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General Background to Legend of Metallogenic Map

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The Metallogenic map of Australia is an aid to science and the mining industry in Australia, and is also a contribution to the projected Metallogenic Map of the World, planned by the Commission for the Geological Map of the World. Metallogenic maps of each continent are being compiled on behalf of the Commission continental committees. Each committee has created or adapted a legend to suit available information, geological conditions, and local philosophy on metallogenesis. The Metallogenic Map of Europe at 1:2,500,000 was originally mooted as the pilot study for the whole world map because information on deposits was readily available and a tectonic map at this scale was in existence. Even this project encountered difficulties when legends based on two different philosophies of metallogenesis were proposed. However a map has been compiled, and two trial printed sheets were displayed at the International Geological Congress at Prague in August 1968. Compilation of the Metallogenic map of North America at 1:5,000,000 using another legend was completed for display at Prague at the same time. A mineral deposit map of Asia and the Far East is available, and a mineral map of Africa has reached proof stage (1968). Metallogenic Maps of South America and Asia are being compiled.

The Australian map at a scale of 1:5,000,000 was begun in early 1966 after pilot compilations at various scales. The legend from the European map has been adapted to suit Australian conditions; the time-tectonic units in particular are peculiar to Australia. During the later stages of compilation co-operation with the Geological Society of Australia's Committee for the Tectonic Map has ensured the co-ordination of the philosophies of both maps, a feature regarded as essential by overseas workers.

The Legend for the Metallogenic Map of Europe at 1:2,500,000

The legend for the Metallogenic Map of Europe is based on the concept that metallogenic events are related to tectonic events and are therefore best depicted in a tectonic framework. Two major divisions to the framework are recognized - orogenic domains and platforms, with the orogenic domains separated by age. The European ideas of platform emphasized the basement more than the cover. All platforms and regions are depicted uniformly in grey, with no direct indication of their age. (This is derived from the Tectonic Map of Europe where platforms are not assigned symbols in the legend but merely indicated by tones of colour used to show the age of the basement.) The time-honoured factors that are regarded as affecting ore deposition, namely rock type, vulcanicity, time-relation of intrusions to tectonism, chemical nature of igneous activity, paleogeographic conditions, structure, and metamorphism are incorporated in the legend to amplify the tectonic framework; some additional factors important in exploration, such as geochemical and geophysical anomalies, lateritization, and palaeosoils are also included. (A concept recently prevalent in Europe in metallogenic thinking is the metallotect- comprising the aggregate of all factors influencing the deposition of metals and the localization of metal concentrations.)

The genetic classification scheme in the European map follows 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 - these terms have different meanings in Australian literature and have not been adopted for the Australian map. Major deposits shown on the European map are 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 is given.

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

The concept of a metallogenic province has caused much discussion in Europe and two separate views have emerged. One is centred on the distinction between monoparagenetic and polyparagenetic (in the European sense) units; monoparagenetic deposits are characterized by a single suite of metals or minerals, and polyparagenetic deposits contain several suites. This viewpoint then allows for minor groupings of monoparagenetic units and the major grouping within the tectonic framework is by polyparagenetic units. An advanced form of this viewpoint allows for a hierachy of units of increasing complexity and, generally, size of metallogenic groupings analogous to the size ranges and generalizations made in groupingstectonic units.

The opposing view is summed up by N.E. Petrascheck (1965, Ec. Geol. Vol 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". The European legend does not indicate which view has been adopted, but brief notes accompanying the legend favour the first, as does unpublished material subsequently issued by the compilers.

The legend for the Metallogenic Map of Australia

The Australian legend has been adapted from the European one. The major change has been in the approach to tectonic units. Not only do the time units differ, but the interpretation of the relationships between tectonic units is new to tectonic maps. The Tectonic Map of Australia has been based on two concepts. The first is best described as progressive cratonization; regions of the Australian crustal block appear to have gone through stages of geosynclinal sedimentation, orogenic deformation, transitional instability, and finally reached an almost stable state subject only to epeirogenic warping. This relatively stable unit is the craton; its stability is reflected by the presence on it of virtually undeformed strata. The highly deformed areas are referred to as shields or fold belts where they are exposed and the undeformed cover is referred to as platform. The craton is regarded as the major tectonic unit. As each fold is stabilized it is welded onto the pre-existing craton, and each succeeding platform overlies both the newly stable and the previously stable parts of the craton, including older platforms. The platform developments are used to classify the underlying fold belts into 'provinces' (as used in the tectonic map) or 'domains' (as used on the metallogenic map; this term will be used in these notes to prevent confusion with metallogenic province). A domain contains all the fold belts incorporated into the craton before a new platform is laid down over the new craton.

