lindgren's range, particularly the differentiation amongst the hypothermal deposits. The classification scheme may well be regarded as the weakest point of the legend: the terms are adopted from common usage, and very often bear entirely different meanings to different people. Alluvial thus may be a purely descriptive term to a field geologist but carry overtones of mechanical winnowing by flood waters, wave action, or wind to a sedimentologist, who may indeed wish to subdivide the class.

There appears to be a pressing need for detailed studies of paragenesis (in the sense of the A.G.I. Glossary of Geological Terms, as a study of the minerals present and the order in which they formed or recrystallized), followed by deductions on genesis, on nearly all ore deposits (except large deposits still being worked) in Australia. However, the material left on the mine dumps or in unproductive parts of abandoned mine workings, which is all that is still available at many known Australian occurrences of metals, is hardly ideal for such studies. Moreover, the extreme depth of oxidation and supergene effects, combined with the common practice of mining only rich supergene ore and abandoning mines at the water table, may well mean that suitable material never reached the surface during mining.

Size Divisions

The European legend suggested that the division between major and minor deposits should be taken at 0.05 percent of the total world production plus reserves of the metal concerned. This total world figure has been difficult to obtain; the set of values was obtained from various sources, mainly Annales des Mines, publications of the United States Bureau of Mines, and World Mining. Most figures are conservative - estimates for the Peoples'' Republic of China and the USSR are inaccurate or out of date. This section of values related to world figures helps to orient Australian deposits better in the world picture, but does magnify the importance of deposits of metals with small total world resources, so that some deposits shown as major are not likely to be economic in the foreseeable future. Major deposits are shown in two ways - either by the appropriate large symbol if isolated, or by a large colour spot if within a province. (In a few examples where provinces are small or form narrow belts, it became necessary to use a large deposit symbol to combine the function of the normal small symbol on the province boundary which indicates the properties of the province, and the colour spot which indicates the site of the large deposit.) Lower limits to the size of individual deposits that would be shown were selected to weed out insignificant but common mineralization, such as small iron skarns. This left the problem of isolated minor deposits that are metallogenically interesting or not yet properly explored; these are shown by small spots

TABLE 1

COMMODITY		SIZE LIMITS		
		Lower limit of major deposit	Lower limit of small deposit	Relation to large size
		tons	tons	%
Antimony Sb.		2 500	25	1
Aluminium		750 000	4 000	0.5
Asbestos		80 000	400	0.5
Barium	($BaSO_4$)	80 000	400	0.5
Beryllium	(BeO)	50 (e.g. 450 tons beryl.)	2 ton beryl.	0.5
Chromium		425 000	2 300	0.5
Cobalt		1 750	10	0.57
Columbium	(R_2O_5)	combined with tantalum		
Copper		150 000	1 000	0.7
Fluorite	(CaF_2)	50 000	500	1
Gold		1 500 000 (oz)	10 000 (oz)	0.7
Iron		40 000 000	500 000 Fe in 50%+ ore	1.2
Lead		68 000	350	0.5
Lithium	(Li_2O)	(16 000 Lepidolite (10 000 amblygonite (20 000 petalite (12 000 spodumene	Prod.	-
Magnesite		4 600 000	23 000	0.5
Manganese		500 000	2 000	0.4
Mercury		500 000	Prod.	
Molybdenum		1 750	10	0.5
Nickel		20 000	500	2.5
Phosphate	(P_2O_5)	25 000 000	120 000	0.5

Table 1 (continued)

COMMODITY		SIZE LIMITS		
		Lower limit of major deposit	Lower limit of small deposit	Relation to large size
		tons	tons	%
Platinum		25 000 oz	120 oz	0.5
Osmiridium		5 000 oz	25 oz	0.5
Silver		13 000 000 oz	100 000 oz	0.7
Sulphur		500 000	2 500	0.5
Tantalum	(R_2O_5)	50 (200 ton conc.)	1 ton conc.	0.5
Thorium	(ThO_2)	310	Prod.	-
Tin		10 000	50	0.5
Titanium	(TiO_2)	120 000	600	0.5
Tungsten	(WO_3)	1 000	5	0.5
Uranium	(U_3O_8)	750	5	0.5
Zinc		65 000	320	0.5
Zirconium	(ZrO_2)	10 000	50	0.5

of colour. Neither small nor minor deposits within provinces are shown; the areas where such deposits are concentrated are indicated by hatching. The figures used for the division into major, small, and minor deposits are given in Table 1.

Chemistry

Metals were grouped according to their most common association. Nothing short of one colour to each metal seems to be ideal; but the breakdown used is the best compromise between map design and possible groupings.

The value of showing the chemical composition of the deposits seems marginal at the scale of the map. Moreover our knowledge of the chemistry of deposits is very patchy for several inter-related reasons.

The long stability, with associated peneplanation, of the present craton from the late Mesozoic onward has led to the extensive oxidation of sulphide orebodies, commonly to depths of 50 to 100 m. In some orebodies an initially very low-grade sulphide deposit has produced a small but rich body of supergene ore and the literature records that many bodies were mined only in the oxidized zone, or abandoned because of low grade below the water table and in many cases the composition below the water table is only hinted or not recorded.

For copper, oxidized deposits of which were particularly important, the composition of individual deposits is shown as recorded in the literature and provinces were drawn according to the overall chemistry recorded. Many gold mines proved economic above the water table, where the oxidation of pyrite from complex gold-pyrite primary ore (found below the water table) freed the gold for easy recovery. Overall, pyrite tends to be unrecorded in the literature, and its absence from the chemistry shown for provinces and deposits is a reflection of this bias in the literature, as well as ofthe ubiquity of pyrite in base-metal sulphide deposits.

Again the European legend allowed for the showing of areal zones of oxidation, but because oxidation is ubiquitous in Australia this has not been done on the Australian map.

Metallogenic Province

The concept of metallogenic province has evoked much discussion and several definitions have been proposed. The Working Group for the Metallogenic Lexicon under the direction of E.T. Shatalov proposed:

'Metallogenic Province. It is a vast folded or platform section of the earth's crust of a definite type and of the period of the tectonomagmatic and metallogenic development with the associations of the mineral deposits characteristic of the latter (with a definite type of mineralization - a complex of basic, secondary and sporadic metals and minerals). The metallogenic provinces can be formed during one tectono-magmatic cycle or they can be bicyclic or polycyclic ones'.

'The metallogenic provinces cover the areas of hundreds of thousands to the first millions of square kilometres within which ore-bearing areas of a smaller order - metallogenic regions or zones can be distinguished. Due to this, the metallogenic provinces cover groups of ore-bearing areas with various parageneses of mineralization, and they are polyparagenetic.'

This definition fits into a hierarchical classification of units by increasing complexity and areal extent.

A somewhat similar view is given by N.E. Petrascheck (1965, Econ. Geol. 70, p. 1620):

'A metallogenic province is the entity of mineral deposits that formed during a tectonic-metallogenic epoch within a major tectonic unit and which are characterized by related mineral composition, form of the deposit, and intensity of mineralization.'

In the compilation of the Australian map no one definition has suited the problems encountered. Some ore deposits have been studied in their regional setting, but most have not. The main problem was the recognition of common factors among deposits, and the emphasis has been placed on common genetic factors. Provinces have been delineated by the grouping of adjacent deposits with apparently common genesis (as far as could be judged from the literature). In European terms each such province has a characteristic and unique metallotect or overall genetic environment. The number of factors recognized in the metallotect varies from province to province; some provinces were long ago recognized and are well defined in the literature, but others are either given passing recognition or are introduced in this map. Some 'provinces' in the literature have proved to cut across tectonic boundaries, or have been shown by isotopic dating to be invalid. Age determinations on the other hand have helped to show that deposits form complex provinces.

Monoparagenetic and polyparagenetic provinces in the European sense have not been distinguished. Some provinces are definite monoparagenetic units: for example the Hamersley Iron Province or the phosphate province in the northwest of Queensland. The most complex polyparagenetic provinces, shown as single provinces in the main map, are the zoned tin-tungsten-molybdenum-copper-lead-zinc provinces. The map is biased towards the common broad or regional genetic factors, not the common metal, in a province. Evaporite sequences within platform sequences are indicated only where drill holes have intersected halides; usually sodium chloride only has been present.

The Role of Age Determinations

Isotopic age determinations, mainly carried out at the Australian National University by a combined University-BMR team, have helped to fit stratigraphic relationships observed in the Precambrian into an absolute time scale, and thus serve as the underpinning for the tectonic relationships; they have also helped to evaluate the sequence of Phanerozoic events, particularly igneous activity. Ore deposits, the spectacularly large ones again apart, have received little attention as yet; reliance has been placed on observable field relationships with nearby dated events. It must be conceded that considerable doubt has been thrown on the validity of recorded values, the relationship between events observed in the field and those isotopically recorded on the rocks, and the wisdom of founding tectonic systems on very limited dating.

TECTONIC FRAMEWORK OF AUSTRALIA

As pointed out in the previous chapter, the tectonic units on this map are classified by the relationship between Platform Covers and Orogenic Provinces.

Four spreads of platform cover are recognized: the first formed in the Lower Proterozoic; the second in the Carpentarian or Middle Proterozoic; the third in the Adelaidean and early Palaeozoic, i.e., late Proterozoic to mid-Devonian times; and the fourth began in the Permian and continued its development to the present. These are called, in order, the West Australian, North Australian, Central Australian, and Trans-Australian Platform Covers.

From the relationship of these to the orogenic domains which they overlie, five Orogenic Provinces are outlined.

These are:

The West Australian Orogenic Province, spanning from about 3 100 m.y. to about 2 400 m.y., i.e., mainly Archaean fold belts and shields.

The North Australian Orogenic Province, containing orogenic domains and their transitional domains formed between about 2 200 m.y. and 1 900 m.y.

The Central Australian Orogenic Province, containing rocks deformed between about 1 800 m.y. and 1 200 m.y.

The East Australian Orogenic Province, which contains rocks formed and deformed between the Cambriwn and the Triassic.

The New Guinea Orogenic Province, containing rocks formed from the Cretaceous to the present, including rocks geosynclinal in facies but relatively undeformed. It is assumed that these constitute an evolving orogenic region.

In addition to these groupings there are four unassigned Precambrian orogenic domains. These are all metamorphic complexes; age determinations from metamorphic and igneous rocks within each indicate a wide time interval between the orogenesis and observed overlying Platform Covers. There are also two late Proterozoic orogenic domains, one in Western Australia overlain by Trans-Australian Platform Cover, and one in Tasmania overlain by 'geosynclinal' deposits during the development of the East Australian Orogenic Province. Both are thought to have deformation histories confined to the late Proterozoic (see Figs 2 and 3).

METALLOGENIC EPOCHS

The term 'metallogenic epoch' as used in the literature generally refers to a limited time span during which the mineral deposits of a given area were formed. Attempts have been made to assess epochs in the past by Browne (1949), Jones (1953), Hills (1965), and Webb (1969), mainly for eastern Australia, where the overlap of tectonic events is extremely complex, so that several similar patterns of mineralization have been formed by overlapping tectonic evolutionary patterns. No attempt is intended with in these to define or redefine metallo g e n ic epochs in Australia.

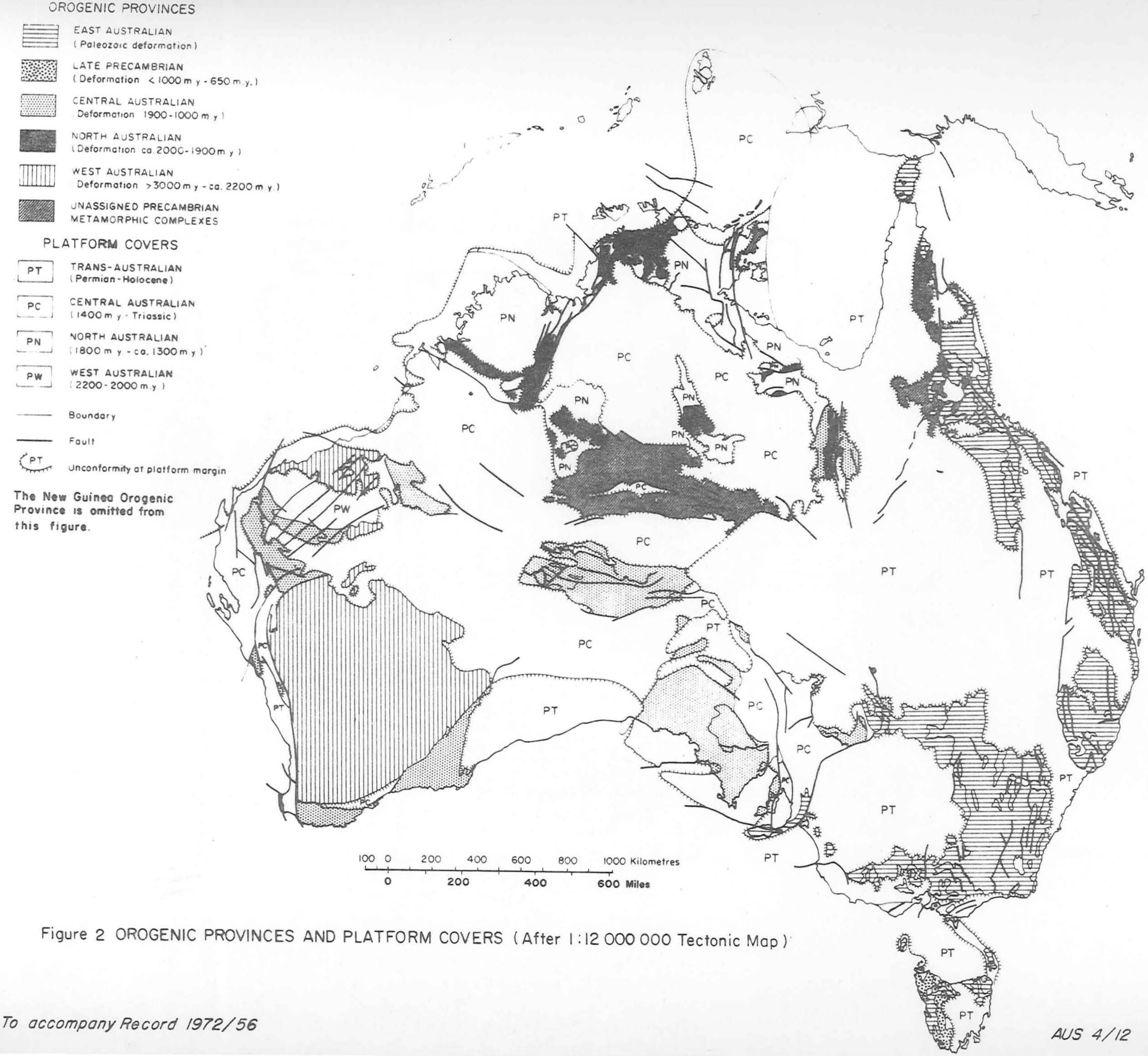

Figure 2 OROGENIC PROVINCES AND PLATFORM COVERS (After 1:12 000 000 Tectonic Map)

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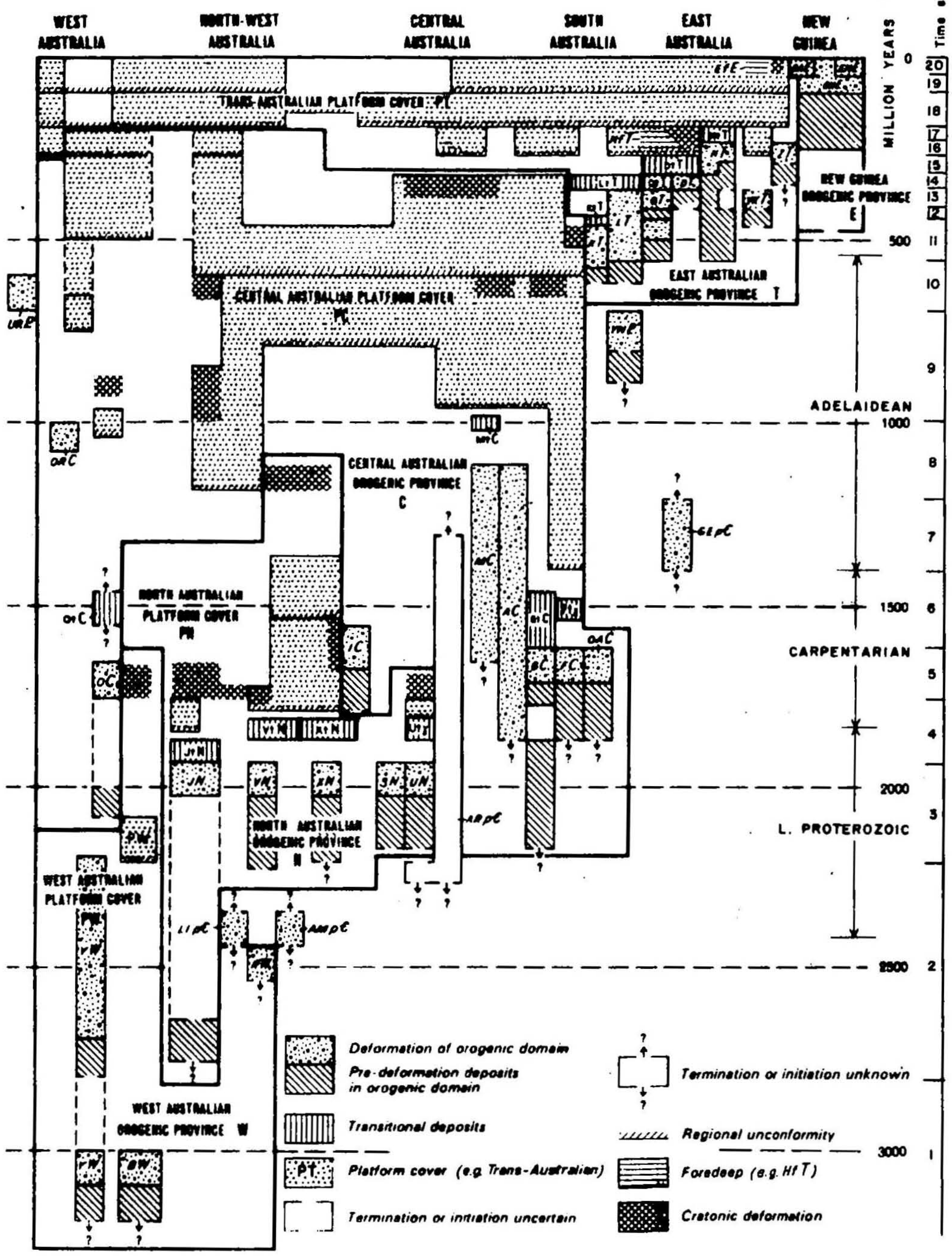

FIG. 3 Diagrammatic and geographical relationship of tectonic units (after Tectonic Map of Australia and New Guinea)

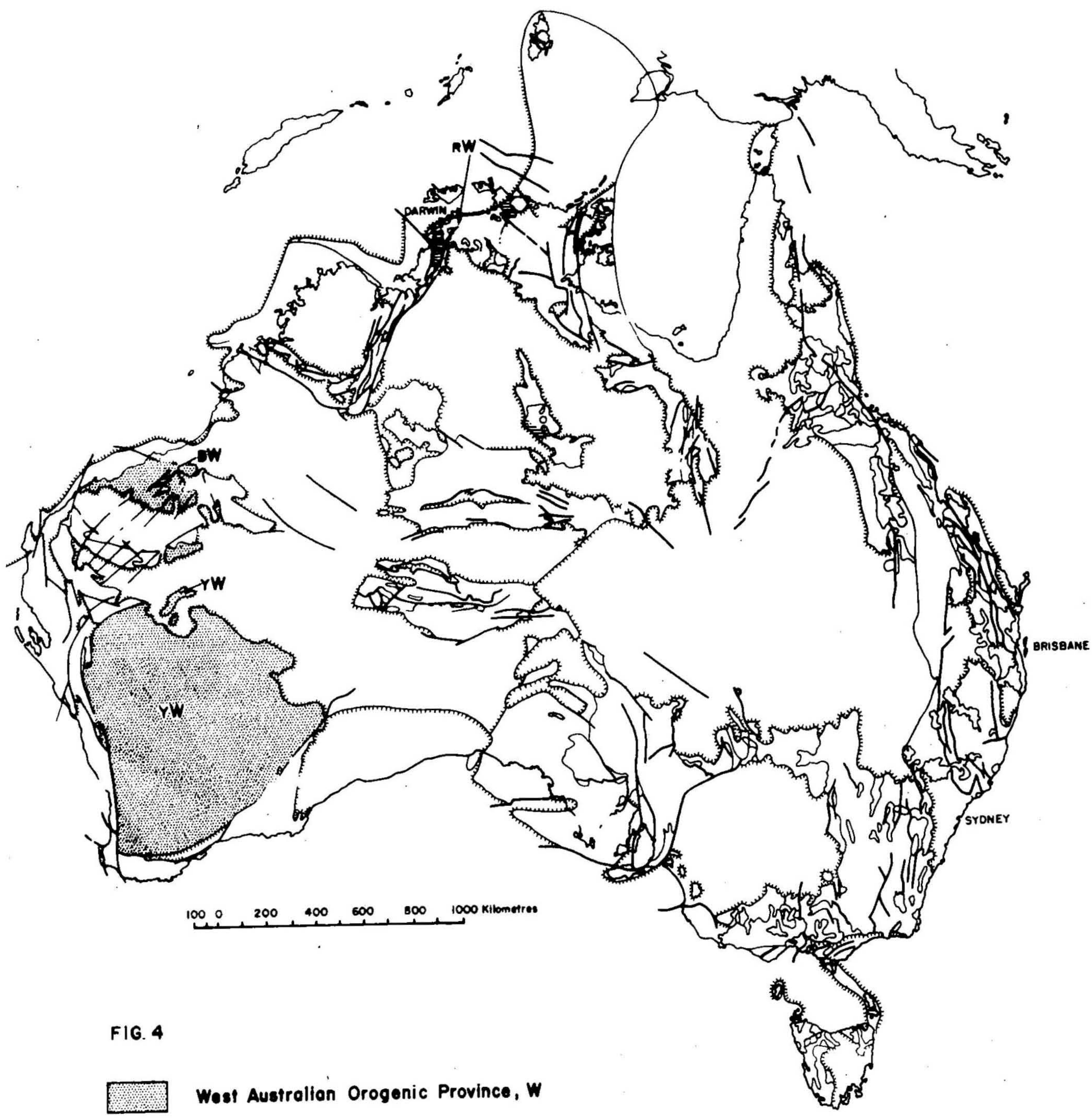

FIG. 4

West Australian Orogenic Province, W

BW Pilbara

YW Yilgarn

RW Rum Jungle

Concealed and probable equivalents

To accompany Record 1972/56

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There is both a pattern of tectonic evolution and a pattern that accompanies it of metallogenic evolution within any given region. During the early development of geosynclinal regions the extensive basic and intermediate volcanic activity with associated black shales is accompanied by the deposition of base metals. It appears that these are mobilized during faulting and metamorphism and syntectonic granite intrusions. Gold may be emplaced at this point, but in general gold seems to be introduced late in the orogenic cycle, commonly during the transitional phase, where both gold and antimony mineralization occur. Late-phase granites are generally associated with a tin-copper-lead-zinc spectrum of mineralization; ultra-basic intrusions generally tend to be associated with the presence of manganese, of copper, and of chrome; and in Australia a halo of mercury sometimes also occurs. Platform cover mineralization includes iron, aluminium, and reconcentrated detrital minerals.

Also, a pattern of metal distribution can be followed from platform cover through the mobile edge of the craton and the edge of the geosynclinal zoneinto the deep water 'geosynclinal facies' zone. The most marked features of this distribution appear to be an assemblage of tin, copper, molybdenum, and tungsten along the edge of the craton and the adjacent edge of the mobile zone, and a 'deep water' facies association with gold-antimony and manganese mineralization.

Although both patterns appear to exist in eastern Australia, they may be incidental to the pattern in time of types of granite, rather than indicating a migration of mineralization from craton to mobile zone.

WEST AUSTRALIAN OROGENIC PROVINCE

The West Australian Orogenic Province is the oldest part of the Australian continental crust. The greatest ages determined - in the vicinity of 3 050 m.y. (Arriens, 1971) - are from granites, implying a sedimentary history extending back even beyond this. The two main units, the Pilbara and Yilgarn Blocks, have lithological characteristics marking them apart from all younger orogenic domains. They consist of belts of low-grade metasediments and meta-acid and basic volcanics in predominantly gneiss and granite terranes with no visible base to the 'sedimentary' piles, a feature shared by other Archaean regions of the world.

Wilson (1971) suggested that Archaean terranes in general have a distinctive metallogeny; this certainly appears true for the nickel-copper and copper-zinc associations toward which exploration is being directed at present. However, although the gold mineralizations in the Pilbara and

Yilgarn Blocks have features in common, they seem to have little resemblance to oversea types. Tin mineralization is common in the Pilbara, but only one worthwhile producing area has been discovered in the Yilgarn Block; tin mineralizationi is mostly of the pegmatitic type of Sainsbury & Hamilton (1967), although it is difficult to classify Greenbushes within that scheme. Antimony appears to be confined to the older parts of the Province - the Pilbara Block and the northwest of the Yilgarn Block.

The only folded rocks outside the Pilbara and Yilgarn Blocks definitely assigned to the West Australian Orogenic Province are in the Rum Jungle Block, basement to the Pine Creek Geosyncline in the north of the Northern Territory. However, equivalents of the West Australian Orogenic Province may well form basement to a large part of the Australian continent - such basement has been recorded beneath the Tennant Creek Block (Crohn & Oldershaw, 1965), and Thomson (1969) regards parts of the Gawler Block as equivalent in sedimentary style and time of deposition to the West Australian Platform. The Arunta Complex in Central Australia may extend back into the Archaean, on the basis of a single age determination of 2 400 m.y. (Compston and Arriens op. cit.)

