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A STUDY OF THE EDIACARA MINERAL FIELD AND A COMPARISON WITH SOME OTHER MINERAL DEPOSITS IN LOWER CAMBRIAN CARBONATES OF THE ADELAIDE GEOSYNCLINE

BY

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SUMMARY

The Ediacara mineral field, situated 30 kilometres west of Beltana on the western margins of the Flinders Ranges, South Australia, has been investigated by detailed mineralogical, petrological, fluid inclusion and sulphur isotope studies. The field occurs in lower Cambrian carbonate rocks which contain anomalous base-metal contents throughout the Adelaide Geosyncline. Several other mineral occurrences in the lower Cambrian carbonates (the Wirrealpa Mine, Western Flinders Ranges and the Sellick Hill Area) have been briefly studied for a comparison with Ediacara.

The main primary ore minerals at Ediacara are galena and pyrite, and very minor chalcopyrite and sphalerite, with rare tetrahedrite and pearceite present as possible exsolution bodies in galena. The gangue consists predominantly of silica (both chalcedony and quartz) with minor dolomite and rare barite. The lead mineralisation is stratabound and confined mainly to a relatively narrow sequence, consisting of two layers about 15 metres apart, and commencing 30 to 60 metres above the Cambrian-Precambrian contact.

The host to the mineralisation, the Ajax Limestone, consists entirely of dolomite and represents a set of complex lithologies, structures and organic traces that indicate a shallow near-shore carbonate environment (sabkha). The lead mineralisation is closely related to units of the Ajax Limestone, the Sandy Cross Bedded Dolomite and the Laminated Dolomite, these units having been deposited in an environment ranging from sub-tidal to bar and channel and a tidal flat environment, respectively. Four types of mineralisation have been recognised; disseminated sulphides of probable syngenetic origin and concentrations along stylolites, in veins and as breccia fillings. The disseminated sulphides were probably formed by the reaction of metals, deposited contemporaneously with sedimentation from erosion of the Willyama Complex, with H_2S produced by the bacterial reduction of sea water sulphate in a tidal flat environment.

Post depositional solution activity has affected a large proportion of the carbonate sequence. The effects of this activity range from stylolites through to stylobreccias and solution collapse breccias. It is thought that the concentrations of mineralisation have been formed by the remobilisation of the disseminated sulphides during solution activity.

The ore and gangue minerals of the remobilised mineralisation display both euhedral, crystalline forms and distinct colloform banding, with the latter forming before the former. Framboidal textures have also been observed in both pyrite and galena, and there is evidence of repeated episodical precipitation. All textural forms are considered to have been produced from silica-rich hydrothermal solutions.

Sulphur isotope determinations have been performed on 41 sulphide samples (mainly pyrite and galena) from Ediacara, and results show a wide spread of values from -12.5 to + 8.6‰ with a mean of 0‰. Three pyrite-galena coexisting samples indicate that sulphur isotope equilibrium between these sulphides was apparently not achieved. The sulphur isotope distribution, which is comparable with that of the Zambian copper deposits, can be accounted for by the bacterial reduction of seawater sulphate in a closed system. This distribution has probably been preserved during remobilisation of the original syngenetic sulphides.

Fluid inclusion studies have been undertaken predominantly on silica and several samples of dolomite associated with remobilised mineralisation in breccias and stylolites. These indicate deposition from saline brines (24 to 27 equivalent weight percent NaCl) at temperatures between 159° and 199°C, the metals being carried as chloride or bisulphide complexes and precipitation having taken place due to oxidation or a decrease in pH. The most likely methods of production of such a brine would be by leaching of

evaporties by connate waters or the processing of sea water in a sabkha environment. The latter method would produce magnesium brines, which could have percolated downward and seaward, dolomitising the sediments (seepage refluxion) at the same time.

A similar process would explain the origin of the sulphides in other lower Cambrian lead-zinc occurrences in the Flinders Ranges, although a slightly different process has been proposed for deposits in the Sellick Hill area. The lower Cambrian lead-zinc deposits of the Adelaide Geosyncline are directly comparable with the Mississippi Valley-type deposits and can be explained as having been formed as a result of post depositional processes that would operate in any large sedimentary basin.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University nor, to the best of my knowledge and belief, does it contain any material previously published or written by another person except where due reference is made in the text.

G.J. Drew

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CHAPTER 1.

INTRODUCTION

1.1 LOCATION AND ACCESS

The Ediacara mineral field is located in the Mt. James Range, approximately 480 kilometres north of Adelaide and 30 kilometres west of Beltana (Figures 1.1 and 1.2). The field comprises four main workings:- Greenwood's Workings, Morish Adit, Black Eagle Mine and Southern Workings (Figure 1.2). The area consists of a dolomite plateau about five kilometres by two kilometres. On the western side of the plateau, sand dunes commence and extend to Lake Torrens, about 11 kilometres to the west. To the east the country consists of a relatively flat alluvial plain subjected to occasional flooding.

Access to the field is via graded tracks from Beltana. The area is subject to extremes of climate with very hot summers and cool and dry winters. Rainfall is low with an average yearly rainfall between 125 and 200 millimetres, most of which may fall during summer thunderstorms.

Vegetation is sparse and consists mainly of stunted saltbush and casaurinas on the ranges and saltbush and acacias on the plains to the east. Vegetation is generally lusher on the sand dunes and consists mainly of acacias. The larger creeks are marked by ghost gums.

1.2 HISTORY OF INVESTIGATIONS

The Ediacara mineral field was originally discovered in the middle of the last century, and the first geological map of the area was prepared by Brown (1892).

The most active period of mining was during the period 1888-1913 when approximately 24,000 tonnes of high grade silver-lead ore (ore from Greenwood's Workings averaged 31.5% Pb and 250 g Ag/t) were mined from shallow pits and underground workings along the western and southern margins of the Ediacara Basin. Most of this came from Greenwood and Southern Workings. Much smaller tonnages of secondary copper carbonates, hand picked to 20% Cu, were won at the Black Eagle Mine and a little lead and barite came from Morish Adit. No further working was carried out until the period 1937-1947. Extensive sampling was carried out in 1938 by the Zinc Corporation Ltd., which concluded that a small tonnage of high grade ore was still available in the old workings, but a large low grade ore body was considered unlikely. During this period the South Australian Department of Mines commenced regional and detailed geological mapping of the mineral field (Segnit, 1939; Broadhurst, 1947). In 1947 geophysical surveys including electromagnetic, magnetic and resistivity methods, were carried out by the Commonwealth Mineral Resources Survey. No anomalies were found over Greenwood's or Southern Workings, but two weak anomalies were found in the South East Gossan area. These were drilled by the South Australian Department of Mines, but proved to be barren except for some pyrite. On the recommendations of Broadhurst (1947) three other holes were drilled on geochemical anomalies in the vicinity of the South East Gossan area and Southern Workings. Two of these were barren and the third showed very sparse lead mineralisation.

The South Australian Department of Mines gave renewed attention to the field in 1961, after Nixon had drawn attention to the stratiform[1] nature of mineralisation and the sedimentary nature of the

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[1] There is confusion in the literature over the terms "stratiform" and "stratabound". The definitions of these terms used by the writer, are those according to Stanton (1972), which are as follows:-

> Stratiform deposits occur as layers that are disposed concordantly with respect to the stratification of the enclosing sedimentary materials.
>
> Stratabound deposits habitually favour specific horizons within local sedimentary sequences and show marked preferences for certain rock types, but do not occur as concordant layers. They are thus confined to particular stratigraphic horizons on a large scale but are usually discordant on a small scale.

This does not mean, however, that the terms used by other workers agree with these definitions.

breccias and other fragmental rocks, which previously were thought to have been of tectonic origin. This led to further field work and detailed mapping during the period 1961-1963 (Nixon 1962, 1963, 1964, 1967). In this programme 30 diamond drill holes were completed, mainly in the northern part of the area.

This work resulted in Nixon (1962) classifying the Ediacara mineral field as an example of "Mississippi Valley-type" deposits. Reserves were estimated at 17.5 million tonnes of ore over a thickness of 15.6 metres and averaging 1.13% lead or 31.8 million tonnes over a thickness of 17.4 metres and averaging 0.9% lead (Nixon, 1967).

A further 11 drill holes were put down by the South Australian Department of Mines for C.R.A. Exploration Pty. Ltd. in 1965 and 1966 (McQueen, 1967), but failed to extend the limit of previously indicated mineralisation. In a view of all previous work, Johns (1972) outlined two mineralised lenses at the northern end of the basin, namely:

(1) 12 million tonnes averaging 0.84% lead

(2) 17 million tonnes averaging 1.23% lead.

C.R.A. Exploration Pty. Ltd. concluded that the density of the drilling and knowledge of mineralisation indicated that the occurrence of an economic deposit of base metals was extremely unlikely.

Further work was carried out between 1970 and 1974 by Carpentaria Exploration Co. Pty. Ltd. (Binks 1975) concentrating on secondary lead and copper mineralisation. Four mineralised bodies were discovered in the vicinity of the Black Eagle Mine and the possible reserves were:

0.194 million tonnes averaging 0.74% copper and 8.25% barite

0.32 million tonnes averaging 0.92% copper

0.225 million tonnes averaging 21.2% barite

1.7 million tonnes averaging 12.0% barite, and 1.0% lead.

This work also disproved the possibility that Cambrian dolomites (and hence possible extension of mineralisation) might have been under the Cainozoic deposits on the western side of the Ediacara Fault (see Figure 1.2).

1.3 AIMS OF THE INVESTIGATION

Following detailed mapping and diamond drilling by the South Australian Department of Mines in the 1960's, the Ediacara mineral field was suggested to have similarities with the Mississippi Valley-type deposits (Nixon, 1962). This conclusion was based mainly on the association of mineralisation in carbonate rocks, and the relationship with sedimentary features, in particular sedimentary breccias, and the stratiform nature of mineralisation as revealed by bore hole geochemical data (Nixon, 1962 p. 105). The aim of this study was initially to further examine this general similarity by considering features not previously studied. These included a detailed examination of the mineralogy and sedimentary petrology, fluid inclusion studies and sulphur isotope studies. This was intended to provide information on the nature of the ore forming fluids and mechanisms of transport, temperatures of deposition of the mineralisation and origin of ore metals and sulphur. Later this approach was extended, in less detail, to some other mineral deposits in lower Cambrian carbonate rocks of the Adelaide Geosyncline, in order to compare them with the Ediacara mineral field.

1.4 REGIONAL GEOLOGICAL SETTING

The Ediacara mineral field is located on the western margins of the Adelaide Geosyncline (Figure 1.1). To the west across the Torrens Hinge Zone, is the Stuart shelf, on which relatively flat lying Precambrian to Cambrian sediments rest unconformably on the Gawler Platform of Proterozoic Age. To the east is the Adelaide Geosyncline, and further east in the Frome Embayment, practically flat lying Cambrian sediments have been recorded in the subsurface. The basement for these sediments is probably a subsurface extension of the middle Proterozoic Willyama Complex. The cover sediments observed in these exceedingly stable platforms are similar in lithology to those found in the fold belt.

At Ediacara upper Precambrian and lower Cambrian sediments occupy a shallow north-south elongate basin (Figure 1.2).

The upper Precambrian Marinoan Series comprises dolomites overlain by shales and succeeded by 150 to 300 metres of Pound Quartzite. As elsewhere in the Flinders Ranges the Pound Quartzite is overlain by the basal Cambrian Worm Burrow Bed. This is succeeded by Transition Shales and then a thick sequence of dolomite, the Ajax Limestone, (Nixon, 1962). The highest unit exposed in the Ediacara Basin is within the Ajax Limestone and contains Archaeocyatha. The succession correlates well with the Cambrian elsewhere in the Northern Flinders Ranges, but is thinner and contains more shallow water sediments than further to the east.

Structurally the gently flexed Ediacara Basin is seen as transitional between the strongly folded Northern Flinders Ranges and the subhorizontal dolomites and sandstones, which cover a wide area west of Lakes Torrens (the Stuart Shelf).

1.5 STRATIGRAPHY (FIGURE 1.3)

1.5.1 Pound Quartzite (Wilpena Group - Upper Proterozoic)

This unit, between 150 and 300 metres in thickness, delineates the shallow closed synclinal basin and is composed of a fairly clean quartz sandstone and quartzite. According to Goldring and Curnow (1967) the upper part of the Pound Quartzite shows three principal facies:-

(a) A cross-stratified and flat-stratified sandstone facies at the top of the formation, which is interpreted as off shore marine sands.

(b) The main fossiliferous horizon about 3 to 5 metres in thickness and occurring about 10 to 20 metres below the top of the formation. This unit is a thinly bedded cross-bedded sandstone, containing a rich fauna of soft bodied animals (the Ediacara Fauna), formed in a local depositional environment.

(c) A massive indurated sandstone with intra-formational conglomerates which is interpreted as a channel fill sediment.

1.5.2 Parachilna Formation (Hawker Group)

In the Cambrian there was a return to a fully marine environment following the terrestrial and deltaic conditions of the upper Marinoan. The transitional beds of the Parachilna Formation give way to the thick marine carbonate sequence of the Ajax Limestone. Only the lower part of the Cambrian is present at Ediacara.