The progress towards stability is marked by a definite sequence in the types of sedimentation, and characteristic suites of igneous rocks. Not all the steps in the sequence or all the suites might be expected in any one region, but the patterns have proved applicable overall to each cycle of tectonic evolution.

The concept of transitional tectonism between the major unstable phase and cratonic stability is an innovation even though it has application to the tectonic setting which leads to deposition of molasse. It was introduced to account for the deformation of the Lambie Group and its equivalents of Upper Devonian age which were laid down after the major deformation of the Lachlan Geosyncline and subsequently folded and intruded by granites. It was extended to cover the style of sedimentation as well as the late acid vulcanism and intrusion that follows the main deformation of other geosynclines.

The Tectonic Map of Australia also incorporates the concept that platforms formed over cratons at the same time as a sedimentation occurred in an adjacent geosyncline. This is shown by the use of colour to show contemporaneous events on the tectonic map but is only apparent on the legend of the metallogenic map, as all platforms are given a grey colour.

The metallogenic map places most emphasis on fold belts, as these are the areas of the most complex and varied mineralization. The classification used for the tectonic map is followed. However, for the purposes of discussion of metallogenic development the emphasis is placed on the history of individual fold belts and not on the relationships between fold belt, platform, and craton; fold belts within a domain have different rates and times of evolution and deformation.

The single colour given to all platforms may make them appear uniform, but this choice of colour follows the European legend, with its emphasis on basement rather than platform. Australian platforms are, however, proving to be metal-bearing in places, so that future metallogenic maps may warrant more detailed treatment of platform cover. On the present map, the different platforms are distinguished by letter symbols and their boundaries shown. The European legend allowed for much more in rock detail in platform regions than has been shown on the Australian map. No attempt has been made to show geophysical features as such but much of the contouring of depth to basement is derived from seismic and aeromagnetic work done by oil companies. The Precambrian platforms are of little interest to oil companies, so their relationship to basement is less well known.

Metallogenesis. A metallogenic map is based on the assumption of relationships between the geological framework and the location of ore deposits; the style of the map depends on what these relationships are assumed to be. Within the framework of the legend for the Metallogenic Map of Australia, provision has been made for broad categories into which existing theories of ore genesis may be fitted without extensive forcing. Many Australian ore bodies were mined and described at a time when most ore bodies were assumed to be of hydrothermal origin, even though the igneous source rocks were not identified. Modern theories involving paleogeographic conditions of sedimentation, groundwater movements and leaching under stable land surfaces are now being applied to studies of the origin of many ore deposits - the resulting conclusions, combined with the 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 these in a tectonic framework. The evolutionary tectonic framework used for the Tectonic Map of Australia is readily adapted to metallogenesis; in particular the evolution of the igneous activity fits very well with the environments proposed for ore genesis.

Metallogenic Provinces

Overseas definitions vary in the aspect emphasized in the definition of metallogenic province. In the compilation of the Australian map no one definition used overseas 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 our 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 this gives each province a characteristic and unique metallotect. The number of factors recognized in the metallotect varies from province to province; some provinces are well defined in the literature, but others are either given passing recognition in the literature 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 link deposits into 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 paragenetic provinces, shown as single provinces in the main map, are the zoned tin-tungsten-molybdenum-base metal provinces. In the enlarged insets the limits of sub-groupings within some of these complex provinces have been shown, but the main map is biased towards the common genetic factors, not the common metal, in a province.

The long stability, with associated peneplanation, of the post-Tasmanide craton from the late Mesozoic has led to the extensive oxidation of sulphide ore bodies, commonly to depths of two or three hundred feet. In some ore bodies an initially very low grade sulphide deposit has produced a small but rich body of supergene ore; the literature records that many bodies were mined only in the oxidised zone, or abandoned because of low grade below the water table. In many cases the composition below the water table is only hinted at or not recorded. 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 maps. For copper, oxidised 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 result of this bias in the literature.

