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GEOCHEMICAL SECTION

RB 53/1

DEPARTMENT OF MINES
SOUTH AUSTRALIA

GEOLOGICAL SURVEY

GEOCHEMICAL SECTION

GENERAL REVIEW OF CAMBRIAN-MARINOAN GEOCHEMICAL INVESTIGATION AND ITS SIGNIFICANCE IN ORE SEARCH.

by

B. P. Thomson,
Senior Geologist

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GENERAL REVIEW OF CAMBRIAN-MARINOAN GEOCHEMICAL INVESTIGATION AND ITS SIGNIFICANCE IN ORE SEARCH.

INTRODUCTION

This report outlines the methods used and the results obtained in this investigation. The significance of the results and other data is discussed.

The writer was appointed Senior Geologist, Geochemistry Section in September 1959. The basis of the appointment was the conduct of regional geochemical surveys and the investigation in detail of particular ore deposits, with attention to the stratigraphic distribution of metals.

The functions of the Geochemical Section have developed along two lines: (1) Building up of data on metal distributions and concentrations in the rocks of South Australia, (2) interpretation of the data in geological terms from the genetic point of view.

Both of these functions have ultimately important practical applications in the search for concealed mineralisation.

The results available to date of the combined geological and geochemical investigations of the Cambrian and Marinoan rocks show very clearly that intelligent interpretation and application of them can only be done by considering the geological and geochemical environments at the time of deposition of the sediments as well as their subsequent geological history.
To date in Australia there has been a marked tendency to regard ore formation as a rather late episode in the history of the host rocks. As an example of the influence of environment, the Pb values in the Nairne Pyrite member show a close relationship

to zones of thickening of the underlying Inman Arkose (see fig. 3 in Report G.S. 1552 "The Adelaide Geosyncline and the Kanmantoo Trough"). Cambrian and Marinoan palaeography, as well as tectonics, structure and metamorphism appears to have been a factor in metal concentration and cannot be neglected. This is a consequence of accepting an initial syngenetic origin for the mineralization. This report is therefore in 3 parts.

(1) Activities of Geochemical Section

(2) Syngenesis in ore deposition as related to the Cambrian geology of South Australia.

(3) Ore Environments in the Cambrian and Marinoan of South Australia. (This part of the report discusses the significance of this approach in ore search in S.A.)

PART I

OUTLINE OF ACTIVITIES OF GEOCHEMICAL SECTION

(1) Selection of Areas

It is suggested that eventually stratigraphic sampling be extended downward to the lowest members of the Adelaide System in the State. Our small staff does not permit the very large scale geochemical surveys of the kind being carried out in Russia today. The writer believes that results will be obtained in a more useful form by systematic stratigraphic sampling.

After preliminary reconnaissance sampling of black shales in the Adelaide System and Kanmantoo Group, the Kanmantoo Group was selected in 1960 as the chief initial sampling project for the section. The Kanmantoo Group occupies an extensive region associated with abundant sulphide mineralisation close to Adelaide. It is also a sedimentary succession which current mapping showed was associated with a variety of environments. Part of the region has undergone metamorphism of varying degree so that mineralisation and host rocks can be studied over a wide range of temperature conditions.

(2) Method

A system was adopted of bulk sampling of rock chip samples on selected sections of the regional stratigraphy. The samples are submitted to A.M.D.L. for semi-quantitative analysis on the optical spectrograph. It was subsequently found that this technique is one of many employed in the U.S.S.R. where 10 million samples or more are collected per year. (Ginzburg, 1960, PXiii) Results show that generally lead values can be reproduced within a suitable range of accuracy but copper and zinc are subject to variation. More extensive use of A.M.D.L. facilities is anticipated in the future with the employment of X-Ray Spectrograph, flame photmeter, and di-thizone and colorimetric methods.

Systematic geochemical investigation of the Cambrian Kanmantoo Group commenced in January 1960, particular attention being paid to the Nairne Pyrite member. To date about 770 samples have been collected from the Kanmantoo Group and submitted for optical spectrographic analysis for Cu, Pb, Zn, Ag, Cr, Co, Ni, V. Numerous sections have been sampled on the Echunga, Adelaide and Mannum sheets. Preliminary reconnaissance sections have been run on the Môbilong, Milang and Truro sheets. In the central area on the Echunga and Mannum sheets, where the pyritic beds are best developed, it has been necessary to map in detail large areas on 1 inch to 20 chains. A large number of petrological samples were taken to measure mineralogical changes in the sediments due to metamorphism.

(3) Results

The systematic sampling of the Nairne Pyrite members revealed values from spectrographic analysis of up to 1% lead in several areas near Harrogate. Recently a specimen was obtained from one of the anomaly sections assaying 12% Pb (by chemical analysis). The mineralisation is in an inconspicuous form, probably as carbonate (due to weathering), and apparently has not been recognized by previous prospectors. This occurrence and others where Pb values exceed several thousand p.p.m., are being examined in more detail by Mr. R. Dalgarno.

(4) Extension to fossiliferous Cambrian

In May 1960 and February 1961 the ferruginous transition beds at the base of the Cambrian near Kulpara were sampled. These beds had been previously mapped by Dr. R. C Horwitz (Wakefield 1 mile sheet). The ferruginous content of these beds suggested to the writer that they represented sulphide gossans somewhat modified by limonite transportation in the zone of weathering. Spectrographic analysis gave above normal values for Cu, Zn and Mn, best results being obtained at the northern end of the outcrop. (Memo. 27th May, 1960, DM1152/60). This evidence, plus the close stratigraphic correlation with the Ediacara (Pb) and Mt. Bayley etc (Cu) deposits, lead to the drilling of a stratigraphic hole in 1960 towards the southern end of the outcrop. The southern site was selected as more likely to give an intersection below the zone of weathering.

The hole was depressed at 60 degrees and was stopped at 388 feet in the arkosic basal beds. Core recovery was poor in the zone of interest and the beds were weathered, so that no primary sulphides were obtained; a distinct rise in the lead spectrographic values occurred in the ferruginous members below the dolomite. The manganese content surprisingly, from the fragmentary core obtained, appears to be higher in the dolomite than in the transition beds, although these weather to a dark ferruginous outcrop. It is probable that some of the Fe and Mn in the unweathered sediments is present as carbonate. The old Port Clinton DDH No. 1 to the south contained traces of pyrite in the transition beds. Core samples show low lead values. These two drill holes suggest that the heavy metal content of the transition beds may increase to the north in this area.

With renewed interest in the Ediacara area in February 1961 it was decided that the systematic investigation by the Geochemical Section of the Kanmantoo Group be extended beyond the Kanmantoo Group to include eventually the rest of the Cambrian sediments in the State.

Detailed sampling of selected sections was decided on as the best method of rapidly building up a picture of the heavy metal distribution. The well established stratigraphy allows a rapid comparison to be made between sections. Deep drill holes in particular provide excellent material.