THE PILBARA BLOCK

All the metasedimentary rocks of the Pilbara Block are assigned to the Roebourne Group (Ryan, 1964). Parts of the sequence have been mapped out into units in limited areas, but the pattern of deposition or stratigraphy of the block as a whole has not yet been studied in detail. Originally it was thought that there were two distinct sequences, an older 'Warrawoona Series', mainly a basic volcanic sequence with some interbedded banded iron formation, and a younger, mainly clastic, 'Mosquito Creek Series'; but these have more recently been shown to be lateral equivalents of each other within the Roebourne Group. Locally the regional metamorphic grade reaches the amphibolite level, but away from the granites the grade is generally low. More than half the area of the block is occupied by granites with gneissic and granitized margins of country rock. There are small masses of ultrabasic rocks which have been mapped mainly in the northwest. The block is cut by quartz veins up to 10 km long and dolerite dykes ranging up to 100 km; the latter postdate the inception of platform conditions over the block. (Ryan, 1966).

The Pilbara Block has been stable since 2 900 m.y., a date obtained at Wodgina from a late-stage undeformed pegmatite. Granites in the block yield dates of 3 050 ± 180 m.y. (Arriens, 1971).

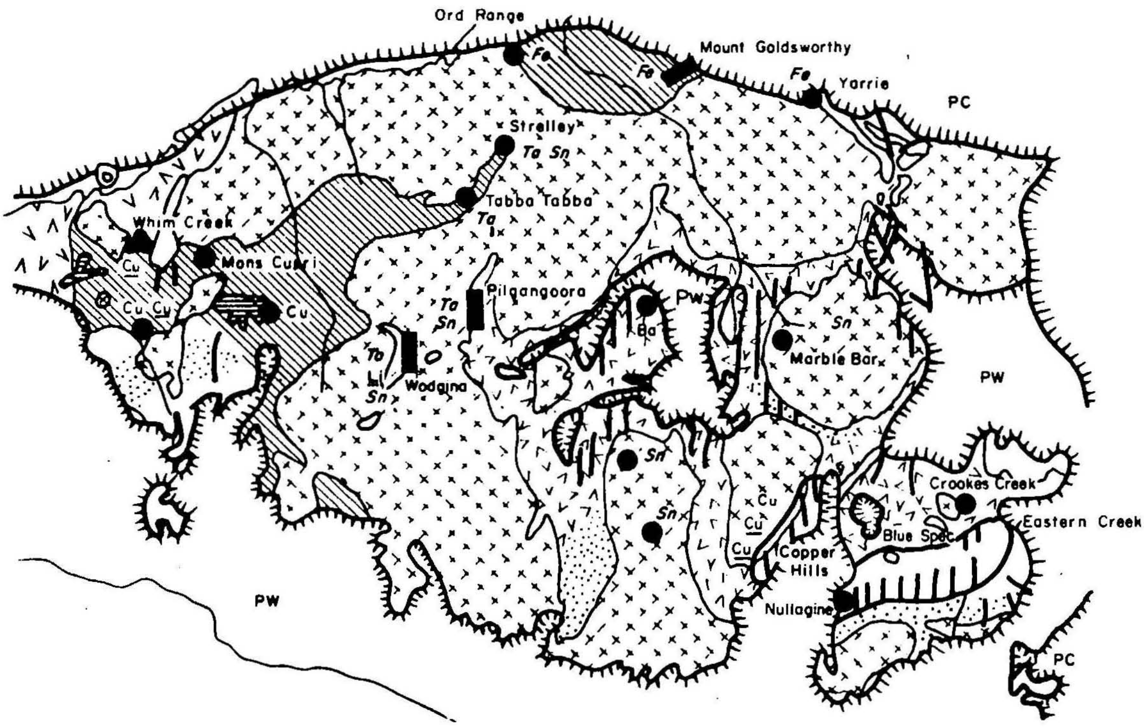

FIG. 5 PILBARA BLOCK (BW)

Platform boundary

Granite

Basic volcanics

Other BW

Regional metamorphism

Early Proterozoic basic intrusives

Gold bearing areas (except Copper Hills, which is copper bearing)

Other symbols as on metallogenic map

0 50 150 200 km

0 50 100 miles

Banded iron formations within the sedimentary sequence have been folded, with some thickening at the crests and keels. Where the beds dip at near-vertical angles, supergene processes have leached the silica content, leaving bodies that are mainly iron oxide; these bodies are resistant to weathering and form low hills of high-grade iron ore standing above the main land surface, as at Mt Goldsworthy (Brandt, 1965). Erosion by mechanical and chemical processes has produced subjacent scree and limonitic deposits from the original beds during platform deposition lapping onto the Pilbara Block at intervals from the Proterozoic to the Holocene.

Gold occurs in quartz veins and in association with antimony. The low-temperature quartz-gold veins were attributed to concealed intrusions of granite, but the close association observed between gold deposits and basic volcanics suggests that the gold may have been mobilized from the volcanics during deformation and deposited in suitable structural sites nearby.

Antimony in mineable concentrations occurs in only two areas. East of Nullagine a line of lodes of gold-stibnite in quartz extends from Blue Spec to Billjim (Noldart & Wyatt, 1962; Finucane, 1939; Finucane & Telford, 1939). Very little is known about its relationship to the regional geology; the line crosses the axial trend of folding at a low angle and therefore must transgress the bedding; there are no nearby intrusions. Cervantite occurs in outcrop at Blue Spec. East and north of Whim Creek, gold-antimony deposits at Mullina, Peewah, and Mount Negri were mined chiefly for their gold content. (Production of antimony in Western Australia was not recorded before 1916 and only spasmodically after then - these deposits were mined in the late 19th century).

Small copper deposits, confined to the metavolcanics, were mined only if the ore was sufficiently rich to repay the cost of transport. Recently, re-examination of Whim Creek has shown a low-grade deposit of a size to warrant large-scale mining; and Mons Cupri nearby has been shown to be a low-grade deposit in a volcanic plug. Both contain lead, zinc, and silver as well as copper. Reappraisal of other deposits such as those in the Kelly's Copper Hills line of lodes may show that the small high-grade bodies that were mined are parts of larger low-grade deposits. All the copper deposits appear to be hypogene.

A barite lode about 40 km west of Marble Bar at Breen's Camp was recorded by Simpson (1948) as one of the largest veins of barite known in Western Australia; but no evaluation of size, grade, or accessory minerals has been published. Simpson also records other occurrences of barite within the Pilbara Block, some as accessory minerals, others as veins or detrital boulders.

The basement that crops out as hills on the southern margin of the West Australian Platform Cover west of Jiggalong Mission is regarded as part of the Pilbara domain - it contains, besides minor gold and barite, the only mined deposit of chromite in the West Australian Orogenic Province (Matheson, 1953). The deposit consists of an interlocking network of lenticular veins over about 2½ km^2 and associated with small meta-ultrabasic dykes.

The granites carry little mineralization except in pegmatites.

Pegmatitic deposits are an important feature of the block. Three groupings may be made:

First are tantalum - niobium-bearing pegmatites, which are characteristic of meta-volcanic terranes. The pegmatite dykes are large crosscutting structures each about 600 m long, carrying tin, lithium, beryllium, cerium, and rare earths as well as tantalum. Although specimens have been collected for identification, no systematic study of paragenesis has been made as yet; Ellis (1950) gives a comprehensive account of the field relationships of the dyke at Wodgina, the main producing centre, the broad distribution of the tantalite within the dyke, and the minerals present.

The second group produces only tin, from eluvial detritus; these bodies are in granite.

Ellis (1967) considers that there is a third group, located in granitic terranes; this group produces beryl, with accessory columbite and lepidolite. They are much smaller bodies than those of the first group; beryl is garnered by hand picking.

Quartz reefs in metavolcanics immediately adjacent to the margin of a granite pluton at Cookes Creek yielded small quantities of both wolframite and scheelite. Simpson (op. cit.) records accessory tungsten-bearing minerals from deposits of other metals in the Pilbara Block, but these appear to be small.

YILGARN BLOCK

The Yilgarn Block is a complex unit; the full history of its geological development is far from unravelled as yet. Age determinations span the interval from 3 100 m.y. to 2 000 m.y. The oldest ages lie close to the western margin. The Eastern Goldfields (Kalgoorlie district) give ages ranging from 2 700+ m.y. to 2 600+ m.y., while granites south of Meekatharra give ages of 2 580 and 2 597 m.y. (Compston & Arriens, 1968;

Arriens, 1971; Turek & Compston, 1971). Parts of the margins adjoin two later, highly mobile zones, the Ophthalmia-Gascoyne Block in the north and the Albany-Fraser Belt in the south and east. These must have imprinted some structures over the adjacent parts of the Yilgarn Block and probably incorporate reworked rocks from the Block. The western margin is the Darling Fault, a major structure on which movement has taken place several times since the late Proterozoic and possibly earlier, but along which structures have been imprinted only over a very narrow marginal zone.

The rocks making up the block may be described in two broad categories: firstly, very low-grade metamorphic rocks formed from ultrabasic, basic, and acid volcanics, related intrusives, and internally derived clastics in belts sharply limited by later granite intrusion; secondly, intrusive granites, gneisses, and other high-grade metamorphic rocks. The second category, because of its low economic interest, has been less studied than the first. Detailed mapping of the Block is considerably hampered by deep weathering, poor exposure, and widely developed Tertiary to Holocene soils, colluvium, and alluvium.

The first category contains what are generally called the 'Greenstone Belts' and 'Whitestones' in the literature. At the time of writing, four 1:250 000 sheets, Boorabbin (1963), Widgiemooltha (1966), Kalgoorlie (1970), and Kurnalpi (1971) were published, and Menzies and Norseman had been mapped, but not in time to be considered in this account.

Eastern Goldfields

The most recent mapping, the Kurnalpi Sheet area (Williams, 1970, unpubl.), has allowed the recognition of a framework that may extend throughout the continuous belt of low-grade rocks of the Eastern Goldfields, and with reservations and limitations may also extend to the other 'greenstone - whitestone' belts of the Yilgarn Block. Williams has recognized an evolutionary pattern made up of three similar cycles, two of two phases and the third containing only the initial phase:

The first phase essentially is a basic to ultrabasic association of volcanics and shallow intrusions with some thinly bedded local clastics (mainly cherts) and carbonaceous and pyritic shales, dolomitic shales and greywackes. The second phase is made up of acid volcanic complexes and clastics derived from these and the earlier phase(s). In the succeeding cycles the first phase contains progressively less ultrabasics, less volcanics and more fine-grained clastics and the second phase less volcanics and more coarse clastics.

Nowhere has evidence been noted for land during the period of sedimentation beyond the present boundaries of the belt of low-grade metasediments running north through the Kalgoorlie district.

The mining history of the belt has been dominated by gold, of which only low-grade ores now remain, and especially by the concentration in the Kalgoorlie - Mount Fimiston - Great Boulder area. Williams (op. cit.) notes, like previous workers, that gold mineralization is confined to non 'granite' regions, and observes that although gold mineralization favours igneous host rocks, all types of rock have contained gold lodes. He also points out a spatial and therefore supposedly genetic link between acid dykes and sills and gold mineralizationnot previously realized. In the chief producing area, the Golden Mile at Kalgoorlie, free gold and gold tellurides occur in pyritic lodes along shears and fractures. A little production has come from gold-quartz lodes in the Kalgoorlie district which contain pyrite but no tellurides (Woodall, 1965). Total production is about 35 million oz troy.

The Sons of Gwalia Mine, some 190 km north of Kalgoorlie, produced 2½ million oz troy from lodes in a zone of intense shearing in an epidiorite. The lodes are in quartz veins and lenses within the schistose zone, and highest gold values were found in drag folds; free gold, pyrite, chalcopyrite, pyrrhotite, some arsenopyrite, and abundant ankerite are present in the lodes (Finucane, 1965).

Some 160 km south of Kalgoorlie several reefs in the vicinity of Norseman have produced 2½ million oz troy of gold. Two types of lode are present: gold-quartz bodies with minor sulphides and tellurides, and quartz-sulphide lodes which occur as replacements of brecciated or folded structures within jaspilites (Hall & Brekker, 1965). Sulphur has been obtained by mining a pyrite orebody near Norseman which consists of massive lenticular pyrite replacements of siliceous metasediments and meta-agglomerates in shear zones (Ellis, 1953).

The major interest in this area at present is the nickel mineralization, the potential of which is still being assessed. Reports indicate that some of the deposits also carry significant copper values; Kambalda ore contains recoverable platinum and palladium; arsenic is present in the lode at Mount Martin, and Scotia is reported to contain economic cobalt. Williams notes the close association between magnesium-rich ultrabasic rocks and nickel deposits, and the limitation of known nickel occurrences (with the exception of Mount Windarra) to a mobile median trough through the Kalgoorlie region in which cherts but not banded iron formation are present (Williams, 1971). At present the best explored deposits are those surrounding the Kambalda dome. They lie at or near the base of an ultrabasic sheet and appear to be comagmatic with the intrusion, but the ore shoots also lie in steeply plunging folds (Woodall & Travis, 1969). All except one of the nickel deposits known to date lie within ultrabasic sill, the exception being that at Carr Boyd Rocks, where the nickel sulphide bodies are in pipes. Some nickel production will probably come from lateritic material developed over nickeliferous ultrabasics, which themselves may have too low a nickel content for direct mining.

The only copper producer in the Yilgarn Block is at Eulamina, east of Leonora; this was also mined for the sulphur content of the associated pyrite. Gold, zinc, and cobalt were also present. The orebody is at the contact between andesitic pillow lavas and metasediments (Low, 1963). A somewhat similar metal association occurred at Murrin Murrin, a little to the northeast, but the copper production was lower and the gold yield more important.

Minor copper mineralization is known in three gold-mining localities within the Kurnalpi Sheet area (Williams, 1970, unpubl.) two in basic igneous rocks, and one in acid pyroclastics. Nowhere in the Yilgarn Block has the copper-zinc association characteristic of other Archaean terranes been discovered.

The western margin of the Kalgoorlie low-grade metamorphic belt from north of Coolgardie southwards to Widgiemooltha contains a zone of lithium-bearing pegmatites, the best known of which is at Londonderry, south of Coolgardie (Sofoulis, 1963). This also contains beryllium and some tantalum. A large but unexploited deposit is currently under study at Mount Marion between Kambalda and Coolgardie.

Small quantities of scheelite have been reported from gold mining areas in a zone from just south of Coolgardie to Higginsville.

Application of theories developed during mapping in the Kalgoorlie region to the other 'greenstone - whitestone' belts of the Yilgarn Block will no doubt cause existing published material to be considerably modified in the future. The distribution of metals in the Kalgoorlie region seems to serve as a model for the Yilgarn Block.

The Ravensthorpe Region

The Ravensthorpe region, south-southwest of Kalgoorlie, was reported on by Sofoulis (1958). He noted the presence of serpentinites, basic volcanic rocks, a 'whitestone phase' which is mainly argillaceous, and graphitic schists, with some dolomitic rocks. In effect these constitute one cycle as defined by Williams (1970), and the low proportion of ultrabasics (2 lenses) together with the absence of acid volcanics and conglomerates suggests that if any correlation with the Kalgoorlie cycles is to be made it will be with the second or the incomplete third cycle. In addition the Ravensthorpe sequence has a granite core which Sofoulis describes as a granitization of the sedimentary pile, a feature not recognized in the Kalgoorlie region. The zonal distribution of all the metalliferous deposits is attributed to the granitization front. The mineralization is mainly gold-copper, with some silver; no zinc is recorded, and individual deposits are small. Many pegmatites are known, but only two carried sufficient minerals of the beryllium-lithium-tantalum suite to be of interest. Magnesite deposits of the region are a result of weathering of the ultrabasics, and discovery of a nickel deposit was reported early in 1971.

The Southern Cross Region

The low-grade belt through Southern Cross west of Kalgoorlie has been described in the 'greenstone - whitestone' format (Clappison & Zani, 1953). The greenstone succession is typical of the basic volcanic phase as described by Williams, containing basic and ultrabasic lavas and tuffs with interbedded banded iron formation. The 'whitestones' are described as metamorphosed sediments, acid volcanics apparently not being present. Gold deposits (with minor tungsten at Westonia) were confined to the 'greenstones'. Lodes were quartz replacements either in tuffs or in banded iron formation adjacent to intersections with quartz veins. The ore was sulphide at depth. Concentrations were related to flat-pitching fold structures.

Northern Yilgarn Block

The rocks in the vicinity of the Big Bell Mine at Day Dawn, 100 km southwest of Meekatharra, have been metamorphosed to biotite-garnet and quartz-muscovite schists; the latter is host rock for the ore (Staff, Big Bell Mines Ltd, 1953). The mine yielded gold and silver in a ratio of 2.3:1 from pyritic sulphide ore also carrying some arsenic, copper, and antimony. The Hill 50 Mine to the south is more like those of the Kalgoorlie region in that feldspar porphyry dykes which antedate the ore are present with the 'greenstone' and banded iron formation of the country rocks.

At Wiluna basic lavas and intrusives are present (Edwards, 1953), but no acid intrusives, although dacitic flows form part of the depositional sequence. Large quantities of arsenic were contained in the orebodies, one of which also contained mineable quantities of antimony.

Iron Orebodies

Although banded iron formations are common throughout the basic volcanic areas, and are commonly the loci of gold deposition in gold mining areas, they themselves have become economic under favourable circumstances: during regional folding, banded iron formations tend to thicken at fold crests, so that where the pitch of the fold is near vertical, supergene enrichment during the prolonged evolution of the current land surface has produced iron ore (hematite and limonite) bodies of sufficiently high grade and size for mining operations. Such lodes often stand 100 m or so above the surrounding plains and the enrichment processes continue some distance below plain level (Connolly, 1959). Little investigation below plain level is recorded; Koolyanobbing (northeast of Southern Cross) at depth consists of bands of magnetite with pyrite (Ellis, 1958), and Mount Cauden (south of Southern Cross) consists at depth of bands of magnetite, siderite, massive pyrrhotite, and ferrosilicates (Macleod, 1965). The Robinson Ranges contain banded iron formations which have been up-graded by secondary deposition (Macleod, in press).

Granites and gneisses of the Yilgarn Block

The major part of the Yilgarn Block is a complex of granites, gneisses, and high-grade metamorphics which appear in part to be metamorphosed rocks similar to those in the low-grade belts. Intrusive granites, including granodiorites and tonalites, have been mapped on the Kurnalpi Sheet area; and as noted earlier, all contacts with the 'greenstone - whitestone' belts and the granites or gneisses are intrusive and occasionally granitized. (It seems that much of the region called 'granites and gneisses' on the face of the map is granite alone, but the distribution and percentage of each is not known. Tomich (1964) in discussion of the bauxite province in the west close to the Darling Fault, states that the amount of bauxite depends directly on the rock type, implying a range of chemical types, but much of this region is shown as granite on available large scale maps of the area. The 'Central Wheat Belts' region contains a variety of high-grade metamorphic rocks, which Wilson (1971) equates chemically with some of the ultrabasics of the Kalgoorlie region; but again large-scale maps show this area as mainly granite.)

The only mineral deposit specifically associated with granite is the small low-grade Mount Mulgine tungsten deposit (Matheson, 1944).

The tin-tantalum alluvial concentrations at Greenbushes (Ellis, 1953) originated from the erosion of veins in quartz-muscovite schists. Only some veins were mineable; most of the yield is from residual deposits, mainly in consolidated alluvium.

Peak Hill District

A sedimentary sequence containing banded iron formations has been mapped in the Peak Hill district (Macleod, 1972). It appears to be a mainly clastic sequence with a mildly metamorphosed base. The gold deposits of Peak Hill occur in quartz veins occupying shear zones in the metasediments, and at Horseshoe the lodes occurred in deeply decomposed and ferruginized sediments.*

THE WEST AUSTRALIAN OROGENIC PROVINCE IN NORTH AUSTRALIA

The problem of dating adequately the supposed Archaean of North Australia is discussed in detail by Dunn (1971). Definite Archaean includes the Rum Jungle Complex and other basement exposed in windows beneath the Pine Creek Geosyncline, and basement detected by drilling beneath the Tennant Creek Block (Crohn & Oldershaw, 1965). Other blocks listed by Dunn as apparent Archaean are classified as unassigned orogenic domains - chiefly because the classification used here is based not on time equivalents but on relationship between orogenic domains and platform covers.

The Rum Jungle Complex (Rhodes, 1965), part of the Rum Jungle Block which forms basement to the Pine Creek geosynclinal deposition, is the only part of the West Australian Orogenic Province in Northern Australia to have proven metallogenic significance. It is composed of schist, gneiss, and granite, which formed a basement high during deposition of the overlying Pine Creek Geosyncline, to which it supplied material. However, since then it has been domed to give flank dips of 30° to 70° in the overlying sediments and Rhodes points out the apparent similarity to one of the several types of mantled gneiss domes known in Europe. Rocks of the Rum Jungle Complex are richer in uranium and thorium than normal granites (Heier & Rhodes, 1966) and may have provided the uranium concentrated in sediments of the Pine Creek Geosyncline overlying the dome. No mineralization is known within the Complex itself.

Recent discoveries of uranium mineralization east of Darwin appear to have similar relationships with other outcrops of the Rum Jungle Block.

* The setting of Horseshoe, Peak Hill, and the Robinson Range iron province shown on the face of the map was consistent with available information. MacLeod's work indicates that the map is wrong, but was not available until after it was drawn. See Fig. 6

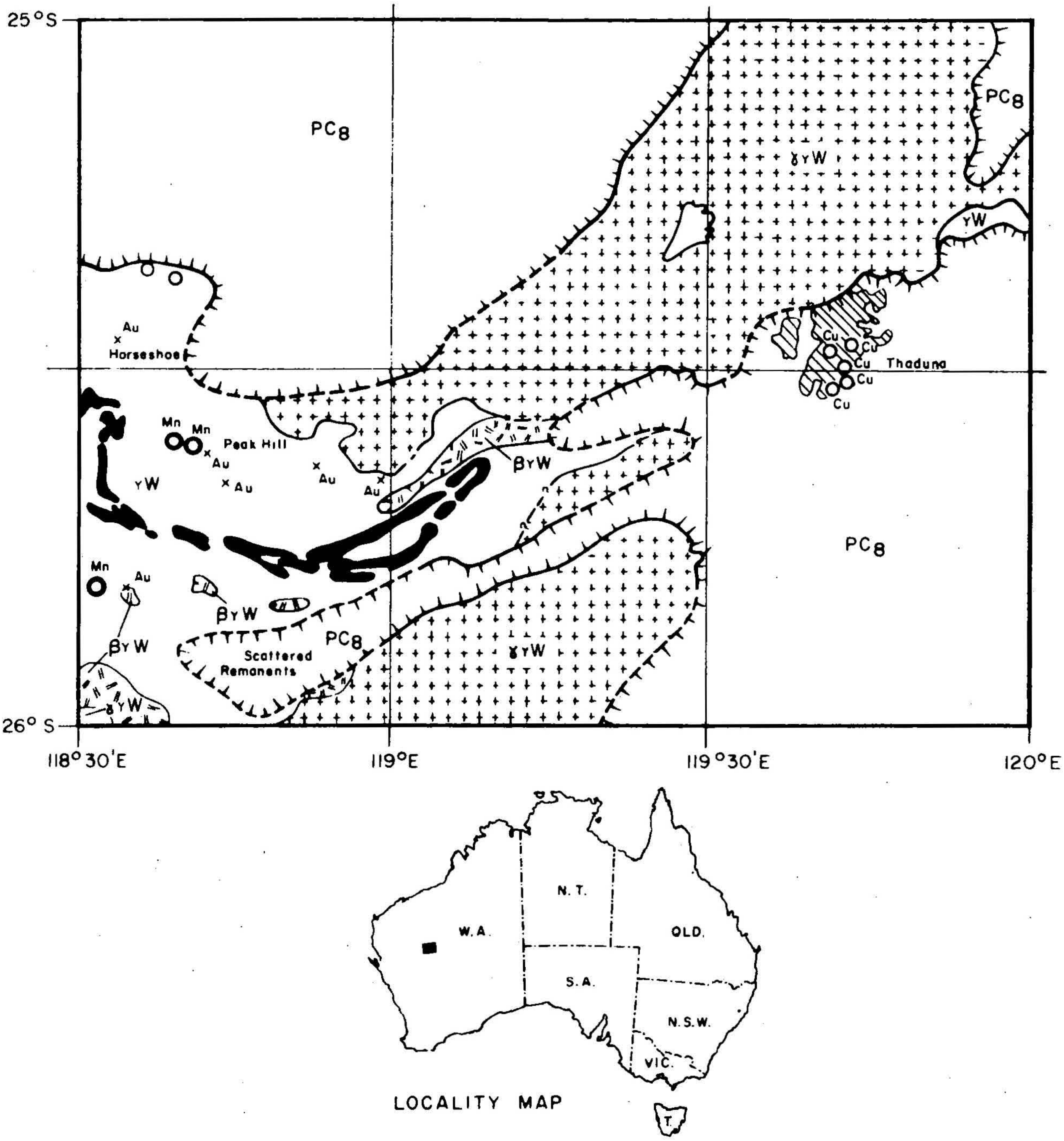

FIG. 6 **PEAK HILL 1:250,000 SHEET AREA AT 1:1,000,000 (AFTER MACLEOD, 1972, IN PRESS)**

PC8 — Central Australian Platform Cover (Bangemall Basin)
Thaduna Beds: greywacke, siltstone, tuff)

YW — West Australian Orogenic Province (Yilgarn Block)
γ Granite - tectonic role uncertain (? 2)
β Dolerite (metamorphosed ? 2)

Robinson Range Beds, (banded iron formation, shale)

Mn — Manganese
× Au — Gold
O Cu — Copper
?2 — Age as in metallogenic map

To accompany Record 1972/56 *G50/A8/2*

THE WEST AUSTRALIAN PLATFORM COVER

Deposition of the West Australian Platform Cover on a basement of West Australian Orogenic Province, specifically the Pilbara Block, began with basic volcanics. Trendall & Blockley (1970) outline the data on the age of the units making up the Platform Cover: the basal Fortescue Group gives an age of 2 200 m.y. on unsatisfactory material; the Hamersley Group contains volcanics with an age close to 2 000 m.y.; and the only reliable guide to the age of the Wyloo Group, the third and uppermost unit, is provided by later intrusions with an age of 1 700 m.y., although an unreliable age of 1 850 m.y. has been obtained on a siltstone.