The Parachilna Formation is divided into two units in the Ediacara area (Nixon, 1962).

Unit 1. Worm Burrow Beds

This unit averages 3 metres in thickness and marks the base of the Cambrian. This unit consists of a gritty sandstone with a clayey and chloritic matrix, the chlorite giving it a characteristic greenish colour. It is rich in vertical worm burrow (Scolithus), which are present over a large area of the Northern Flinders (Dalgarno and Johnson, (1962). This unit makes an excellent marker for the Ediacara structure.

Unit 2. Transition Shales

These average 15 to 20 metres in thickness and consist dominantly of shales, with interbedded sandstone and dolomite. This unit outcrops around the margins of the Ediacara Basin and is deeply affected by weathering.

According to Goldring and Curnow (1967) the sequence from upper Pound Quartzite through to the Parachilna Formation, corresponds to the frequently observed regressive unit followed by a transgressive unit in deltaic sedimentation. Hence they support the idea that the Parachilna Formation records a major transgression (a local unconformity has been found in this stratigraphic position further east in the Flinders Ranges) - in other words, in part the sea transgressed over unlithified sediments, as shown by worm burrows penetrating the Pound Quartzite (Nixon, 1962 : Curnow and Goldring, 1967).

1.5.3 Ajax Limestone

The Parachilna Formation is overlain conformably by Cambrian dolomites. Nixon (1962) has referred to the carbonate sequence of the Cambrian at Ediacara as the Ajax Limestone, by drawing an analogy to the limestones of the nearby Mt. Scott Area (Daily, 1956). Nixon has recognised a three fold subdivision of the Ajax Limestone at Ediacara on the basis of detailed field mapping. The total thickness of Cambrian at Ediacara is 320 metres.

Unit 1. Sandy Cross Bedded Dolomite (To be Referred to as the Sandy Dolomite)

This is the oldest unit, varying between 0 and 100 metres in thickness, and is presently only in the north and south of the basin, lensing out towards the centre. Nixon (1962) has interpreted this as indicating shoreline conditions in the north and south with a trough occupying the central area. The sandy dolomites are fairly well bedded and commonly cross bedded, with some interbedded fine grained grey or greenish grey massive dolomites. These are frequently brecciated and sometimes strongly mineralised. Layers of breccia up to a metre in thickness are common. Primary lead mineralisation occurs in these breccias.

Unit 2. Laminated Algal Dolomite (To be Referred to as the Laminated Dolomite)

This unit is between 35 and 40 metres in thickness and consists of pale buff and grey laminated dolomites, with interbedded lenses and beds of dark grey massive dolomites. Structures thought to be stromatolites occur, particularly in the north west part of the basin. Breccias, many metres thick, are common and one persistent siliceous, manganese and iron stained breccia occurs near the base of the unit. Detailed mapping by Nixon (1962) has shown these breccias to be approximately conformable to bedding (see Figure 1.3). Primary lead mineralisation is common in the breccias. The algal beds tend to change along strike into oolitic dolomite in places.

Unit 3. Massive Dolomite

This unit, at least 150 metres in thickness, is the youngest unit exposed and an unknown thickness of it has been eroded. It is a massive, finely crystalline, grey dolomite with nodular and bedded chert. Occasional archaeocyatha have been found in this unit, particularly towards the top. Minor breccias occur and only traces of primary lead mineralisation are known.

The dolomitic breccias are of interest and importance. They appear to be conformable as shown by detailed mapping (Figure 1.3). They occur from a few centimetres to several metres in thickness and quantitatively make up an important portion of the dolomite sequence. Individual breccias may not have great persistence along strike, but at least one seems to occur fairly persistently, though in a lenticular fashion, just above the base of the Laminated Dolomite. This breccia, and some others, principally or entirely in the Laminated Dolomite, contain abundant siliceous fragments and manganese and iron staining. The majority of the breccias consist of angular fragments of dolomite in a fine grained or sandy dolomitic matrix.

CHAPTER 2.

SEDIMENTARY PETROLOGY
- EDIACARA

2.1 INTRODUCTION

The petrography of the host-rocks has been studied in both hand specimen and thin section. Two diamond drill holes, E32 and E33A were examined and logged in detail (See Appendix). Representative samples for examination were taken and numbered, such that the first part of the number refers to the hole and the second part to the depth in feet (e.g., 32/352 refers to a sample taken at depth of 352 feet in hole E32). The same numbering procedure was used for subsequent samples taken for mineragraphic, sulphur isotope and fluid inclusion studies. The carbonate sediments are classified according to the scheme of spectral subdivision outlined by Folk (1968). Carbonate minerals were identified by staining techniques described by Friedman (1959). The descriptions have been subdivided according to the units recognised at the surface (Section 1.4), although the recognition of the carbonate units in drill core can be very difficult.

2.2 POUND QUARTZITE

This is a medium grained feldspathic quartzite. The grains were originally subangular to subrounded in shape, but grain boundaries are indistinct because of recrystallisation. Quartz (90%) is the predominant mineral present and many grains show undulose extinction. Feldspars constitute 5 to 10% of the rock and include microcline, plagioclase and orthoclase. In places barite (up to 5%) is found cementing grains. Accessory minerals include zircon, tourmaline, sericite and about 1% of opaques.

2.3 WORM BURROW BEDS

This is a medium to coarse grained sandstone, with quartz (85%) existing in two distinct grain sizes. Some grains are reasonably coarse (0.5 to 1.5mm) and well rounded whereas others are much finer (0.05 to 0.1mm) and subangular to subrounded. Well rounded feldspar grains (plagioclase and microcline) constitute 2 to 5% of the rock and fine grained clays and chlorite, 5 to 10%. Accessory minerals include a small percentage of well rounded tourmaline and rare zircon.

2.4 TRANSITION SHALES

This unit consists predominantly of interbedded dolomitic and siliceous units.

2.4.1 Greywacke

This is a poorly sorted rock containing fragments of siltstone and argillaceous sandstone and rounded quartz grains in an extremely fine grained matrix. The argillaceous fragments are composed of subangular to subrounded quartz and feldspar grains in a sericitic matrix. Siltstone fragments contain predominantly sericite and minor quartz. The rounded quartz and occasional feldspar grains (microcline with some plagioclase) average 0.5mm in diameter. The matrix of the rock is composed of subangular to subrounded quartz and feldspar, sericite and muscovite. Accessory minerals include zircon, tourmaline, sphene and opaques.

2.4.2 Sandstone

The grains are subangular to subrounded in shape and range from 0.03mm to 0.1mm in diameter. Quartz (95%) is the predominant constitutent with minor feldspar (orthoclase, plagioclase and microcline). The matrix is extremely fine grained and consists of sericite and iron oxides. Accessory zircon and tourmaline are present.

2.4.3 Sandy, Finely Crystalline Dolomite

Dolomite (55%) is the dominant mineral with minor quartz and feldspar (microcline and plagioclase). The grains average 0.05mm in diameter and are mostly subangular to subrounded in shape. Sericite (5%) occurs in bands and fine grained opaques are disseminated through the rock. Accessory minerals present are tourmaline and zircon.

2.4.4 Sandy, Oolitic, Medium Crystalline Dolomite

The main constituents are dolomite and quartz with minor feldspar and sericite. The texture is predominantly oolitic with the oolites composed of dolomite, with occasional centres of quartz grains or previously formed oolites. The earlier oolites contain fine opaques, which show up their concentric and radial structure. Some of these early oolites have been broken and others show replacement by later dolomite. Cavities occur between the last formed oolites in one part of the specimen, but in the remainder these cavities have been filled with coarser grained dolomite. The oolitic section grades into a sandy dolomite. This consists of abundant rounded quartz and chert grains in a matrix of finer, more angular quartz and feldspar. Zircon, tourmaline and fine grained opaques also are present.

2.4.5 Dolomitic Siltstone

The rock is distinctly banded with pink bands containing mainly quartz and dolomite and green bands sericite, in addition to the quartz and dolomite. The more sandy bands are coarser with subangular to subrounded grains. Dolomite and quartz occur in approximately equal amounts, sericite is a minor constituent and feldspar is rare. Accessory minerals are sphene and opaques. The opaque mineral is iron oxide, which occurs as fine disseminated grains and also as euhedral grains, probably pseudomorphing pyrite.

2.5 SANDY CROSS BEDDED DOLOMITE

2.5.1 Finely Crystalline, Sandy, Oolitic, Intraclastic Dolomite

Dolomite fragments and oolites occur in a matrix of dolomite and quartz grains. The clasts (10%) are up to 3mm in length and are of sandy and massive dolomite. Ooolites (40%) have an average diametre of 1mm and many have a well defined concentric structure. Several have dolomite clasts or quartz as a nucleus. Quartz occurs in two distinct sizes - coarse

(1.0mm), well rounded grains, which are probably quartzite fragments and much finer (0.1 - 0.2mm) subangular to subrounded grains. The cement consists of fine grained dolomite (0.03mm) and minor feldspar (microcline and plagioclase) and accessory tourmaline are present.

2.5.2 Medium Crystalline Sandy Oolitic Dolomite (Figure 4.1b)

Oolites (0.3 to 1.0mm in diameter), which make up about 50% of the specimen, consist of very fine grained dolomite with fine concentric structures frequently visible. The cement consists of much coarser (0.05 to 0.1mm) clear dolomite, and in places is replaced by pyrite. Minor subangular to subrounded quartz (0.1 to 0.5mm diameter) and less than 5% opaques are present. Accessory minerals include tourmaline and zircon.

2.5.3 Very Finely Crystalline - Finely Crystalline Sandy Dolomite (Figure 2.1a)

Dolomite (40 - 70%) is fine grained generally ranging in size from .01 to .05mm, but in places averages 0.1mm. It is usually a brownish colour, but in places cavities are filled with clearer and coarser grained dolomite. In parts the dolomite has a dark appearance due to very finely disseminated opaques (galena and pyrite), which make up to about 5% of the rock (e.g., Figures 4.2a and 4.2b). Detrital quartz (10 - 50%) and feldspar (0 - 10%) generally constitute the remainder of the rock. Feldspar forms about a quarter of the total quartz and is predominantly microcline, with some plagioclase and a small amount of orthoclase. The quartz and feldspar grains are subangular to subrounded and range from 0.1mm to 0.5mm in diameter (average 0.2mm) and in places show evidence of recrystallisation. Occasional oolites may be present and accessory minerals include well rounded zircon, tourmaline (average 0.2mm diameter), muscovite flakes and opaques. In places the sandy dolomites are banded, with bands rich in quartz and feldspar and others rich in dolomite. There may also be a grain size difference between bands. This banding probably corresponds to the cross bedding observed at the surface. Some bands also contain rounded fragments up to 1 centimetre in length, that are very similar to the matrix. Cross-cutting silica veins display concentric banded growth structures and contain a large number of inclusions which are often aligned. These inclusions were identified as prehnite. The veins contain mineralisation and are described in detail in Section 4.2.3.

In places, stylolites are present in the sandy dolomite (Figure 4.7d). These are very distinctive in appearance and contain clays, detrital quartz and feldspar and fine grained opaques, all of which are residues from the solution of the dolomite. In addition to the insoluble concentration, there is material which was deposited from the dissolving solutions or later solutions moving along the stylolitic seams. This includes silica, which is generally in the form of coarse interlocking grains rich in inclusions, dolomite and opaques. The dolomite (iron rich) is coarser grained (0.4 to 0.5mm in diameter) and clear and the opaques consist mainly of galena and pyrite. This material is very similar to the silica veins (Section 4.2.3) which therefore are probably related to stylolites and solution activity.

Finely crystalline massive dolomites are interbedded with sandy dolomites. Dolomite (average 0.05mm) constitutes about 95% of these beds, with 2 to 3% of subangular and subrounded quartz (average 0.05mm) and fine grained disseminated opaques. Stylolites are usually common and contain clay concentrations, detrital quartz, opaques and silica.

2.5.4 Dolomitic Feldspathic Sandstone

This occurs occasionally as thin interbeds. Detrital quartz (70%), feldspar (5% microcline, orthoclase and minor plagioclase) are subangular to rounded and have an average grain size of 0.1mm. Accessory minerals are well rounded tourmaline (1%) and rare zircon and muscovite. The cement consists of finely crystalline dolomite (15 - 20%), opaques (5%) and clays. Clasts of the underlying sandy dolomites are often present in these interbeds, which probably represent channel deposits.

2.5.5 Medium Crystalline, Sandy Intraclastic Dolomite (Figures 2.1b, 2.6a, 2.6b and 4.1c)

The clasts are mainly sandy dolomite in a matrix of brownish dolomite (average 0.1mm diameter), which shows a weak banding. A few oolites are also present, along with minor detrital quartz. The dolomitic section is gradational into very sandy sections containing up to 90% quartz, as well as dolomite, microcline, accessory tourmaline and zircon, and a concentration of opaques and clays. Stylolitic seams are present in these sandy sections, along with coarse patches of pyrite and galena. It is thought that these sandy sections represent concentrations by solution activity.