The European legend suggested 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 attached set of figures were obtained from various sources, mainly Annales de Mines, publications of the United States Bureau of Mines, and World Mining. Most figures are conservative - estimates for mainland China and the USSR are inaccurate or out of date. The only comparable figures available are those used for the compilation of the North American map, and these were related to the size range of north American deposits, not world figures. This selection of values related to world figures helps to show Australian deposits better in the world picture, but does magnify the importance of deposits of metals with small total resources. Some deposits shown 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 2 mm spot of colour if they are within a province. (In a few cases where provinces were small or formed narrow belts, it became necessary to 'short-hand' this procedure, using 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 2 mm 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 in significant 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 1 mm spots of colour. Neither small nor minor deposits within provinces are shown; the areas of metal concentration are indicated by hatching. The figures used for the division into major, small, and minor deposits are given in Table 1.

TABLE FOR COMMODITIES

COMMODITY	WORLD			POSSIBLE SIZE LIMITS		
	Reserve	Production	Total	0.05% World Total	Adopted Lower Limit	Relation to large size
	Tons	Tons	Tons	Tons	Tons	%
Antimony Sb.			5,000,000	2,500	25	1
Aluminium	1,440,000,000	60,000,000	1,500,000,000	750,000	4,000	0.5
Asbestos	100,000,000	60,000,000	160,000,000	80,000	400	0.5
Barium ($BaSO_4$)			160,000,000	80,000	400	0.5
Beryllium (BeO)			100,000	50 (e.g.450 tons beryl.)	2 ton beryl.	0.5
Chromium	800,000,000	50,000,000	850,000,000	425,000	2,300	0.5
Cobalt			3,500,000	1,750	10	0.57
Columbium (R_2O_5)	9,000,000	50,000	9,000,000	combined with tantalum		
Copper	200,000,000	100,000,000	300,000,000	150,000	1,000	0.7
Fluorite (CaF_2)	43,000,000	50,000,000	100,000,000	50,000	500	1
Gold	31,100	50,000	81,000	1,500,000(ozs	10,000(ozs)	0.7
Iron	72,000,000,000	5,000,000,000	80,000,000,000	40,000,000	500,000 Fe in 50%+ ore	1.2
Lead	45,000,000	90,000,000	135,000,000	68,000	350	0.5
Lithium (Li_2O)			2,000,000	(16,000 Lepidolite (10,000 ambly. (20,000 petal (12,000 spodumene	Prod.	-
Magnesite			8,300,000,000	4,600,000	23,000	0.5
Manganese			1,000,000,000	500,000	2,000	0.4

COMMODITY	WORLD			POSSIBLE SIZE LIMITS		
	Reserve	Production	Total	0.05% World Total	Adopted Lower Limit	Relation to large size
	Tons	Tons	Tons	Tons	Tons	%
Mercury			1,000,000	500,000	Prod.	
Molybdenum			3,500,000	1,750	10	0.5
Nickel			40,000,000	20,000	500	2.5
Phosphate (P_2O_5)			50,000,000,000	25,000,000	120,000	0.5
Platinum	32,000,000 troy ozs	18,000,000 troy ozs	50,000,000 troy ozs	25,000 ozs	120 ozs	0.5
Osmiridium			10,000,000 troy ozs	5,000 ozs	25 ozs	0.5
Silver	2,800,000,000 troy ozs	23,000,000,000 ozs	26,000,000,000 ozs	13,000,000 ozs	100,000 ozs	0.7
Sulphur			1,000,000,000	500,000	2,500	0.5
Tantalum (R_2O_5)			100,000	50 (200 ton conc.)	1 ton conc.	0.5
Thorium (ThO_2)			625,000	310	Prod.	-
Tin			20,000,000	10,000	50	0.5
Titanium (TiO_2)			250,000,000	120,000	600	0.5
Tungsten (WO_3)			2,000,000	1,000	5	0.5
Uranium (U_3O_8)	1,000,000	500,000	1,500,000	750	5	0.5
Zinc	78,000,000	52,000,000	130,000,000	65,000	320	0.5
Zirconium (ZrO_2)			20,000,000	10,000	50	0.5