The complete Cambrian section and upper part of the Marinoan sequence at Sellick Hill was selected as a standard section for comparison with Yorke Peninsula and Kanmantoo Group data. The section has been surveyed and sampled in detail. A strong lead anomaly in the transition beds was found stratigraphically at the same level as the lead high obtained in Kulpara D.D.H. No. 1.

The following holes, Minlaton, Stansbury, Wilkatana No. 1 and Ediacara 1-12, 2-11, 3-6, have been relogged in detail. Traces of galena, chalcopyrite, pyrite, fluorite, were observed in the Minlaton bore. These cores are being sampled and submitted for spectrographic analysis for Pb, Ag, Cu, Zn, V, Cr, Co, Ni, Sb, Mn and Ba. Representative samples of the carbonate facies are being submitted for $MgCO_3$, $CaCO_3$, Insolubles and P_2O_5. It is suspected from published evidence in the Mississippi Valley mining fields, U.S.A., that dolomitization is in some way associated with heavy metal mineralization.

(5) Flinders Ranges Sampling

Sections of the Lower Cambrian have been sampled at Mern Merna (Edeowie sheet) and Parachilna Gorge (Parachilna sheet).

Later in the year and next year it is planned to sample sections in the Angepeena, Copley, Cadnia, Blinman and Arrowie sheets. On the Arrowie sheet it is planned to extend the sampling down into the Marinoan to include the copper stained shales and limestone mapped by Horwitz overlying the A.B.C. Range Quartzite stratigraphic level. Reconnaissance sections will also be run between Blinman and Wilpena Pound, as persistent Cu staining has recently been reported in that area at a similar stratigraphic level.

To date 350 samples have been submitted for spectrographic analysis as part of the extended Cambrian investigation.

(6) Study of Mining Records and mapped areas

Abundant data on metal distribution is available in the old mining records and lease plans. As small ore deposits and prospects are in a sense geochemical anomalies they are considered part of the present study. The problem is often one of locating the mineralization stratigraphically. J. E. Johnson has commenced recording such occurrences on the 1 mile sheets comprising the Barker and Adelaide 4 mile sheets. Useful results can be obtained in areas in which published maps are not available by tracing transparent overlay sheets showing formation boundaries from interpreted air photo mosaics. The stratigraphic interpretations have in a number of areas been done by the Regional Mapping Section. The overlay sheet is then checked against a 1 mile to 1 inch lease plan. In this way valuable clues were obtained by J. E. Johnson of stratigraphic control and influence of diapirs etc. on mineralisation in the Blinman and Oraparinna 1 mile sheets. It is planned to cover in this way the areas on the Parachilna and Orroroo 4 mile sheets showing Cambrian and Marinoan outcrops.

PART II

SYNGENESIS IN ORE DEPOSITION AS RELATED TO THE CAMBRIAN GEOLOGY OF SOUTH AUSTRALIA

(Note: Part II was presented as a paper at the 1961 ANZAAS Symposium on Syngenesis in Ore Deposition).

Syngenesis is defined in this paper as the sedimentary processes by which metals accumulate in sedimentary rock. It should be noted that chemical and biogenetic factors are operative alongside the purely mechanical one (Ginzberg, p.56).

Included as part of syngenesis is the chemical re-organisation (diagenesis) which takes place in sediments prior to uplift or consolidation. The subsequent chemical processes which take place in the sediments are said to be epigenetic and metamorphic. Pettijohn (p.648), points out that diagenesis is in fact the beginning of metamorphism and a boundary cannot be drawn between diagenetic and epigenetic processes. The overlapping character of these processes makes very difficult the demonstration or proof of syngenetic origin for large metallic accumulations in sediments which are sufficiently concentrated or extensive as to constitute ore bodies. Ideally, what is required is an historical study of the whole sedimentation environment into which the event of ore deposition can be logically fitted. Rarely, if ever, is this done during exploration, nor is the geological record sufficiently complete, or decipherable in the host rocks of most ore bodies for such a study to be possible. The author believes however that the sedimentary record of the Cambrian is sufficiently complete for some conclusions to be drawn as to the origin of certain sulphide ore bodies which these sediments contain.

The Cambrian Sedimentation in South Australia

General:

Cambrian sediments occur in South Australia at intervals along a belt extending for some 400 miles from the Northern Flinders Ranges to Kangaroo Island. The folding by the Palaeozoic orogeny and subsequent erosion has provided numerous good natural sections in this belt. The bio-facies has been outlined by Daily (1956). Systematic regional mapping has been done in the northern and southern parts of the zone by the Geological Survey of South Australia. Recently, systematic geochemical sampling of the stratigraphic distribution of heavy metals has been commenced by the Geological Survey in the southern part of the region. This work will eventually be extended to the central and northern regions.

Northern and Central Regions - Shelf Zone and Marginal Geosynclinal Zone:

Synclinal outliers of Cambrian sediments occur in the Northern and Central Flinders Ranges and represent the youngest fossiliferous Cambrian in the Adelaide Geosyncline (Sprigg, 1952). Cambrian sedimentation closes with the Lake Frome Group shales, sandstones and arkosic cross bedded sandstone which has the aspect of a molasse facies. The thickest measured fossiliferous Cambrian section represents 17,000 feet, Daily (p. 102). The lower part of the Cambrian is marked by extensive development of carbonate facies which are frequently dolomitic. Recently a fixing of the Pound Sandstone as Upper Precambrian in age, Glaessner and Daily (1959), Webb and Horwitz (1958), has highlighted the "transition beds" at the base of the Cambrian as an interesting locus of heavy metal mineralisation. The transition beds are calcareous and sandy shales which pass upwards into dolomitic fossiliferous limestone. Segnit (1939) considered these beds to rest disconformably on the Pound Sandstone. The Ediacara Pb/Cu/Ba deposits occur in the transition beds and are stratigraphically disposed in an isolated synclinal structure on the western side of the Flinders Ranges. The type of mineralisation and geological setting of the Ediacara deposit are similar to the Mississippi Valley type deposits * as described by Ohle (1959).

* F.M. Krause in a 1891 report on the Ediacara Mine to the Ediacara Consols Silver Mining Co. N.L. compared the deposit to the Missouri, Wisconsin etc. deposits of the Mississippi valley.

Farther east on the Copley, Angepeena and Cadnia 1-mile sheets, small copper bodies (Ajax, Mount Bayley, Sliding Rock, Copper King) occur in the lower calcareous members close to the base of the Cambrian. These beds are also marked in places by small ochre deposits. Farther to the east no mineralisation is known in the base of the beds although Horwitz on the Arrowie sheet has mapped extensive shale members in the Upper Precambrian (Marinoan) which contain calcareous members showing persistent copper traces. The Marinoan sediments have a statewide association with barite mineralisation which is believed to have been deposited originally as a barium rich sediment. The Wirrealpa Mine (Ridgway, 1947) is a Pb/Cu/Ba stratiform deposit located on a conglomeratic or sedimentary breccia horizon in the archaeocyathid limestone.