Though the platform cover now laps the Pilbara Block on all margins except the northwest, and outliers rest on the block, the greatest thickness of sedimentation was in the south of the currently preserved cover in a downwarp with a west-northwest axis.

Early sedimentation was dominated by outpourings of volcanics, both pyroclastic and lava, some acid but the majority basic. These were followed by chemical sediments containing chert, dolomite, and banded iron formation, and then a return to more clastic sedimentation. It is thought that the iron in the banded iron formations had its source in the basalts at the base of the sequence. The platform was folded at about 1 700 m.y., most strongly in the southwest, adjacent to the Ophthalmia-Gascoyne domain, and diminishing northeasterly.

Isoclinal folding within the basin has produced structures within the banded iron formations that, during long periods of peneplanation and of leaching in the Phanerozoic and possibly earlier, have facilitated leaching of silica. Consequently very large bodies of near-pure hematite have formed in the Hamersley Ranges, such as those at Tom Price, Mount Whaleback, and Brockman (Macleod, 1966; Trendall & Blockey, 1970). During the Tertiary, iron-bearing run-off from this region precipitated goethite in swampy drainage basins flanking the ancestral Hamersley Ranges. Subsequent dissection has revealed blankets of goethite 10 - 30 m thick and several hundreds of square kilometres in extent. Several overlapping iron provinces may now be recognized: each of the primary banded iron formations forms a metallogenic province within the terms of the definition; the pockets of supergene enrichment are a superimposed province; and the dissected goethite deposits form a third. 'The Hamersley Iron Province' as used by Macleod (1966) and subsequently by other authors includes all three units. The banded iron formations and the area of supergene enrichment have been shown combined as a province on the map, with the boundary outlining the limits of the primary banded iron formation, and the hatching showing the main areas of supergene enrichment. The Tertiary(?) goethite-bearing province is shown separately.

Small copper and lead deposits occur in the northwest of the Hamersley Basin; they are structurally controlled and may have their source within the platform sediments or in the underlying basement; they lie northeast of the area of granite intrusion but may have been mobilized during the folding movements. A number of small lead deposits forming the Kooline Lead Field lie near the folded southwest margin of the platform. Aged at 1 700 ± 150 m.y. on a galena sample, they post-date the main folding and are structurally controlled by it. They contain accessory barium (Daniels, 1966b).

Uneconomic uranium has been reported in conglomerates to the west of Nullagine (Richards, 1972, unpubl.).

At Braeside lead-vanadium ores occur in quartz veins, east of Marble Bar, apparently introduced during the mobilization of the folded region to the east.

The literature gives a profusion of names based on this platform cover. The sediments were first noted resting on the folded Pilbara Block, which was always assigned an Archaean age, at the gold mining centre of Nullagine; there the basal gold-bearing conglomerates within the platform cover were referred to as the 'Nullagine conglomerates'. The term 'Nullagine' was extended indiscriminately to refer to undeformed ancient sediments elsewhere in Australia, and hence was applied to stratigraphically unrelated units of similar appearance, and generally with an Upper Proterozoic connotation. Much of the confusion has been removed by regional mapping and age dating. The time term Nullaginian was then proposed for the lower Proterozoic time span (Dunn, Plumb, & Roberts, 1966) but has not gained wide acceptance. Daniels (1966a) proposed that the deep basin which laps onto the Pilbara Block, and of which the Nullagine Conglomerate is a basal unit, should be called the Nullagine Basin, but subsequently it has been called the Hamersley Basin by Daniels & Horwitz (1969). This sedimentary basin, the only known depositional basin of the West Australian Platform Cover, then corresponds in part to the area of the Hamersley Ranges, incorporates within its sedimentary sequence the Hamersley Group (Daniels, op. cit.), and contains the Hamersley Iron Province (Macleod, 1966). 'Nullagine Basin' has also been informally used to apply to the small embayment of West Australian Platform Cover immediately west of the township of Nullagine (Richards, 1972, unpubl.).

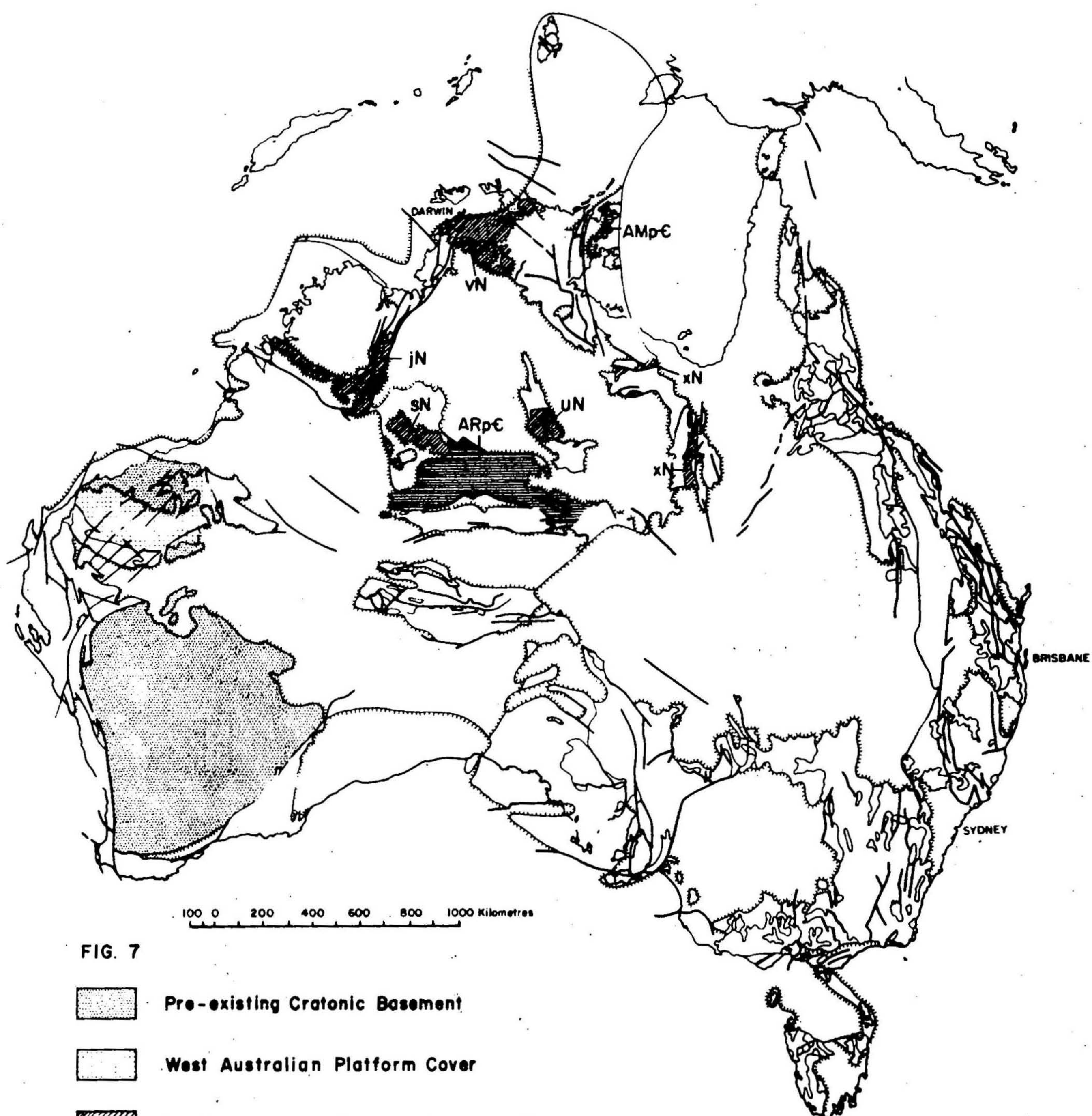

FIG. 7

Pre-existing Cratonic Basement

West Australian Platform Cover

North Australian Orogenic Province, N
jN Halls Creek, vN Pine Creek, uN Tennent Creek
xN Nicholson, sN Granites - Tanami

Possible equivalents of North Australian Orogenic Province
ARp€ - Árunta Block AMp€ - Arnhem Block

To accompany Record 1972/56 *AUS/4/15*

THE NORTH AUSTRALIAN OROGENIC PROVINCE

The five orogenic domains and their associated transitional domains within the North Australian Orogenic Province are all overlapped by the North Australian Platform Cover.

They are generally areas of low-grade metamorphic rocks, deposited partly on continental crust during the early Proterozoic (Nullaginian). They characteristically lack synorogenic granites, but post-tectonic granites and acid volcanics are known in all except the Granites-Tanami Block.

HALLS CREEK BELT AND KING LEOPOLD BELT

The Halls Creek Belt and King Leopold Belt are two linear belts in which the main deformation took place in the early Proterozoic but which have been partly reactivated at widely spaced intervals since. There is no reason to suppose that the present narrow zones exposed between the cover of younger platforms represent the original extent of the activity, and correlations with belts of similar age in the Northern Territory have been inferred although confirmatory evidence is lacking.

Halls Creek Belt

In the northeast-trending Halls Creek Belt the basal unit consists mainly of basic volcanics, followed by a thin shallow-water clastic formation, and then by the Biscay Formation, a mixed clastic and basic volcanic sequence with dolomitic horizons. The uppermost unit is a thick monotonous sequence of turbidites and some conglomerates.

The sedimentary sequence was tightly folded, slightly metamorphosed, and intruded by basic igneous magma, which formed dolerite dykes and sills and also large gabbroic masses containing some ultrabasic basal differentiates.

A second, more intense period of deformation produced metamorphism ranging up into the granulite facies and anatectic granite. The metamorphics yield a date of 1 961$\pm$27 m.y. (Rb/Sr) for the second deformation.

Acid volcanics post-dating the deformation are intruded by numerous stocks, mainly granitic but with some more basic representatives (Dow & Gemuts, 1969).

King Leopold Belt

The King Leopold Belt, which trends northwest, appears to have a similar history; the areal extent of the sedimentary sequence preserved is less and metamorphism is more widespread but of lower grade (Gellatly, Sofoulis, & Derrick, in prep.).

Neither belt is known to contain any sizable mineral deposits. Early mining activity concentrated on the gold near Halls Creek, initially on alluvial material but on lodes when the alluvium was exhausted. The mines exploited veins conformable with the enclosing folded rocks. The richest veins occurred at the base of the turbidite sequence, but others occurred in the dolerite dyke at the top of the underlying Biscay Formation and in that formation itself. The lodes are quartzose, and pyritic below the oxidized zone (Dow & Gemuts, op. cit.).

Several small copper-lead-zinc occurrences in the Biscay Formation have received attention, but those examined in detail have so far proved to be uneconomic, although the Angelo Prospect contains 500 000 tons of low-grade ore (McNeil, 1966).

Small chromite lenses occur within the ultrabasic phases of the basic intrusives, but appear more interesting for their platinum content than as sources of chromium.

Tin and niobium were obtained from pegmatites and derived alluvium at Mount Dockerell in the south of the Halls Creek Belt.

A small showing of tungsten and tin in the King Leopold Belt was investigated by Finucane (1938), who reported that the ore consisted of cassiterite and wolfram in metamorphic rocks and the deposit seemed suitable only for small-scale selective mining.

THE PINE CREEK BLOCK

The rocks in the Pine Creek Block were deposited in the Pine Creek 'Geosyncline' during the early Proterozoic on an Archaean basement of metamorphic and igneous rocks. They were folded at abou 1 900 m.y. and intruded by post-tectonic granites at 1 830-1 820 m.y. Walpole, Crohn, Dunn, & Randal (1968, p. 19) described the setting as an intracratonic basin rather than an orogenic belt, going on to point out the shallow nature of the depositional basin and the lack of severe regional metamorphism.

The following description and the accompanying Figure are taken from Walpole et al.

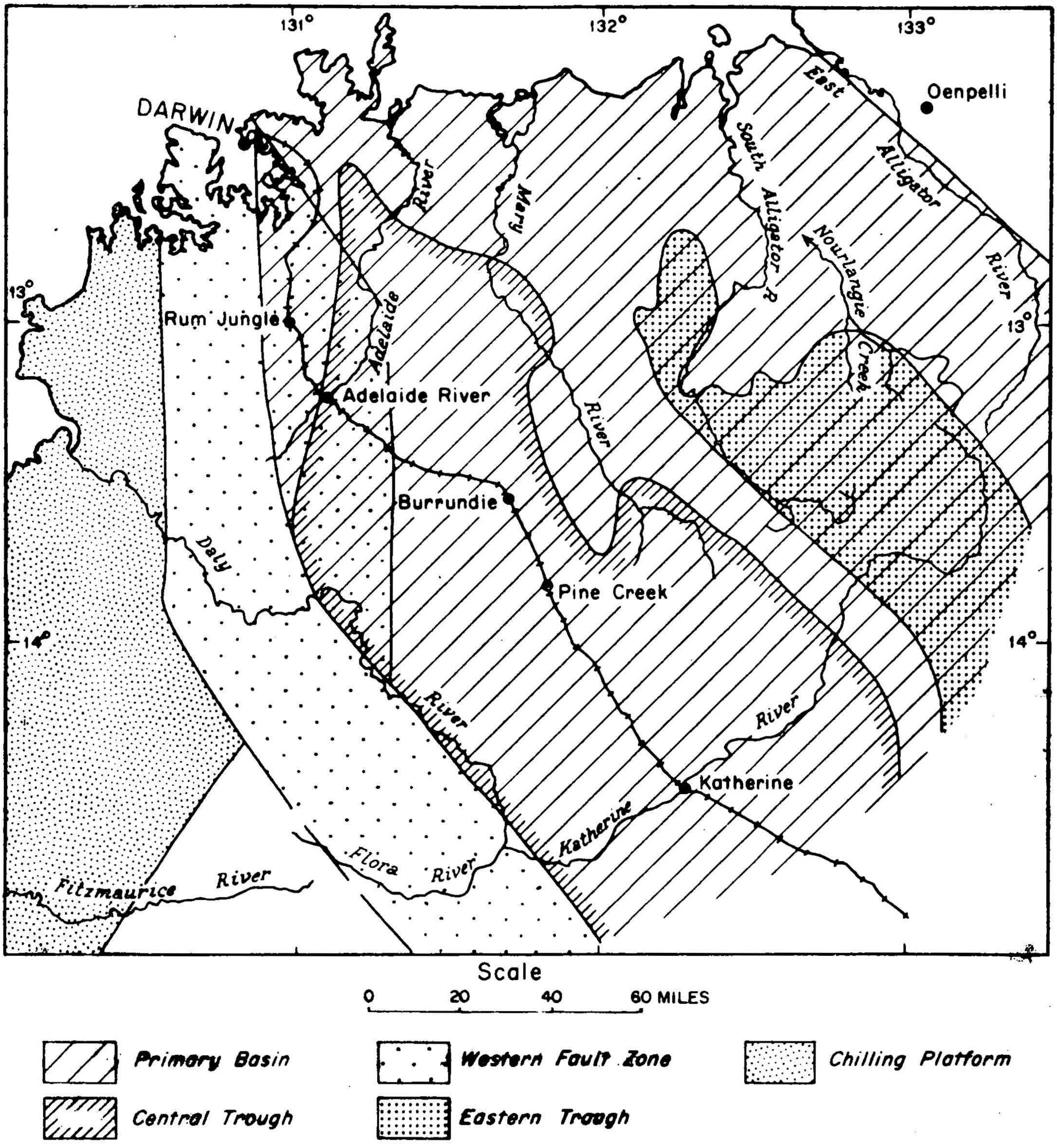

Fig. 8 Major structural elements, Pine Creek Geosyncline

(After Fig. 8 of Walpole, Crohn, Dunn, Randal, 1968)

'The Pine Creek Geosyncline is a shallow composite structure developed during Lower Proterozoic time. Initial sedimentation was from the north and east into a northwest-trending asymmetrical basin (the Primary Basin). The sediments comprise an arkose/quartz greywacke/ siltstone/chert/dolomite assemblage (Goodparla and Batchelor Groups) in which the proportion of clastics decreases towards the centre of the basin. The second phase of sedimentation was from the west into a newly developed north-trending Western Fault Zone and the central part of the Primary Basin (the Central Trough). The sediments comprise a turbidite assemblage of greywacke and siltstone (Finniss River Group) and minor volcanics; the coarser-grained sediments lens out to the east. Easterly derived sediments were still being deposited in the Central Trough when the second phase of sedimentation started, but they were cut off when the Eastern Trough was formed on the eastern side of the Primary Basin. The Eastern Trough contains a siltstone-chert-dolomite assemblage (South Alligator Group). The final phase of sedimentation in the Pine Creek Geosyncline was the deposition of sandstone (Chilling Platform) in the southwestern part of the geosyncline.'

The folding is moderate to tight - some incompetent beds are isoclinally folded and occasionally overturned; the trend of the axes ranges from northwest through north to a few degrees east of north, and is modified by intrusive granites; there is also some modification by cross-folding. It appears that the three principal fault directions also controlled the form of the depositional basin, and were therefore features of the pre-existing basement. The Giants Reef Fault, a major wrench fault which cuts across the Rum Jungle Dome, is in its present form a much later feature, cutting later platform cover. However, it was suggested that it follows a much older lineation.

The region was intruded by transitional granites, in particular the large mass of the Cullen Granite, which also domed up parts of the basin; they were accompanied by acid volcanics and minor sediments.

Crohn (in Walpole et al., op. cit.) points out the marked stratigraphic control apparent in much of the mineralization; but some appears zoned around the granites, and some is related to fault zones.

In recent years the most important metal mined has been uranium, which occurs in two major areas, and in scattered occurrences including several recent large discoveries southwest of Oenpelli and one to the east. In the west the Rum Jungle area has been the focus of exploration for the last twenty years. Heier & Rhodes (1966) pointed out that the Archaean Rum Jungle Complex itself has a higher content of thorium and uranium than most granitic rocks. It appears to have acted as a depositional high during sedimentation and the rocks of the Pine Creek Geosyncline resting immediately on it are mainly chemical sediments of the basal unit; so that conditions were favourable for syngenetic trapping of uranium. If the original concentration were syngenetic, subsequent tectonic events have modified the deposits, and their origin has been the subject of considerable dispute.

The main deposit at Rum Jungle, Whites Orebody, was a disseminated uranium-copper body, with cobalt and lead also present. Several low-grade lead deposits also occur in the zone rimming the Rum Jungle Complex (Spratt, 1965; Berkham, 1968; Crohn, Langron, & Prichard, 1967).

Any appraisal of the literature on the Rum Jungle area and of any other uranium-bearing area in northern Australia should take account of the fact that the main studies were carried out during the period when there was an extreme bias towards a syngenetic origin for orebodies. Little attention was paid to the effects of land surfaces and groundwater movements in the region, and the results these may have had on distribution of uranium.

The second important area of uranium mineralization is the northwest-trending belt along the course of the South Alligator River. The mineralization is partly within chemical sediments of the South Alligator Group of the Pine Creek Geosyncline and partly in acid volcanics of the transitional phase and in the basal beds of the overlying North Australian Platform Cover. A zone of faulting parallel to the mineralized zone was active during sedimentation.

The association of uranium mineralization with juxtaposed acid volcanics of transitional domains and basal basic volcanics of the platform cover is very widespread across northern Australia. The influence of groundwater in the original distribution and any redistribution of the uranium needs also to be considered. The gold occurring with the uranium in the South Alligator Valley also presents a metallogenic problem yet to be explained. Age determinations have been unsatisfactory, giving ages considerably younger than any allowed for in geological interpretations (Prichard, 1965; Taylor, 1968).

The apparent zoning of gold, lead, tin, and tungsten around the late-phase granites and particularly round the large body of the Cullen granite may be a result of complex intrusions, or of tectonic mobilization of concentrations of metals existing before the intrusion, or even of remobilization of material from the basement. It is not a normal zonation progressing outward from the granite: various metals predominate in areas around the granite margins, as is well shown in Walpole et al. (1968, pl. 32). The Yeuralba-Maranboy region is characterized by tin and tungsten deposits; the Wolfram Hill/Mount Todd area by gold, tungsten, tin, and a little molybdenum; the Northern Hercules/Coronet Hill area by copper, lead, and a little tin. The deposits all occur in a dominantly chemical and restricted basin facies unit of the Goodparla Group.

In the west, along the faulted and mobile western margin of the Pine Creek Geosyncline, is a province of tin, tantalum, and lithium deposits. The setting suggests possible mobilization of metals from the basement; the metal association is more characteristic of the West Australian Orogenic Province than of younger orogenic domains.

The phosphate southeast of Rum Jungle is at the pre-platform cover surface developed on the Pine Creek Block, and is thought to be a supergene concentration from the weakly phosphatic underlying dolomite in the Pine Creek 'Geosyncline'.

TENNANT CREEK BLOCK

The Tennant Creek One-Mile Map (Crohn & Oldershaw, 1965) gives details of the Tennant Creek Block in the vicinity of the Tennant Creek area. (Regional mapping of the remainder of the Block was begun in 1969.) At Tennant Creek the block is made up of early Proterozoic deepwater sediments - greywacke, shale, and siltstone, with bands of hematitic shale serving as markers. Basement is not exposed, but drill holes to the southwest of Tennant Creek encountered significantly different rocks which are interpreted as Archaean basement, beneath 30 m of much younger cover. This area of the Northern Territory has been affected by several cycles of deep weathering which make mapping and exploration difficult.

The rocks are not severely folded; the main structural features are strong shears and faults, some of the latter being quartz-filled. Crohn & Oldershaw point out the difficulties of assessing the regional metamorphic grade, which seems to be greenschist, because fresh specimens come only from the mines which are on shears and hence the sites of considerable alteration effects.

The mineralization takes the form of gold-copper sulphide orebodies; these occur in close association with tabular and pipe-like quartz hematite and quartz-magnetite bodies and in major shear zones. The major gold producers appear to be confined to the vicinity of a hematite shale marker bed, but the major copper producers appear to be at the intersections of major shear zones (Crohn & Oldershaw, op. cit., p. 38). The orebodies are in general gold or copper-gold, but ore from the Juno mine carries significant bismuth. Silver, lead, and zinc have been reported, but not in significant quantities.

Elliston (1966) postulated that the metals concentrated as the crosscutting Peko orebody originated in the underlying sediments and were reconcentrated by colloidal precipitation during folding. However, the latest mapping hints that these deposits may be typical transitional-phase type mineralization.

GRANITES - TANAMI BLOCK

The Granites-Tanami Block is a poorly exposed block in the west of the Northern Territory, extending into Western Australia. It is difficult of access, and the geology is known only by reconnaissance mapping and some air-photo interpretation. The major trends are northwesterly, and lineations on trend in the Arunta Complex suggest that the Block continues into it southeastwards (Walpole, Roberts, & Forman, 1965). The King Leopold Belt is on trend as a possible continuation to the northwest. Two different sequences are recorded: one of mica schist and metasiltstone as at The Granites, the other of quartz-hematite beds at Tanami, comparable to those at Tennant Creek (Anon., 1961). The block has been intruded by later unstressed granites, possibly of Carpentarian age by analogy with similar granites cutting the Tennant Creek Block.

Only two centres of mining activity occur in this region; the small, mainly alluvial goldfield at Tanami (Hossfeld, 1940) and the slightly larger lode and alluvial deposits at The Granites (Hossfeld, 1938; Hall, 1953; Crohn, 1961). The deposits at The Granites are varied; one area contains small quartz stringers in tightly folded schists and quartzites; in a second area, a mineralized zone may be traced over 1.5 km but appears to have contained only two rich subzones of limited extent. It is confined to a poorly exposed schist horizon.

The mining centre of Tanami on the latest photo interpretation of this region lies not in the orogenic domain but in North Australian Platform Cover.

THE NICHOLSON BLOCK

The small Nicholson Block lies in the east of the Northern Territory and the far northwest of Queensland.

It is a metamorphic unit - 'geosynclinal pelitic and quartzofeldspathic sediments and volcanics, isoclinally folded about an east-west axis and intruded by granite'. The metamorphic grade is greenschist, and the granite has foliated margins (Roberts, Rhodes, & Yates, 1963).

[1]The area is (1972) being systematically mapped by the Bureau of Mineral Resources.