2.5.6 Dolomite Breccias

(a) Mineralised dolomite breccias with silica cement (Figure 4.3a)

The dolomite blocks are finely crystalline and contain a small amount of detrital quartz and minor disseminated opaques along grain boundaries in the dolomite. The edges of the blocks are often marked by a concentration of clays and detrital quartz, indicating solution activity. The cement, which consists of opaques, silica and coarser grained clear dolomite, is described in detail in Section 4.2.4.

(b) Sandy dolomite breccia

The dolomite blocks (20 - 50%) are up to several centimetres in length, and consist of massive and sandy dolomite. The cement consists of quartz ranging from well rounded grains, averaging 0.5mm in diameter, to subrounded to subangular grains averaging 0.1mm in diameter, feldspar (microcline with rare plagioclase), dolomite (average 0.03mm diameter) opaques, clays and rare tourmaline and zircon. This breccia appears to be of sedimentary origin (a slump-type breccia), but the possibility of a solution origin cannot be overlooked.

(c) Solution collapse breccia (Figure 2.5a)

The dolomite is present in three distinct grain sizes. The first is very finely crystalline (average 0.003mm diameter) and represents the original host rock dolomite. Associated with this dolomite is minor detrital quartz (5%) and abundant, very fine grained disseminated sulphides. The second type is finely crystalline (0.01 to 0.05mm diameter) and the third is medium to coarsely crystalline (0.1 to 0.4mm) clear dolomite, associated with patches of sulphides along thin veinlets and stylolites. The latter two types of dolomite are deposited as a result of solution activity, the coarse clear dolomite having been deposited last along with sulphides. During this solution activity the finely disseminated sulphides appear to have been leached from the host dolomite and concentrated along the veins and stylolites (See Chapter 4).

2.6 LAMINATED ALGAL DOLOMITE

From surface mapping this unit overlies the Sandy Dolomite. However, it is very difficult to pick this unit in drill core, as the laminated nature obvious at the surface, is only apparent in the top 20 metres.

2.6.1 Dolomite Breccias

(a) Laminated dolomite breccia (Stylobreccia) (Figures 2.1c, 2.6c, 4.4b and 4.4d)

These distinctive breccias mark the beginning of the Laminated Dolomite. They consist of a large proportion of laminated dolomite blocks (up to 50%), which are up to 5 centimetres in length, in a fine grained cement. The latter consists of mainly fine grained dolomite (average

0.02mm diameter) with subangular to subrounded quartz (0.2mm) minor microcline, oolites, clays, small dolomite fragments, silica (colloform banded chalcedony and euhedral quartz crystals both containing galena inclusions conforming to colloform or growth banding), and accessory tourmaline and zircon. The cement also contains euhedral pyrite and galena. Many of these breccias are probably due to solution activity, since the cement is similar in appearance to the material in stylolites, and the margins of many of the blocks are clearly marked by stylolites (Figure 4.4b). Very similar structures have been described by Logan and Semeniuk (1976) as stylobreccias. These are structures where stylolites circumscribe carbonate fragments and Logan and Semeniuk believe that these stylobreccias are formed by a combination of pressure solution and shear fracture during low grade metamorphism (moderate pressure, low temperature). Collins and Smith (1972) have also described similar structures in the lower Ordovician carbonates of Western Newfoundland. They termed these structures "pseudobreccias" and suggested that they were formed during the ultimate phase of diagenesis.

(b) Solution collapse breccia (Figure 2.1d)

This thin breccia (0.6 metres thick) occurs at the contact between a massive, finely crystalline dolomite and porous, laminated dolomite. It consists entirely of well laminated dolomite blocks in a matrix of galena and pyrite (see Section 4.2.4). It is thought that solutions would be concentrated in a porous unit at the contact with a low porosity unit, which would lead to dissolution and then collapse of laminated dolomite. Later solutions have deposited pyrite, galena and dolomite around these blocks.

(c) Dolomite breccias (Figure 2.2a and 2.2b)

These breccias occur frequently through the Laminated Dolomite. They consist predominantly of clasts of finely crystalline dolomite (average 0.01mm diameter) up to several centimetres in length, set in a matrix of coarser clear dolomite (average 0.1mm diameter). Other fragments include oolites, chert and occasional laminated and sandy dolomite blocks. Minor subangular detrital quartz (average 0.1mm diameter) is also present. Silicification is common with chalcedony occurring as colloform banded cavity fillings. Opaques (galena and pyrite) are present in places as concentrations along stylolites in fractures or patches in the coarser dolomite cement. The origin of these breccias is probably due to sedimentary slumping, although solution activity cannot be ruled out. Some dolomite breccias (Figure 4.4a) have a larger range of dolomite fragments, and a larger proportion of cement. The cement consists of clays, detrital quartz (with rare tourmaline and microcline), fine grained dolomite, spheroidal pyrite (0.3 to 0.5mm in diameter) and silica (chalcedony coating pyrite grains and as coarser patches, rich in inclusions.)

2.6.2 Finely Crystalline, Laminated Dolomite (Figures 2.4a and 4.1d)

This is well developed in the top 20 metres of the unit. It consists of finely crystalline dolomite (average .01 to .05mm) with very minor detrital quartz (1-2%) and rare dolomite clasts (up to 5mm in diameter) and oolites. The laminations, which are due to variations in grain size (Figure 2.6d), are usually not continuous but show a disturbed appearance, probably due to slumping. In places the dolomite contains very finely disseminated opaques. Stylolites are present and contain detrital quartz, opaques, clays and dolomite.

A very distinctive "clastic dyke", about 1.5 centimetres wide, occurs in hole E32 (Figure 2.2d). This contains laminated dolomite blocks (70 - 80%), chert fragments, euhedral quartz crystals and detrital quartz grains in a cement of fine grained dolomite (average 0.05mm diameter). The dolomite fragments can be correlated with overlying dolomite, and it is thought that this "dyke" is a solution structure, with the fragments being derived from above. The euhedral quartz crystals contain abundant inclusions, a feature which is characteristic of the quartz in the mineralised silica veins and breccias.

2.6.3 Finely-Medium Crystalline (Stylolitic) Dolomite

Dolomite (0.01 - 0.10mm diameter) is the dominant constituent making greater than 95% of the rock. Some coarser grained, clear dolomite patches occur and rare ghost clasts and oolites are also present. Subangular detrital quartz (average 0.05mm diameter) and fine grained, disseminated opaques constitute the remainder. Stylolites are common and contain clays, detrital quartz, rare tourmaline and zircon, opaques, (pyrite and galena) coarser grained clear dolomite, and colloform banded chalcedony. In places the stylolites are so abundant that the rock has a brecciated appearance (stylobreccia), (Figures 2.5b, 2.7a and 2.7b). These dolomites are found above the laminated dolomite breccias and below the overlying laminated dolomites. They are interbedded with minor oolitic dolomite, laminated dolomite and dolomite breccias.

2.6.4 Medium Crystalline, Oolitic, Intraclastic Dolomite

More than 50% of the rock consists of relict oolite structures up to 1mm in diameter which are cemented together by medium grained clear dolomite (0.1 to 0.3mm diameter). Relict clasts of laminated, massive and oolitic dolomite are present, along with a small amount of detrital quartz. Stylolites are common and contain clays, concentrations of galena and pyrite and chalcedony.

2.6.5 Silica Veins (Figures 2.3a, 4.2c and 4.2d)

The details of the mineralogy of these veins are described in Section 4.2.3. The boundaries of the veins are marked in places by iron staining and an increase in detrital quartz and clays, suggesting that solution activity may be important in the origin of these veins.

2.7 MASSIVE DOLOMITE

2.7.1 Dolomite Breccias (Figures 2.2c, 2.3b, 2.3c and 2.3d)

Distinctive dolomite breccias mark the beginning of the Massive Dolomite. They are quite variable in nature. Some contain a large proportion of finely crystalline dolomite fragments in a cement of slightly coarser dolomite, minor detrital quartz and fine grained, pyrite, galena and sphalerite. Patches of sulphides up to 1mm in diameter are present. In places the cement is stylolitic in nature.

Another distinctive breccia contains some chalcedonic fragments up to 1 centimetre in length. These fragments display features that are characteristic of the silica veins:- colloform banding, corroded dolomite rhombs, inclusions of sulphides (galena and sphalerite) conforming in places to the colloform banding. The other fragments are finely crystalline dolomite up to 2cm in length and the cement consists of fine grained dolomite (average 0.05mm diameter), detrital quartz, clays, opaques (galena and sphalerite) and rare tourmaline. Clearly this breccia has developed after mineralisation in the silica fragments.

2.7.2 Finely Crystalline (Massive) Dolomite (Figure 2.4b).

This rock type forms the bulk of the Massive Dolomite unit. It consists of finely crystalline dolomite, with less than 2% subangular quartz (average 0.1mm diameter). In places possible relict clasts are present. Stylolites are common and contain detrital quartz, opaques (iron oxides and sulphides), clays, chalcedony and coarser clear dolomite. Fine grained opaques also occur disseminated through the dolomite.

2.7.3 Finely Crystalline, Oolitic Dolomite (Figure 2.7d)

Oolites, which make up to about 50% of the rock type, are about 0.5mm in diameter on average, and consist of very finely crystalline (0.005 - 0.03mm) dolomite. Concentric banding is visible and some oolites contain cores rich in fine opaques. The cement to the oolites consists of coarser clear dolomite (0.05 - 0.15mm). Minor subangular to subrounded quartz grains (0.1mm average diameter) are also present. Some oolites are made up of an outer coating of chalcedony. Occasional stylolites contain detrital quartz, opaques (predominantly galena), clays and barite, which is associated with the galena.

2.8 SEDIMENTATION

The Parachilna Formation and Ajax Limestone represent a carbonate interruption of a terrigenous filling of a geosyncline. Some event caused the cessation of terrigenous influx and resulted in the development of a thick carbonate sequence. These carbonate rocks represent a set of lithologies, structures and organic traces that would characterise a shallow near-shore carbonate environment. Table 2.1, after Laporte, (1969) and Thomson and Thomasson, (1969) is a composite listing of environmental features observed in shallow water near-shore environments, normally associated with an epeiric sea. Table 2.1 includes suggested zonations of Ediacara carbonates in terms of the information presented. Predominantly the Ediacara carbonate sequence represents a tidal flat situation grading to open shallow shelf. The Worm Burrow Beds, the Transition Shales and the Sandy Dolomite were deposited during the main trangressive phase of the lower Cambrian. Oolites and cross bedding are common in the Sandy Dolomite, as they are in most shallow water carbonate environments. They are formed by strong tidal current action on shallow stable shelf environments (sub-tidal). Intraclasts have been derived by erosion of semiconsolidated carbonate material. Zones of more abundant distribution of intraclasts probably indicate more agitated waters (higher energy environment). Terrigenous detritus (mainly quartz) has been introduced by drainage waters from the adjacent land mass. The energy variations within the environment are reflected in the content of terrigenous detritus in the sediments of the different zones. Hence the sandy dolomites represent higher energy environments (sub-tidal to bar and channel), whereas the laminated and massive dolomites represent lower energy situations (tidal flat or open shallow shelf). Similarly a time-energy variation is reflected within each zone due to seasonal variation.

Following the deposition of the Sandy Dolomite, there was a minor regression, and the Laminated Dolomite was deposited in a tidal flat environment. This tidal flat environment was characterised by an alternating process of submergence and exposure, leading to the development of the interbedded laminated dolomites and massive intraclastic dolomites. These laminated dolomites contain only a very small amount of detrital material, indicative of their low energy environment of formation. During exposure of the tidal flat a special type of sedimentation proceeded. Organic sediments were built up by the binding activity of organisms. These organisms displayed a sensitive response to depth and their activity was confined to the exposed tidal flat. The former presence and activity of the algae is evidenced by stromatolite structures in the sediments. These laminated dolomites would have been formed in the supratidal and intertidal environments of the tidal flat (Lucia, 1972), and interbedded massive dolomites in the marine environment. No attempt has been made to differentiate between supratidal and intertidal - they are both referred to as supratidal. Irregular laminations caused by a combination of periodic sedimentation and algal structures are the most characteristic features of the supratidal environment. The exposure of this environment would lithify and tend to break up the supratidal sediment into clasts, which would then be transported and thus deposited in other environments (intraclasts are common in the interbedded massive dolomites).

The Massive Dolomite was deposited during the following transgression in a sub-tidal to open shallow shelf environment. The environment was clean, with freely circulating water of a depth of 50 to 100 metres, as indicated by archaeocyathids. The low energy of the environment is indicated by the very low detrital content of the dolomites. Fluctuations in sea level occurred, resulting in deposition of oolitic dolomites and laminated dolomites in much shallower water.

If the tidal-flat environment progrades seaward (Lucia, 1972) marine sediment should be overlain by intertidal and supratidal sediments. This sequence should be found laterally as well as vertically and repetition of prograding tidal-flat sedimentary cycles should also take place. Figure 2.8 clearly shows the vertical sequence at Ediacara does in fact agree with this. Figure 2.9 shows that lateral variations between different environments may have occurred. This is contrary to earlier work (Nixon, 1962), which considers each of the major units to be separate time-stratigraphic lithological units. Figure 2.9 suggests that some of the units are in part time-transgressive and interfinger laterally. For example, the upper part of the Parachilna Formation in the southern half of the field is possibly a facies equivalent of the lower Sandy Dolomite in the northern half of the field.