According to Sprigg (1952), Cambrian sedimentation in the Adelaide Geosyncline shallows to the west on the Stuart Shelf. Therefore, it is of interest to note that the Ediacara deposit is located closer to the more stable area to the west whereas the copper deposits extend farther east into the deeper environment. This region will be sampled systematically to enable a clearer picture to be obtained of the distribution of the heavy metals in the basal Cambrian Sequence. On the Willochra sheet in the Central Flinders Ranges, B. P. Webb (personal communication) has mapped in the transition beds a sulphurous "stinkstone" member overlain by a ferruginous zone. At the stratigraphic level of the ferruginous zone is located the old Comstock Mine iron deposit as well as a number of small copper deposits. Farther south in the Wilkatana area similar "stinkstones" and oolites in the transition beds have been noted by B. P. Webb and the writer in an exploratory oil bore. Traces of iron and copper sulphides are also present.

In Yorke Peninsula the fossiliferous Cambrian overlaps thinned members of the Precambrian Adelaide System and farther west it rests on the Archaean core. On the Wakefield sheet ferruginous outcrops are located in the zone of the transition beds at the base of the Cambrian. A recent geochemical survey by the Mines Department showed high zinc and copper anomalies associated with these ferruginous beds. Recently the basal beds were tested by an exploratory diamond drill hole in the Kulpara area. Unfortunately deep weathering prevented an intersection of primary sulphides. Geochemical sampling of the core showed definite enrichment in lead, zinc, and copper in the transition beds. This, however, may be partly the result of downward leaching due to weathering, as sampling of an earlier drill hole (Port Clinton D.D.H. no. 1) showed only relatively weak anomalies in the unweathered transition beds which are there associated with traces of pyrite. The Minlaton exploratory bore on Yorke Peninsula which penetrated 2,600 feet of Cambrian sediments extending from Middle Cambrian to the transition beds shows traces of galena in thin dolomitic limestone at the base of the evaporite sequence near the top of the hole. Traces of galena, pyrite and chalcopyrite are also visible in the lower part of the Kulpara Limestone immediately above the transition beds. Recently, geochemical traverses of the Sellick Hill section has shown a lead anomaly (800 ppm) in the Cambrian siltstones immediately above the basal arkosic grit bed which here marks a distinct unconformity of the Cambrian with the underlying Upper Precambrian sediments of the Adelaide System.

In conclusion, the question of the cause of these geochemical anomalies and traces of mineralisation in the basal Cambrian can be best attributed to an original feature of sedimentation. The writer can see no reason why this syngenetic process cannot be extended to include the small ore bodies of the Ediacara and the Ajax type.

<u>Mount Lofty Ranges and Kangaroo Island - Trough Zone</u>:

A profound change in the character of the Cambrian sediments takes place in this southern zone with the appearance of the Kanmantoo Group (Campana and Sprigg, 1953), (Horwitz (1960) and the widespread development of the greywacke (Flysch-type) sediments, (Horwitz, Thomson and Webb, 1959). The dolomitic carbonate facies of the more stable zone to the west change to pure limestone and orthoquartzite on the shelf edge before giving away to a greywacke facies. This change in facies is attributed to a difference in tectonic setting. The development of a distinct unconformity with the underlying Adelaide System and Archaean proves that the basement was tectonically active during sedimentation and the Cambrian sediments rapidly filled a deep trough-like zone extending to the west and to the northeast. The Flysch-like character is intermittent and clearly a cyclic character is evident in the Kanmantoo stratigraphy as the Flysch-like greywackes are followed by a molasse phase represented by coarse cross bedded arkoses, locally conglomeratic, which produced very shallow water conditions due to the abundant supply of sediment. The arkose varies fantastically in thickness from a few hundreds to some 30,000 feet and emphasizes the rapid subsidence in parts of the trough.

A temporary lull in tectonic activity is marked by the sudden appearance in the sequence of the Nairne Pyrite Member recently described by Skinner. This member is part of a fine grained sequence of sediments, foń which the name Nairne Formation is proposed. Mapping on the Milang, Echunga, Encounter and adjacent sheets has shown conclusively that this pyrite deposit is one of many similar lenticular deposits in this extensive fine grained formation of the Cambrian. The environmental conditions were complex and the lenticular character of the deposits can be clearly attributed to intermittent restriction of circulation within the sedimentary basin in which the original carbonaceous muds were deposited. On the Truro sheet Coats has mapped highly carbonaceous shales in the stratigraphic position of the Nairne Formation. The writer believes the complex character of the environment at the Nairne Formation time is due to the dismembered character of the trough, the basement rocks of which were broken into a block-like pattern. Individual blocks appear from detailed sedimentary studies to have been able to move independently of each other.*

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* Recently card deck experiments by Mr. E. S. O'Driscoll have shown that the thickness variations may result from the interference of two directions of shear folding -

The pyritic sediments are overlain by coarse greywacke which is overlain in turn by later pyritic sediments. Further evidence of the cyclic character of the Cambrian sedimentation is given by the carbonaceous and pyritic shales with occasional phosphate nodules which were correlated by Campana and Wilson (1954) across the regional anticlinorium of the Mount Lofty Ranges. On the western side of the ranges they have been recently described by Abele and McGowran (1959) as the Heatherdale Shales. Recently, sampling of these shales at Sellick Hill has shown them to be only feebly pyritic but they are highly carbonaceous, vanadium rich and contain abundant phosphatic nodules. These beds show a decline in phosphate content as they extend east into the trough and a marked rise in the pyrite content until they resemble a facies identical in character with the Nairne Formation which is stratigraphically many thousands of feet above them. The spectrographic values for heavy metals in the Sellick Hill area in the shales show only 50 ppm of Cu, 40 ppm of Pb and about 50 ppm of Zn.

The results of sampling of the pyritic trough equivalents are not yet available.

The Nairne Formation:

Detailed mapping and sampling of the Nairne Formation is being carried out by the Geological Survey and a drill hole section has been closely sampled. Surface samples have been taken for 25 miles on sections of the pyrite member at 1 mile intervals or closer. Values for heavy metal have been determined spectrographically and these show marked correlation with thickness variations in the Nairne Pyrite member and are interpreted as having been controlled by local hinge lines and basement highs in the original basin of sedimentation. Lead values of up to 1% have been obtained. The main Nairne Pyrite member forms a lens which is exposed over a strike length of 20 miles and it varies in thickness from zero to 700 feet.

Skinner has interpreted graded bedding which he observed in the Nairne pyrite to indicate deposition by turbidity currents and to transport of iron sulphide in a hydrous state from a shallow to a deep water environment. The writer considers that this graded bedding and minor slumping is only a local development, as the Brukunga area where Skinner made his observations is located close to a marked zone of thickening in the original basin of sedimentation and is close to a fault zone which was active during Cambrian sedimentation.