The Cliffdale Volcanics and the Norris Granite, which are metallogenically important, represent the transitional unit within the Block. Close to the contact with overlying conglomerates of later platform cover the Cliffdale Volcanics carry extensive though somewhat low-grade uranium-copper deposits with a little gold, which have been mined at Pandanus Creek (Morgan, 1965) and elsewhere in the Northern Territory. A larger deposit at Westmoreland is now (1970) under investigation in the Queensland part of the block. The mineralization extends from the volcanics into the overlying conglomerates and basic volcanics. This association has been recognized elsewhere in North Australia as a favourable host for uranium; opinions so far incline to the acid volcanics as the primary source rocks, with redistribution and concentration by groundwater.

Tin occurs in quartz veins in a late phase of the Norris Granite, but most of the production has been from alluvial and eluvial material. Tungsten is also recorded; but the yield was very small.

THE NORTH AUSTRALIAN PLATFORM COVER

During the Carpentarian, widespread platform cover formed over the stabilized North Australian Orogenic Province, and is now preserved in a broad zone from the Kimberley Basin in the west across Arnhem Land and the southern shores of the Gulf of Carpentaria to the deformed Mount Isa Belt, with which it merges. A small area of platform cover of similar age is exposed lapping onto the Tennant Creek Block and a little-known area exists in the Tanami area.

The Kimberley basin (Plumb, in prep.) still extends virtually to its depositional limits against the Halls Creek and King Leopold Belts; the sediments dip and thicken to the northwest away from the mobile belts, on which they rest unconformably. Elsewhere in North Australia acid volcanics like those of the Belts are the locus of uranium mineralization, and an intensive search for such mineralization in the basal units of the basin adjacent to the Halls Creek Mobile Belt has been undertaken. The basin contains a basic volcanic unit, and laterites developed over this are the source of economic bauxite deposits in the Mitchell Plateau. A thick dolerite sill formed part of the basin but carries no economic mineralization.

The margin of the Kimberley Basin near the extreme northwest of the King Leopold Belt contains beds carrying detrital hematite which grade into orebodies on Koolan and Cockatoo Islands (Reid, 1965). These beds are tightly folded and have undergone low-grade regional metamorphism during cratonic folding late in the Proterozoic. The development of canga apart, the deposits are unusual in that iron was concentrated into ore-grade material during sedimentation, supergene processes having played little part. On the eastern margin of the basin similar detrital hematite beds form low-grade deposits; the largest is at Pompeys Pillar (Dow & Gemuts, 1969).

The part of the North Australian Platform Cover bordering the Gulf of Carpentaria has been divided into a number of shelf and basin regions (Carter, Brooks, & Walker, 1961; Roberts, Plumb, & Dunn, in prep.; Dunn, Plumb, & Roberts, in prep.). The sediments rest disconformably or unconformably on late acid volcanics and granites of the North Australian Orogenic Province. Frequently basic volcanics occur low in the sedimentary pile above the unconformity; uranium mineralization has been observed to favour this environment, but so far most of the uranium discovered is below the unconformity. However, at South Alligator (p.v.) some of the uranium is above the unconformity, and minor uranium occurrences are known in platform cover adjacent to the Nicholson Block (p.v.).

The McArthur River bedded lead-zinc-silver (pyrite) sulphide deposit lies in relatively undisturbed tuffaceous and carbonate rocks; the ore itself occurs in very fine-grained, thinly-bedded black dolomitic carbonaceous shale. The consensus of opinion is that the metals are syngenetic precipitants (Cotton, 1965). So far the metallurgical problems raised by the fine grain-size have prevented economic exploitation, and reserves have not been quoted. The major fault immediately east of the McArthur River deposit is thought to have been active during sedimentation - a deep trough sequence to the west, which includes the restricted basin facies of the ore-bearing beds, passes across the fault into a thin, shallow water, lateral equivalent. Nearby very small lead deposits in fault zones may represent mobilized material from equivalents of the McArthur River deposit.

The Bulman lead-zinc deposits, which lie some 350 km to the northwest of McArthur River, are confined to one stratigraphic level in an undeformed dolomitic sequence in a stratigraphic correlate of the sequence at McArthur River (Patterson, 1965).

Copper occurs in volcanic breccia at Redbank to the east of McArthur River near the Territory border (Roberts et al., 1963), and also in the Platform Cover adjacent to the Mount Isa Belt (Carter et al., 1961).

Southeast of McArthur River in northwest Queensland is a group of small silver-lead-zinc deposits at Lawn Hill. They are described as complex fissure veins, in places containing brecciated country rock (Murray, 1965). The zinc content is appreciable, but no zinc production is recorded; the ore at the Silver King mine also carries cadmium. The deposits represent material mobilized during folding extending from the adjacent Mount Isa Belt.

Adjacent to the Mount Isa Belt there is a regional unconformity in the North Australian Platform Cover which passes westward into a regional disconformity. It followed folding of the belt. Deposition above this regional break includes sedimentary iron formations in two areas. Northwest of Mount Isa in the Constance Range an ironstone containing oolitic siderite, hematite, and chamosite with secondary hematite and limonite round the rims of complex structural basins. The deposit is regarded as subeconomic because although high-grade ironstone is exposed in hogback ridges most of it is covered by considerable thicknesses of lower grade material and overburden (Harms, 1965). In the Roper River area of the Northern Territory similar deposits occur in two areas. They are oolitic, mainly hematitic where supergene enrichment has occurred, but carry siderite and chamosite below the alteration zone (Canavan, 1965).

The Platform Cover south of the Tennant Creek Block in the Davenport 'geosyncline' has been intruded by small bosses of Carpentarian granite. It contains the tungsten-producing centres of Hatches Creek and Wauchope. At Hatches Creek, quartz veins carrying wolfram, some with scheelite and small quantities of copper and bismuth, occur in faults cutting quartzite, shale, and volcanic rocks. There are no granites in the immediate neighbourhood of the deposits (Ryan, 1961). At Wauchope the enclosing rock is described as a sericite-quartz-tourmaline hornfels, although the nearest known granite is 4 km to the northwest. The wolfram occurs in narrow quartz reefs, commonly with large 'bunches' at small faults and flexures (Sullivan, 1953). The area also contains small gold deposits and some uranium mineralization, which has not so far proved economic.

A small trough of sediments southeast of Kalgoorlie gives an age similar to that of platform-cover sediments within the North Australian Platform Cover and is hence equated with it. It may well be the only preserved remnant of more extensive cover developed contemporaneously with downwarp in the Albany-Fraser Belt.

CENTRAL AUSTRALIAN OROGENIC PROVINCE

The blocks and belts making up the Central Australian Orogenic Province show a wide time-span of development and a range of tectonic styles from the intensely and repeatedly metamorphosed Musgrave Block to the strongly folded but only moderately metamorphosed Mount Isa Belt. On the whole, metamorphism and deformation are much more intense than in the North Australian Orogenic Province.

MOUNT ISA BELT

The Mount Isa Belt in northwest Queensland has received a great deal of attention as the locale of the Mount Isa copper and lead deposits, the Cloncurry copper district, and uranium mineralization, including the large deposit at Mary Kathleen. The regional geology at a scale of 4 miles to the inch was mapped in the late 1950s (Carter, Brooks, & Walker, 1961); considerable detailed attention has been given to mineralized areas; and the area is now (1969 onwards) being remapped in detail at a scale of 1:100 000.

Carter, Brooks, & Walker (op. cit.) worked out a history for the development of the belt which is being confirmed with some changes in minor detail by more recent work. They recognized a continental-type basement older than the Mount Isa Geosyncline, which is exposed as highly deformed metamorphic rocks, granite, and acid volcanics along the geanticlinal axis between the eastern and western troughs of the Mount Isa Geosyncline. As a result of detailed mapping, it is now considered that this basement is an extension of the Nicholson Block to the northwest; and therefore may have played an important role in the uranium mineralization of the Mount Isa Block. The area west of the geanticlinal ridge is now interpreted as deposition on continental crust and the area east as geosynclinal deposition sensu stricto. Basic volcanics overlie the ridge, a sequence also recognized to the northwest in the platform cover overlying the Nicholson Block. After the basic volcanics were deposited, the median ridge began to rise and divide the eastern and western troughs. Carter et al. recognized two phases of deformation, each accompanied by granite intrusion. Metamorphism, generally greenschist to lower amphibolite, is widespread. Two separate types are recognized: a regional 'thermal' metamorphism and a sodium-chlorine metasomatism widespread in the eastern trough. It is suggested that the latter may have originated from the sodium chloride content of connate water in the sediments, rather than as an external addition to the elements (R. Hill, pers. comm.). Current mapping is delineating the metamorphic zones in some detail, and it is hoped to show any relationship between them and mineralization.

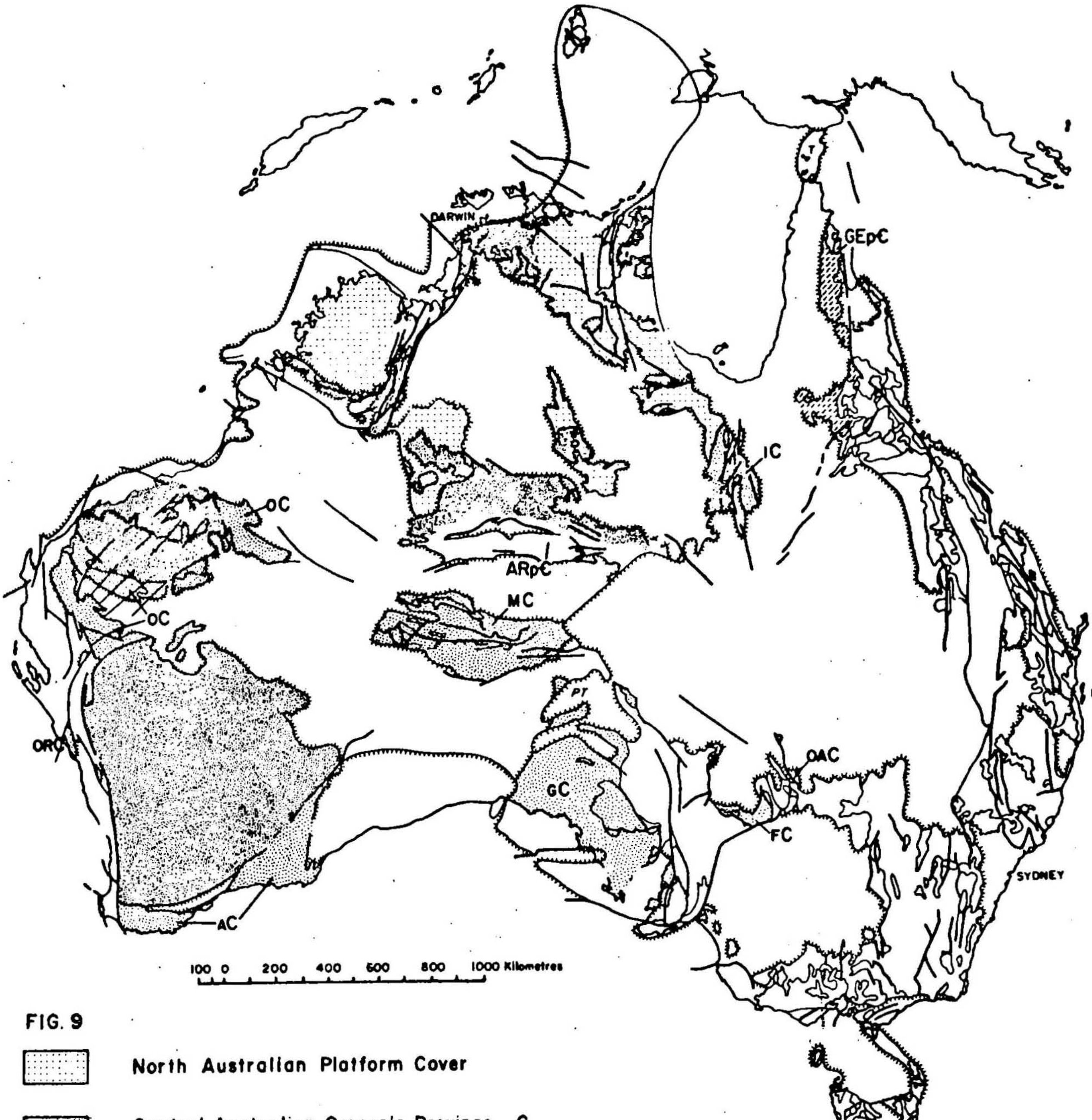

FIG. 9

North Australian Platform Cover

Central Australian Orogenic Province C
OC Ophthalmia-Gascoyne, MC Musgrave, FC Willyama
ORC Northampton, GC Gawler, OAC Wonaminta, IC Mount Isa
AC Albany-Fraser

Pre-existing Cratonic Regions

Possible Equivalent of Central Australian Orogenic Province
GEp€ Georgetown Block
ARp€ Arunta Block also probable part equivalent

To accompany Record 1972/56 AUS/4/16

The region has been invaded by dolerite dykes and sills. Some of these may have been feeders to the early basaltic lavas; some are conformable bodies that may have been flows; and some are definite sills. All are metamorphosed and altered; and some relatively unaltered later dykes are also known.

The metal which first attracted miners to the region was gold. Very small amounts of alluvial and some reef gold were won, mainly south and southeast of Cloncurry. The area was soon recognized as a copper-bearing region; the lead and uranium deposits were found much later.

The copper deposits appear to fall into two broad regions with the single deposit at Mount Isa standing apart. In the median ridge and eastward most deposits are small to very small. Some of the largest mines were shut down when the price of copper fell in 1919, at which time they were in the primary sulphide zone, and with the rich supergene ore gone reopening has not generally considered to be economic. Small rich mines in the eastern trough have been operated for many years by single prospectors or small parties, but the current interest in large but lower grade deposits has resulted in reappraisal of some deposits and some larger-scale operations as at the Winston Churchill and Great Australian larger-scale operations. Some lodes in the eastern section carried gold, the best gold values occurring in lodes in the south of the region. Copper mineralization favours slate and shale host rocks, and appears closely related in space, and hence, by inference, genetically, to basic igneous rocks. Although the carbonate rocks of the eastern trough are unfavourable host rocks, some low-grade bodies of chalcopyrite in calcite have been mined for flux in the smelting of the ores at Mount Isa. Deposits tend to lie close to shears and fault zones which have a north-northwest trend.

The major copper deposit at Mount Isa lies west of the median ridge, it is contained in 'silica dolomite', a rock type which takes four forms:

(a) Crystalline dolomite;
(b) Irregularly brecciated dolomitic shale in a crystalline carbonate-quartz matrix;
(c) Partly recrystallized shale;
(d) Fractured and brecciated siliceous shale.

The resemblance of this assemblage to modern reef complexes has been recognized and the presence of biogenic remains in the dolomite has been reported; hence it has been postulated that the orebodies are syngenetic (Bennett, 1965). The picture is complicated by the separate but adjacent lead-zinc-silver deposits. Smith & Walker (1972) offer evidence for derivation of the copper from the basic volcanics underlying the orebodies, but favour a syngenetic origin for the nearby lead-zinc-silver orebodies. The basic volcanics beneath the orebody have been depleted of copper, and the copper-bearing solutions have migrated up fractures.

Mount Isa apart, copper orebodies in the western trough are confined to the northern section, where the deformed Mount Isa Belt merges into the North Australian Platform Cover. Three of the deposits in this area have recently been shown to have substantial tonnages of lower grade ore than that originally mined. One of these, Mount Oxide, lies in a crush zone in a moderately folded, slightly metamorphosed silt and shale unit. Another, the Lady Annie, has been described as 'a disseminated replacement deposit in shale on the hanging wall of a prominent easterly-trending fault plane' (Carter et al., p. 217). The third is the Mammoth where chalcocite and malachite occur in a brecciated quartz sandstone (Brooks, 1965).

The lead-zinc-silver orebodies at Mount Isa are generally agreed to be syngenetic. The ore minerals, pyrite, galena, sphalerite, argentite, and tetrahedrite, occur bedded with black carbonaceous dolomitic shale, in places contorted. The ore contains enough cadmium for economic recovery in such a large mining operation. Some of the folds are interpreted as slump structures, others as tectonic. The ore mineral shows flowage into the crests of folds with a consequent increase in grainsize.

The Dugald River deposit lies in the eastern trough. It is a silver-bearing zinc-lead lode confined to a graphitic shale bed within a dolomitic succession. The country rocks are mildly metamorphosed and slightly metasomatized. The deposit is accepted as syngenetic (Knight, 1965). Other small silver-lead deposits in the eastern trough have been mined only in the oxidized zone for the enriched silver content. They have the appearance of hypogene deposits.

The uranium and rare earth deposit at Mary Kathleen has been interpreted as a skarn deposit in metasomatized carbonate sediments largely converted to garnet and scapolite. The uranium occurs as uraninite accompanied by allanite, stillwellite, and fluorapatite; minor sulphides are also present. The garnetization of the country rock is most intense in the vicinity of the orebody. The mineralization is attributed to a deep-seated differentiated granite intrusion 3 km to the east which has metasomatized the country rock (Hughes & Munro, 1965). Granite occurring 2 km west of the orebody is considered to be not related to it.

Other small uranium deposits occur in the eastern trough; all carry davidite and commonly are in pegmatites.

The uranium occurrences of the western trough are generally in zones of fracturing and faulting and exhibit no regional stratigraphic association. They have shallow oxidized zones above disseminated uraninite mineralization. Only one has proved sufficiently rich for small-scale mining, although many are being reappraised.

Cobalt is found in the copper and lead-zinc orebodies of Mount Isa in trace quantities, but is not known elsewhere in the western trough. In the eastern trough a north-south zone of cobalt occurrences, mostly very small, has been recognized. The cobalt occurs as sulphides with copper. At Mount Cobalt small quantities of cobalt ore were extracted from a narrow shallow orebody in a north-south shear zone between a metadolerite and quartz-mica schist. The ore was mainly low-grade, but some shoots of rich direct-shipping ore were obtained. Scheelite was mined in small quantities in the same shear zone about 1 km to the north.

Banded iron formations occur in the eastern trough and iron occurs in skarn type deposits. At Mount Philp a narrow body of hematite, magnetite, and quartz in a fault zone contains only medium-grade ore.

Although scheelite occurs in many places in the gangue of deposits of other metals, only one deposit apart from Mount Cobalt has produced any quantity of ore. This deposit, northwest of Cloncurry, occurs in quartz veins associated with a calcite lens in hornblende schist and carried a little copper.

Small deposits of manganese formed by secondary concentration during weathering are common, particularly in the southern part of the eastern trough, and one small deposit was mined to provide material for the Mary Kathleen treatment plant.

Pegmatites along the eastern intrusive margin of granite about 10 km southwest of Mount Isa have yielded beryl and carry small quantities of tin and tantalum minerals. Most of the production is alluvial (Brooks, 1963; Brooks & Shipway, 1960).

THE OPHTHALMIA-GASCOYNE BLOCK

The Ophthalmia-Gascoyne Block lies to the north of the Yilgarn Block in Western Australia, and may incorporate parts of this and also highly deformed western extensions of the Hamersley Basin. Only sketchy information was available at the time of writing. One feature of the deformation is major northeast shear zones which die out as flexures in the Hamersley Basin; and isoclinal folding along northwest axes, which occurs in the western parts of the Hamersley Basin, becomes much more intense in the Block itself (cf. Western Australian Platform). The mineral deposits so far mined are isolated and small.

The pegmatites at Yinnietharra which lie within the Ophthalmia-Gascoyne Block yielded small quantities of beryl and contained limited quantities of tantalum minerals (Matheson, 1945). Most of the production was eluvial.

The Dalgety Downs copper deposit also lies within the block. Low (1963) records it as having been introduced by acid dykes in a gneissic country rock. Low also mentions other very small copper deposits which may fall within the boundaries of the block.

The block is reputed to contain possible carbonatites, but these have not been assessed as yet, and their exact location has not been disclosed.

The deformed rocks to the east of the Pilbara Block known as the Paterson Province are equated with the Ophthalmia-Gascoyne Block. Daniels (pers. comm.) considers that this region contains folded Bangemall Basin sediments (Central Australian Platform Cover) over probable Lower Proterozoic metamorphics which may incorporate some reworked Archaean rocks but very little is known of the area, which equally may be a continuation of the Musgrave Blocks to the southeast. The Braeside lead-vanadium deposit occurs in West Australian Platform Cover, but was probably introduced by igneous activity occurring in the adjacent mobile region to the east.

UNITS OF THE CENTRAL AUSTRALIAN OROGENIC PROVINCE IN SOUTHERN AUSTRALIA

From western New South Wales westwards to about 132°E a number of basement units of approximately the same age are now separated by Central Australian and Trans-Australian Platform Covers. Two, the Willyama Block in the east and the Gawler Block in the west, are major units. The remainder form small windows in the broadly folded Adelaide 'Geosyncline'; three in the mountains east of Adelaide, and the Mount Painter Block and the Peake-Denison Block in the central north of South Australia.

The Willyama Block extends from western New South Wales into South Australia, where it is referred to as the 'Olary Province' (Campana & King, 1958). The eastern part contains the Broken Hill lead-zinc-silver orebodies and has therefore been intensively studied, mainly in the vicinity of the orebodies. This part is a triangular block with a narrow embayment of platform cover. The metamorphic grade is highest in the southeast and decreases northwesterly, subparallel to the general fold trend. The northwest has been invaded by late-phase granites with ages of about 1 560 m.y. The gneisses in the southeast give ages from 1 650 m.y. to 1 700 m.y. (Vernon, 1969; Compston & Arriens, 1968). The metamorphic rocks in the vicinity of the main Broken Hill lode may be classified on their apparent original composition as either arenaceous or argillaceous derivatives: it has been shown that the lode consists of three lensoid bodies conformable with the compositional banding of the enclosing rock and confined to argillaceous facies rocks. Each lens has its own characteristic metal ratio and gangue (Carruthers, 1965; Pratten, 1965; Lewis, Forward, & Roberts, 1965). A number of geologically similar but much smaller orebodies are known in the region (Anon., 1968).

A much later event corresponding to deformation in the Kanmantoo Fold Belt to the east is represented by resetting of biotite ages and the introduction of pegmatites with an age of 495 m.y. Small lead-silver cross-cutting bodies appear to have been introduced by this event, mainly in the north and west; these are mineralogically distinct from the Broken Hill type of orebody, and are typified by the Thackaringa Deposit (King, 1953).

The pegmatites carry beryl and feldspar; small quantities of beryl have been mined by small-scale operators at several localities, and eluvial tin from one locality north of Broken Hill.

The South Australian portion of the Willyama Block is noted chiefly for its uranium (davidite) deposits. King (in Campana & King, op. cit.) states in a review of the mineralization of the Olary Province that deposits are genetically related to the intrusive granites, and in one locality recognized five zones rimming the granites; however, he also related the granites and pegmatites of the area to the one event. Thomson (in Parkin, 1969, p. 35) states that the uranium deposits are of the same age as the Broken Hill mineralization, that is, antedating the granites. Although the uranium occurrences have been thoroughly investigated in both states (see also Rayner, 1960), only three deposits were mined, all in South Australia. The largest is at Radium Hill (Parkin, 1965); it is a davidite deposit carrying appreciable quantities of rare earths, from which a small quantity of scandium only has been recovered.

Copper has been mined from small deposits in South Australia, and cobalt, nickel, and tungsten (scheelite) mineralization of a minor nature is described by Campana & King (op. cit.). Scheelite is common, but of unknown metallogenic significance, in the Broken Hill area (B.P. Thomson, in pers. comm.). Campana and King (op. cit., p. 101) reported scheelite developed in calcareous sediments.

Banded iron formation is poorly exposed near the state border, but it appears to have no economic potential at present (Whitten, 1965).

The Wondminta Block is the small area of metasediments and volcanics northeast of Broken Hill along the eastern margin of the Bancannia

Trough. It is thought to be equivalent to those in the Willyama Block (E. Scheibner, 1972a). The only mineral deposits are small copper deposits introduced during Kanmantoo events.

The Peake-Denison Block carries small copper deposits, and gold has also been reported. It is a structurally complex area with early Palaeozoic granites intrusive into low-grade metasediments and the mineralization is akin to that in the folded Adelaide 'Geosyncline' (Reyner, 1955; Thomson in Parkin, 1969 p. 37-8).

The small inliers near Adelaide carry little mineralization, and most of this appears sufficiently similar to that within the surrounding platform cover to be considered as having been introduced by the Ordovician Kanmantoo event. However, the uranium mineralization at Myponga, where two small erratic lodes occur in shear zones, may be related to similar uranium mineralization on Eyre Peninsula in the Gawler Block and in the Mount Painter and Willyama Blocks (Parkin, 1957).

The Mount Painter Block consists of two units which form windows along a basement ridge in the north of the Adelaide 'Geosyncline'. The block consists of metamorphosed deltaic sediments and acid volcanics intruded by two phases of granites, one Proterozoic and the other Palaeozoic. The only mineralization within the block is contained in a number of low-grade uranium-horium deposits, of which Mount Painter is the only one large enough to have been mined (Coats & Blissett, 1971).

The Gawler Block occupies Eyre and Yorke Peninsulas, being split by the Tertiary downwarp of Spencer Gulf, and is poorly exposed beneath a veneer of Tertiary and Quaternary consolidated and unconsolidated sediments.

The oldest rocks are folded high-grade metamorphics with evidence of granitization in places, dated at about 1 780 m.y. A granite gives an age of 1 730 m.y., with a broad scattering of ages (Thomson in Parkin, 1969, p. 30). The metamorphics are overlain by a deformed porphyry and intruded by granites at 1 590 m.y. These in turn are overlain by relatively undeformed sediments and a vast spread of acid volcanics, and intruded by small acid stocks which constitute the transitional domain.