Comparison of a number of features suggests that an applicable model for the area is that of a sabkha (evaporite flats that form along the sub-aerial landward margins of regressive seas). These environments, as described by Shinn et al., (1965), Illing et al., (1965), Deffeyes et al.,(1965) and Wood and Wolfe (1969), are marked by penecontemporaneous dolomite formation and stromatolite development. No calcite is present at Ediacara, suggesting that penecontemporaneous dolomite formation may have taken place. It is generally thought that dolomite does not form as a direct precipitate from sea water, but rather is produced by alteration of previously deposited carbonates by sea water derived brines (Lippman, 1973).

Modern carbonate tidal flats commonly contain dolomite. This dolomite is believed to be formed from sea water which has been concentrated to gypsum saturation (Deffeyes, et al, 1965). The sabkha produces the necessary conditions for sea water evaporation to the point where gypsum will precipitate and thus produce a dolomitising solution.

Dolomitisation requires a source of Mg^{++} ions, plus conditions of high salinity and temperature. A number of mechanisms have been proposed for increasing the salinity of sea water and supplying the necessary Mg^{++}ions. These have been reviewed by Friedman and Sanders (1967). Hypersaline brines can be formed by "capillary concentration" or by "refluxion" in areas where evaporation exceeds precipitation plus run-off. Capillary concentration of sea water requires a sediment-air interface; evidence for associated dessication is lacking, at Ediacara, hence precluding this mechanism. The model for dolomitisation by seepage refluxion was developed by King (1947) and has been refined by subsequent workers, (e.g., Adams and Rhodes,1960). Heavy supersaline brines enriched in Mg^{++} sink from the supratidal surface and flow seaward down the sloping shelf. The surface currents from the ocean tend to replenish the water loss over the tidal flat. If the brine flowing seaward is impeded by natural barriers, it migrates to the lowest topographic depressions and moves through the underlying sediments, which are progressively dolomitised. Most workers consider dolomitisation by seepage refluxion is part of the geological cycle inherent with tidal-flat sedimentation, particularly in arid and semi-arid climates. Evaporites, the precipitation of which produces the dolomitising fluid, are clearly very susceptible to removal by shallow ground water, producing solution collapse breccias and cavities.

2.9 SUPERIMPOSED PRODUCTS OF POST DEPOSITIONAL SOLUTION ACTIVITY

2.9.1 Stylolites

Solution phenomena during loading may have reduced the thickness of the carbonate sequence by several hundred metres. Stylolites resulting from loading are developed on an extensive scale throughout the carbonate sequence. The insoluble residue within the stylolites, consists of terrigenous detritus (mainly quartz with minor feldspar), clays and opaques (iron oxides and sulphides). The material expelled during the reduction of the formation migrated as soluble carbonates in connate or groundwaters. Sulphides and quartz were also taken into solution during this process. Part of this dissolved material is represented by the coarse grained clear dolomite, chalcedony and euhedral quartz and sulphides of the solution breccias, veins and other cavity fillings.

The stylolites at Ediacara are of two types:- the horizontal stylolites which are parallel or nearly parallel to the bedding (Figures 2.1a, 2.1b, 2.7d and 4.1b) and the interconnecting network (of) stylolites, which often gives the dolomite a brecciated appearance (Figures 2.2b, 2.5a, 2.7a and 2.7b). The nature and origin of stylolites have been reviewed by Park and Schot (1968). They recorded examples of stylolitisation serving as an enrichment process of disseminated ore minerals and with fluorite and sulphides being enriched along the stylolitic seams (see Figures 4 and 10 in Park and Schot, 1968). The silica in the stylolites observed by Park and Schot is of three types; detrital grains, euhedral crystals and patches of chalcedonic quartz. This is identical to the observations of the silica in the stylolites at Ediacara. Park and Schot (1968) and Amstutz and Park (1967) favour a diagenetic pre-lithification origin of stylolites through solution pressure during compaction. This is a lengthy continuous process that operates throughout the diagenetic history of the host rocks. The pH of the pore solutions affects the solubilites of dolomite and silica inversely; with increasing pH the solubility of silica increases, while that of dolomite decreases. If the pore solution, undersaturated with respect to dolomite, becomes gradually acidic upon migration, silica, when present in solution, will precipitate and dolomite may dissolve. This may explain the frequent occurrence of silica within stylolitic seams.

2.9.2 Solution Breccias

Existence of solution (collapse) breccias has been demonstrated at Ediacara. These breccias are of two main types. In the first variety the relations of adjoining fragments have only been slightly disturbed (Figure 4.4c) and in the second type adjacent fragments normally have come from appreciably separated sources and have no apparent primary sedimentary relationship to each other (Figures 4.4b and 4.4d).

In the Viburnum Trend of Southeast Missouri, lead, zinc and copper sulphides occur in solution-induced collapse breccias in the upper part of the Bonneterre Formation (Davis and Brown, 1973; Davis, 1975). Individual breccia bodies are as wide as 75 metres and as thick as 25 metres, with a basin-shaped base.

Similarly, in the Mascot-Jefferson City District of Tennessee (McCormick, et al., 1971; Ridge, 1968; Kendall, 1960 and Hoagland, et al., 1965) ore structures are thought to be solution collapse breccias, produced by a palaeoaquifer system that was developed in a karst terrain. Meteoric waters supposedly moved downward and laterally through the underlying carbonate formations dissolving limestone along bedding planes and fractures. Similar karstic topographies have been recognised in lower Cambrian carbonates in the Wirrealpa area (P. Haslett, pers. comm.). Very reddish coloured dolomites in the Massive Dolomite (32/75) may represent sub-aerial weathering.

Solution of dolomites would leave voids or unconsolidated zones into which the overlying beds would collapse. Alternatively, volumes of breccia may have been formed by hydrothermal solutions that penetrated unbrecciated beds along innumerable minor fractures (Ridge, 1968). Examples of solution collapse breccias are shown in Figures 2.1d, 2.2c, 2.2d and 2.5b.

Another possibility for breccia formation is simply the dissolving of dolomite along thin interconnecting seams (stylolites), the net result being the breaking of dolomite beds into fragments and the infilling of the spaces between the fragments with the dissolved primary dolomite, silica and sulphides. This would probably lead to the development of stylobreccias. Variations in the physical appearance of the stylobreccias (See Figures 2.5a, 4.3, 4.4b and 4.4d) are probably directly related to the intensity of solution.

According to Binks (1972), the distinctive breccias that occur around the periphery of the Ediacara Basin in dolomites at the base of the Ajax Limestone, are due to intense leaching during Mesozoic and Tertiary times. This leaching process has resulted in enrichment of secondary copper and lead mineralisation in a thick material zone of residual clayey material overlain by dolomitic collapse breccia.

2.10 ORIGIN OF THE BRECCIAS

The origin of the breccias, many of which are mineralised, can be ascribed to either sedimentary (slump) or solution processes. However, in some cases it is difficult to distinguish which of the two processes was important.

2.10.1 Sedimentary Breccias

Surface mapping has shown that many breccias are conformable with bedding and are therefore probably of sedimentary origin. The mineralisation, lithologies and sedimentary breccias are comparable with those described by

Snyder and Odell (1958) and Snyder and Gerdemann (1968) in the Old Lead District of Southeast Missouri, where sedimentary breccias are important ore-controlling structures. Figures 2.10 and 2.11 show the strong similarities between the generalised stratigraphic sections at Ediacara and Southeast Missouri.

The sedimentary breccias in the Old Lead District are considered to represent the primary or penecontemporaneous product of slump or intrastratal flow. They formed by submarine slides into nearby depositional basins. Lithofacies studies indicate that environments of deposition were dominated by two main elements, depositional ridges and basins, the ridges being composed of calcarenite and reef deposits and the basin sediments of fine grained carbonate and argillaceous muds. The analogy at Ediacara to these two elements would be the laminated (algal) dolomites and sandy oolitic dolomites of supra-tidal to sub-tidal environments and massive finely crystalline dolomites which would be of deeper depositional environments (see Unit 2 in Figure 2.11). According to Snyder and Odell (1958) differential compaction could lead to oversteepening of slopes in the gradational zone, between the ridge (shelf) and basin deposits and initiate movement of unconsolidated and partially lithified sediments. These would slide by gravity into the depositional basins producing the thick breccias.

Slump brecciation mixes various sediment types and can alter the density from the enclosing sediments. Therefore, certain types of slumped sediments can probably lithify to rocks varying in density and permeability from the enclosing rocks. This would be important in ore localisation. Elliston (1960) believes this to be the case at Tennant Creek.

2.11 SUMMARY AND CONCLUSIONS

1. The Parachilna Formation and Ajax Limestone, which are the hosts to the mineralisation of Ediacara represent a set of complex lithologies,

structures and organic traces that would characterise a shallow near-shore carbonate environment.

2. The Sandy Dolomite was deposited in an environment which ranged from sub-tidal to bar and channel, the Laminated Dolomite in a tidal flat environment, and the Massive Dolomite in an environment ranging from sub-tidal to open shallow shelf.

3. It is suggested that both vertical and lateral variation between different environments may have occurred. This would mean that the major units are in part time-transgressive, rather than separate time-stratigraphic lithological units.

4. An applicable environmental model for the area is that of a sabkha. This environment could produce the necessary conditions for dolomitisation by seepage refluxion.

5. Breccias, which range from a few centimetres to several metres in thickness make up a large and important part of the carbonate sequence, since they are often strongly mineralised.

6. The origin of the breccias can be ascribed to either sedimentary or solution processes, but in some cases it is difficult to distinguish between these processes. Solution activity is thought to be the dominant process.

7. Post depositional solution activity has affected a large proportion of the carbonate sequence. The effects of this activity range from stylolites through to stylobreccias and solution collapse activity.

8. Sulphides and quartz represent the major components concentrated during solution activity.

9. The Ediacara mineral field has many similarities with the Old Lead District of Southeast Missouri where sedimentary breccias are important ore-controlling structures.

CHAPTER 3.

MINERALISATION - EDIACARA

3.1 SURFACE WORKINGS

3.1.1 Greenwood's Workings

The workings which mark the most northerly extent of known lead mineralisation are located at the northern end of the field (Figure 1.3) and were the most important. It is estimated that Greenwood's workings produced some 8,800 tonnes at an average grade of 31% lead and 250 gm per tonne silver, over an average thickness of 0.6 metres (Broadhurst, 1947). High grade lead ore occurs near the top of the Sandy Dolomite in a 0.6 metre thick zone of conformable breccia of probable sedimentary origin, dipping south east at about 10 degrees. This zone can be correlated with the mineralised layer intersected in the Sandy Dolomite by drill holes to the south-west. The chief ore mineral is cerussite with some minor malachite and these occur as matrix to dolomite blocks in the breccia.

3.1.2 Southern Workings

These are located at the southern end of the field in weathered calcareous shales and siltstones which, according to Nixon (1962), are the lateral equivalent of the Sandy Dolomite of the northern part of the field. This would agree with the suggestion made in Chapter 2 that the Transition Shales in the southern part are a facies equivalent of the Sandy Dolomite in the northern part. The rocks are fairly well laminated and there is a suggestion of breccia in places. Production is estimated to have been of the order of 15,000 tonnes at an average grade of 12% lead and 28 gm per tonne silver, over an average width of 1.4 metres. Most of the ore mined was cerussite, although malachite was reported at the surface. The workings occur as a narrow ore body, elongate north-south and dipping at low angle to the north, parallel to bedding.

3.1.3 Black Eagle Mine

This mine is located on the western side of the field and is the only one to produce an appreciable amount of copper. The chief mineral was malachite which occurs in a bed of weathered limonitic earthy material one to three metres thick. This probably represents a badly weathered and leached pyritic dolomite breccia. On the surface the dolomite around the Black Eagle Mine is much more reddish than dolomite in the rest of the field probably reflecting the more intense weathering in this area. Manganese is also more abundant in the dolomite in the immediate vicinity of the mine than elsewhere in more massive dolomite.

The stratigraphic position of this mine is uncertain due to the very weathered nature, but Nixon (1962) suggests that it is above the level of mineralisation in the northern and southern areas. One hole (D.D.E7) has been drilled 76 metres east of the Black Eagle Mine (Figure 1.3). The hole intersected 7.6 metres averaging 1.1% copper, from 41 to 49 metres, and 9 metres averaging 1.0% lead, from 65 to 74 metres. The intersection of 1.1% copper, which would most likely represent the extension of the Black Eagle mineralisation, would appear to be in the Transition Shales, as it is most likely that both the Sandy Dolomite and the Laminated Dolomite are not present in this area (see Figure 2.9). The recorded production was 264 tonnes of ore averaging 7.2% copper.

3.1.4 Morish Adit

This is located west of Greenwood's Workings, within a zone of fracturing associated with the Gap Creek fault. Barite is abundant and associated with the crushed zone. The lead mineralisation, in the form of cerussite, occurs in the Sandy Dolomite, as at Greenwood's Workings, along flat lodes parallel to bedding. Production is unknown, but it would seem that very little ore was mined from this adit.