The presence of carbonaceous material has been confirmed in the pyritic beds both in the field and the laboratory. Thickness studies of the Kanmantoo Group and the environment clearly show that the pyritic beds are essentially 'in situ' in their original sedimentation environment.

A zone of pyritic lenses at or above the Nairne Pyrite member stratigraphic position continues to the north and the south. The complete section of the Kanmantoo Group along Mount Barker Creek has been geochemically sampled. The section represents some 16,000 feet true thickness. The results show a marked rise in heavy metals with the onset of the Nairne Pyrite Member and these high values continue for many thousands of feet above it in relatively fine grained sediments. These higher members include the fine grained pyritic schists in which occur the Callington (Cu), Aclare (Pb,Zn) and Wheal Ellen (Pb,Zn) deposits. These sediments have been elevated to a higher metamorphic grade than the lower members of the Nairne Formation but laterally these horizons can be traced into lower grade metamorphic areas where they occur as beds lithologically similar to the Nairne Pyrite member. Detailed mapping has shown that it is very probable that these three ore bodies occur at or very close to the same stratigraphic position. This fact, together with analogies and similarities with the Nairne pyrite member clearly support an initial syngenetic origin for these ore deposits which have been subsequently severely modified by high temperatures and stresses associated with an early Palaeozoic orogeny.

PART III

ORE ENVIRONMENTS IN THE CAMBRIAN AND MARINOAN SEDIMENTS OF SOUTH AUSTRALIA

ANALOGIES WITH OVERSEAS ORE DEPOSITS

The classical work of Harold L. James of the U.S.G.S. on the Precambrian Iron Formation of Lake Superior region represents a major advance in our understanding of iron ore formation. This work is outlined in his paper "Sedimentary Facies of Iron Formation"(James 1954). Figure 1 and 2 are taken from his paper and show that iron compounds may be precipitated in restricted basins as either the oxide carbonate silicate or <u>sulphide</u> facies. The facies are controlled by the Eh and pH conditions in the environment. The theoretical physical chemical aspects of such environments have been discussed in numerous recent publications by Huber , Garrels and others. The occurrence of Nairne pyrite in the trough zone of the Cambrian is a significant example of iron in the sulphide facies. Much work remains to be done to extend the investigations to include other metals. Krauskopf (1955) summarized in masterly fashion the data on sedimentary deposits of rare metals. He stressed the lack of field data, the complexity of the chemistry of the natural environment and the importance of organic processes. Two recent publications by Baas-Becking et al. on "Limits of Natural Environment (1960) and "Biogenic Sulphides" (1961) represent a first step in this direction with the important role of bacteria in sulphide formation being clearly demonstrated. It has been demonstrated by him and his colleagues that galena, , argentite and sphalerite, can be precipitated as minerals at 30° centigrade under special conditions in the laboratory. This discovery vitiates the formerly accepted role that these sulphides can only be formed under the higher temperatures of hydrothermal conditions. On the other hand it is now possible to seriously consider that they have also been produced under sedimentary conditions. These chemical and bacteriological investigations give promise of important discoveries in the origin of sulphides in sedimentary environments. The mechanism of concentration of sulphides into ore bodies remains a major problem.

Last year, the writer visited the White Pine copper deposits of Michigan where extensive underground mining for copper is taking place in persistent cupriferous members of the Proterozoic Nonesuch Shale. The ore mineral is predominantly chalcocite. The copper bearing beds are in the lower 20-25 feet of the shale. U.S.G.S. geologists White and Wright (1954) have concluded that most likely the copper was dropped into or precipitated within the original mud under shallow water conditions. These writers state ... "the extent of individual copper bearing beds 1 to 3 feet thick is measurable in square miles." I visited the White Pine Mine accompanied by Dr. J. Brummer, formerly of Roan-Antelope, Rhodesia. Although the Chief Mine Geologist supported a hydrothermal origin, the deposit could only be satisfactorily explained by accepting a syngenetic origin for the copper. The sediments overlie the volcanics of the Keeweenaw Peninsula containing the world famous copper deposits such as the Calumet & Hecla.

Recently, Kendall (1960) described sphalerite ore layers associated with dolomitised reefs at the Jefferson City Mine, Tennessee. Kendall favoured a sedimentary origin for the zinc, by absorption from sea water by marine organisms and subsequent reduction of the organo-metal complex to sulphide during burial. It was interesting to note that E. Ohle in a discussion on this paper put forward, as an argument against the sedimentary origin for the zinc, the presence of fluorite and barite in a similar environment at Sweetwater, Tennessee and asked the question, "Can algae precipitate fluorite and barite?" The writer believes that fluorine and barium can be trapped in certain sediments during diagenesis. Rankama & Sahama (1950) p. 763 state that in sea water ...."Calcium fluoride is removed by coprecipitation with barium sulphate, calcium carbonate and calcium phosphate and consequently enters into many marine organisms."

The writer also visited Nova Scotia last year and saw the work being done by Consolidated Zinc Corporation of Canada under the direction of their consultant, Dr. Frank Moss. In the Truro area of Nova Scotia there is widespread development of Mississippian Limestone associated in part with evaporites. Some lead zinc mineralisation occurs near the contact with the underlying Mississippian Horton Group which includes a chocolate shale associated with barite deposits. One of the world's largest barite deposits, near Walton occurs in these beds. The lithological resemblance of these beds to the Marinoan chocolate shales is remarkable.

THE MARINOAN MINERALISATION IN SOUTH AUSTRALIA - Ba, Cu, Mn ASSOCIATION:

Mawson and Segnit (1948) discuss the nature and genesis of the purple and chocolate shales and slates of the Adelaide System (Marinoan); they remark (p. 276)..... "we have observed that these shales in some areas at least have a notable content of barium and even copper; veins of barytes are a common associate and the occurrence of blue and green copper stains between the laminae of the shale have been observed in a number of localities...." One analysis was made of purple slate from Mt. Deception. It indicated MnO - 0.10%, BaO - 0.10%, CuO - 0.02%, Fe_2O_3 - 1.94%, FeO - 2.80%. Certain features of the beds suggest a tuffaceous origin. Mawson and Segnit believe that the chemical and mineral composition do not correspond well with a volcanic origin. They prefer to adopt a very shallow water terrestial origin for the purple shales and a terrestial loessal origin for the chocolate shales. While mapping on the Truro sheet, the writer was struck by the significance of the fact that barite deposits in the Upper Glacial (Marinoan) Sequence there, also occurred at the same stratigraphic position on the Echunga sheet. Study of the records and of published sheets by the writer, Horwitz and others, shows that barite mineralisation can range over the entire Marinoan stratigraphy in the Flinders Ranges. Horwitz in his current facies and thickness study of the Adelaide Geosyncline is finding that barite mineralisation is a useful guide to distribution of chocolate and purple shales. Barite deposits also occur in a number of places in Torrensian sediments. Recently B. P. Webb visited Pernatty Lagoon and Mount Gunson areas and noted (personal communication) the occurrence of Upper Glacial (Marinoan) type rocks in the vicinity of the mineralised horizons. In this area barite is associated with copper and manganese. Mr. Webb has also noted in various reports to the Mineral Development Committee that on the Willochra-Quorn-Hollowilina-Arrowie and Blinman sheets there is a strong association of manganese with the Upper Glacial Sequence and notes that manganese has been mapped in a similar position in the Northern Flinders Ranges.