By far the most important mineral deposits are the iron ores. These have been mined for many years in the Middleback Ranges, where the iron-bearing beds occur in a linear much folded belt with a strike length of 40 km. The important deposits are all in tight synclines. The original jaspilite ores have undergone surface enrichment to high-grade hematite ore, but at depth contain magnetite, dolomite, and talc, as well as hematite (Owen & Whitehead, 1965).

Many magnetic anomalies have been drilled to reveal iron formations below the veneer of superficial cover. In the northwest of the Gawler Block very fine-grained jaspilite deposits near Tarcoola contain 40 - 50 percent iron in parts, and farther northwest at Mount Christie metajaspilites in granulite terrain show some degree of surface enrichment (Whitten, 1965).

Quartz veins near Tarcoola in low-grade metasediments and intrusive granites were mined for gold - the lodes contained iron oxides at the surface and probably became pyritic at depth. Lead and bismuth were noted in the gangue of one deposit (Gee, 1908, pp. 284-307).

Gold was mined near Earea Dam, 56 km southeast of Tarcoola. A showing of tin in a quartz vein is also recorded from here.

A minor occurrence of molybdenum and tungsten is recorded on Spilsby Island (Blissett & Warne, 1967).

Along the eastern margin of Eyre Peninsula a number of small deposits of lead, silver, and copper occur in metasediments. None appears to have produced any quantity of metal, although rich specimen material was obtained. Radioactive anomalies have led only to trace quantities of uranium (Johns, 1961).

The copper deposits of Wallaroo and Moonta on Yorke Peninsula were large and initially very rich, but towards the cessation of production the grade was falling below 4% copper. The Moonta lodes occur in late-phase acid volcanics. They formed three concentric arcs convex to and dipping steeply to the northwest. Pyrite became dominant at depth. The nearby Wallaroo lodes were in schist and phyllite, and contained galena and scheelite with chalcopyrite as the principal copper mineral (Crawford, 1965). Smaller deposits in the area were rapidly worked out.

ALBANY-FRASER BELT

The Albany-Fraser Belt wraps round the southern and eastern margins of the Yilgarn Block. It has been interpreted as a later metamorphic belt imposed on rocks deposited in the Archaean (Morgan, Horwitz, & Sanders, 1968). However, Wilson (1969) considers the Albany-Esperance (the southern) section of the belt to be a 'late Proterozoic orogenic belt', and considers the northern Fraser section as resembling the Grenville Front of Canada as it is cut off from the Yilgarn Block by a marked fault zone. Wilson suggests metamorphism at about 1 330 m.y. for the Fraser Range, followed by gabbroic intrusions in the late phases of metamorphism, and late-phase pegmatites. In the Albany-Esperance section both homogeneous and folded foliated granites post-date the metamorphism, and a similar granite occurs at the southern end of the Fraser section.

The belt has only a few scattered traces of metalliferous minerals, mainly copper in the Fraser section. The best possibility of economic mineralization would appear to be in laterites developed over the gabbroic bodies, which might bear nickel. The veneer of cover of the Tertiary Eucla Basin is thin for a considerable distance eastward, but thick enough to defeat current geophysical prospecting methods.

MUSGRAVE BLOCK

The Musgrave Block straddles the western part of the border between Northern Territory and South Australia and extends into Western Australia. Its tectonic history is complex, with multiple deformations which make its evolution very difficult to unravel.

Thomson (in Parkin, 1969, pp. 39-46) states that the oldest rocks are granulites with metagranites; these and younger rocks deposited on them were affected by two periods of severe deformation at about 1 150 m.y. and 1 040 m.y. Between these periods basic and ultrabasic intrusions were emplaced about 1 090 m.y. in a pattern determined by block faulting.

Daniels (in prep.) has mapped the Western Australian portion of the block. Again granulites form basement to later sequences. He has noted the same sequences of events, but has placed different interpretations on them. The granulites are overlain by a sequence of volcanics, both acid and basic, and sediments including quartzites which were folded and then intruded by thick gabbroic and ultrabasic sills. At the same time cauldron subsidences developed and were filled by acid volcanics and granites with occasional basic intrusives, suggesting contemporaneity with the gabbro-ultrabasic intrusions. These were followed by acid and basic volcanics with some interbedded conglomerates, and the whole folded at about 1 040 m.y.

Nickel is the major metal occurrence so far discovered in the area. The ultrabasic intrusions carry small quantities of nickel substituted for iron-magnesium in the lattice structures of olivine. The nickel has been liberated in weathering and concentrated in laterites, but the low grade (1% Ni or less) and the remoteness of the deposits have not encouraged exploitation (Sprig, 1965).

Minor copper deposits are present on the block in South Australia and Western Australia; a small amount of oxidized copper ore has been mined in the Warburton Ranges. Daniels (1969) noted copper minerals occurring in basalt interbedded with conglomerate, and tungsten with lead and zinc in acid volcanics of a cauldron subsidence area.

Magmatic layering in gabbros in the Jamieson Range and at Domeyer Hill in Western Australia contains magnetite bands that are enriched in titanium and vanadium. Daniels (in prep.) quotes figures for average vanadium content of 1.21% V_2O_5.

Pegmatites in the southeast of the Musgrave Block contain thorium-bearing monazite, but no production has been recorded.

Wilson (1969, a & b) has suggested that the Musgrave Block with its largely granulite terrain owes its apparent sparse mineralization to two factors: the absorption of available metal ions by substitution in small proportions into mineral lattices which do not normally accommodate them; and the formation of unusual mineral species which may be high in desirable metal content. In view of these possibilities attention should be paid to geochemical methods of exploration and to laterites developed on the granulites.

THE NORTHAMPTON BLOCK

The Northampton Block in Western Australia has also been referred to as the Greenough Block (Daniels & Horwitz, 1969). It consists of garnet-bearing granulites with an apparent age of 1 040 ± 50 m.y. (Compston & Arriens, 1968) and a high Sr^{87}/Sr^{86} ratio, suggesting reworked older material. The only well delineated units are prominent complexly folded quartzite units (Jones & Noldart, 1962).

The block is cross-cut by numerous dolerite dykes, all with a northeast trend and, where followed in mine workings, a steep dip to the northwest. All known metalliferous deposits lie in or next to the dolerite dykes, which are hydrothermally altered. The lodes are of two types - either lead-bearing or copper-bearing: each carried only a little of the other minerals. The lead lodes contained zinc and a little silver. Information on the copper lodes is scant, but they carried no gold and were small (Campbell, 1965).

CENTRAL AUSTRALIAN PLATFORM COVER

Deposition of the Central Australian Platform Cover occurred during Adelaidean and early Palaeozoic times in a broad north-south zone westward from about 142°E across Australia.

The Arafura Basin, which developed late in the Proterozoic, appears to extend from the Northern Territory under the Arafura Sea into the western part of New Guinea. The only known metalliferous deposits in this basin are on offshore islands and have developed because of lateritization of favourable rock types. Small beds of sandy hematite and hematitic sandstone have been derived from iron-rich sediments on Elcho Island. Bauxite occurs along the chain of islands (the Wessel Islands) which includes Elcho Island; it apparently formed from one favourable formation and now occurs along its strike (Roberts, Plumb, & Dunn, in prep.).

The broad swath across North Australia of the Central Australian Platform cover is made up of Adelaidean sediments, mainly to the west in the Victoria River Basin; and the spread of the Georgina-Wiso-Ord-Daly River Basins in which deposition started very early in the Palaeozoic as basic volcanics flooded across the region (Dunn & Brown, 1969). The basalts of carry a little copper in the west, but mineable concentrations have yet to be discovered. In the east, where the cover laps onto the Mount Isa Block, Mid-Cambrian limestones have recently been recognized as host rocks for sedimentary phosphate deposits in the Georgina Basin. The deposits are confined to areas where sedimentation was very slow and restricted, and some secondary processes are probably involved (Thieme, 1971; Thomson & Russell, 1971; de Keyser and Cook in press). Phosphates were also deposited in the Amadeus Basin and the Adelaide Geosyncline during the Cambrian, but no large deposits have yet been found.

Large galena crystals in Cambrian dolomite near the southern margin of the Georgina Basin have been recorded (Smith, 1965), but the occurrence appeared to be only of mineralogical interest.

Apart from minor showings of copper, no mineralization has been detected in the Amadeus Basin, nor in the Ngalia or Officer Basins. The Adelaide 'Geosyncline' is the site of widespread mineralization, but it has been treated in this commentary with the Kanmantoo Belt because the mineralization is continuous from one to the other, and appears to be the result of Kanmantoo diastrophism (see p. 53).

The Bangemall Basin contains manganese deposits in the north, east of the Pilbara Block, where they result from secondary concentrations of manganese-rich late Proterozoic sediments, probably mainly during the Tertiary (Noldart & Wyatt, 1963). Similar residual and sedimentary deposits in the Horseshoe/Peak Hill district have a similar origin (Macleod, in press). The copper mining centres of Thaduna (Blockley, 1968) and Ilgarari (Low, 1963) lie in sediments of the Bangemall Basin. Thaduna mineralization is in a fault zone and Ilgarari in discordant quartz veins.

In Western Australia the Canning and Carnarvon Basins began to form in the late Proterozoic and sedimentation continued until the Permian. The Narlar[illegible] lead-zinc deposit is situated in Devonian limestone (Halligan, 1965) within the Canning Basin in the mobile margin of the Fitzroy Trough,

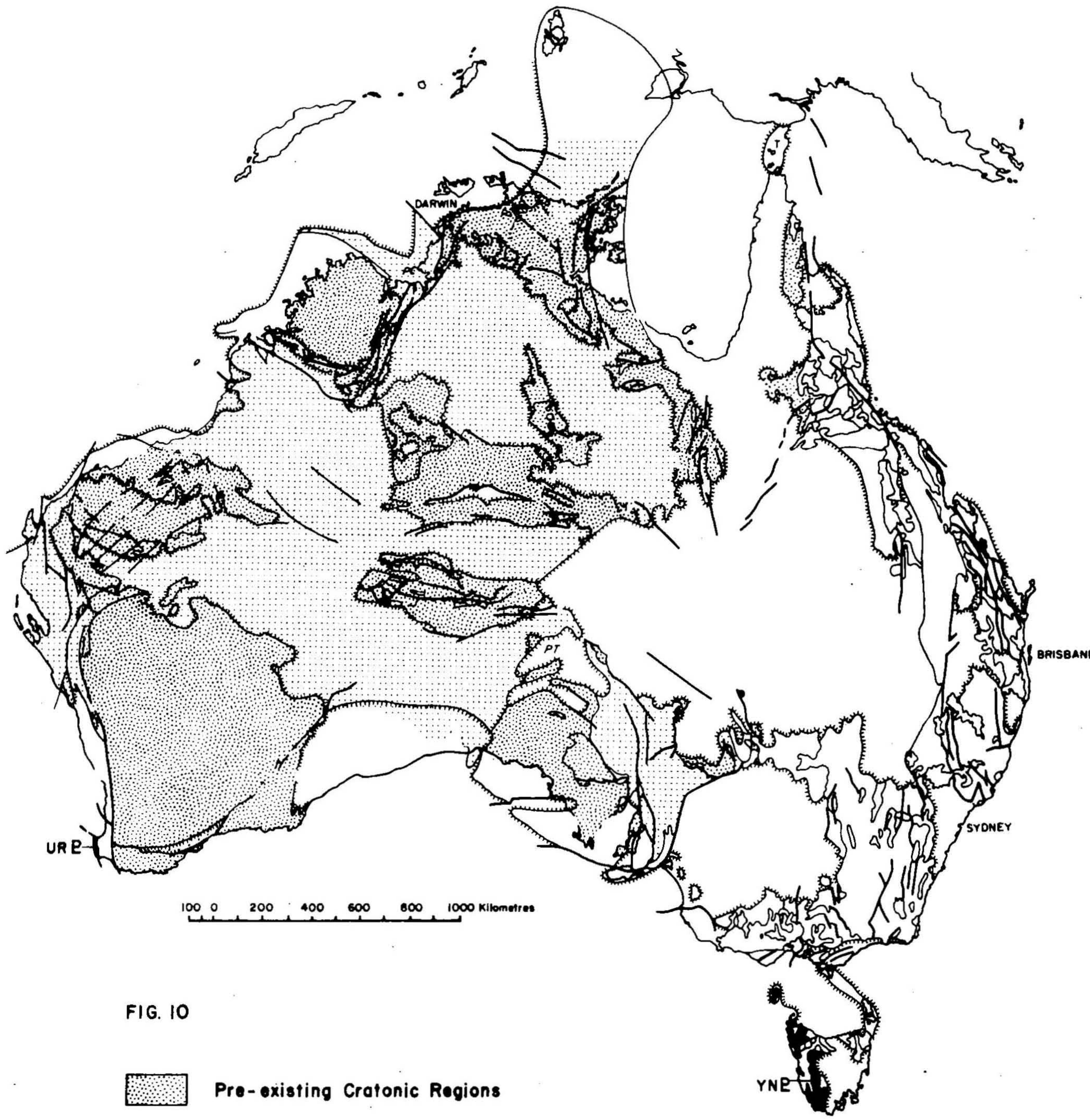

FIG. 10

Pre-existing Cratonic Regions

Central Australian Platform Cover

Late Precambrian Orogenic Domains P

URP Naturaliste

YNP Tyenna-Rocky Cape

To accompany Record 1972/56

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close to its boundary with the King Leopold Mobile Belt. It is an irregularly shaped body of coarse-grained ore material within the limestone, with no obvious hypogene characteristics. Two origins have been suggested: that the ore minerals were introduced by groundwater percolating from the basement; and that the ore was a detrital concentration, later remobilized to some extent.

THE LATE PRECAMBRIAN OROGENIC DOMAINS

Two distinct units belong to the Late Precambrian Orogenic Domains. One is the Tyenna/Rocky Cape Block in Tasmania; the other, the Naturaliste Block, which crops out in the extreme west of the continent, may form basement beneath the Perth Basin.

In addition to these units there is evidence of craton mobility in several areas. The King Leopold Mobile Belt and the southern margin of the Kimberley Basin (North Australian Platform Cover) was folded by an event about 600 m.y., after which the Fitzroy Trough and the Bonaparte Gulf Basin were initiated. The northern margin of the Musgrave Block and the southern margin of the Amadeus Basin were involved in folding movements toward the end of the Precambrian with a subsequent downwarp in the Amadeus Basin. Aeromagnetic and seismic work suggests that similar structures continue northwest beneath the southwestern margin of the Canning Basin.

The Adelaide 'Geosyncline' was mildly folded at intervals during its downwarp in the late Proterozoic, with regional unconformities and movements in the diapiric structures.

THE TYENNA/ROCKY CAPE BLOCK

Basement beneath Cambrian and later platform cover in Western Tasmania is made up of two low to medium grade deformed metamorphic units referred to in Tasmanian literature as the Older and Younger Precambrian. The Older Precambrian consists of schist, phyllite and amphibolite, and the Younger Precambrian is made up of relatively unmetamorphosed rocks of similar parent lithology. The two may be separated by an orogenic event, or the Younger Precambrian may be the undeformed equivalent of the Older Precambrian. Lower limits set to their age are given by a 700 m.y. date from a dolerite dyke and a total rock age of 835 $\pm$ 60 m.y. on an intrusive granite on King Island (Solomon, 1965; Compston & Arriens, 1968).

The rocks of the block are hosts to mineralization introduced by Devonian granites which belong to the transitional domain of the Lachlan in Tasmania but also carry iron deposits apparently introduced before the Cambrian. These include the minor iron occurrences of the Penguin district on the north coast and the major deposits of the Savage River region in the west. The Savage River deposits contain magnetite in or adjacent to schistose amphibolites. Some pyrite and a little chalcopyrite are present. The area underwent carbonate metasomatism at about the same time as the formation of the orebodies, which are interpreted as hydrothermal (Urquhart, 1966).

THE NATURALISTE BLOCK

The Naturaliste Block has been shown by regional mapping to consist of three layered units, all granulites, intruded by sheets of granite-gneiss (Lowry, 1967). It is separated from the Perth Basin by a fault zone. Age determinations give a date of 650 m.y. for the metamorphism (Compston & Arriens, 1967).

There is no recorded mineralization in the block.

UNASSIGNED PRECAMBRIAN OROGENIC DOMAINS

Several blocks cannot be assigned to Provinces, either because their age is unknown, or because the platform that overlaps them is so much younger than the age of stabilization of the block that the relationship between Platform Cover and Province does not hold. They are: the Arunta Block (probably a composite unit), the Georgetown Block (definitely composite), the Arnhem Block, and the Litchfield Block.

THE ARNHEM BLOCK

The Arnhem Block appears to be Archaean in age (Dunn, 1971). Its main economic interest lies in the important bauxite deposits developed on the Cretaceous (or pre-Cretaceous) land surface over granites of the block at Gove.

THE LITCHFIELD BLOCK

The Litchfield Block may in part be Archaean (Dunn, 1971) but the granites that intrude it may be younger. No economic mineral deposits have yet been found in it.

THE ARUNTA BLOCK

The metamorphic complexes making up the Arunta Block are poorly exposed, and regional mapping has mainly been confined to the margins, adjacent to younger platform cover. The Tanami-Granite Belt may well be continuous with the northern Arunta Block. At least two periods of sedimentation and deformation can be deciphered (Shaw & Warren, in prep.), and the Block may contain equivalents of both the North Australian and Central Australian Orogenic Provinces.

Detailed studies are revealing several overprinted events in the Precambrian, and a well defined Devonian-Carboniferous event - mobilization along the northern margins of the Amadeus and Ngalia Basins (Wells, Forman, Cook, & Ranford, 1971), when structures were overprinted on the existing metamorphic complex.

Age determinations in the range 1 700-1 800 m.y. (R. Bennett, pers. comm.) indicate affinities with the Central Australian Orogenic Province. Two facts tend to support this: platform cover on the Arunta Block is at oldest Central Australian Platform Cover except in the Barrow Creek district; and the Tennant Creek Block and the North Australian Platform to the northeast are cut by platform granites with similar ages to syntectonic and post-tectonic granites along the northern margin of the Arunta Block. Nevertheless, part of the Block must be older tha Central Australian Orogenic Province.

Mineralization is sparse and most known metal occurrences are small.

In the northeast, the Jervois mining area contains copper lodes over a stretch of 10 km, with some lead, bismuth, and tungsten. Small-scale operations have produced less than a thousand tons of copper in various forms (Smith, 1964), but recent drilling indicates the presence of at least two larger orebodies with good grades of copper, lead, silver, and bismuth. The lodes lie along one stratigraphic horizon within a synform with a northerly plunging axis. The pattern of metal distribution suggests a syngenetic origin. The area also contains stratigraphically controlled but hypogene scheelite mineralization and some fluorite (Robertson, 1959).

The Home of Bullion lode lies within the Arunta Block, close to the northeast margin at a discordant junction between two groups of metamorphic rocks. It was mined for its copper content but lead and zinc are also present. Sullivan (1953) estimated the reserves of ore to be considerably larger than the recorded production to the time when the mine closed in 1955. Small-scale production has begun again more recently.

Some very small lead, copper, and gold mines were worked close to the Devono-Carboniferous structures north of the Amadeus Basin, and are presumed to be of this age.

The only carbonatite so far definitely identified in Australia lies in the Arunta Block. (The presence of others in Western Australia is rumoured - see p. 40.) It has been disjointed by later faults. It has been investigated for rare earths and phosphate, but appears to have little economic potential beyond specimen material (Gellatly, 1969).

GEORGETOWN BLOCK

The Georgetown Block consists of three exposures separated by Trans-Australian Platform Cover: the Georgetown Inlier, the Yambo Inlier to the north, and a narrow basement high in Cape York. The three appear to have acted as a unit since the early Palaeozoic, but their inter-relationship before that time is not clear.

Georgetown Inlier

At least two cycles of deposition and deformation are known in the Georgetown Inlier: a sequence of high-grade gneiss intruded by granites, and a younger, less deformed but thick sequence also intruded by the granites. The age of the rocks is uncertain. A date of 1 000 m.y. was obtained on metamorphics in the northeast; the Forsayth Granite gives an age of 1 200 m.y., and the Robin Hood Granite appears slightly younger; and the Croydon Volcanics in the west have an age of 1 460 m.y. (Richards, White, Webb, & Branch, 1966).

Much of the mineralization in the Inlier has been introduced by activity spreading from younger mobile zones.

The Woolgar Goldfield is situated in an inlier of high-grade metamorphics south of the main Georgetown Block; the lodes occur along the margins of pegmatitic granite dykes which intrude the metamorphics (Saint-Smith, 1922).

The Halls Reward copper lode, close to the Burdekin Fault which marks the southeast margin of the Block, is also situated in the old metamorphics, but within a shear zone. The ore came mainly from the oxidized zone and carried variable gold and silver values. Again the age of mineralization is not known, but the intrusion of nearby ultrabasics during the Devonian appears the most likely causal event.

The younger rocks are lower-grade metamorphics, which have been mapped out in more detail (White, 1965). They serve as host to silver-lead mineralization southwest of Georgetown, copper at Ortona and near Gilberton south of Forsayth, and gold adjacent to later granitic intrusions. None of these deposits is large.

The Block is cut by granites of several ages. The oldest include the Forsayth and Robin Hood Granites, both of which are hosts to gold mineralization. The lodes in the Forsayth Granite are localized in fissures. All the information available has been summarized by White (1965): few mines produced more than 10 000 oz and mining was generally confined to the enriched ore above the water table, below which the ore became refractory.

The Croydon Volcanics and the Esmeralda Granite have been the subject of some controversy. Age determinations indicate a Precambrian age. The Volcanics have an age of 1 460 m.y. and the granite a reset age of 515 m.y., although a more probable age is 1 200 m.y. (Richards et al., 1966). These are consistent with field observations by Jensen (1940) and Clappison (1940) that the Esmeralda Granite intrudes the Croydon Volcanics. Both granites and volcanics are hosts to gold-silver ores at Croydon (Edwards, 1953). The main control seems to be fissuring, but the presence of graphite correlated with the location of richer zones of ore. South of Croydon the Esmeralda Granite carried minor tin mineralization (Clappison, 1940; Jensen, 1940).

The Mid-Devonian granite intrusions seem to be barren. Ultrabasics, also Mid-Devonian, which lie partly in the Georgetown Block and partly in the Broken River Embayment, introduced chromite. The Tertiary laterites developed over them are nickel-bearing, and include the Greenvale nickel deposit.

Igneous activity of the Hodgkinson transitional domain is confined to ring structures and cauldron subsidence areas (Branch, 1966) within the Block, but is more widespread along the margin of the Block adjacent to the Hodgkinson Belt. Several phases of granite have been recognized, and various authors have assigned metallogenic provinces to one phase or another depending on the relationships observed in the areas they have mapped (refer to the Hodgkinson Fold Belt for detail). Branch (1966) is of the opinion that much of the mineralization, including tin, tungsten, lead, copper, and fluorite, in the Georgetown Inlier was introduced during this later tectonic episode. The copper ore at Einasleigh occurs in high-grade metamorphics which were intruded by amphibolite, deformed, and intruded by aplite and porphyry, which all antedate the orebody (Queensland Department of Mines, 1953). Since the porphyry is part of the transitional phase, the igneous activity of the Hodgkinson domain to the east of the mineralization is also a late Hodgkinson event. The lodes, localized in favourable bands in the schists, contain copper, molybdenum, and zinc sulphides in pyrrhotite.

The Yambo Inlier

The Yambo Inlier (Willmot et al., in press) appears to be best correlated with the high-grade metamorphics in the north of the Georgetown Block. Granite samples have given Devonian isotopic ages, but Wilmott et al.

incline to the view that this is an overprinted age of Precambrian granites. Mining activity in the Inlier has been confined to the recovery of alluvial gold which was carried by the Palmer River from lodes in the nearby Hodgkinson Belt.

The 'Spine of Cape York'

The 'Spine of Cape York' is a basement ridge of Precambrian rocks extending from 12°S to 16°S down the eastern margin of Cape York. It consists of low-grade metamorphics, intruded by granites which, like those in the Yambo Inlier, give a Devonian isotopic age but which are also more probably overprinted Precambrian. Late Carboniferous to Permian volcanics and granites which intrude the 'Spine of Cape York' may correlate either with late Hodgkinson or early Hunter-Bowen events to the south - the two overlap in time. The ridge is separated by a shallow trough of Trans-Australian Platform Cover from the Torres Strait Basement High, which contains only late Palaeozoic volcanics and granites without any visible older basement. Several units have been recognized in the metamorphics. At Iron Range a small hematite lode occurs in metamorphosed iron-rich sediments (Canavan, 1965). Apart from some small antimony lodes, the main metal mined has been gold. Two gold fields, Coen and Ebagoola, are aligned with shear zones.

The tungsten at Bowen and minor tin deposits seem to have affinities with Hodgkinson Transitional Phase mineralization farther south, having been introduced by the late Palaeozoic acid igneous activity.

THE EAST AUSTRALIAN OROGENIC PROVINCE

The folded rocks of eastern Australia were formed and deformed by a number of partly overlapping tectonic events from Cambrian to Upper Triassic, giving rise to sub-parallel belts elongated nearly north-south with the older rocks to the west and the younger in the east. The area has been referred to in older literature as the 'Tasman Geosyncline', a term now falling into disuse.

The Kanmantoo Belt in South Australia and western New South Wales is the oldest part of the province; the only deformation occurred early in the Ordovician, and affected the adjacent platform margin. Contemporaneous movements occurred in Tasmania but did not mark the end of sedimentation in that area.