3.1.5 South-Eastern and South-Western Gossans

Gossans occur in zones around the south-eastern and south-western edges of the basin. Broadhurst (1947) described them as being up to one hundred metres wide, and each occurring over a length of 1,000 metres and associated with the occurrence of quartz reef.

Nixon's mapping has shown that the wide expression of bouldery and rubbly limonite (manganese-coated in part), hematite and psilomelane is largely due to the spread of scree. The quartz reefs mentioned by Broadhurst (1947) seem to be similar in all respects to the siliceous breccias which occur in the northern area. The south-western gossans are characterised by one lenticular limonite and manganese stained siliceous breccia horizon, about 1.5 to 2 metres thick, and the south-eastern gossans by a number of similar breccias occurring over a greater thickness of the sequence. Binks (1972) has suggested that these breccias are of collapse origin, produced by intense leaching around the periphery of the Ediacara Basin during Mesozoic and Tertiary times.

The gossan areas were sampled in 1938 (Broadhurst, 1947) and the results indicated some patchy copper mineralisation in pits and adits at a number of points in both areas. At least some of these are associated with the Transition Shales rather than the siliceous breccias. Four diamond drill holes, E11, E12, 1-11 and 1-12, have been drilled to test any down-dip extension of the south-eastern gossans. Apart from a little pyrite in E12 and iron and manganese staining in all holes, no mineralisation was recorded. Two holes, E9 and E10, were drilled just down-dip from the south-western gossan. E10 intersected 6 metres averaging 1.5% lead and 0.4% copper in the Transition Shales and up to 0.65% lead and 0.53% copper in dolomite just above the Transition Shales. No mineralisation was recorded in E9. All holes show a high degree of weathering.

The siliceous breccias of the gossan areas can probably be correlated with the siliceous breccias just above the Sandy Dolomite in the northern area. As the breccias of the gossan areas almost entirely overlie the Transition Shales, it means that the Sandy Dolomite is absent in these areas.

3.2 DIAMOND DRILLING

The area has been subjected to extensive diamond drilling, with a total of 46 holes being drilled into the Ediacara mineral field. These can be summarised as follows:-

1946/47	Holes 1-12, 2-11, 3-6, I.P.1 and I.P.2 drilled by S.A. Department of Mines (Broadhurst, 1947).
1961/63	Holes E1 to 24, E31 to 34 and E39 by S.A. Department of Mines (Nixon, 1967).
1965/66	Holes E40 to 50 by C.R.A. Explorations Pty. Ltd. (McQueen, 1967).

Metal values (Cu, Pb, Zn, Co, Ni, Ag, Cr, V, Mn and Ba) and carbonate analyses have been determined for 3 metre intervals for most of the holes (except E40 to E50). Table 3.1a shows a summary of lead, copper, zinc and silver intersections in all drill holes and Table 3.1b shows summarised geological logs, enabling correlation between mineralised intersections and lithologies.

Results indicate that the best of the lead mineralisation occurs in a stratigraphic thickness of about 30 metres, having its base 10.5 to 15 metres above the top of the Transition Shales. Within this zone there is a tendency for a layer up to 10 metres thick to occur in the Sandy Dolomite and another one up to 15 metres thick to occur just above the base of the Laminated Dolomite (although still probably sandy). These layers are about 15 metres apart (see Figure 3.1 for summarised geological and geochemical logs of selected drill holes). Grades of the individual selected intersections representing these preferred layers are mostly 1 to 2.5% lead, but in hole E6, 4.5 metres of 7.3% lead and 4.2 metres of 4.0% lead were intersected in separate layers. Between, above and below the preferred layers, mineralisation is either absent or present in trace amounts, although lead values are still relatively high in comparison with average contents for carbonates. Some holes have been drilled without intersecting any significant mineralisation.

Mineralisation is most significant on the north-western flank of the basin, trending to lower grade and pinching out to the south (Figure 1.3). Johns (1972) has estimated the reserves in this area as follows:-

1. Body in Laminated Dolomite - 12 million tonnes average 0.84% lead.
2. Body in Sandy Dolomite - 17 million tonnes average 1.23% lead.

Overall the pattern of lead mineralisation in the northern area seems to be one of high grade pods in two otherwise weakly mineralised layers, within an overall stratigraphic thickness of 30 metres. The relatively high grade intersections in hole E6 fit this concept. Had they outcropped, secondary enrichment would probably have resulted in their being similar occurrences to those in Greenwood's Workings.

3.3 MINERALISATION AND STRATIGRAPHY

Figure 3.2 shows an isopach map of the Sandy Cross Bedded Dolomite. Comparing this with Figure 1.3 shows that it is closely related to the area of significant mineralisation. Clearly the most significant lead mineralisation is associated with the greatest thickness of Sandy Dolomite and as the thickness decreases, then the grade of mineralisation tends to decrease.

Any significant copper mineralisation (e.g., holes E7 and E10), which is associated with the Transition Shales, occurs in areas where Sandy Dolomite is absent (the Transition Shales are thought to be a facies equivalent of the Sandy Dolomite in the southern part of the field). Nixon (1962) also noted the strong association between stratigraphy and mineralisation. For instance Greenwood's Workings is the northern-most limit of significant mineralisation and this he concluded coincides with a change in facies from algal dolomites to oolitic dolomites.

Copper and zinc values tend to be much more random in their distribution, in places following lead values, but in many cases being completely unrelated (see Table 3.2). This can be clearly seen from the plots of metal values against geological logs (Figure 3.1). For example, in hole E32 maximum lead values averaging 2.2% lead, which occur between 97.6 and 103.6 metres, correspond with maximum zinc (0.4%) and copper (0.1%) values, whereas above this zone there is no consistent relationship between lead and zinc and copper. In hole E33A, maximum lead values averaging 1.03% lead occur between 93.1 and 114.1 metres in the same stratigraphic position as the above mineralisation in hole E32. However, copper and zinc values for this interval are very low (average copper 40 ppm, zinc 50 ppm), but maximum copper and zinc values occur between 36 and 54 metres (copper average 280 ppm, zinc average 0.22%).

TABLE 3.2

CORRELATION COEFFICIENTS FOR VARIOUS METAL COMBINATIONS

HOLE	Pb-Ag	Pb-Zn	Pb-Cu	Zn-Cu
E32	0.926	0.848	0.409	0.287
E33A	0.747	-0.055	-0.128	0.489

There also appears to be some lithological control on copper and zinc mineralisation. If the copper and zinc values do not occur with the main lead mineralisation (as in E33A), then they have a strong association with specific carbonate units; zinc (in particular) and copper are associated with distinctly laminated dolomite, and copper with oolitic dolomite units. This is not to say all laminated and oolitic units have anomalous values.

Silver values are closely associated with lead values (Table 3.2) which suggests that silver is associated with galena either in solid solution or as separate silver bearing minerals included in the galena.

3.4 SUMMARY AND CONCLUSIONS

1. Lead mineralisation is stratabound and confined mainly to a relatively narrow sequence, consisting of two layers about 15 metres apart, and commencing 30 metres to 60 metres above the Cambrian-Precambrian contact.

2. Mineralisation appears to be related to lithological and sedimentary features - lead and silver mineralisation associated with sandy and algal dolomites and copper and zinc mineralisation associated with some laminated algal zones and oolitic dolomite.

3. The Sandy Dolomite occurs only on the north-western flank of the basin and thins out to the south. Nixon (1962) has suggested that the lead mineralisation may be related to an old shoreline in a similar fashion to the Zambian Copperbelt. Certainly some general type of zoning seems to exist at Ediacara, highest copper values occuring in the southern part of the field and highest lead values in the northern part, with the highest zinc values being recorded in the most northerly drill hole (E3).

4. It is suggested that at least some of the metals were initially deposited contemporaneously with sedimentation, evidence for this being the

existence of syngenetic sulphides (Sections 2.5 and 4.2.1) and the association of metals with a specific environment of sedimentation (tidal to sub-tital - Section 2.8).

5. If the metals were initially deposited contemporaneously with sedimentation two possible sources can be considered: submarine exhalations and weathering solutions derived from surrounding land masses.

6. Whatever the source or sources may have been, it is thought that without the existence of the climatically controlled formation of the host rocks (particularly algal dolomites), no mineralisation may have taken place.

7. The reason for selective concentration of certain elements within specific lithologies is suggestive of direct environmental control (different energy levels, organic content, pH and Eh).

CHAPTER 4.

ORE PETROLOGY

- EDIACARA

4.1 INTRODUCTION

Holes E32 and E33A were chosen for detailed study of the ore. These two holes were selected for the following reasons:-

1. They contained predominantly primary mineralisation, although some oxidation was observed in places, even to depths of up to 100 metres in E33A. Nearly all other holes intersected predominantly oxidised material, particularly around the margins of the basin.
2. The holes contained reasonably high grades of mineralisation.
3. Both holes penetrated the complete Cambrian sequence present at Ediacara and hence any relationship between mineralisation and sedimentary and/or later features could be studied.

The following minerals have previously been identified (Nixon, 1967) from the almost completely oxidised ore bodies.

calcite
gypsum
dolomite
barite
barito-calcite
quartz
cerargyrite ($AgCl$)
galena (PbS)
cerussite ($PbCO_3$)
anglesite ($PbSO_4$)
lanarkite (Pb_2SO_5)
phosgenite ($(PbCl)_2CO_3$)
covellite (CuS)
melaconite (CuO)

connellite (probably $CuSO_4 \cdot 2CuCl_2 19Cu(OH)_2 H_2O$)

malachite ($CuCO_3 Cu(OH)_2$)

lampadite (cuprous manganese 4-18%Cu)

psilomelane and pyrolusite (MnO_2)

pyrite (FeS_2)

wad (cobaltiferous)

The main ore minerals present in the three largest workings are cerussite and malachite. No secondary mineralisation was studied in this work.

Thirty four specimens were studied from holes E32 and E33A in both polished and thin sections and the following sulphide minerals have been identified:

Minerals	Frequency of occurrence in specimens (%)
Pyrite	100
Galena	94
Sphalerite	26
Chalcopyrite	24
Tetrahedrite	21
Covellite	18
Marcasite	6
Pearceite ($Ag_{16}As_2S_{11}$)	3

Gangue minerals that have been recognised are silica (quartz and chalcedony), dolomite and rare barite.

Electron microprobe studies which were made on the JEOL Microprobe at AMDEL, were used to identify pearceite and some fine grained sulphides.

4.2 ORE TYPES

In hand specimen the mineralisation apparently occurs in a large variety of types. However, detailed petrological examination has shown that these can be considered as variations of four basic types.

1. Disseminated sulphides
2. Concentrations along stylolites and in areas of coarse grained dolomite
3. Mineralised dolomite and silica veins
4. Breccia fillings

4.2.1 Disseminated Sulphides

Fine grained disseminated sulphides, which are the most common occurrence throughout the carbonate sequence, are most abundant in laminated and sandy zones. In laminated dolomites the sulphides (mainly pyrite and galena, with rare sphalerite) have been identified by electron microprobe studies and range in size from 0.005 mm to 0.02 mm and are, in places, aligned with the laminations (Figure 4.4d). The disseminated pyrite and galena are often recrystallised into much coarser patches or concentrated into stylolites (the recrystallisation is probably in response to the pressure involved during very low grade metamorphism).

The sandy dolomites in places generally contain a much larger percentage of disseminated sulphides. Hand specimens of sandy dolomite show distinct "bleached" zones (Figures 4.2a, 4.2b, 4.3b). Microscopic examination has shown that the darker areas contain a considerable amount of finely disseminated galena and pyrite. The pyrite grains range from less than 0.001 mm up to 0.005 mm in diameter and the galena is slightly coarser (Figure 4.7c). In contrast the lighter zones show a marked lack of opaques. However, the notable feature of the lighter zones is that they contain veins and stylolites, which have concentrations of coarser grained galena, pyrite, dolomite and euhedral quartz as well as clays and detrital quartz.

It appears that the fine grained disseminated sulphides are of sedimentary origin (syngenetic) and that they have been concentrated by solution activity, during diagenesis. This process involves both the dissolution and reprecipitation of sulphides as well as the concentration of insoluble residue into stylolites. However, it is also possible that at least some of these disseminated sulphides are of diagenetic origin.

Fine grained disseminated opaques (predominantly pyrite) are also present in oolitic dolomites in both the Ajax Limestone and Transition Shales. The fine opaques (average diameter 0.001 mm) are much more abundant in the oolites than in the coarser dolomite cement. These opaques occur as concentrations in the centre of the oolites or they outline the concentric growth structure of the oolites, giving clear evidence for a syngenetic, chemical precipitation origin for them (Figure 2.4d). Stylolites in these oolitic zones contain concentrations of opaques and detrital quartz (Figures 4.5d, 2.7d).

Pyrite also is present in oolitic dolomites as coarse patches apparently replacing the dolomite cement and leaving remnants of dolomite in the cement (Figure 4.15b) or clearly filling pores that exist between oolites. This pyrite varies from very fine pellets and framboidal aggregates (average 0.002 mm diameter) to coarser grained euhedral pyrite. Rare galena is found with the pyrite, and in places, rare chalcopyrite fills cavities between oolites. The coarser patches of pyrite apparently represent porous areas where concentration has taken place during diagensis. Since rare chalcopyrite is found with the coarser pyrite, then presumably some also occurs as disseminated fine grains.