CAMBRIAN MINERALIZATION:

On a recent visit to the Ediacara area the writer (G.S. No. 2030) was impressed by the association of manganese and barite with the lead mineralisation in the transition beds. Small occurrences of manganese have also been noted at many places elsewhere in the Flinders Ranges in these beds.

The writer believes that these metal associations both in the Marinoan and Cambrian reflect a special sedimentation environment. There seems little doubt that the manganese is an original sedimentary feature. Extensive sedimentary manganese deposits in Eocene marine sediments have recently been proved in U.S.S.R. (Gryazinov and Selin, 1961). The Russian geologists consider the manganese to be deposited as oxide in the shallow near shore portion of the sedimentary basin and as complex manganese carbonates in the off-shore position. Ronov & Ermiskina (1959) discuss generally the distribution of manganese in sediments on the Russian platform.

A. M. Lurye (1957) has shown that in Palaeozoic sediments in Central Karatau, Kazakhstan, there is a marked stratigraphic control of Pb, Zn, Ag, Ba, Mn and Fe generally in dolomitic facies over at least 30 square kilometres. The metals are concentrated at least a 100 times their normal abundance and Lurye believes they represent primary sedimentary accumulations. Lurye considers this concentration to be of some importance in solving the problem on genesis of the nearby Migralimsai lead zinc deposit, since its ores differ from the host rocks by just this association of elements. It is also just this association of elements that tends to be stratigraphically disposed in the Cambrian and Marinoan sediments of South Australia.

The association of evaporite deposits with the Mississippian mineralisation at Nova Scotia has a parallel with the occurrence of alunite at the base of the Cambrian in the Angepeena region and possibly also with gypsum veins noted in the transition beds at Ediacara. The association of sulphides with an evaporite environment may not be anomalous, as Baas-Becking et al. (1961) have demonstrated that chrysacolla may be reduced to covellite under anaerobic conditions today in a locality such as Pernatty Lagoon.

OUTLINE OF SEDIMENTATION ENVIRONMENT:

Figure 3 shows a diagrammatic section showing the possible variations in the environments of Cambrian and Marinoan sediments between the Pernatty Lagoon and Kanmantoo Trough areas. A feature of this section is the shifting to younger beds of the known Cu Pb metal concentrations from the Marinoan at Pernatty Lagoon eastwards to the base of the Cambrian at Ediacara and to above the Archaeocyatha Limestone at Wirrealpa and in the southeast to the Nairne Pyrite position and above in the Kanmantoo Group.

The structural details of the geology are far more complex than the sections show. In the Kanmantoo Trough Zone the relationship between zones of sedimentary thickening and unconformities is still being worked out. Mapping and sampling shows conclusively that the thickness of Cambrian sedimentation is related to development of unconformity with the Precambrian change of facies and metal content of the sediments. Fig. 3 shows in more detail a generalized section somewhat south of Fig. 2 section and demonstrates the marked influence of the Gawler Nucleus on the sedimentary succession. The nucleus would appear to have been an important source area for Cambrian sediments. Isolated tectonic highs within the basin of sedimentation also contributed. Evidence was found during recent visit to the Gawler Ranges by B. P. Webb, A. R. Crawford and J. E. Johnson that the Gawler Range Porphyry is probably pene-contemporaneous with the Corunna Conglomerates. B. P. Webb and A. R. Crawford (personal communication) suggest that the conglomerate and the porphyry which locally has extrusive character may be Torrensian or Willouran in age. R. C. Horwitz suggests from thickness studies of the sediments in the Flinders Ranges that the Gawler Ranges region is the source area for sandstones and purple sediments in the Marinoan.

It is apparent that geochemical sampling of the Gawler Range porphyry for Cu, Fe, Mn and Ba would be of interest in order to assess the importance of this region as a source area in the sedimentation environment and in its own right as a possible cupriferous province as already recommended by A. R. Crawford 1960 (p. 78).

Shallow marine shelves and restricted basins would offer the greatest opportunities for the trapping in sediments of part of the metal content of the sea water in its passage to the oceans which lay probably to the southeast. An important clue on the physical, chemistry of the environment is given by the form of iron mineral in the sediments in terms of the concepts outlined by H. James. The behaviour of Cu, Pb, etc. is obscure. The form of the original ore mineral is unknown. Cu together with Mn and Ba appears to favour the Fe oxide facies environment. Cu may also be present in the Fe sulphide environment with carbonaceous and argillaceous sediments. Mn and Ba may overlap into the carbonate environment where Pb may be associated. At present the behaviour of Zn is largely unknown although it has been detected in varying amounts in the Fe sulphide environment and with Mn in the Cambrian. It is surprising that it is not more abundant in the dolomite environment of the lower Cambrian.

SUBMARINE EXHALATIVE HYPOTHESIS

A factor that should be considered in the Cambrian and Marinoan sedimentation is the possibility of the local enrichment of sea water along sinking coastlines by the addition of metalliferous solutions along deep seated fracture zones and in areas of submarine volcanic activity.

German and Scandinavian geologists have considerable evidence for this process having lead to the formation of certain concordant sulphide deposits classed by Schneiderhöhn as "submarine exhalative sedimentary ore bodies." David Williams (1960) (P.273-275) reviews some of the published evidence for this hypothesis. A number of exploration geologists have applied it with success in Canada, e.g. in New Brunswick area (personal communication). R. L. Stanton has also advocated it as an explanation for some Cu deposits/in the Palaeozoic of eastern Australia (e.g. Burraga). The writer thinks, it possible that the White Pine deposit was influenced by the adjacent cupriferous volcanics province of the Keeweenaw Peninsula. The volcanics underlie the White Pine sequence containing the orebeds.

In the South Australian Cambrian there are a number of points of interest in connection with this hypothesis. The occurrence of heavy metal enrichments along the flanks of zones of thickening with the Kanmantoo Trough Zone (Thomson, 1960) points to "local edge of shelf environments" which may owe their abnormal metal content originally to a submarine exhalative process. This factor being deep seated is unpredictable. Geochemical sampling may reveal characteristic metal association in the margins of enriched areas. Dr. Horwitz has advised the writer that his preliminary isopach and facies study of the sediments in the Adelaide Geosyncline suggests that areas of known mineralisation tend to occur along the edges of zones of rapid increase in thickness.