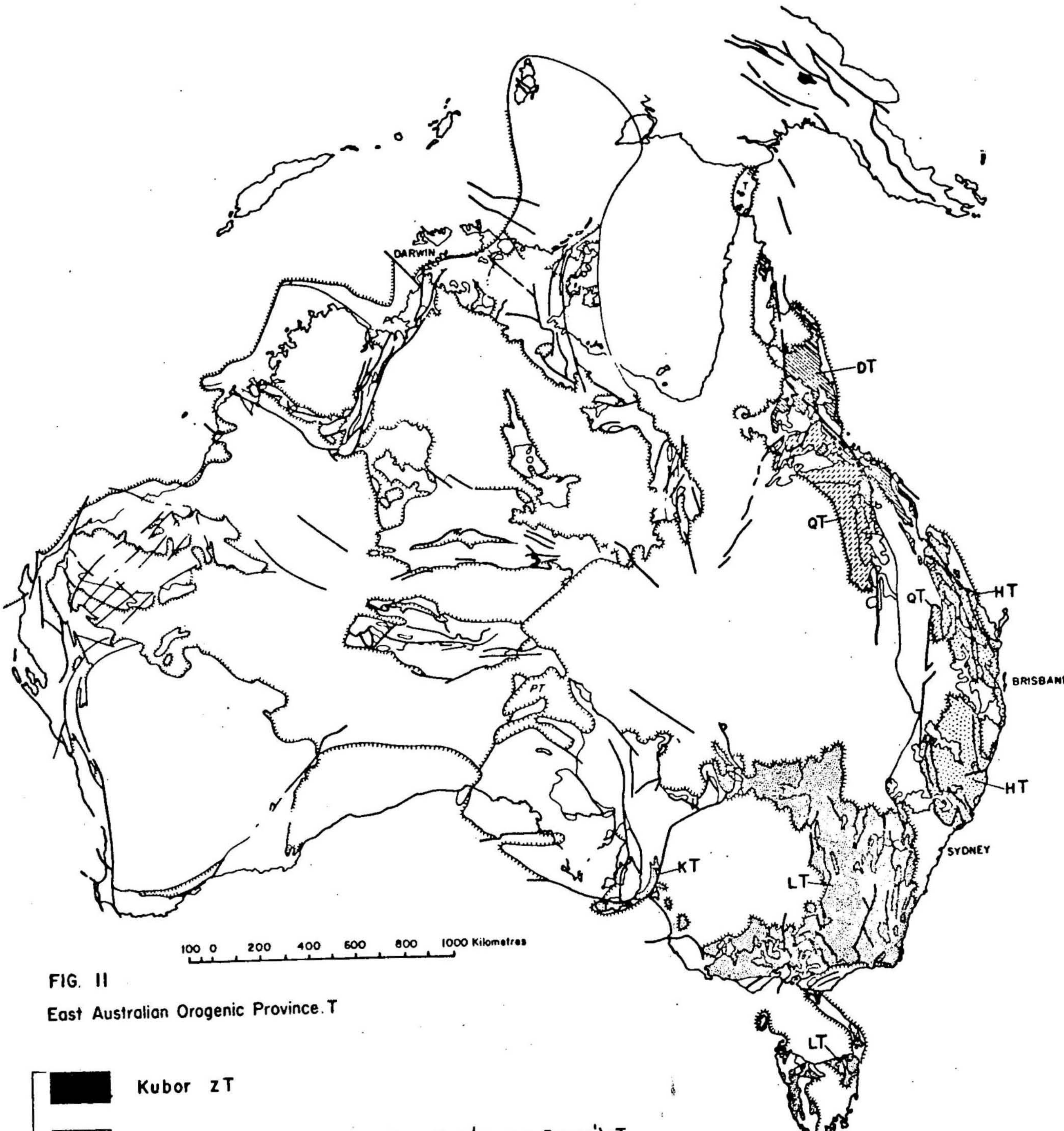

FIG. 11

East Australian Orogenic Province. T

Orogenic Domains

- Kubor ZT
- New England - Yarrol (formerly called 'Hunter - Bowen') HT
- Hodgkinson DT
- Lachlan LT
- North Queensland QT
- Kanmantoo KT

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Apart from the Kanmantoo Belt, the western part of the East Australian Orogenic Province is made up of the Lachlan Belt and its time equivalents in north Queensland. The western margin is visible only along the fault-bounded trough of the Broken River Embayment in north Queensland. The Cork Line under the Great Artesian Basin appears to be both the linear continuation of the margin of the Broken River Embayment and the division between Precambrian and Palaeozoic basement beneath the Basin. Several deformational events from the Lower Ordovician to the Mid-Devonian affected these domains, and transitional domains developed during the Carboniferous. Granites corresponding to all the phases of deformation are known. Rocks thought to be originally deformed by Lachlan events are known in the younger fold belts to the east of the Sydney-Surat-Bowen Basins.

The folded Hodgkinson Belt is separated from the Precambrian Georgetown Block by a major fault, whose suspected southeasterly extension would also divide it from the north Queensland blocks. The Hodgkinson Belt was deformed in the Lower Carboniferous, after which a short period of sedimentation was followed widespread acid volcanism along the faulted margin which with comagmatic granite intrusion extended into the older craton. This activity died down by the Permian. However, the Hodgkinson Belt was twice intruded by granite and block-faulted during the Permian, at times that may be correlated with movements in the Hunter-Bowen area.

The youngest fold belt, formerly known as the Hunter-Bowen Belt from its approximate southern and northern limits, has been called the New England-Yarrol Belt for the Tectonic Map. As mentioned above, it may incorporate a basement of Lachlan and North Queensland domain, but the major phases of deformation occurred in the Upper Carboniferous, Permian, and earliest Triassic with transitional developments during the Triassic. Instead of the recognizable sub-belts and basins of the Lachlan Belt, this region is characterized by block faulting. The only recognized troughs are along the western margin: the Tamworth Trough and the Yarrol Basin, the latter passing into deformed platform cover to the west and north of the Gogango Zone of overfolding.

THE KANMANTOO BELT (with the adjacent folded Central Australian Platform Cover)

The Kanmantoo Trough in South Australia developed as a marked downwarp along the eastern margin of the Adelaide 'Geosyncline' in the Cambrian, and was deformed early in the Ordovician to form the Kanmantoo Belt. The deformation extended into the Adelaide 'Geosyncline' and severely affects the platform cover north to the Willyama Block. Deformed Kanmantoo rocks have also been recognized to the northeast of Broken Hill.

The Adelaide 'Geosyncline' is regarded as platform cover - although it is very thick, basement is exposed on both margins and the deformation is in the form of broad folds and faults which widen into breccia zones and 'diapirs'. Much of the deformation is attributed to movement of basement blocks at several stages during the sedimentation, which began about 1 400 m.y. ago. Basic volcanics appear close to the base of the succession in the west and against the basement upwarp of the Mount Painter Block. The succession includes a persistent sedimentary magnesite bed and two episodes of glacial sedimentation (Thomson, 1965; Thomson in Parkin, 1969, p. 49-83). The diapirs appear to have been formed by the upward movement of fine-grained semi-plastic sediments from low in the sequence under stress at times of tectonism. Those studied in detail carry large exotic blocks and their margins show evidence of several upward movements (Coats, 1963).

The Kanmantoo Belt and the adjacent Adelaide Geosyncline are characterized by widespread deposits of copper, lead, gold, zinc, and barium, and a more limited zone of manganese deposits. B.P. Thomson p. 107 in Parkin 1969 considers that most of the mineralization was introduced during the early Ordovician deformation and metamorphism of the Kanmantoo Trough (Delamerian Orogeny). Gold is confined to the eastern section of the folded region - a zone in the Mount Lofty Ranges in and to the east of the basement highs, a small area near Orroroo and Peterborough, and a zone along the southwestern margin of the Willyama Block. This rims broadly the area of granite intrusion and corresponds to the biotite zone of Oppler & Fleming (1968). The richest deposits were in the southern section. Dickinson & Sprigg (1953) also show occurrences in the Flinders Ranges, but these were very small.

The copper, lead, and zinc mineralization is more widespread. The largest copper mines were mostly either in the Kanmantoo Belt (e.g. Kapunda) or not far from it (e.g. Burra). There are two exceptions, he Blinman Mine and the Mount Gunson deposit. The Blinman Mine is situated in an exotic block brought up in the Blinman Dome, one of the diapiric structures. The diapirs form one locus of copper mineralization in the Flinders Ranges; another is unconformities, especially those associated with glacials, and a third the basic volcanics rimming the Mount Painter Block (Johnson, 1965). The Mount Gunson deposits lie in the thin, relatively undeformed western margin of the Adelaide 'Geosyncline'. They are irregular tabular bodies, almost horizontal in sub-horizontal sandstone, grit, and dolomite (Johns, 1965). Recent studies by Lambert, MacAndrew, & Jones (1971) indicate that present day groundwater circulation is causing leaching of the old deposits and reprecipitation in the adjacent lagoon. They consider that the older deposits are not hypogene. Manganese and bauxite occurs nearby (Pernatty Lagoon, q.v.).

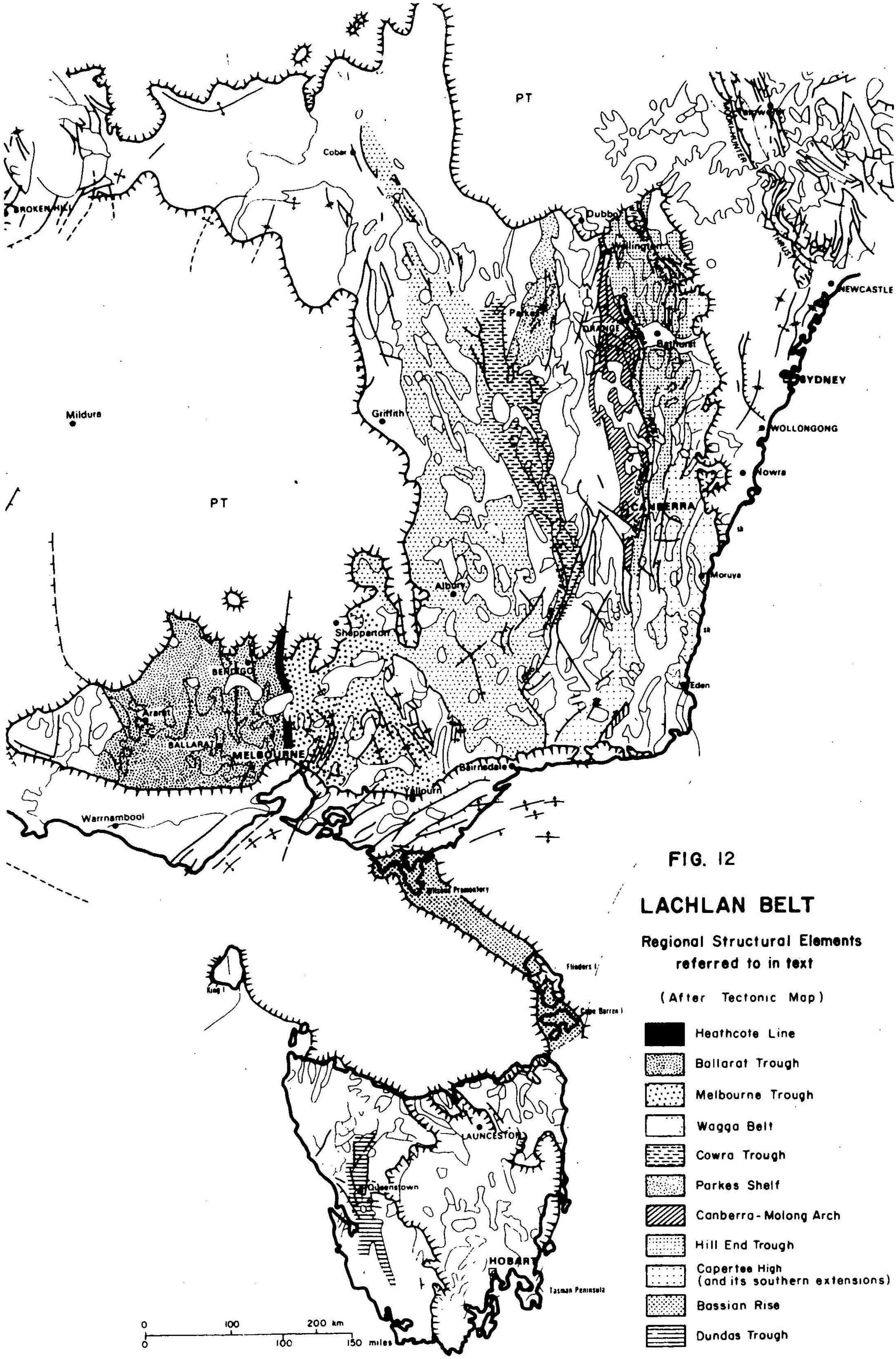

FIG. 12

LACHLAN BELT

Regional Structural Elements referred to in text

(After Tectonic Map)

Lead occurs less commonly than copper; the deposits tend to be small. Johnson (op. cit.) observes that Lower Cambrian dolomites are the most favourable host rock - the Ediacara deposit is a large, low-grade dissemination of silver-bearing galena in Lower Cambrian dolomite with minor copper. Sedimentation features appear to have a control over the location of mineralization.

Zinc was largely ignored in the early mining history of the region. The complex oxidized zinc-copper-silver silicate ores at Mount Fitton, in the extreme north, received some attention, but metallurgical problems discouraged progress (Ridgeway, 1950). A large zinc silicate deposit at Beltana is being evaluated at present.

Barite is widespread, both in the folded region and in the shelf zone at Mount Whyalla southwest of Port Augusta. Most lodes are either veins or lenses; there seems to be no stratigraphic control. The Pernatty Lagoon deposit (Mount Gunson area) contains barite closely allied to manganese. Many of the deposits carry iron oxides as impurities.

Manganese in the Pernatty Lagoon deposit forms residual cappings over manganiferous dolomite. Other manganese lodes are confined to an area northeast of Port Augusta in the folded zone - they are either veins or in fault and crush zones. Some supergene enrichment may have occurred.

Within the Kanmantoo Trough a sedimentary pyrite bed has been traced over many kilometres. Although it is quarried for its sulphur content, the bed also carries several times background values of lead, zinc, copper, and silver (Mirams, 1965).

In the northwest of New South Wales, rocks of similar age to those in the Kanmantoo Belt have been mildly to extensively deformed by events during the late Cambrian and Ordovician. They are overlain unconformably by less deformed Ordovician sediments (Kanmantoo transitional domain also referred to as the Gualta Transitional Province). The region carries minor copper and lead mineralization. The small gold deposit at Tibooburra was introduced by a granite that has been dated as Silurian (Rose & Brunker, 1969, Pogson & Scheibner, 1971; Scheibner, 1972).

LACHLAN BELT

The Lachlan Belt occupies the southeast of Australia, extending from Tasmania northwards to Bourke in central western New South Wales and west to the border between Victoria and South Australia. The eastern margin lies beneath the Sydney Basin, and the junction in the west with the

Kanmantoo Fold Belt is obscured beneath basin fill of the Darling Basin (part of the transitional Lachlan domain) and Trans-Australian Platform Cover. The granites near Hungerford on the southern Queensland border are inliers of the Lachlan. The older rocks caught up in the New England-Yarrol Belt will be discussed as part of that belt.

The Lachlan Belt may be divided into a number of units with different histories (Fig. 12), both in style and time of sedimentation and in type and time of deformation. Boundaries between these units are rarely clearcut, but broad units may be recognized, as for example those outlined by Packham (1969) or those proposed by Schneiber (1972).

The Ballarat Trough

In western Victoria, west of the Heathcote line made up of the Mount William, McIvor, and Mount Ida faults, an area of sediments ranging in age from Cambrian to late Ordovician has been strongly folded along north-south axes. The Cambrian is exposed only as thin slices immediately west of the Heathcote line as a mainly basic volcanic sequence with interbedded cherts and black shales (Talent & Thomas, 1967). The Ordovician sediments are a deepwater sequence of geosynclinal greywackes with some interbedded pyritic shales (Singleton, 1965). The age of the deformation is uncertain; early workers thought it to be Mid-Devonian, but by consideration of the remainder of the Lachlan region it is more likely to have occurred late in the Ordovician during the Benambran Orogeny.

This region of folded rocks has been shown on the map as virtually coincidental with a gold province, but the pattern of metallogenesis is quite complex. The close, often isoclinal folding has provided suitable lower pressure sites for mineralization at the axes of folds - Bendigo was famed for its saddle reefs (Thomas, 1953), but saddle reefs were also prominent in other fields. On the Ballarat-Wedderburn line of lodes, faults with strikes nearly parallel to the fold axes post-date the folding and cut the axial planes of the folds at acute angles, in places following the limb of a fold. These faults bore gold, but concentration increased spectacularly where the fault crossed certain favourable beds, in particular a pyritic shale (Baragwanath, 1953).

The granitic intrusives in the area are of several ages; Singleton (op. cit.) states that gneissic granodiorites at Ararat and Pyrenees have gneissic margins, and so these are classed as synorogenic; whereas a number of later granites such as the Harcourt Granodiorite crosscut the grain of the country and have been classified as part of the late Devonian-Carboniferous Lachlan transitional domain, extending beyond the Ballarat Trough.

The information on gangue minerals and associated metals is far from complete, and detailed studies should prove rewarding - at present only generalizations are possible. McAndrew (1965) implies that most lodes in the Ballarat Trough would be quartz-gold with pyrite. However, zinc and lead sulphides occur in the lodes at St Arnaud and the Pyrenees (where there are syntectonic granites); arsenic-bearing lodes have a wide distribution; and antimony-gold lodes occur but are more widespread in the tectonic units to the east, suggesting that these at least belong to the later phases of tectonism.

Molybdenum and bismuth at Maldon are sited close to the margin of a transitional domain granite.

Mining concentrated on gold, and the literature is therefore extremely biased toward gold. Studies are also handicapped by the lack of geological mapping in the mines during their working history, and of mineragraphic studies. Mining began with the readily accessible alluvial gold, extended to deep leads beneath the Tertiary basalt cover, and only as the easily won surface gold was depleted did attention swing to the lodes, some of which were found by tracing alluvial leads to their source.

The Melbourne Trough

The Melbourne Trough developed east of the Heathcote line and west of the southern part of the Wagga Metamorphic Belt. Both the western and eastern margins supplied sediments which were deposited mainly in shallow water. The Trough formed in the early Silurian on a relatively undeformed Ordovician sequence after the Benambran Orogeny and was terminated by the Tabberabberan Orogeny in the mid-Devonian, the effects of which were much more marked along the eastern margin. The eastern margin was also later the site of volcanic activity during the Lachlan transitional phase, and Lachlan transitional domain granites were intruded both along this margin and within the trough.

The folded rocks of this trough are extensively mineralized; most deposits were mined for gold and recorded primarily as such, but antimony seems to have been present in many lodes. At Costerfield the lodes were mined first for their gold content but later also for their antimony content - they are quartzose veins, which post-date folding and faulting (Stillwell, 1953) but are not close to any igneous activity.

Many of the gold deposits of the Walhalla Synclinorium occupy fracture systems within basic dykes. All the lodes are quartzose, but the minor sulphide content varies - antimony, arsenic, lead, zinc, and copper are all recorded (Edwards, 1953). At the southern end of the synclinorium the Thompson River copper mine has yielded small quantities of copper and platinoid metals. The lode also carried nickel, but it is associated with a hornblende diorite dyke, and there are no ultrabasic rocks in the vicinity.

The dykes in the Melbourne Trough are referred to by Edwards (op. cit.) as Devonian - it would seem that they either antedate or belong to the same Kanimblan igneous activity as the Lachlan transitional domain volcanics along the eastern margin of the Melbourne Trough and may therefore be late Devonian or early Carboniferous. As the mineralization post-dates the intrusions (though the time interval may be slight) it must be regarded as late Kanimblan. Also, as both the Kanimblan granites and the gold-antimony association are known west of the Heathcote line, it is likely that detailed field analysis would subdivide the single gold province shown west of the Heathcote line into two provinces, one Benambran and the other Kanimblan in age.

The eastern Lachlan (excluding the Hill End Trough)

East of the Melbourne Trough and excluding the Hill End Trough, the elements that make up the Lachlan Belt in mainland Australia have a sufficiently simple history to be treated as one unit for the purposes of this commentary.

The oldest dated rocks are Ordovician, although highly deformed rocks near Moruya are tentatively assigned to the Cambrian. The Ordovician sediments are quartzose greywackes, acid to andesitic volcanics, and black shales and carbonates which were folded by the Benambran Orogeny, which began late in the Ordovician and continued into the Silurian. Accompanying metamorphic effects were limited to the Wagga Metamorphic Belt in the west and a discontinuous belt extending from Cooma southwards into Victoria in the east. Granites giving an age of 415 m.y. have been recognized in northeastern Victoria (Evernden and Richards, 1962) and granites of similar age may exist in the 1:250 000 geological map sheet areas of Cobar, Nymagee, and Cargelligo.

After the Benambran events the region formed several ill defined units (Fig.12). Silurian sedimentation, which was thin and shelf type over the Benambran highs, thickened in the Cowra Trough along the western margin of the Canberra-Molong Arch. Widespread acid volcanics towards the close of the Silurian are preserved in belts paralleling Benambran structures; they precede granites of the Bowning Phase at the close of the Silurian. Along the eastern margin of the Wagga Metamorphic Belt in southern New South Wales a discontinuous narrow belt of serpentine is thought to have been emplaced during Bowning deformation. Northern extensions of this belt are postulated to swing northwest, apparently across the Benambran structural grain, taking in the basic intrusions at Fifield and Honeybugle. Post-Bowning sedimentation is confined to small structural basins near Yass and at Lobbs Hole, which contain (volcanolithic) sediments and marine limestones. The basins are mildly deformed, either by the Mid-Devonian Tabberabberan movements or by the Kanimblan event. The only recognized Kanimblan granites occur in the belt east of the Hill End Trough (and in the trough itself).

Because of the limited information on the age of mineralization, and intrusive rocks in this region, only broad generalizations have been made - postulated provinces have been confined to tectonic units.

The serpentinite zone along the eastern edge of the Wagga Metamorphic Belt highlights a dominant trend of mineralization in the belt. Clustered along the serpentinite zone in the south are deposits of chromite and very small base-metal deposits. The Fifield platinum-gold deposit in the north lies on the postulated northern extension, but the source of the platinum and gold is an ultramafic intrusion, not a serpentinite. West of the serpentinite zone is a zone of gold-quartz deposits corresponding in the south to the axis of the metamorphic zone. The metamorphic effects wane to the north, but the zone of gold occurrences persists to Lake Cargelligo. Farther to the west again but overlapping the gold zone, a zone of tin-tungsten deposits stretches discontinuously from Glen Wills in Victoria to Tallebung, south of Cobar (Cochrane, 1971). In northern Victoria and southernmost New South Wales molybdenum also occurs, but not farther north. There seems to be a spatial relationship between these deposits and a belt of granites, of which those that have been dated belong to the Benambran. However, tin deposits in general tend to be introduced by high-level transitional phase granites

The CSA mine, 11 km north of Cobar, is the largest occurrence in a narrow zone of deposits stretching over some 30 km. The basal unit in the Silurian Cobar Trough is a volcanically derived greywacke, followed by slate and a siltstone which has been metamorphosed to greenschist. Deposits occur in all three units. Although there seems to be some degree of stratigraphic control, the main contact is structural; suitable structures developed during folding and shearing movements. All lodes contain pyrite, pyrrhotite, chalcopyrite, sphalerite, and galena; silver is common and the deposits close to Cobar also contain gold (Kappelle, 1970).

McClatchie (1969, unpubl.) has pointed out the widespread association between Silurian andesitic volcanics and copper occurrences throughout the Lachlan of New South Wales. Few of these deposits are of any size.

Copper mineralization occurs at several localities within the Girilambone Beds east of the Cobar Trough. The age of these beds is unknown, as is the age of the mineralization. Any genetic link amongst these deposits is obscure but McClatchie (op. cit.) postulates a link with ultrabasic bodies to the west; but the haloes of base-metal deposits about ultrabasics tend to be narrow, whereas these deposits are spread over a broad area.

The gold-bearing zone extending northwards from Grenfell through Forbes, Parkes and Peak Hill to Tomingley is sited in a belt of Ordovician sediments and andesitic volcanics overlain conformably by Silurian sediments (Andrews, 1910). The area lies on the eastern margin of the Parkes Platform as defined by Packham (1969, p.6), but seems to have been more mobile than the remainder of the platform. The copper and gold lodes of the Canberra-Molong Arch, in its very faulted northern section where its separation from the Hill End Trough is less distinct, have been related by McClatchie (op.cit.) to Ordovician andesites. Scheibner (pers. comm.) considers that the Forbes-Tomingley zone and the small lodes in the north of the Canberra-Molong Arch are part of the same province, disrupted by later events; the source of the metals would appear to be the Ordovician andesites, affected by the mobility of the region.

Within the Canberra-Molong Arch, scattered very small tungsten and tin deposits in the Frogmore district may be associated with Bowning granites, but the small copper-lead-zinc base metal deposits belong to McClatchie's Silurian acid volcanic group. A gold-bismuth occurrence at Nanima, northwest of Canberra, is in Ordovician rocks, as are numerous very small gold-quartz lodes, and may have been introduced dring the Benambran deformation.

To the east of the Hill End Trough the rocks are folded Ordovician sediments intruded by Benambran, Bowning, and Kanimblan granites. The gold deposits that straddle the New South Wales-Victorian border near Delegate may be comparable to those in the axis of the Wagga Metamorphic Belt to the west in that they lie on the axis of the less well defined metamorphic belt through Cooma.

Very little is known about the deposits of the molybdenum province from Mallacoota north to Bega, with the exception of the well documented Whipstick Mine, which produced gold, molybdenum, and bismuth (Jack, 1953) from pipes near a granite margin. Other deposits in the province are considerably smaller.