4.2.2 Concentrations along Stylolites and in Areas of Coarse Grained Dolomite

In hand specimen many samples of massive, finely crystalline or sandy dolomites show patches of galena up to 1 mm in diameter (Figures 4.1a and 4.1c), or concentrations along stylolitic seams (Figures 4.2a and 4.2b). The galena splashes are predominantly cavity fillings which, in places, are thinly lined with galena and filled with barite (Figure 4.5a), indicating deposition of galena preceded barite.

Galena occurs as thin seams and patches along stylolites associated with coarse euhedral quartz (1 mm diameter). Minor pyrite ranging from subhedral to spheroidal in shape, may be associated with the galena. The quartz is of two forms; large equant grains and elongate crystals, up to 1 mm in length (Figure 4.5c). A distinctive feature of both of these forms is that they contain abundant elongate inclusions of prehnite.

In places, pyrite is much more abundant than galena forming large spheroidal grains (up to 1 mm). Galena is also associated with areas of coarse grained dolomite, forming patches up to 5 mm in diameter, or as patches along stylolites with coarse grained dolomite and chalcedony. Rare tetrahedrite, sphalerite and chalcopyrite occur as small inclusions in galena. The dolomite host rock containing the mineralised stylolites, always contains very finely disseminated opaques (see Section 4.2.1).

The distinctive "bleached" zones in some parts of the sandy dolomites have already been mentioned (Section 4.2.1). These zones contain mineralisation along veins and stylolites, both of which are closely related to solution activity, (Figures 4.2a and 4.2b). In-filling of open spaces developed along stylolites is present in places (Figure 4.7d). In the coarser patches and veins, pyrite is associated with the galena as euhedral grains (0.1 mm to 0.3 mm in diameter) that are concentrated towards the centre of the veins, or as minor colloform and framboidal masses in places along the margins (Figures 4.7a and 4.7b). Rare tetrahedrite is found as inclusions in the galena. The only gangue mineral observed is coarse grained clear dolomite.

4.2.3 Mineralised Dolomite and Silica Veins

(a) Silica veins (Figures 4.2c and 4.2d)

Silica veins and pods contain sparse mineralisation, predominantly galena, with minor pyrite.

Silica

Silica (SiO_2) is the most abundant constituent of these veins occurring in a variety of forms, which can be summarised as follows:-

(I) euhedral quartz crystals, often showing growth zoning, lining the walls of cavities in the veins (Figures 4.8a and 4.8b)

(II) aggregates of large interlocking quartz grains (Figure 4.8d)

(III) intricately banded chalcedonic material with the chalcedony appearing to consist of radiating fibres in cross polarised light (Figures 4.8c and 4.8d and 4.9b)

(IV) microcrystalline aggregates (Figures 4.8a and 4.8b)

Forms (I) and (II) would correspond to "megaquartz", form (III) to "chalcedonic quartz" and form (IV) to microcrystalline quartz according to the terminology of Pittman (1959). A distinctive feature of forms (I) and (II) is that they contain abundant inclusions. These include rod and tablet shaped solid inclusions (predominantly prehnite) that often show a strong alignment (Figure 4.9a), and two phase fluid inclusion (see Chapter 7).

Colloform banding in the silica is very common, the banding usually shown by very fine opaques (Figure 4.8c). When viewed in thin section, many areas where one would expect to see finely crystalline chalcedony are found to consist of aggregates of crystalline quartz in large interlocking grains (up to 1.0 mm) with the colloform banding still preserved in them (Figure 4.8d).

The microcrystalline silica is, in places, associated with blebs of opaques that under high magnification reveal a framboidal texture (Figure 4.8a).

Both colloform and crystalline quartz are present in most samples. The colloform material has been precipitated first, followed by deposition of crystalline quartz in any remaining cavities and fractures. Evidence for this is in the form of thin veinlets of growth zoned quartz cutting across the colloform material.

Dolomite

Minor clear coarse dolomite is associated with both colloform and euhedral quartz. With colloform silica it appears that dolomite is replaced by silica, evidence being corroded dolomite rhombs (Figures 4.9b and 4.9c). Where the dolomite is associated with euhedral quartz it occurs as a filling in the open spaces around quartz crystals (Figure 4.9d).

Barite

A small amount of barite was identified in the silica veins. It was found as scattered irregular masses or conforming to the colloform banding in chalcedonic material (Figure 4.10a) and as cavity fillings developed around galena coated, euhedral quartz (Figure 4.10b).

Galena

Galena is the dominant sulphide, occurring as scattered inclusions in colloform silica (Figure 4.9b). In places these inclusions tend to develop a colloform type of banding (Figures 4.9c and 4.10c). Some framboidal galena is developed in microcrystalline silica (Figure 4.8a). Galena is also associated with euhedral quartz as cavity fillings and as thin bands, marking pauses in growth of quartz linings, and as coatings on quartz crystals (Figure 4.8a). This implies that numerous openings existed at the time of vein filling and that the solutions and/or the conditions that caused deposition were quite variable, at times depositing quartz and at times depositing sulphide (both galena and pyrite).

Pyrite

Pyrite is less abundant than galena but shows very similar textural features. It is observed as fine inclusions in colloform silica, as coatings on quartz crystals and a small proportion as euhedral grains.

Sphalerite

Rare sphalerite is found as an infilling deposited on a layer of galena and hence clearly deposited after the galena.

Chalcopyrite

Rare chalcopyrite occurs as inclusions in galena.

(b) Other veins

Minor coarse grained galena and euhedral pyrite are associated with cross cutting coarse grained white dolomite veins (Figure 4.1d). Galena is the dominant sulphide, partially filling cavities in the dolomite (often lamininated), and pyrite is found as euhedral crystals up to 0.3 mm in diameter (Figure 4.6a), which are partly corroded possibly indicating replacement by the galena. Some pyrite also forms along cleavage in galena indicating either replacement of the galena or crystallisation after the galena. Small orientated exsolution rods and blades of pearceite ($Ag_{16} As_2 S_{11}$) occur in places in the galena (Figure 4.6b), as do inclusions of tetrahedrite. The tentative microscopic identification of pearceite was confirmed by electron microprobe study.

Rare sphalerite and chalcopyrite are found as inclusions in the pyrite.

It is likely that these veins are related to stylolitisation, as they appear to pass into thin stylolitic seams containing concentrations of opaques and detrital quartz (Figure 4.6c).

4.2.4 Breccia Fillings

Three different types of mineralised breccias have been recognised.

(a) Sulphides as cement in dolomite breccia (Figures 4.3a and 4.3b)

This breccia (32/337) which hosts the most significant mineralisation studied, consists of dolomite blocks (containing minor disseminated sulphides) cemented by a matrix of silica and sulphides. The silica has essentially the same characteristics as the silica in the veins suggesting that the veins and this breccia are closely related, the only difference being that dolomite blocks have been incorporated into the vein giving an apparent breccia.

Silica shows very similar textural relationships to that in the silica veins with the forms (I), (II) and (III) described in Section 4.2.3 being present, that is both colloform and euhedral quartz are present. Coarse grained clear dolomite (0.5 to 1.0 mm in diameter) is the only other gangue mineral present.

Galena, the major sulphide mineral, forms a matrix to other ore minerals (See Figures 4.11 to 4.13 for the ore minerals and their textural relationships).

Pyrite is present in two distinct forms, the first as euhedral crystals (0.1 to 0.5 mm in diameter) and the second showing extremely well-developed colloform banding. The euhedral crystals are often highly fractured with chalcopyrite and sphalerite filling the fractures (Figures 4.11a and 4.12a). The colloform material consists of alternating layers of chalcopyrite and pyrite with some galena between these layers (Figure 4.12b). In places, the chalcopyrite bands contain extremely finely dispersed galena (Figure 4.11b) and many of the pyrite bands show euhedral outlines (Figure 4.13b). Chalcopyrite is present as individual grains in the galena, only rarely. The colloform texture in places show some similarities to oolitic textures (Figures 4.12b and 4.13a).

Sphalerite occurs as scattered inclusions, up to 0.2 mm in diameter, through the galena matrix, apparently forming after the colloform material and euhedral pyrite (Figure 4.11a). In one sample a small stylolite connected to a prominent silica vein shows an area of colloform material containing bands of silica, galena and sphalerite (Figure 4.14a). Sphalerite is also found as scattered grains, up to 0.05 mm in diameter, in the dolomite blocks along the margins of the mineralised cement (Figure 4.13a). Minor tetrahedrite grains are present in the galena (Figure 4.13a).

The deposition of ore minerals, as shown by the textural features in this sample, is clearly a complex process. The fragmental nature of the colloform material suggests that it has been partly dissolved by later solutions. It is thought that the colloform material was deposited first, followed by euhedral pyrite and then galena and sphalerite. This conclusion is similar to that reached for the silica of the silica veins (colloform banded silica followed by euhedral quartz).

(b) Disseminated fine to medium grained sulphides, predominantly pyrite and galena, forming part of the cement in dolomite breccias (Figures 4.4a, 4.4b and 4.4d, 2.3b)

Pyrite is the most abundant ore mineral in the cement of these breccias, commonly forming separate spheroidal and partly spheroidal grains, up to 1.0 mm in diameter (Figure 2.4c). In places spheroidal (colloform) pyrite aggregates coat dolomite blocks, with chalcedony coating the pyrite

(Figure 4.14b). Some samples contain a much larger amount of sulphides (almost entirely pyrite) in the cement (Figure 4.4a). Galena is present, not uncommonly, as cavity fillings in the cement. Rarely sphalerite is associated with galena as scattered inclusions and small colloform masses (Figures 4.14c and 4.14d).

(c) Coarse grained galena, pyrite and dolomite, as the cement of solution collapse dolomite breccias (Figure 4.4c)

Pyrite forms coarse grained aggregates (up to 1.5 cm in diameter), which exhibit growth zoning (Figure 4.15a). In places the zoning has an appearance more like that of colloform banding. Galena is present as an infilling, deposited after pyrite, in cavities between the dolomite blocks. Minor sphalerite is found as inclusions in pyrite and a trace of tetrahedrite is present in the galena. Some of the growth-zoned pyrite consists of marcasite cores.

Sulphides, particularly sphalerite, occur along stylolites and as very fine disseminations in the dolomite. The only gangue present is coarse grained clear dolomite.

4.3 SIGNIFICANCE OF TEXTURAL OBSERVATIONS

4.3.1 Framboidal Textures

The interpretation of framboidal textures has produced a great deal of literature, which has been reviewed by Love and Amstutz (1966) and Trudinger (1976). Some workers (e.g., Schneiderhohn, 1923; Ramdohr, 1953; Love, 1957; Love and Zimmerman, 1961; Love and Murray, 1963) have favoured biological activity for the formation of pyrite framboids. They considered that the pyrite framboids represented micro fossils of sulphate-reducing bacteria, within which iron and other metals had precipitated as sulphides. Other workers, however, believe framboidal pyrite to be of inorganic origin (e.g., Schouten, 1946; Vallentyne, 1963;

Rickard, 1970), the pyrite having pseudomorphed a pre-existing spherical body. These may be gaseous vacuoles (e.g., framboids in andesites; Love and Amstutz, 1969) or organic globules (Rickard, 1970), which means that framboids are not necessarily indicators of sedimentary environments, although they probably form at low temperature.

Recent investigations (Berner, 1969; Sunagawa et al.,1971; Sweeney and Kaplan, 1973) have confirmed the purely inorganic formation of at least some framboidal pyrite. Berner (1969) has demonstrated the formation of framboidal pyrite at low temperatures (at 65°C) and neutral pH. Berner (1970) however, has not ruled out the possibility that bacteria are involved in the formation of framboids and has proposed that the major steps involved in the formation of pyrite framboids are as follows:-

1. The bacterial reduction of sulphate to form H_2S
2. The reaction of iron minerals with H_2S to form inorganic monosulphide precipitates.
3. The reactions of iron monosulphides with elemental sulphur to form pyrite.

Creelman (1974) has listed the following major requirements for the formation of framboidal pyrite in sediments:-

1. The existence of sulphate-reducing bacteria and an adequate source of organic nutrient for the bacteria.
2. A constant supply of sulphate into the sediments or sulphate already available in the sediments.
3. Availability of iron, either as iron minerals or in aqueous solution.
4. The production of an essentially saturated H_2S environment, and the production of elemental sulphur.

Hence the presence of framboidal textures (in both pyrite and galena) at Ediacara is not diagnostic of either a biological or inorganic origin of the sulphides. The framboids have only been recognised in the epigenetic (or diagenetic) sulphides (that is, in veins and stylolites) and not in the synsedimentary sulphides. For this reason it is suggested that they are of inorganic origin and have developed during diagenesis at relatively low temperature and neutral pH in an environment where the above requirements may have been fulfilled (including the presence of bacterially produced H_2S).