In the Cambrian the only contemporaneous volcanics known to the writer occur at the base of the Cambrian on the Truro sheet near Dutton and further north near Australia Plains on the Eudunda sheet. Recent geochemical sampling in the Dutton area showed no spectacular rise in heavy metals in the region. Although there is in the highest volcanic member, local copper enrichment and also there is a possible erosional interval immediately subsequent to the volcanic episode. Nairne Pyrite sedimentation occurred later, although it is still possible that basic bodies intrusive into the Kanmantoo Group on the eastern portions of the Truro and Cambrai sheets may be feeders to later extrusives.

In the Flinders Ranges, the diapir bodies (Webb, 1960), containing basic volcanics, were undoubtedly actively pushing upward through the sedimentary pile during Marinoan and Cambrian sedimentation. The possibility of persistent gradual leakage of metalliferous solutions or gases upwards through the disturbed diapir zone is an interesting speculation. B. P. Webb (personal communication) believes the development of crosscutting siderite veins in the rocks around the Blinman diapir occurred as a closing spasm of the Cambrian orogeny. The proposed detailed mapping of the Blinman diapir by the Regional Mapping Section will be of critical importance in establishing the essential geological data for any future geochemical work in the area.

ORE LOCALISATION:

There is as yet no clear proof, apart from Fe and Mn, that economic ore bodies of other heavy metals can be produced under normal sedimentation conditions without the operation of some abnormal factor. Such a factor may be the addition of metal ions to sea water in the submarine exhalative process, or in the unknown process by which most of the Mississippi valley type deposits were apparently formed during or shortly after sedimentation. The influence of nearby source areas possibly rich in heavy metals is incompletely understood. A good example of source area influence is given by the Fe rich Willyama Province south of Broken Hill providing the Fe for the

Sturtian sedimentary Braemar Iron Formation. Later factors to operate are epigenetic in the sense that migration of the metal compounds or ions, due to pressure differences, takes place along the beds and in rock openings. The Oraparinna barite deposit may be of this character (Nixon 1960). It appears to have formed in a cross cutting fracture in the Ba rich Marinoan purple shales by a lateral secretion process which is as yet very imperfectly understood. This deposit would provide an excellent opportunity to test this hypothesis.

The writer believes after studying the distribution of mineralisation on the Oraparinna 1 mile sheet that fracture systems related to a large diapiric zone to the southwest have localised many of the small Ba, Cu deposits in the sediments which surround the diapir. R. C. Mirams recently confirmed that the Fountain Head Pb, Ag. deposit and another lead prospect on the Blinman sheet appear to have been influenced by their proximity to a diapir containing volcanics.

With rising temperature, marked migration of metal along the beds into tight-folded structures and into cross cutting shears takes place as appeared to have occurred in the environments of the Aclare, Paringa, Bremer ore bodies in the Kanmantoo Group. The intervening portions of bed are impoverished. The next step appears to be the development of hydrothermal type veins moving at random through the stratigraphy.

<u>CONCLUSION</u>

Evidence available to date shows that heavy metal distributions in the Cambrian and Marinoan sediments in the State tend to have a stratigraphic habit. Metal associations tend to vary with changing sedimentary environments and points to an early syngenetic control.

Later features which are of great importance in local concentrations to ore grade are tectonic. Metamorphic factors also operate. An unknown factor at present is the role of vulcanism in establishing local ore environments within the Cambrian - Marinoan sedimentation. The problem can best be studied by means of a continued systematic sampling campaign.

The long range search for heavy metal deposits in this state should be considered as comparable both in scale and technique of investigation with the current search for oil and the writer believes that the proposed thickness study of Dr. Horwitz will be equally valuable to the Geochemical Section as to the petroleum investigation. The current commitments of the section in the northwest of the state prevent a sustained sampling and mapping campaign in the Flinders Ranges until September. In the meantime, Mr. R. Dalgarno is continuing his work on the Kanmantoo Group.

A long range objective in the work of the section is the production of geochemical maps. The following comments by David Williams (1959, p. 154) are significant.

"It is reported that the use of geochemical prospecting techniques is now mandatory for the 6000 or so exploration parties sent out annually by the government of the U.S.S.R. and that the Russians have been analysing about six million samples each year, equivalent to three times the rate of the rest of the world. Geochemical survey maps indicating localities of various metal concentrations determined by water, soil and sediment analyses have already been published for enormous areas in Kazakhstan and elsewhere, and it is claimed that many recent discoveries are rich in base metals, Sb, Be, Hg, Ni, Sn, W and V. It is not too much to hope that in the near future similar geochemical surveys will be carried out in other parts of the world, and that maps will be issued illustrating the distribution and concentration of various elements within different regions. Such maps would be a boon to the prospector."

RECOMMENDATIONS

1. Continuation of systematic sampling of Kanmantoo Group.
   (a) Further detailed sampling of Nairne Pyrite
   (b) Detailed sampling of mineralised horizons from Bremer mine to Aclare, Wheal Ellen and Strathalbyn mine.

(c) Regional reconnaissance sampling to be continued from Echunga sheet to Jervis sheet and north to Eudunda sheet.

2. (a) Mapping and sampling vicinity of Western River lead mineralisation on Cassini and Borda 1 mile sheets Kangaroo Island.

(b) Reconnaissance sampling Kangaroo Island Group.

3. (a) Reconnaissance sampling of Arrowie sheet Marinoan Cu mineralisation and basal Cambrian.

(b) Reconnaissance sampling Marinoan and Cambrian on Blinman, Oraparinna and Wilpena sheets.

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B. P. THOMSON
Senior Geologist,
Geochemistry Section