Numerous gold localities are recorded in the folded belt north of the Bega Batholith, but even the information concerning the chief producing areas near Braidwood and Araluen is slight. The lodes were confined to a small area of the Bowning Braidwood Batholith, but much of the production was from alluvial material. The gold deposits at Yalwal to the north are adjacent to a Kanimblan granite (Gibson & Le Mesurier, 1962).

A complex copper-tin-arsenic lode at Tolwong in the gorge of the Shoalhaven River occurred in a vien which crosscuts the structure of the folded Ordovician. The metallurgy proved difficult and the amount of metal recovered was not large (Carne, 1911).

The lead deposits at Yerranderie west of Sydney are Kanimblan, occurring in veins cutting Upper Devonian tuffs and lavas near the contact with a Carboniferous acid intrusion (Lawrence, 1953).

The Hill End Trough

The Hill End Trough has been treated separately because of its markedly different history during the Silurian and early Devonian. The belt is at its widest north of the Kanimblan granite at Bathurst and becomes narrower southwards; it is hemmed in between faulted margins towards Captains Flat, south of which it is entirely faulted out.

The basal Ordovician sequences contain andesitic volcanics, with greywackes and some limestones. During the Ordovician there seem to have been no clear-cut margins to the Hill End Trough - preserved Ordovician sequences in the north of the Canberra-Molong Arch and the Capertee Geanticline are very like those exposed in parts of the trough. In the Silurian, however, much thicker sequences containing acid and andesitic volcanics formed in the Trough and this pattern of sedimentation persisted to the mid-Devonian, so that the Bowning Orogeny had little effect on the Hill End Trough. However, the Tabberabberan Orogeny in the mid-Devonian terminated sedimentation.

The mineralization in the Hill End Trough may be divided into three main groups.

Stanton (1955) noted the close spatial relationship between copper ore deposits and subjacent Ordovician andesitic volcanics containing limestone lenses, and concluded that the source of copper was the andesites; the copper, having migrated during folding movements into nearby favourable beds containing large quantities of iron sulphides, was localized in replacement-type orebodies. These deposits occur south of the Bathurst Granite.

The second group is associated with Silurian volcanics, as at Captains Flat. The deposits contain copper, lead, and zinc, with some gold. Most lie close to the western margin of the Hill End Trough, which is now a strongly developed set of faults. The concentration of metals may have been syngenetic, but the deposits have many features of replacement orebodies. The best documented occurrences are those in the Captains Flat Syncline (Oldershaw, 1965). Deposits with a similar suite of metals occur south of the Captains Flat Syncline in Silurian rocks in a trough in the Canberra-Molong Arch on the Bega 1:250 000 Sheet, but on the regional trend of faulting marginal to the Captains Flat Syncline.

The gold deposits of the Hill End Trough, which virtually all lie north of the Bathurst Granite, are most probably all transitional Lachlan (Kanimblan) in age. They occur in a wide variety of host rocks in an area of extensive intrusion by transitional Lachlan granites.

The Lachlan Domain in Tasmania

The rocks of Tasmania involved in major tectonism during the Palaeozoic are broad correlates of the Lachlan domain of the mainland. However, although sedimentation coccurred during the same span of time as on the mainland, the detailed pattern of sedimentation and diastrophism is somewhat different.

The sediments of Western Tasmania were laid down on a basement of late Proterozoic deformed rocks. During the Cambrian, sediments with a high proportion of lithic fragments accumulated in unstable basins on the present west coast. To the east, volcanics which are probable part time equivalents include keratophyres, quartz porphyry, and quartz feldspar porphyry, with interbedded pyroclastics. Small areas of similar sediments are known along the central north coast, where they are disrupted by younger rocks; and a Cambrian sequence is known in the northwest of the island. The Jukesian movement late in the Cambrian or early in the Ordovician considerably reduced the area of sedimentation in the west so that the less extensive sedimentation in the Ordovician-Devonian was shallow shelf facies. Three small granite bodies are thought to have been emplaced during the Jukesian event, but the major igneous intrusions were serpentinites (Solomon, 1965a).

The Cambrian volcanics served as host rocks and very probably source rocks as well for important copper-gold deposits centred on Mount Lyell which antedate an early Ordovician land surface (Solomon, 1967). However, the overlying Ordovician also contains probable syngenetic copper (Solomon, 1969), which may have been recycled during erosion of the nearby volcanics. The Read-Rosebery ore deposits appear to have had a similar genetic history to the Mount Lyell deposits, but the ores are dominantly lead-zinc. Hall et al. (1965) regarded the orebodies as replacement-type but conceded the possibility of Devonian remobilization of Cambrian concentrations.

The Jukesian granites appear to have only minor mineralization associated withthem; the serpentinites are more important: they serve as the source of alluvial platinoids, are responsible for copper-nickel deposits at Cuni, and are the source material for primary and lateritically derived presently uneconomic nickel deposits both on the west coast and at Beaconsfield.

The effects of the Mid-Devonian orogeny (Tabberabberan) were widespread in Tasmania, with both folding and faulting movements. Some low-temperature mineraization such as the lead-silver-zinc lodes at Mount Farrell are localized in Tabberabberan structures - the source of the metals appears to be subjacent Cambrian volcanics (Solomon, 1965b). The ores at Mount Lyell and in the region between there and Mount Farrell were affected and mobilized to varying extents by the orogenic events.

The Mid-Devonian orogeny was followed by a period of granite intrusion ranging from Mid-Devonian into early Carboniferous - most intrusives antedate the Kanimblan Orogeny in its type area, and are possibly better described as late-tectonic rather than post-tectonic granites. Those in northeastern Tasmania are older, with ages of 370 m.y., while the western Tasmanian granites give ages ranging from 360 m.y. to 340 m.y. (McDougall & Leggo, 1965). Tin, tungsten, and base metals accompanied the intrusion of these granites. In the northeast molybdenum also occurs, and the primary mineralization shows apparent zoning around granite bodies. Alluvial tin also occurs along the basement high that stretches from north-east Tasmania through Flinders Island to Wilson's Promontory in Victoria, suggesting that the tin deposits of southern Victoria belong in the tin-bearing regime of Tasmania.

A number of occurrences of uranium minerals are recorded from the tin-tungsten province centred on Aberfoyle (Ostle, 1956), but not in economic quantities. Both Aberfoyle and Storeys Creek are major tungsten deposits and Aberfoyle is also a major tin deposit - the deposits are situated in metasediments close to an intrusive granite margin.

In the far west a zoned tin-iron-base-metal province extends from Trial Harbour to Mount Bischoff. The zoning in the Heemskirk-Zeehan area (A.B. Edwards, 1953; Both & Williams, 1968 a & b) is broad, the zones being spread over 15 km, with tin lodes in the granite giving way to pyrite-lead-zinc followed by siderite-lead-silver. Copper is present, but not in economic quantities. Edwards also shows bismuth and tungsten as being present, but again not in quantity. Farther to the northeast zoning is compressed within single orebodies, as at Mount Cleveland. In the northwest, a deposit at Interview River and an apparently zoned province centred on Mount Balfour appear to be similar to the Trial Harbour/Mount Bischoff province, but are of small economic significance.

The distribution of gold in Tasmania was outlined by Carey (1953). However, he assigned only broad ages to the mineralization. Solomon (1965b) mentions only late (Kanimblan) gold. Some of the gold deposits in the Rocky Cape/Tyennan folded rocks may be linked with pre-Lachlan events. The gold deposits near Golconda occur close to small granitic intrusives, but no granite occurs farther west at Lefroy and Beaconsfield; Tasmania workers, however, regard all as falling in the one metallogenic province. A distinct linear belt of gold deposits trends from Mathinna north-northwest to Forester, but the nature of the controlling structure is unknown and so is the age of the deposits; a Kanimblan age might be conjectured.

The scheelite on King Island has been interpreted as pyrometasomatic replacement of carbonate rocks during the intrusion of an early Kanimblan granite (345 m.y.) into a Precambrian carbonate series (Knight & Nye, 1965).

Lachlan Transitional 'Basins'

The rocks deposited during the wane of tectonic activity over the Lachlan domain during the late Devonian and early Carboniferous were sandstones and siltstones in the main, but some acid volcanics also occur in a zone in the east stretching from Cape Howe northwards to the Bathurst Granite and east of the Hill End Trough.

These antedate the Kanimblan granites, which have been variously estimated as lower to upper Carboniferous, and are confined to the Hill End Trough and the belt to its east in New South Wales, and appear to have introduced gold mineralization.

The post-kinematic sediments become progressively less deformed to the west of the Hill End Trough, and their equivalents west of the Cobar Trough have virtually the character of platform cover; they are only mildly deformed, but their thickness and the nature of the basement beneath them are unknown.

Volcanics and some sediments occur in ring and cauldron structures in Victoria. Granites of late Devonian age may have introduced gold and gold-antimony mineralization in Victoria.

In Tasmania late granites introduced tin, tungsten, copper, and base metals.

NORTH QUEENSLAND BLOCKS

The exact relationship of tectonic events represented in folded Lower Palaeozoic rocks in Northern Queensland to those affecting the Lachlan Belt proper is not known, although continuity between the two under the Trans-Australian Platform Cover seems certain.

Three distinct tectonic units together constitute the North Queensland Blocks - the Anakie High, the Lolworth-Ravenswood Block and the Broken River Embayment.

Very little is known about the ages of the folded rocks in either the Anakie High or the Lolworth-Ravenswood Block beyond metamorphic dates falling in the Ordovician. The bulk of the granitic intrusives (the Ravenswood Granodiorite Complex) in the Lolworth-Ravenswood Block also are thought to be Ordovician (Wyatt, Paine, Clarke, Gregory & Harding, 1971). It is possible that these two blocks are in part equivalents of the Kanmantoo domain (Plumb, in prep.). The Broken River Embayment contains sediments ranging from Silurian to mid-Devonian in a fault bounded trough tending southwest across the grain of the older Lolworth-Ravenswood Block.

The Anakie High

The Anakie High consists of poorly exposed schists and acid volcanics intruded by Devonian granite. Mineralization is sparse. A copper deposit a few kilometres southwest of Clermont is localized in a zone of shearing in greenstones. The primary ore is chalcopyrite disseminated with pyrite - most of the mining activity was concentrated on the zone of secondary enrichment (Mines Department, Queensland, 1953). An area of small gold deposits north of Clermont is in schistose rocks, but most of the yield was from alluvial workings in sediments of Permian, Tertiary, and Quaternary ages.

The Lolworth-Ravenswood Block

The Lolworth-Ravenswood Block is a complex of metamorphics and granites which outcrop as two large and several small basement inliers in an area about 150 km to the west of Townsville square. The metamorphics are mainly metasediments, with some metavolcanics southeast of Charters Towers. The granites which form part of the Block are of two ages: most is probably Ordovician but some is mid-Devonian. There are also a series of granite intrusions ranging from Carboniferous to Permian introduced by igneous activity spreading out from adjacent younger mobile zones(Wyatt, Paine, Clarke, Gregory, & Harding, 1971a; Heidecker, 1972, unpubl.).

Along the edge of the coastal alluviated plain northwest of Townsville small inliers of low-grade metamorphics also probably belong in the Lower Palaeozoic. They are too small to show on the map, but seem to indicate that north Queensland basement extends virtually to the coast near Townsville; so that the postulated extension of the Palmerville Fault along the coast appears to mark the junction between the younger Hodgkinson Belt and the North Queensland Block.

The Lolworth-Ravenswood Block has yielded a considerable amount of gold, mainly from three centres: Ravenswood, Charters Towers, and Cape River; the greatest quantity (222 000 kg) came from the Charters Towers mines. The Ravenswood and Charters Towers mining centres lie within the Ravenswood Granodiorite Complex, but the age of mineralization is not known. At Ravenswood the intrusives that on field evidence were thought to have introduced the ore have been shown to be older than the ore-bearing rocks by age determination (Clarke, 1971). Since the ore-bearing rocks are Devonian, the mineralization is either Devonian or else post-dates the North Queensland Domain.

The mesothermal lodes at Charters Towers occurred in two intersecting sets of faults; they were quartzose lodes carrying pyrite, galena, and minor sphalerite (Blatchford, 1953); Charters Towers produced more than 6 million oz of gold with some silver and a little lead; Ravenswood, though principally a gold-mining centre, was also the centre of silver and lead mining (See also Heidecker, 1972; Levingston, 1972).

The lode deposits at Liontown, south of Charters Towers, lie subjacent to the intrusive contact of the Ravenswood Granodiorite Complex with older folded rocks. As at Charters Towers, the lodes yielded gold and silver as well as lead, but they were generally regarded as lead mines.

The lodes of the Cape River Goldfield in the west of the Lolworth-Ravenswood Block appear to be in part related to the Ordovician and Devonian intrusions and in part to Permian intrusions of alater tectonic cycle. In the north of the Lolworth-Ravenswood Block several small silver deposits are recorded, but their age is unknown. The small gold deposits north of Mingela at least post-date the folding of the transitional basin, in the early Carboniferous, but again their age is unknown.

The Broken River Embayment

The Broken River Embayment is a partly concealed trough with a strongly faulted margin against the Georgetown Block to the northwest and a suspected but masked fault zone against the Lolworth-Ravenswood Block. The oldest exposed sediments are marine Silurian, and marine sedimentation continued until the early Devonian, when the axis of sedimentation shifted into the basins of the transitional north Queensland domains. Devonian granites intrude the Georgetown Block adjacent to the Embayment, and the Lolworth-Ravenswood Block to the southeast, but have no effect on the Embayment itself.

The mineralization associated with the Broken River Embayment may be divided into three groups. The large lateritic nickel deposit at Greenvale on the northwest margin has resulted from the weathering of ultrabasic rocks emplaced during Devonian folding movements; nickel and cobalt have been concentrated in the deeply weathered zone. The second group consists of two small antimony deposits; one in the sediments of the Broken River Embayment and the other in mid-Devonian sediments of the Burdekin Basin, suggesting that the mineralization is related to events in the younger Hodgkinson domain. Small tin and tungsten deposits, the third group, are an extension of similar mineralization introduced by transitional Hodgkinson granites.

Transitional North Queensland Domains

After the mid-Devonian igneous events (possibly early Devonian in part), acid volcanics were laid down in either side of the Anakie High; they may be traced as far as the coast near Sarina, where they become andesitic, and into the Connors Arch; but their major exposure today is to the west of the Anakie High, where they form the basal units of the non-marine late Devonian to Carboniferous Drummond Basin. To the north of the Lolworth-Ravenswood Block sedimentation in the Burdekin Basin commenced in the mid-Devonian and spread across the folded Broken River Embayment and onto the Block itself; and was folded in the mid-Carboniferous. Unlike most transitional basins, which are characteristically non-marine the Burdekin Basin is partly marine. It contains only minor mineralization, probably related to much later events.

The silver, gold, and copper deposits of Selheim and Rutherfords Table lie in a zone rimming a late Devonian-Carboniferous intrusive about 120 km southeast of Charters Towers.

Minor mineralization, mainly gold and silver, and major tin mineralization on the Townsville 1:250 000 Sheet area, although contained in host rocks of the north Queensland domain, were most probably introduced by tectonic activity in younger overlapping domains (Levingston, 1971).

THE HODGKINSON BELT AND HODGKINSON TRANSITIONAL DOMAIN

The Hodgkinson Belt developed to the northeast and east of the Georgetown Block as a sedimentary basin in the Silurian with shelf-type mixed clastics and limestones. The main downwarp is filled by a monotonous alternating sequence of arenite and shale with occasional beds of chert, volcanics, and limestone, whose thickness is not known. The age is uncertain - fossils from the limestones indicate a middle Devonian age and plant fossils from apparently high in the sequence a late Devonian age (de Keyser & Lucas, 1968). The whole sequence is strongly folded and in the east metamorphosed, the highest-grade gneisses being exposed at the coast and on coastal islands (de Keyser, 1965). The age of deformation likewise is not precisely known - a small downfaulted block contains a Middle Carboniferous flora in sediments unconformable on the folded Hodgkinson sequence. Two sedimentary sequences (part of the transitional development), also unconformable on the Hodgkinson sequence, antedate these Middle Carboniferous sediments - this would place the folding somewhere in the early Carboniferous. No event of comparable age is recorded in nearby tectonic units - isotopic dates in the Georgetown Block are partly reset by a Devonian event, which may correspond to the inception of geosynclinal sedimentation, but no early Carboniferous event has had any effect in the Georgetown Block and sedimentation in the Burdekin Basin shows no major break during the early Carboniferous. The junction between the Hodgkinson and Georgetown domains is a major fault, the postulated southern extension of which would also separate the Hodgkinson from the North Queensland Blocks.

Late in the Carboniferous acid volcanism broke out along part of the Palmerville Fault, accompanied by several phases of acid intrusion. Both spread widely into the Georgetown Block and the postulated southward extension of the major fault is marked by similar acid volcanism, although the individual acid intrusions are smaller in the south. These igneous events have been classified as transitional Hodgkinson events. Two distinct suites of cratonic granites, one of early Permian and the other of late Permian age, correlated with movements in the Yarrol-New England Belt to the south.

The mineralization within the Hodgkinson Belt proper has not yet been studied in detail; de Keyser & Lucas (op. cit.) offer some regional comments on structural and stratigraphic controls in their account of the geology of the Hodgkinson Basin. The pattern of mineralization introduced by the transitional Hodgkinson granites has been examined in some detail by de Keyser & Wolff (1964) and Blake (1972).

The only mineralization that can be confidently assigned to the pre-orogenic and orogenic phases is minor manganese which was mined south of Cairns (Morton, 1943). The Cairns district contains manganese-rich metasediments, but no other deposits are known.

The gold, antimony, and gold-antimony mineralization which lies in a zone sub-parallel to the Palmerville Fault but some 30 km to the east may be syntectonic. However, this zone is also west of the early Permian granites and may have been introduced during their intrusion. No gold lodes occur in close proximity to granites and the richest producers were far removed from outcrops of granite. The Palmer Goldfield in the north of this zone was a major producer, but most of the yield was from alluvial sources; the Palmer River spread the gold for over 60 km downstream across the Yambo Inlier. Lodes were generally difficult to mine and the rewards were poor - the best producers were in the Hodgkinson goldfield at the southern end of the zone, where some antimony was also mined. The central parts of the zone have produced mostly antimony.

Gold-antimony deposits to the north of Cooktown may be syntectonic, or alternatively the late Permian intrusions which occur in the region may have introduced the mineralization.

The transitional phase granites are confined to the margin of the Belt, but extend into the pre-existing Georgetown Block and into Cape York as far north as the Torres Strait High. Southward, granites of this phase extend as far as the Auburn Arch. The best studied region is the Mungana-Herberton zone (de Keyser & Wolff, 1964; Blake, 1972). In these areas the close association between one phase of the high-level granites and mineralization can be demonstrated. De Keyser & Wolff considered all the mineralization in the Mungana-Almaden district to be high-temperature, either hypothermal or pneumatolytic; Blake considers some of the mineralization in the Herberton-Mount Garnet to be mesothermal, but mostly it is hypothermal. Mineralization includes tungsten, molybdenum, tin, copper, lead, fluorite, and bismuth. Zoning is sometimes compressed (Wolfram Camp lodes contain tungsten, molybdenum, and bismuth) or more broadly spread as in the Mount Garnet-Herberton district, where tungsten, tin, and copper occur in separate deposits.

Intrusions of the Hodgkinson transitional phase within the Georgetown Inlier have introduced tungsten, tin, and copper deposits, including the copper deposits at Einasleigh (p. 51) (Branch, 1966). Deposits in Cape York at Bowden (tungsten), Cape York (tin), and Banks Island (tungsten) also are contained in acid igneous rocks. The Torres Strait High appears to contain zoned tungsten-tin-copper type mineralization, but the incomplete exposure limits detailed studies (Wilmott, Whitaker, Palfreyman, & Trail, in press).

The Kangaroo Hills mining district, northwest of Townsville, contains tungsten, molybdenum, tin, and copper deposits introduced by high-level granites of Hodgkinson transitional age along the southeasterly extension of the Palmerville Fault. Some similar deposits occur within the Broken River Embayment (de Keyser, Fardon, & Cuttler, 1964).

The granites of the Hodgkinson transitional phase which occur in the Urannah Arch and Auburn Arch are virtually devoid of associated mineralization; but they are very deep seated granites: high-level intrusions either were absent or have since been eroded.

The gold province extending south from west of Cairns corresponds both to the zone of biotite-gràde metamorphism (de Keyser & Lucas, 1968) and to the area of intrusion of the late Permian Mareeba Granite. Of the small goldfields making up the province, only the Jordan River Goldfield is actually situated in granite, but the other fields are not far removed from granite intrusions.

The tin and wolfram deposits south of Cooktown and at Noble Island correlate with the late Permian granites which intrude the area.

NEW ENGLAND - YARROL BELT

The New England-Yarrol Belt is a region best considered for the present as consisting of subunits each of which has a somewhat different history of development. Some boundaries between these subunits are clear-cut, others are ill defined so that some units may merge into each other.

Northwards from the Gogango Overthrust Zone the belt passes into platform cover overlying transitional phase volcanics of the older North Queensland Blocks; also the late-phase acid volcanism and intrusions from the Hodgkinson Belt extend southwards so that there is a complex area of overlap. Most of the mineral deposits of the Gogango Overthrust Zone are related to later events. Minor gold deposits at Grasstree and Yatton may have been introduced during Permian block faulting, but they equally well may have been introduced during the earlier North Queensland transitional phase. Cratonic granites of Cretaceous age occur in this area also; and these have introduced gold lodes west of Mackay.

South and east of the Gogango Overthrust Zone the Yarrol-New England Fold Belt may be split into two main divisions, the Yarrol-Tamworth Trough system, and a more complex eastern region.

The Yarrol-Tamworth Trough system, known as the Yarrol Basin in Queensland and the Tamworth Trough in New South Wales is separated from the eastern unit by a series of thrust faults, some with serpentinites. The oldest sediments in the Tamworth Trough are Ordovician; the main period of sedimentation was from late Devonian to early Permian. Scheibner (1972) interprets the Tamworth Trough as a marginal sea developed in the Devonian-Carboniferous over an older frontal arc region. The Tamworth Trough contains no known metal deposits. Silurian marine sediments in the Mount Holly Block south of Rockhampton are the oldest sediments recognized as part of the Yarrol Basin succession, but the main period of sedimentation in the Yarrol Basin was from the mid-Devonian to the early Permian. The middle to late Devonian sedimentation was characterized by acid to intermediate volcanics which appear to have affinities with the transitional phase of the North Queensland Blocks. At Mount Morgan a granitic stock intrudes comagmatic mid-Devonian volcanics. Coincident with or immediately after its intrusion hypogene gold-copper-pyrite-quartz mineralization was introduced into tuffs and volcanics immediately adjacent to the stock (The Staff, Mount Morgan, 1965). The remainder of the Yarrol Basin carries only minor mineralization, generally of post-orogenic origin.

The Bowen-Surat-Sydney Basin is a downwarp of Trans-Australian Platform Cover which began to form and fill in the earliest Permian, at about the same time as the earliest phase of orogenesis in the Yarrol-New England domain - the basin is asymmetrical, with the deepest and most folded parts adjacent to the mobile belt, while the edge lapping onto the Lachlan and North Queensland domains is thin and undeformed. The silver-gold deposits at Cracow (Brooks, 1965a) and the gold deposits at Mount Coolon (Coldham, 1953) are in early Permian andesites near the base of the Bowen Basin succession.

Within the main Yarrol-New England domain the most intense phase of deformation ranges in age from latest Carboniferous in parts of New England to Triassic in the Gympie district, but in general is in the Permian. Syntectonic granites are rare.

The eastern complex unit may be best subdivided into two geographically distinct subunits separated by the east-west transgression of Trans-Australian Platform Cover. These two subunits have been treated separately in previous literature because of their geographical separation, and as they have slightly different tectonic histories they are also treated separately here.

The Queensland part of the fold belt east of the Yarrol Basin has been referred to in previous literature as the 'South Coast High' - a term which applies to the behaviour of the unit in the late Mesozoic and Cainozoic. Both Kirkegaared et al. (1970) and Ellis (1968) avoid use of the term and describe the deformed Palaeozoic and early Mesozoic in terms of fault-bounded blocks: the area is broken into elongate blocks by a series of north and north-northwest-trending faults with some east-west cross faults. Broadly the rocks in this belt may be subdivided into highly deformed metamorphics and less deformed, mainly Permian successions which have some Triassic metamorphism (Ellis, 1968; Runnegar & Ferguson, 1969).

Deposition appears to have started during the Silurian. A thick monotonous quartzose sequence east and northeast of Rockhampton is regarded as Lower Palaeozoic (Kirkegaard et al., 1970), and repeatedly deformed schists near Brisbane are traditionally referred to the Lower Palaeozoic but without indisputable fossil evidence in either case. The Maryborough 1:250 000 geological map shows Lower Palaeozoic sediments and volcanics, but in the accompanying text Ellis (1968) refers to these as undifferentiated Palaeozoic, pointing out that the only indication of their age is a possible unconformity with a Permian formation. It is possible that these sequences represent, in terms of plate tectonics, melange zones that developed during the late Devonian or Carboniferous. Minor manganese mineralization occurs within these units and has been mined at Mount Miller near Gladstone (Kirkegaard et al., 1970) and in the Upper Mary Valley (Brooks, 1965).