4.3.2 Colloform Textures

Roedder (1968) has given a detailed review of the published evidence for the origin of colloform textures in ore minerals. Colloform textures have generally been considered to have been deposited from colloidal gels (e.g., Rogers, 1917; Rust, 1935; Bastin, 1950) and the following textural criteria have been proposed for recognising colloidal deposition:-

1. Rounded, more or less spherical forms representing the classical "colloform" texture
2. Shrinkage or syneresis cracks
3. Concentric banding and radial structures
4. The colloidal state as a necessary intermediary during condensation.

Roedder (1968) has studied "colloform" sphalerite-wurtzite assemblages from various deposits, including samples used by earlier workers as evidence for colloidal origin, and has found each of the textural criteria proposed for colloidal deposition to be invalid or ambiguous. He concluded that "colloform" textures of these ores do not necessarily originate in deposition from colloidal gels, but may grow directly as crystals on a surface in contact with the ore fluid. The banding present in these ores would then be considered as arising from periodic variations in the ore fluid composition.

Samples of colloform textures at Ediacara clearly show that some pyrite bands consist of euhedral crystals (e.g., Figure 4.13b), supporting a noncolloidal origin. Fluid inclusion studies (Chapter 7) have shown that the ore solutions are highly saline, which, according to Barnes and Czamanske (1967), precludes colloidal origin for the sulphides. Obviously, to produce a "colloform" texture from direct crystallisation requires the maintenance of a large number of crystal nuclei, which Roedder attributed to relatively high supersaturation, and therefore high nucleation and growth rates. Roedder also concluded that concentric banding associated with "colloform" material probably formed under shallow conditions (that is, at low temperature). The alternating bands of pyrite, chalcopyrite, galena, silica and at times sphalerite at Ediacara indicates that either periodic variations in the ore fluid composition, or in the conditions that caused deposition, have occurred. The colloform textures also provide supporting evidence for the very low grade of metamorphism of the carbonates, as the delicate textures would not survive much in the way of metamorphism.

Reviews on the genesis of colloform banded chalcedony have been given by Ball and Burns (1975) and Sunagawa and Ohta (1976). Until recently most workers have believed that chalcedony formed from a silica colloidal gel (e.g., Frondel, 1962). This is analagous to the situation with regard to the origin of colloform banding in ore minerals. Some authors, however, believed chalcedony to be formed by deposition from silica rich hydrothermal solutions (e.g., Sim, 1974). Recent studies by Sunagawa and Ohta (1976) have shown that the colloform banding in chalcedony and the polygonal growth banding in well crystallised quartz crystals have the same origin (see Figures 4.8a and 4.8c for examples from Ediacara). They concluded that both were deposited from hydrothermal solutions which have entered into cavities repeatedly. These silica-rich hydrothermal solutions would have low viscosities, in contrast to silica gels, and could therefore freely enter the cavities through narrow ducts. They also concluded that the deposition of colloform and fibrous chalcedony should precede the deposition of coarse crystalline quartz. This situation has been observed at Ediacara.

Sunagawa and Ohta (1976) have also pointed out that chalcedony is the principal product in the case of cavity-filling, whereas coarse crystalline quartz and not chalcedony is the principal product in the case of hydrothermal veins. The reason for this is that cavity filling takes place in a closed system from a solution which is not strongly agitated, whereas in the case of hydrothermal veins, it takes place in an open system, in which there is continuous flow of solution. They explain that the continuous flow results in coarse crystalline quartz whereas the closed system leads to fibrous and colloform chalcedony due to a strong effect from the cavity wall. The banding in chalcedony can then be explained by simple and rhythmical precipitation. They also consider that there are not large differences in chemistry between the solutions from which chalcedony is formed and ore-forming hydrothermal solutions. This obviously is true at Ediacara where chalcedony is quite clearly closely related to mineralisation.

Thus it appears that both euhedral crystalline quartz and colloform banded chalcedony have been deposited from silica-rich hydrothermal solutions. Since chalcedony is dominant, deposition would have taken place predominantly in cavities (closed system) rather than hydrothermal veins (open system).

4.4 SUMMARY AND CONCLUSIONS

1. Four types of mineralisation have been recognised:- disseminated sulphides of probable synsedimentary origin and concentrations along stylolites, in veins and as breccia fillings.

2. The concentrations represent variations of the one type; finely disseminated sulphides concentrated from the dolomites by solution activity, probably during diagenesis.

3. The main ore minerals present are pyrite and galena, with minor chalcopyrite and sphalerite. Rare tetrahedrite and pearceite are present as possible exsolution bodies in galena. The gangue consists predominantly of silica (both chalcedony and quartz) with minor dolomite and rare barite.

4. The ore and gangue minerals display both euhedral crystalline forms (with occasional growth banding) and distinct colloform banding, with the latter forming before the former. It is thought that both textural forms have been produced from silica rich hydrothermal solutions. Framboidal textures have also formed from these solutions.

5. The ore and gangue minerals show evidence of repeated episoidic precipitation, and therefore no simple paragenetic sequence can be determined.

6. Quite clearly, numerous openings existed at the time of vein filling, and deposition probably took place at relatively low temperature (see Chapter 7).

CHAPTER 5

REGIONAL ASPECTS OF LOWER CAMBRIAN STRATIGRAPHY AND BASE-METAL OCCURRENCES

5.1 INTRODUCTION

In order to compare the Ediacara mineral field with other mineral deposits in the same stratigraphic position as Ediacara, a general account of the lower Cambrian stratigraphy of the Adelaide Geosyncline is given in this Chapter. More detailed descriptions of individual deposits are given in Chapter 6. In addition, the distribution of all known base-metal occurrences has been compared with a possible palaeogeographical model to establish whether there is any apparent relationship between mineralisation and sedimentary environments, as noted at Ediacara (Sections 2.8 and 3.3).

5.2 LOWER CAMBRIAN STRATIGRAPHY AND PALAEOGEOGRAPHY OF THE ADELAIDE GEOSYNCLINE

5.2.1 Flinders Ranges

The Hawker Group, which contains the lower Cambrian carbonate sediments of the Flinders Ranges (Figure 5.1) has been described in detail by Daily (1956), Dalgarno and Johnson (1963) and Dalgarno (1964). Much of the following information is taken from Daily (1976).

The base of the lower Cambrian throughout the Adelaide Geosyncline and adjoining Stuart Shelf is marked either by a sedimentary hiatus or a local unconformity with the underlying upper Proterozoic sediments. In the northern Flinders Ranges the new cycle of sedimentation commences with the Parachilna Formation, which ranges up to over 460 metres in thickness but is seldom more than 60 metres thick.

With increasing carbonate content these sediments pass upwards abruptly, or through transitional beds (as at Ediacara), into a thick sequence of dolomite and limestone, the Ajax Limestone or equivalent Wilkawillina Limestone. This was deposited during a prolonged phase of carbonate sedimentation and the types and thicknesses of the resulting carbonates were largely determined by varying water depths and subsidence rates. The Ajax and Wilkawillina Limestones were deposited on relatively stable shelves but in basinal areas thicker, darker and impure limestone and shale were deposited (e.g., Parara Limestone).

The depositional environment of the stable shelf carbonates are variable, reflecting progressively less restrictive conditions and in general a gradual deepening of the depositional environment from rarely fossiliferous, intertidal and supratidal environments to warm clear waters with normal salinities and good circulation. Small fluctuations in water depth displaced the sedimentary environments laterally resulting in an intertonguing complex of stable shelf carbonates. Unconformities within the shelf carbonates may be recognised by red weathering surfaces.

Recent lithofacies studies of the Hawker Group sediments of the Flinders Ranges by Wopfner (1968) delineate a stable shelf platform to the west, a central depositional ("negative") basin and a substable shelf to the east (Figure 5.2). The western stable shelf was shallow and received very little clastic material and, hence, chemical precipitation dominated, with the formation of dolomites and cherts. Maximum accumulation occurred in the central basin area. The break (Hinge Line) between the stable shelf and the "negative" basin, furnished the environment for accumulation of reef type Wilkawillina Limestone. To the east of the "negative" basin, the sand content in the lower Cambrian sequence increases markedly indicating proximity of a landmass to the south east supplying detritus to the basin. This land mass may have been the Willyama Block.

5.2.2 Sellick Hill Area

The Normanville Group (which contains the lower Cambrian sediments) is the equivalent of the Hawker Group of the Flinders Ranges (Daily, et al., 1976). Their distribution and component formations are shown in Figure 5.3 and Table 5.1. The Normanville Group is composed of five main formations, which appear to reflect two cycles of shallow shelf sedimentation separated by an erosional break (disconformity) between the Wangkonda and Sellick Hill Formations (Daily, et al., 1976). The following descriptions are taken largely from Daily, et al., (1976):-

Mount Terrible Formation

The Mount Terrible Formation rests unconformably on Precambrian sediments. The basal part of this formation consists of pebbly and coarse grained feldspathic sandstones and arkoses and is overlain by about 60 metres of siltstone followed by 18 metres of cavernous and ferruginous sandstone.

Wangkonda Limestone

This formation is 120 metres thick and composed of thick massive blue grey recrystallised limestone, with minor sandstone. It consists of two shallowing upward cycles of carbonate-rich rocks, each commencing with calcareous sandstones and siltstones, which are overlain by dark grey mottled limestone and are capped by unfossiliferous pale grey limestones deposited under more restrictive marine conditions. These unfossiliferous limestones show evidence of deposition in intertidal to supratidal environments.

Sellick Hill Formation

This formation disconformably overlies the Wangkonda Formation and varies between 210 to 360 metres in thickness. The base is sandy but the formation becomes more calcareous upwards. The major part of the formation consists of scantily fossiliferous dark grey mottled and banded silty limestones and appears to have been deposited in a marginal basin in which poor water circulation and hence stagnant bottom conditions prevailed. However, archaeocyatha present in the upper levels suggest a general shallowing and better water circulation at that time.

Fork Tree Limestone

The lower member of the Fork Tree Limestone is commonly a massive light grey, finely crystalline and very pure limestone and is about 240 metres thick. Abundant archaeocyatha which characterise this member, together with calcareous algae and stromatolites, suggest a continuation of the shallowness of depositional environment that prevailed during the deposition of the upper Sellick Hill Formation. The upper member consists of dark blue-black angular fragments of limestone surrounded by yellow brown calcareous shaly material, giving a distinctive mottled appearance. This member varies from 15 to 30 metres in thickness and probably reflects a deeper more reducing environment of deposition than the lower member.

Heatherdale Shale

This is divided into two members, a lower calcareous member and an upper dark coloured to black shale and siltstone. The unweathered rock is carbonaceous and pyritic .

5.3 LOWER CAMBRIAN BASE-METAL OCCURRENCES

On a regional scale the lower Cambrian sediments are characterised by anomalously high lead, zinc and, to a lesser extent, copper contents. In 1960 a regional geochemical survey of the lower Cambrian was initiated by the South Australian Department of Mines. Stratigraphic drill cores and chip samples from measured stratigraphic sections were analysed for the elements Pb, Zn, Cu, Ag, Cr, V, Co and Ni (Thomson, 1962). Figures 5.4 and 5.5 show the distinct base metal enrichment at several localities at the base of the Cambrian. There is evidence that within a narrow stratigraphic interval copper is associated chiefly with sandstone and shale in the Parachilna Formation, whereas lead, zinc and silver occur in the overlying carbonates. (Thomson 1962). Much of the following information is taken from Johns (1971) and Johns (1972).

5.3.1 Copper Distribution

Copper mineralisation within the Parachilna Formation has been worked at many places in the Flinders Ranges including Sliding Rock, Mount Arden, Kanyaka, Moro, Moorowie and Balcanoona Mines. Several copper mines are also associated with the overlying limestones (e.g., Ajax and Black Eagle Mines), the mineralisation occurring as near surface, secondary enrichments of copper ores. Mineralisation in the Parachilna Formation is confined to areas of less than 120 metres in thickness where a kaolinitic facies rather than a dolomitic facies is developed.

5.3.2 Silver-Lead-Zinc Distribution

Anomalous concentrations of lead and zinc with minor silver have been found widely distributed within lower Cambrian carbonates throughout the Flinders Ranges and in the Sellick Hill Area. The values are considerably in excess of the values obtained by Graf (1960) as the average values for carbonate sediments. Galena carrying silver was formerly recovered at Ediacara, Wirrealpa (Section 6.2), Flinders, Fountain Head, Mount Lyall and Mount Chambers Mines in the Flinders Ranges, and galena with minor sphalerite at Barritt's Mine, Pipeline Prospect and Sellick Hill Prospect in the Sellick Hill area (Section 6.4). In recent years exploration activity by mining companies has continued to demonstrate the anomalous base metal content of the lower Cambrian and several ore deposits of economic potential have been discovered (Figure 5.6).

Anomalous lead and zinc contents have been discovered over a length of 32 kilometres from Parachilna Gorge to Edeowie Gorge, along the western side of the Flinders Ranges (Section 6.3), and in the Willochra region minor concentrations have been defined along a length of 27 kilometres. Extensive investigation by the companies involved has shown the existence of galena and sphalerite, but no economic base metal mineralisation was encountered.

Geochemical investigation resulted in the discovery of a high grade zinc deposit at Puttapa. The zinc occurs as willemite (zinc silicate) and drilling has proved about one million tonnes of ore (Johns, 1972). Similar deposits have been located near the Aroona Reservoir, at Reaphook Hill and Third Plains.