BPT:CERF
6/7/61

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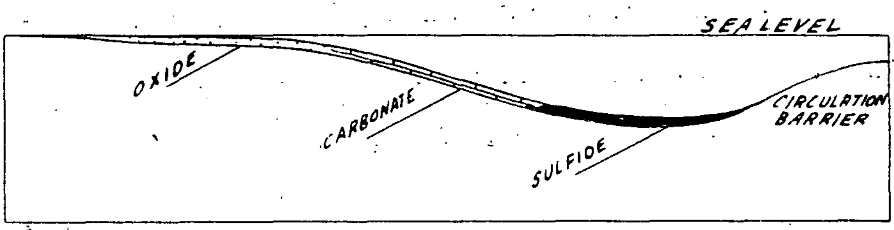
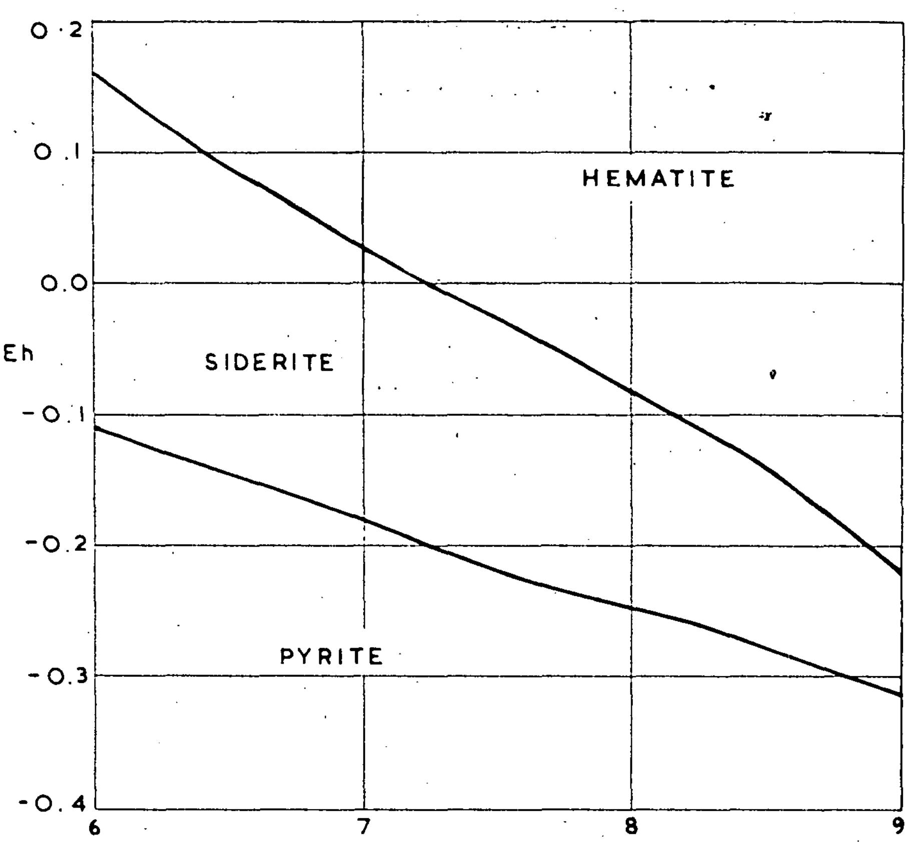


Depositional zones in a hypothetical restricted deep basin in which iron compounds are being precipitated. Highly diagrammatic.

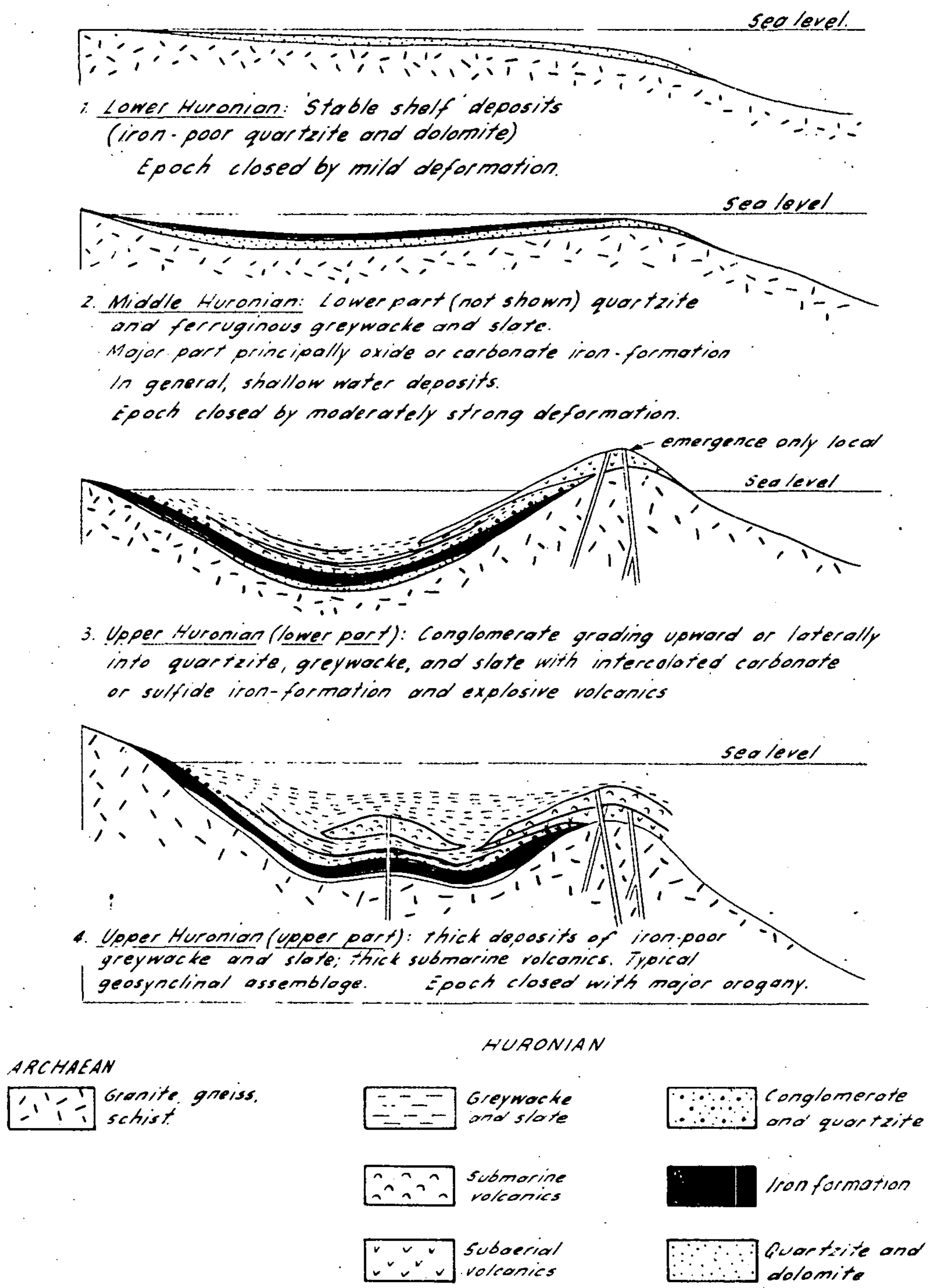


Stability fields of hematite, siderite, and pyrite
(from Krumbein and Garrels)

FIG. I

S.A. DEPARTMENT OF MINES					
Approved	Passed	Drn.	SEDIMENTARY FACIES IRON FORMATION (AFTER H. L. JAMES 1954)	D.M.	Scale
		Tcd. 4.W		Req.	S2827 MG
		Ckd.			
Director		Exd.			Date 4-7-61

200—7·61 3805



AFTER H.L. JAMES

FIG. 2

S.A. DEPARTMENT OF MINES

Approved	Passed	Drn.	DIAGRAMMATIC OUTLINE OF HURONIAN DEPOSITIONAL HISTORY IN MICHIGAN	D.M.	Scale
		Tcd. A W.		Req.	S2828
		Ckd.			MG
Director		Exd.			Date 4-7-61