An ultrabasic belt stretching from east of Rockhampton northwest towards Marlborough separates the supposed Lower Palaeozoic rocks from a Permian trough filled with volcanics. The serpentinites have been interpreted by Murray (1969) as Devonian intrusives remobilized in the Permian. Chromite has been obtained from small lensic bodies (Ridgeway, 1953). Deep weathering has produced magnesite from the ultrabasics, but individual deposits are small (Ridgeway, 1941; Brooks, 1964). Nickeliferous laterites have developed over the ultrabasics south of Marlborough. Gold deposits in the serpentinite may be Permian or introduced by younger granite intrusions to the south.

The small ultrabasic bodies at Kilkivan, north-northwest of Brisbane, are at the focus of varied mineralization. A number of very small mercury-bearing lenses and stockworks occur in a broad north-northwest belt over a distance of about 20 km. The total mercury production has been less than 10 tonnes (Mines Department, 1953E). The Kilkivan district also contains small copper and gold deposits with some arsenic, bismuth, and cobalt, probably also introduced by the same intrusions.

Apart from the deposits mentioned above, most of the mineralization appears to have been introduced during the transitional phase in the Triassic.

The copper-gold ores at Mount Chalmers, northeast of Rockhampton, occur in Permian volcanics and sediments which have developed local schistosity. It is thought the mineralization, which follows the schistosity, was introduced by later quartz porphyry intrusives (Fisher & Owen, 1952). These intrusives may be upper Permian or Triassic, and hence the mineralization may be part of the widespread Triassic mineralization associated with granites farther south; however, the mineralizing solutions may be mobilized reconcentrations from within the andesitic sequence itself.

Glassford Creek copper lodes occur as skarns in limestone within the Yarrol Basin close to a Triassic granite (Mines Department, Queensland, 1953c). Small gold deposits westward are also situated either within or close to the margins of Triassic granites intruding Yarrol Basin sediments.

Near Mount Perry, both east and west of a major north-northwest fault, copper, copper-gold, copper-molybdenum, and gold-arsenic lodes have been mined (Ellis, op. cit.). Although the host rocks west of the fault are early Upper Permian granites, it seems possible that all these deposits may have been introduced by Triassic granites. A small rutile deposit east of Mount Perry may be metamorphic in origin. In the Biggenden area, southeast of Mount Perry, gold, gold-bismuth, copper, and magnetite lodes lie close to the margin of a Triassic granite. A zinc-silver lode about 30 km south of Biggenden lies close to a zone of faulting; it also appears to have been introduced by Triassic granite nearby.

Although similar small deposits of gold, lead, copper, arsenic, and silver southwards towards Brisbane can be related to Triassic granites, the largest concentration of metal in the region, the gold lodes at Gympie, does not fit into the pattern. The Gympie lodes lie in a series of Lower Permian to Lower Triassic marine sediments and andesitic volcanics which were deformed in the Lower Triassic (Runnegar & Ferguson, op. cit.). Granite intrudes the sequence, but not within the area of mineralization. The lodes lie in quartzose reefs, striking with the country rocks and dipping at right angles to them. Gold content increased markedly where the reefs intersected carbonaceous shales within the sequence - the productive zone was thus limited to a small section of the total sequence. The gold occurs with some pyrite and occasionally with minor quantities of lead, zinc, copper, silver, and tellurium, but was evidently all free milling ore (Mines Department, Queensland, 1953d).

The New England section of the Yarrol-New England Fold Belt extends south from Warwick in Queensland into northeastern New South Wales. Along its western margin it is separated from the Tamworth Trough by a major thrust fault which passes into a system of arcuate faults in the southeast; characteristically the faults are zones of serpentinite intrusion. Immediately east of the fault system is a narrow zone with deposits of chromite, manganese, copper, and magnesite extending from Bingara in the north to the Walcha district in the southeast; these deposits are regionally zoned: the chromite occurs within the serpentinites of the fault zone and the manganese generally lies closer to the fault than the copper deposits.

In the northeast (northwest of Grafton), serpentinites following a fault also contain lenses of chromite (Raggatt, 1925). In this region, however, there appears to be a halo of mercury and antimony mineralization somewhat resembling the mineralization in the Kilkivan region in southern Queensland. To the southeast, near Port Macquarie, a small lateritic nickel-cobalt-manganese body has formed on serpentinized ultrabasics (Jacquet, 1898; Harrison, 1952).

The whole New England section east of the major thrust faults is complex. The earliest known sediments are Ordovician (Chestnut, Offenberg, & Blackshaw, in prep.), and small inliers of other Lower Palaeozoic rocks also occur; but most of the area of folded rocks is Upper Devonian or younger. In the northwest, Permian rocks rest unconformably on markedly more deformed older rocks (Olgers & Flood, 1970, unpubl.). Eastward on the coast strongly deformed rocks have been shown to be Permian sediments (Leitch, Neilson, & Hobson, unpubl.), so that the major phase of deformation appears to be progressively younger eastward.

The transitional phase is represented by two small areas of Triassic sediments in the southeast in the Lorne Basin, the all-but concealed Triassic Ipswich Basin to the north and east, and extensive granite intrusives with coeval acid volcanic spreads.

The most important deposits of this section are the tungsten-molybdenum-tin-base metal-arsenic suite introduced by the final very acid phases of the Triassic transitional-phase granites (Robertson & Flood in Olgers & Flood, 1972; Saint-Smith, 1914). Tin was mined mainly from alluvium and deep leads. Robertson (Robertson & Flood, op. cit.) notes that the lodes within the Queensland portion are small. Carne (1911) lists numerous lode mines in the Emmaville-Tinga district, but again all were small-scale operations, and it appears that the same was also true of the Wilsons Downfall district east of Stanthorpe.

Tungsten (as wolframite) occurrences are restricted to the central part of the area of acid intrusives. The main centre was at Torrington, where ore was obtained from many quartz-topaz lodes close to contacts between country rock and granite (Carne, 1912). The lodes carried a wide range of metals in the gangue, including bismuth, which was present in recoverable amounts in some mines. Although molybdenum occurrences are widespread over the same region as the tin deposits, most production came from a small district at Kingsgate, where numerous pipes lie near the contact between metasediments and a coarse-grained acid granite (Andrews, 1906, 1916).

Peripheral to the tin-bearing region is a zone of complex base-metal and arsenic mineralization in low-grade metasediments, presumably also introduced by the same granites. Most deposits were small, and contained several metals. The ores from the Conrad mine at Howell near Inverell were so complex as to defy economic metallurgical recovery of the metals in the ores (Carne, 1908; Robertson & Flood, 1972).

The New England Fold Belt contains two gold provinces. One lies near Warwick in Southern Queensland - all the scattered lodes here were small (Robertson in Robertson & Flood, 1972); the other is in the Armidale district of New South Wales, where most mines were also small, and many fields were virtually alluvial along. Hillgrove was an important gold-bearing centre; the numerous lodes were originally worked for gold but later for antimony and finally for tungsten (scheelite); they are in early Permian metasediments and intrusive late Permian granites. Harrison (1953) describes the mineralization as having been introduced in three phases along the same main lines of lode, with some earth movements between phases.

Antimony lodes occur in the centre and east of the New England Fold Belt. No obvious factor governs their distribution.

The Drake district, east of Stanthorpe (Andrews, 1908), is a gold and copper mining area with numerous veins and lodes in silicified Permian volcanics; they may be part of the zoned province to the west, but appear to be part of a separate phase introduced during the volcanism.

Transitional New England - Yarrol Domain

The essential features of the Triassic transitional phase have already been described (p.73). Sediments were deposited in the Lorne and Ipswich Basins, the Esk Rift, and, as thin spreads, south from Rockhampton. Acid volcanism was widespread and andesitic volcanics occur in the Esk Rift. Granites intrude the whole belt and were responsible for introducing much of the mineralization.

THE KUBOR BLOCK

The Kubor Block in New Guinea forms an uplifted sliver of basement on the active margin between the continental crust of Australia and the mobile region of New Guinea.

It consists of Permian and earliest Triassic sediments intruded by an early Triassic granite. It contains no known mineral deposits.

A small outcrop of granitic basement has been found in the Western Highlands exposed in a river gorge cut through the Eastern Australian Platform Cover. It is inferred to have a similar age to the granites in the Kubor Block.

TRANS-AUSTRALIAN PLATFORM COVER

The Trans-Australian Platform Cover began to develop during the early Permian and very locally in the late Carboniferous; sedimentation spread during the Triassic and reached its maximum in the Cretaceous, after which deposition has continued in the pericontinental area and the southern parts of New Guinea.

Although the cover contains most of Australia's coal reserves, mainly in the Bowen-Surat-Sydney Basins it contains little mineralization.

In central Queensland the Dawsonvale iron deposit occurs in Jurassic sediments; it is oolitic, with massive beds ranging up to 3 m thick and a grade of 33-44% Fe (Urquhart, 1965).

During the Cretaceous marine incursion across northern Australia small manganese deposits formed through the north of the Northern Territory and a large deposit on Groote Eylandt. The Groote Eylandt deposit consists of pisolithic beds of pyrolusite and cryptomelane which are thought to have been deposited in a restricted shallow marine basin during the Albian (Smith & Gebert, 1969).

Uranium mineralization has recently been reported from the Lake Frome Embayment - a Jurassic to Tertiary onlap of the Trans-Australian Platform Cover onto the uraniferous Willyama and Mount Painter Blocks. The uranium occurs in non-marine Tertiary sediments.

At Scott River, in the south of the Perth Basin, lateritization of a Tertiary ferruginous sandstone has produced low-grade iron ore (Burns & Carruthers, 1965).

Low-grade phosphatic sediments north of Perth contain iron and alumina in quantities that prevent economic beneficiation. They are contained in two beds in ferruginous sandstone, glauconitic sandstone, and chalk of Cretaceous age (Matheson, 1948).

In northeastern Australia, plugs and bosses of granite were intruded during the Cretaceous. Acid volcanics, mostly exposed on off-shore islands, were deposited at this time. The granites introduced small gold lodes west of Mackay, and copper lodes occur close to a plug in the Bowen Basin.

Small gold lodes occur adjacent to Cretaceous peralkaline plugs at Mount Dromedary, south of Sydney, and at Cygnet, south of Hobart.

THE TERTIARY AND QUATERNARY IN THE AUSTRALIAN CRATON

From the late Cretaceous onwards the Australian craton has been extremely stable; sedimentation has been confined to the continental margin and to small local downwarps on the exposed craton.

The most extensive area of sedimentation on the currently exposed continent is the Murray Basin, which contains both marine and non-marine sediments. Sedimentation is still continuing in the intracratonic Carpentaria Basin. The large pericontinental basins include the Gippsland, Bass, Otway, and Bowes Basins.

The small downwarps include the Lake Eyre Basin, the surface of which is below sea level at present and which is the site of a present-day saline lake. They also include numerous small basins in the Northern Territory, important as groundwater reservoirs and as possible uranium depositional loci. In Western Australia there are numerous calcrete-filled river channels in the Yilgarn Block which are also potentially uraniferous. The limonitic ores of the Hamersley region are Tertiary in age, having been deposited in stream channels and swamps draining the iron rich Proterozoic rocks of the area. Salt lakes occur on the Yilgarn Block as the result of drainage reversals coupled with reduced rainfall.

Raised beaches in Western Australia contain heavy-mineral-bearing sands. Lake McLeod near the Western Australian coastline contains potassium-bearing evaporites which are considered to be an economic source of potassium.

During the Quaternary the Great Barrier Reef developed and sedimentation continued in the offshore basins. At various times during the Pliocene and Holocene both the Bass Rise and Cape York-Oriomo Rise have been exposed above sea level, although at present both are a few metres below sea level. In some areas round the continental margin high sand-dunes have built up, particularly along the southern Queensland coast and on Eyre Peninsula in South Australia. The interior of the continent has passed through phases of climate both more and less arid than the present climate. During the more arid times sand-dunes built up and wind spread broad sand drifts across most of northern Australia. Most of these dunes are now stable; only small areas are mobile in the Simpson, Great Sandy, and Great Victoria Deserts.

On the eastern seaboard, the beach deposits and dunes contain appreciable quantities of heavy minerals, including zircon, monazite, and rutile, and less economically significant ilmenite, leucoxene, and garnet. The zircon and rutile are thought to have originated in the Precambrian gneissic terranes of central and western Australia, were deposited in Jurassic sandstones of the Trans-Australian Platform Cover, and are now being recycled. The ilmenite is supplied from erosion of Tertiary basalts. Fossil beaches exist above, at, and below present sea level. Concentration of the heavy minerals has been affected both by wave action and longshore drift (Gardner, 1955; Whitworth, 1956).

In Western Australia deposits exist along the southern and western seaboards, the best being in the Bunbury region, where several fossil beaches exist above the present sea level. Some of the deposits along the southern coast of Western Australia are large considered against the world supply of zircon, but are rendered uneconomic by their grade and inaccessibility (Low, 1960). Beach sands are also known to exist north of Perth, although their relationship to the present sea level and coastline are still being assessed. Heavy mineral sands in the north of the Yilgarn Block contain vanadium-bearing minerals.

Virtually all the continent has been deeply weathered, in several episodes. The oldest probably began to develop in the Mesozoic. The main phase in the Northern Territory is early Tertiary, although a later Tertiary land surface with deep weathering exists in the north (Hays, 1967). In Cape York Peninsula the main phase is early Tertiary (H.F. Doutch, pers. comm.).

Bauxite occurs in north Australia, at Weipa, at Gove, and in the Mitchell Plateau, in vast blanket deposits. In these regions deep weathering during periods of rainfall higher than at present has produced chemical layering of the regolith; the zone has since been eroded and the bauxite redistributed, with pelletic and nodular concretions. The deposits at Weipa generally contain 1 to 5 m of mineable bauxite under about 1 m of overburden; their lateral extent is in tens of kilometres. Similar deposits also occur in the Darling Escarpment of Western Australia, both east of the Darling Fault, where they have developed over the Yilgarn Block, and to the west over sediments of the Perth Basin. Small deposits of bauxite of lateritic origin occur throughout eastern Australia, usually over volcanic rocks.

Lateritic nickel deposits have developed over nickeliferous ultrabasic rocks at Greenvale (west of Townsville), at Marlborough (northwest of Rockhampton), in the Blackstone Ranges (in the Musgrave Block), and in the Yilgarn Block north of Kalgoorlie.

Residual manganese deposits occur in Western Australia, developed from manganese-rich sediments in the Adelaidean Bangemall Basin.

Magnesite has developed in the Yilgarn Block and elsewhere from the deep weathering of magnesium-rich rocks. (Sedimentary magnesite also exists in Australia).

The effect of the deep weathering on the mining development of northern Australia should not be underestimated. Supergene enrichment due to deep weathering has considerably redistributed metals, particularly copper, silver, and zinc in base-metal deposits, in much of northern Australia. Many small deposits in the Mount Isa Block, the Pine Creek Block, and the Tennant Creek area could not have been economically mined without the enrichment that has occurred in the upper 30 to 100 m of the deposits. Many pyrite-gold lodes throughout eastern and northern Australia have proved mineable only because the gold was freed from the pyritic ore during deep weathering. Many mines were abandoned at the water table, when either grade fell suddenly or the ore became metallurgically difficult to work.

Widespread flood basalts, mainly alkaline, occur along the eastern margin of the craton, corresponding broadly to the East Australian Orogenic Province. The age of these basalts ranges from Eocene to Holocene, with one culmination in the Oligocene and a second in the Pliocene. The area of basalt corresponds broadly to the Kosciusko upwarp, a late Tertiary uplift of the eastern seaboard of Australia by about 100 m.

Erosion of tin, gold, and other heavy-mineral-bearing deposits has produced important placer deposits throughout much of eastern Australia and in the Yilgarn and Pilbara Shields of Western Australia as well as smaller deposits elswhere. These deep placers may represent concentrations many times that in the original lodes. Some tracts of alluvium have been large enough for dredging operations, which are still continuing in North Queensland and central western New SouthWales on tin-bearing gravels. Study of both present and past landforms is often necessary to assess these deep leads. Some have been trapped beneath basalt flows so that the fossil stream patterns have very little relation to present-day topography. Such basalt-trapped deep tin-bearing leads proved important on the Atherton Tableland in north Queensland, in the tin-bearing regions of northern New South Wales, and in the gold-mining districts of Victoria and southern New South Wales, and also in Tasmania.

NEW GUINEA OROGENIC PROVINCE*

Continental crust of the Australian craton extends northward from Australia under the island of New Guinea beneath a wedge of Trans-Australian Platform Cover to meet the mobile zone of northern New Guinea and the active island arc systems to the north and northeast along the mountainous backbone of the island.

The mobile region may be subdivided into two main units. The mountains and some of the islands contain rocks folded and metamorphosed in the late Cretaceous and early Tertiary which constitute the Highlands Fold Belt. The second unit consists of rocks deposited since the early Miocene which have the characteristics of 'geosynclinal' sedimentation and 'island arc' environment but are relatively undeformed except for syndepositional folding and block faulting. Two subunits may be recognized within this unit: the Aure Trough between the craton edge and the geanticlinal Highlands, and the North New Guinea Mobile Zone which includes the northern margin of New Guinea, New Britain and the islands of the Solomons, Bougainville, New Ireland, and Manus.

THE HIGHLANDS FOLD BELT

The boundary between the cratonic margin and the Highlands Fold Belt in the west is a major fault trending east-southeast, the Lagaip Fault, across which there is an abrupt change in type and thickness of

* Commentary deals only with Papua New Guinea. The units extend beyond the political boundary, as is shown on the Tectonic Map of Australia and New Guinea.

sediments. Traced eastward this fault passes under the shield volcanic complex of Mount Hagen into the upwarped craton basement, the Kubor Block; from here the junction between craton and mobile region swings east-southeast beneath the Aure Trough and thence to the western margin of the sphenochasm(?) of the Coral Sea Basin.

Western Highlands

North of the Lagaip Fault the sediments consist of Triassic and Jurassic Marine basic volcanics and Triassic to Eocene shales, turbidites, and limestones. There are no Oligocene sediments, but basic volcanics and reworked sediments were laid down in the early Miocene. At the end of the lower Miocene intense movements resulted in the emplacement of andesitic plugs, diorite plutons, and ultramafic bodies. Regional metamorphism, generally greenschist but locally reaching eclogite and blueschist grade, is thought to have occurred at this time. Island-arc style volcanics pass upward into clastic sediments which terminate in the upper Miocene (Dow, Smit, Bain, & Ryburn, 1972). The folded zone disappears northward beneath the Sepik plain and is cut off eastward by the Ramu-Markham Fault.

Small alluvial gold and platinum prospects exist in the major valleys; the platinum comes from erosion of the ultramafics, and gold from porphyry stocks and basic to ultrabasic intrusives, but source lodes are very low grade. The area near Porgera has yielded about 10 000 oz of gold and some silver from occurrences within a few kilometres of the village. Miocene gabbro and Pliocene andesites intrude this region.

The major economic interest in the area is copper mineralization. Two prospects are under study and a third is reputed to exist west of the Territory border. The earlier discovery was the Frieda Prospect, in which disseminated copper sulphides and pyrite are associated with hydrothermally altered stocks and dykes of andesite porphyry (Dow et al., op. cit.). The other is the Ok Tedi Prospect, which occurs as disseminated copper sulphides in a porphyry stock about 1 m.y. old, intruded into the mobile edge of the craton south of the Lagaip Fault.

The ultrabasics might be expected to produce nickeliferous laterites under the weathering conditions of the region, but none of sufficiently high grade nor size for mining has yet been recognized; nor have any chromite deposits been found, despite the favourable geological setting. Towards the east, in the mineralized area surrounding Kainantu, small deposits of gold, copper, and lead-zinc are known.

Eastern New Guinea

Along strike the Highlands Belt swings more southerly and passes into the complex belts of Eastern Papua and the Louisiade Archipelago. Two major zones of sialic material are separated by basic rocks, apparently emplaced by a fault that has thrust a slice of crust and mantle westwards over an older geosynclinal pile, which was consequently metamorphosed. The region may be described as a series of partly submerged geanticlinal ridges, containing pre-middle Miocene geosynclinal facies rocks metamorphosed about the middle Miocene.

The Owen Stanley Fault is the thrust along the western margin of the Papuan Ultrabasic Belt where a slice of ocean floor is thought to have been thrust over continental crust (Davies, 1971).

A zone of metamorphosed Cretaceous mudstones lies immediately west of the fault and is flanked westward and southward by metamorphosed Eocene sediments and Oligocene granodiorite. There are three important areas of mineral deposits in this region. At Riga, southeast of Port Moresby, manganese has been mined from rocks interpreted as deep-sea oozes. The deposits themselves are small, and have been remobilized during folding and later enriched by weathering. Northeast of Port Moresby, copper, gold, silver, and zinc have been mined from three larger and many small lodes within the Astrolabe district. All the major orebodies occur in Eocene black shale and grey siltstone, and are conformable. Gabbro occurs nearby but is thought to post-date the ore. The evidence favours a syngenetic origin (Yates & de Ferranti, 1967). The large gold production of the Wau and Bulolo Valleys has mainly been obtained from alluvial sources. Small lodes are associated with Pliocene andesitic porphyry intrusions post-dating deformation of the area. Gold, in less promising lodes, also occurs in this area in older intrusives, which have also contributed to the alluvial deposits. Small gold placer deposits occur at Yodda near Kokoda within the metamorphic belt.

The Papuan Ultramafic Belt is thought to be oceanic crust and mantle of Cretaceous age thrust up over sialic rocks during the Miocene and uplifted by isostasy into its present position (Davies, op. cit.). It shows little evidence of deformation and is devoid of major mineralization. Nickeliferous laterites of mineable grade that might be expected to form under local climatic conditions have been sought without success. Streams in the area carry small quantities of detrital gold and platinum, but no payable lodes are known.

A series of belts of partly submerged folded sialic rocks lies east of the Papuan Ultramafic Belt. One belt takes in the southeast of Papua, the D'Entrecasteux Islands, and the chain of islands southeast of New Guinea, including the Louisiade Archipelago. It has a basement of metamorphics, reaching amphibolite grade locally on Misima Island; and it contains five active volcanoes and the active downwarp of the Cape Vogel Basin. Alluvial gold and platinum have been obtained from streams in the Milne Bay area, but no economic lodes are known. Traces of copper are also recorded, near the intrusive contact between gabbro and metavolcanics. The most important deposit is on Misima Island, where a number of gold-bearing lodes have been mined in the past. One is now being reassessed; it is reputed to contain large tonnages of pyritic ore carrying gold and silver and is also reported as containing some copper and a lead-zinc body. The lodes are epithermal and lie close to the contact between greenschist metamorphics and intrusive andesitic porphyries, which are thought to be responsible for the mineralization (de Keyser, 1961).

The second belt takes in the Trobriand Islands and Woodlark Island; it appears to have a pre-middle Miocene core with a veneer of young sediments. Woodlark Island consists of volcanic detritus, lavas, and limestones intruded by dolerite and by granite bodies. Gold-bearing deposits on Woodlark Island occur in volcanics and in the intrusive granites within shear zones. These lodes also contain sphalerite, galena, pyrite, chalcopyrite, quartz, and calcite. There are some pyritic beds within the volcanic and sedimentary pile. Iron-bearing skarns and a little minor manganese occur (Trail, 1967).

Basic References

Much of the information summarized above is taken from Thompson & Fisher (1967) and Davies & Smith (1970, unpubl.), which are themselves reviews partly based on unpublished material.

NORTH NEW GUINEA MOBILE ZONE

The area shown as the North New Guinea Mobile Zone consists of two active island arcs, the Solomon-Manus arc along the Pacific Ocean margin and the North New Guinea/New Britain Arc.

North New Guinea/New Britain Arc

The North New Guinea/New Britain Arc involves the Torricelli Mountains, beneath which an active subduction zone dips southward, the Adelbert Mountains north of the Ramu-Markham Fault, the string of active volcanoes from north of Wewak (offshore) to the northern edge of New

Britain and the island of New Britain west of the Gazelle Peninsula. A subduction zone dips north beneath New Britain from the New Britain trench system. The only mineral deposit of economic interest has been the alluvial gold taken from the southern fall of the Torricelli Mountains near Ambunti. Chromite beach sands exist along the northern coastline. Transient sulphur deposits form on the flanks of the volcanoes, but are not mined. The climatic conditions are ideal for the formation of bauxite, but no workable deposit has yet been located. Small showings of copper, lead, and zinc in New Britain are currently under investigation.

The Solomon - Manus Arc

The Solomon - Manus Arc takes in Bougainville, New Ireland, Manus, and the Gazelle Peninsula of New Britain within Papua New Guinea. It is an active volcanic zone with trench and subduction systems. The exposed islands consist of Tertiary volcanics and limestones with small late Tertiary to early Quaternary intermediate to acid intrusions (Blake & Miezitis, 1967). There is evidence that this zone is a favoured site of porphyry copper deposits. The best known of these is the very large low-grade copper-gold sulphide orebody at Panguna on Bougainville Island, which is contained within a stock of quartz diorite and granodiorite intruded into andesite. The richest concentration of metals rims a granodiorite stock and a leucocratic quartz diorite within the intrusion which is dated at about 5 m.y. (MacNamara, 1968).

Again it may be said that the combination of rock type and climate is suited to the development of bauxite. One small occurrence on Manus Island has resulted from the weathering of a dacite body (Owen, 1954); no others have yet been located. Small copper showings are at present under investigation on Manus Island.

AURE TROUGH

The Aure Trough lies at the margin of the Australian Craton between the down-hinged margin of the Australian continental crust and the ridge of the Highlands Fold Belt. It began as a downwarp in the Miocene. The fill is mainly turbidites, partly derived from contemporary andesitic volcanism and partly from the geanticline to the northeast. No metalliferous deposits are known.

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