300—2·61 3835

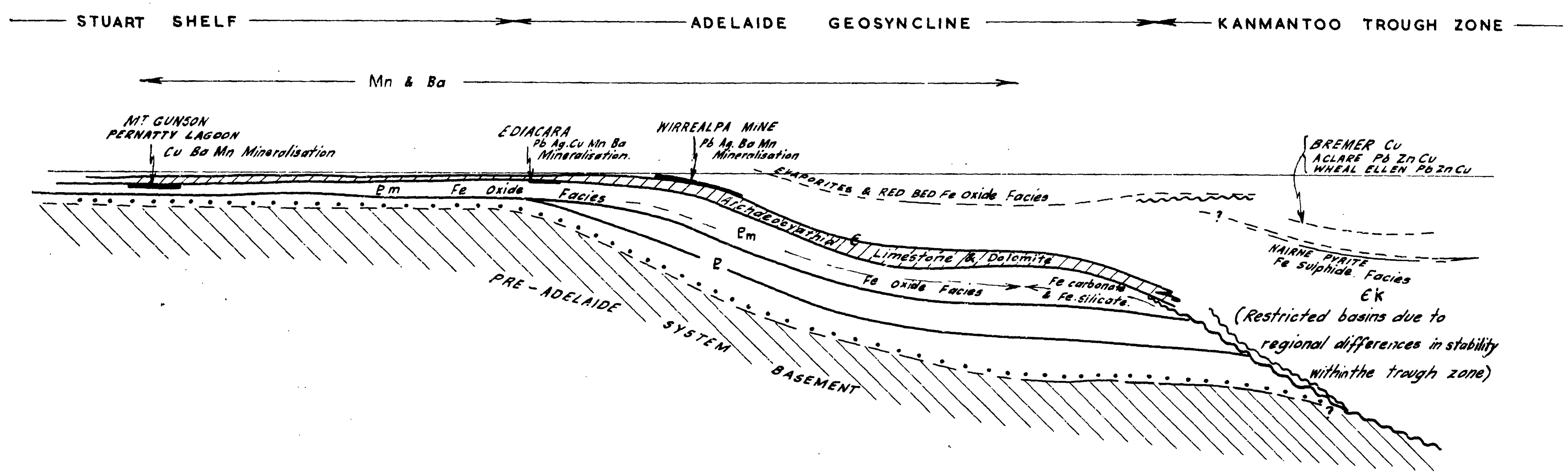


FIG.3

To accompany report GS2049 by B.P.C. Thomson

S.A. DEPARTMENT OF MINES

DIAGRAMMATIC SECTION
PERNATTY LAGOON TO
KANMANTOO TROUGH
IN MIDDLE CAMBRIAN TIME

Approved | Passed | Drn. Tcd. AW Ckd. Exd. | Scale: 61-490 MG Date 5-7-61

Director

No. | Amendment | Exd. | Date

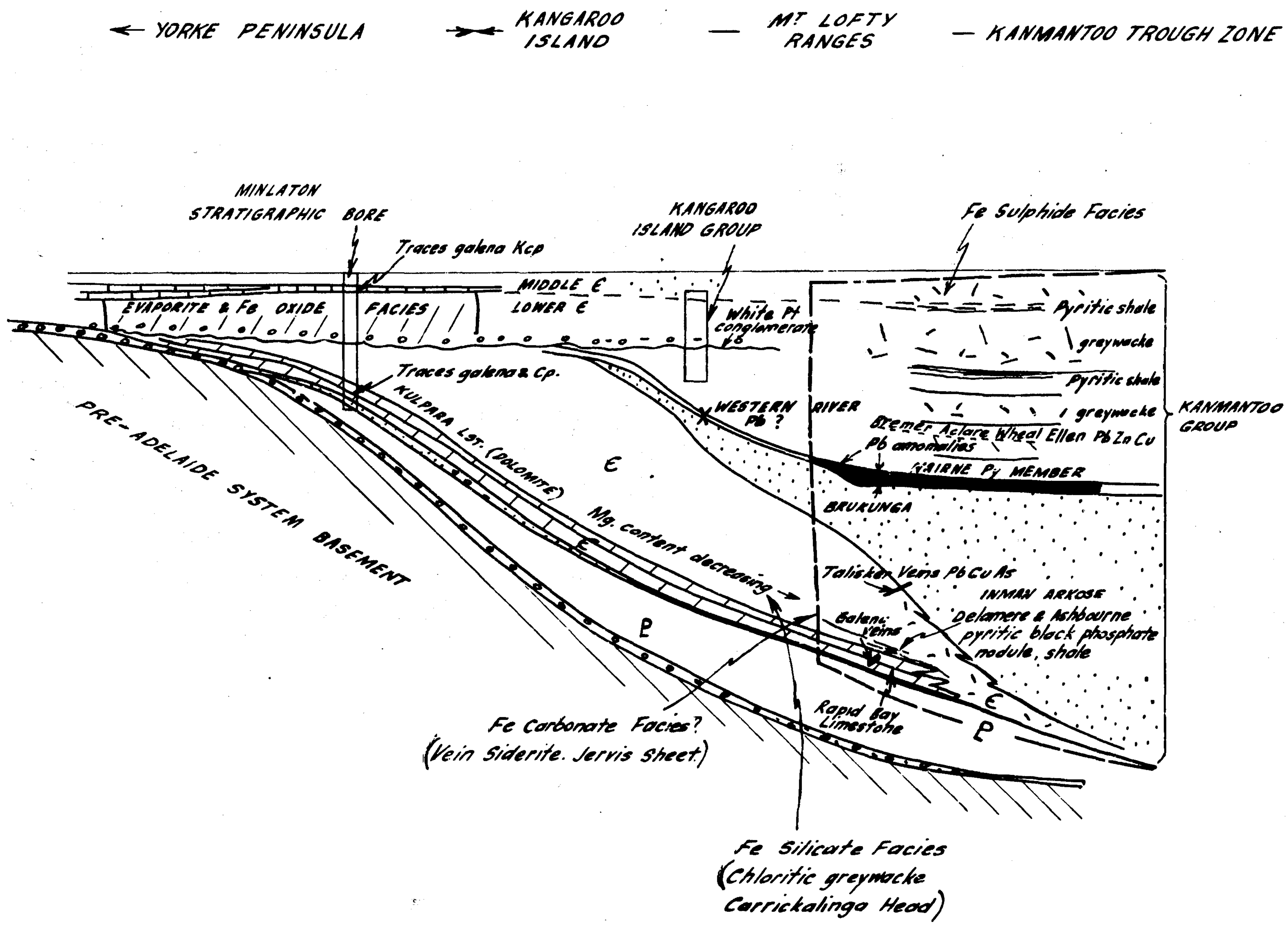


FIG. 4

To accompany report GS2049 by B.P.C. Thomson.

S.A. DEPARTMENT OF MINES

SCHEMATIC DIAGRAM SHOWING RELATIONSHIP BETWEEN CAMBRIAN FACIES & MINERALISATION IN YORKE PENINSULA & KANMANTOO TROUGH ZONE ENVIRONMENTS

No.	Amendment	Exd.	Date

Approved	Passed		Scale:
Director		Drn. Tcd. A.W. Ckd. Exd.	61-491 MG Date 5-7-61