Detailed geochemical investigation by the South Australian Department of Mines has shown anomalous values of lead and zinc within the lower Cambrian carbonates of the Sellick Hill area, over a strike length of 24 kilometres from Sellick Hill to Normanville (Wright, 1968a).

Geochemical results show that the lower dolomitic part of the Hawker Group has much higher lead and zinc values than other limestone sections. This is seen quite clearly in Figure 5.5 and from metal contents at Ediacara.

Figure 5.6 shows the distribution of the lower Cambrian sediments of the Flinders Ranges, and associated copper, lead and zinc mineralisation. Superimposed on this is the lithofacies map of the Hawker Group (Section 5.2.1). This clearly demonstrates that the known lead and zinc mineralisation occurs along the margins of the "negative" basin area as defined by Wopfner (1968).

These shallow water areas would be suitable for the development of reef complexes, carbonate shelves and other specific carbonate environments (e.g., lagoonal and sabkha). Monseur and Pel (1972 and 1973) have demonstrated that in the various facies units, certain mineral associations are selectively concentrated. In Cambrian bioherms, for example, copper is formed on the shelf side and lead-zinc in the biohermal carbonates. This latter sequence is to a certain degree indicated by the geochemical studies of a number of lower Cambrian bioherms undertaken by the South Australian Department of Mines (Thomson, 1965), where the bioherms show the highest lead-zinc values, whereas copper tends to be higher on the shelf. This also seems to be true at Ediacara, where copper is highest in the Parachilna Formation in the southern half of the field whereas lead-zinc are highest in the dolomites in northern half, which were sufficiently rich in organic matter to bring about precipitation of metals from solutions.

5.4 SUMMARY AND CONCLUSIONS

(1) The lower Cambrian sediments of the Adelaide Geosyncline contain anomalous copper, lead and zinc values.

(2) On a regional scale this mineralisation is stratabound; the copper is assocated with the basal Parachilna Formation and lead and zinc usually occur separately and within the lower part of the carbonate sediments, particularly dolomitic sections.

(3) Lithofacies study of the Hawker Group has revealed a central "negative" basin, bounded by shelf areas to the west and east, with the source area being the Willyama Block to the southeast. The areas of known lead and zinc mineralisation occur in the shelf areas.

(4) The Willyama Block has been shown to be the provenance area of the Hawker Group and it is proposed that erosion of the mineralised Willyama rocks (including Broken Hill and Thackaringa type Pb-Zn-Ag mineralisation) provides a likely source of base metals, which may explain the anomalous content of the lower Cambrian sediments.

(5) Consistent association of copper with argillaceous sediments of the Parachilna Formation suggests that copper was taken from solution and adsorbed onto clay minerals. This would leave lead and zinc in solution until carbonate formation, when they would readily be taken up as sulphides or in carbonates, in specific sedimentary environments. This is quite reasonable since copper is known to be adsorbed onto clay minerals much more readily than lead or zinc.

(6) Hence it is concluded that areas of anomalous base metal values were originally due to specific palaeogeographical features and their present form is due to later modification by diagenesis and remobilisation.

CHAPTER 6.

OTHER DEPOSITS IN LOWER CAMBRIAN CARBONATES

6.1 INTRODUCTION

Several other mineral deposits in lower Cambrian carbonates were examined for comparison with the Ediacara mineral field. These were the Wirrealpa Mine, the Western Flinders Ranges, the Sellick Hill Prospect, the Pipeline Prospect and Barritt's Mine. Each of these deposits was briefly examined in the field and samples collected for petrological, sulphur isotope and fluid inclusion studies. The aim of this Chapter is to give a brief description of the local geology of each of the deposits and any petrological work undertaken. The results of the fluid inclusion and sulphur isotope studies are given in Chapters 7 and 8.

6.2 Wirrealpa Mine

6.2.1 Introduction

The Wirrealpa Silver-Lead Mine, situated about 29 kilometres east of Blinman, was the second largest lead producer, after Ediacara, in the Flinders Ranges. Silver-bearing galena has been mined to a depth of 58.5 metres from several shafts and underground workings, with recorded production exceeding 1,000 tonnes of ore at 70% lead and 140 to 220 gm of silver per tonne.

6.2.2 Geology (Figure 6.1)

The Wirrealpa Mine is in an area of carbonate lithologies where significant changes in facies and thickness occur across the east trending Wirrealpa Hill hinge zone (Haslett, 1976) (Figure 6.1). Southeast of Wirrealpa Hill, Woodendinna Dolomite is overlain by the bioclastic and oolitic Wilkawillina Limestone formed in shallow shelf conditions. To the northwest across the hinge zone thicker and darker coloured limestones constitute the bulk of the carbonates, reflecting increasing water depths (Daily, 1976). The Wirrealpa Mine occurs in the upper part of the Wilkawillina Limestone above the top of Faunal Assemblage No. 2 of Daily (1956) (pers. comm., D. Gravestock). This would put it above the level of mineralisation at Ediacara and the Western Flinders Ranges, but in a similar position to that in the Sellick Hill Area. To the west of the mine the Wirrealpa Diapir breaches the Cambrian succession. Haslett (1976) has suggested that several phases of diapirism took place in the early Cambrian, with diapiric highs, which stood out as islands in the shallow Cambrian seas, supplying detritus to the Wilkawillina Limestone. The upper levels of the Wilkawillina Limestone have been, in places, reddened by sub-aerial erosion.

6.2.3 Mineralisation

Galena occurs as course grained "slugs" up to 6 cm in diameter, with associated barite, in a brecciated dolomitic limestone (Figure 6.4a). Mining was concentrated on richer pockets of the silver-rich galena which, according to Ridgway (1948), was associated with a conglomerate (probably a sedimentary breccia). Small workings in this galena extend over a length of 780 metres. Galena also occurs as occasional coarse grained "splashes", up to 2 cm in diameter, in the underlying finely crystalline archaeocyatha limestone. Microscopic examination revealed the only ore minerals to be galena and cerussite, with minor barite gangue. Other reported gangue minerals include quartz, siderite, calcite, jasper and gypsum. Smelter returns showed the presence of small quantities of zinc, arsenic, antimony, gold and silver (Ridgway, 1948).

6.3 WESTERN FLINDERS RANGES

6.3.1 Introduction

Geochemical exploration and surface mapping were undertaken during 1966 and 1967 by Mines Exploration Pty. Ltd., along the western flank of the Flinders Ranges between Parachilna and Edeowie Gorges (Johns, 1972). The lower Cambrian carbonates were found to have anomalous lead and zinc contents and galena mineralisation was reported 9 kilometres north of Brachina Gorge (Galena Creek Area) in basal Cambrian beds and at Bunyeroo Gorge in a basal Cambrian dolomite horizon approximately 3 metres wide (Figure 6.2).

6.3.2 Geology

The extent of lower Cambrian carbonate rocks in this region is shown in Figure 6.2. The Parachilna Formation consists of white argillaceous sandstone with vertical worm burrows overlain by sandy and shaly units with oolitic limestones (total thickness less than 24 metres). Conformably overlying the Parachilna Formation is the Wilkawillina Limestone, which can be divided into two main members (Glover, 1968). The lower member is arenaceous and shaley with a paucity of fossils and is dolomitic, bedded and frequently oolitic. Near the top of the lower member there are algal rich units. The upper member consists of relatively pure, light coloured, massive, thick bedded archaeocyatha limestones. According to Haslett (1975) the lower member roughly corresponds to the Woodendinna Dolomite and the upper member to the Wirrapowie Limestone of the Wirrealpa Area. The lower member is probably equivalent to the Sandy Dolomite and Laminated Dolomite at Ediacara and the upper member to the Massive Dolomite. The conditions operating in the environment of deposition of the sediments in this area were probably very similar to those at Ediacara, the lower member being deposited during the main transgressive phase of the lower Cambrian with a minor regression as indicated by stromatolites and the upper member deposited in the following transgression. Dolomitisation by seepage refluxion, as was suggested by Glover (1968), seems to be the most logical explanation for the lower member.

6.3.3 Mineralisation

Two broad types of mineralisation are present (Johns, 1972), these being:

(a) Generally conformable galena occurrences forming two distinctive horizons varying from 1.5 to 3 metres, but up to 6 metres in width within the lower dolomitic member of the Wilkawillina Limestone. Galena occurs as disseminations, as isolated small cubes and in fine fracture fillings, films and veinlets. Minor sphalerite, associated with galena, and pyrite is also present. Calcite and silica are the gangue minerals.

(b) Less extensive galena mineralisation is present in the upper limestone member, in association with breccia zones and with calcite veining. Galena occurs spasmodically as fine to medium grained disseminations, veinlets and coarse grained masses. Minor sphalerite and calcite and silica are also present.

6.3.4 Geochemistry

Geochemical traverses (Glover, 1968) across the lower Cambrian sequence, have shown the Wilkawillina Limestone, and in particular the lower dolomitic member, to be highly anomalous in lead and zinc (Figure 5.5). Average lead and zinc values are 10 to 40 times greater than the average values for limestones. Electron microprobe analysis was used by Glover in an attempt to investigate lead and zinc content of the carbonates but the values were below the lower limit of detection (about 500 ppm) of the probe.

6.4 SELLICK HILL AREA

The distribution of lower Cambrian rocks in the Sellick Hill Area is shown in Figures 6.3a and 6.3b. The stratigraphy has been discussed previously (Section 5.2.2). Three mineral occurrences from the area were sampled and are described below.

6.4.1 Sellick Hill Prospect (1.2 km south of the Sellick Hill Hotel).

Geology

A zone of coarse calcite between 4.5 and 18 metres wide, in the upper part of the massive archaeocyatha limestone member of the Fork Tree Limestone, contains disseminations and small veinlets of galena, sphalerite and pyrite. According to Wright (1968a) this zone can be followed along strike for over 1.6 kilometres. A geochemical rock traverse carried out by Wright across the strike of the zone, found it to contain up to 300 ppm lead and 1400 ppm zinc. The average background values for the adjacent massive Fork Tree Limestone were 10 ppm lead and 20 ppm zinc.

Petrology

Thin sections revealed that the mineralised samples have a brecciated nature. The blocks are random in size and nature, ranging from 0.1 millimetres to several centimetres, and cemented by relatively clear, coarse grained calcite. Many of the blocks show a concentration of fine grained opaques along grain boundaries of calcite, and patches of chalcedonic silica are found in places. Sphalerite and silica are closely associated in areas of silicified archaeocyatha. Patches of silica appear to replace calcite and contain very fine grained opaques and coarser grained (up to 0.1 mm) euhedral pyrite. Minor coarse grained patches of galena occur as cavity fillings. One area of pyrite in silica shows a patch of framboidal pyrite in a matrix of sphalerite, within a subhedral pyrite grain (Figure 6.7a). It is thought that this zone may represent a zone of solution activity, which may have been modified by later recrystallisation.

6.4.2 Pipeline Prospect (3.2 km south of Sellick Beach, near the Myponga Reservoir pipeline)

Geology

Galena-calcite lenses, ranging from 1 to 30 centimetres in width, occur in a cross cutting joint or shear zone (Rowley, 1955) in the mottled upper limestone member of the Fork Tree Limestone (i.e. just above the stratigraphic position of the Sellick Hill Prospect).

Petrology

Hand specimens show that the lenses consist of coarse grained galena, clear calcite and blocks of the surrounding Fork Tree Limestone (both fine grained dark limestone and yellow brown shaley blocks) in a matrix of fine grained calcite, clays and iron oxides (Figure 6.4b). The surrounding rock is a dark, fine grained limestone, which in thin section shows a small percentage of detrital quartz and disseminated opaques. It appears to consist of about 50 percent relict clasts (average size about 0.1 mm). The contact between the lenses and the country rock is quite sharp with the detrital material in the lenses being quite clearly derived from the country rock.

The cement consists of coarse grained calcite and galena, minor euhedral quartz (the quartz appears to be replaced by calcite and commonly coats limestone blocks) and minor fine grained disseminated galena. Textural evidence suggests that the galena and calcite have crystallised concurrently. Rare sphalerite grains were observed associated with galena.

6.4.3 Barritt's Mine (4 km north of Normanville)

Geology

The mine, which was first worked in 1862, is situated on a 0.3 to 1.0 metre wide lode, in the same stratigraphic position as the Pipeline Prospect (i.e. in the upper mottled limestone of the Fork Tree Limestone). Brown (1908) reported that the dressed ore contained about 60 percent lead and from 80 to 140 gm of silver per tonne. He also noted that blocks of almost pure galena, weighing up to 100 kilograms, were mined. The lode consists of a shear or fracture zone (Wright, 1968a) filled with blocks of limestone, yellow calcareous shale and dark grey shale in a matrix of coarse grained calcite, quartz, galena and occasional yellow-orange sphalerite, indicating low iron content and typical of low temperature deposition.

Petrology

Quartz

Coarse grained euhedral quartz (up to 3 mm) commonly occurs, lining the cavities in the cement and as coatings on the blocks. Growth zoning is very common and is usually marked by very fine grained inclusions (Figures 6.5c, 6.6a). Elongate quartz crystals (up to 1 mm in length) are found in places as a comb-like structure coating blocks (Figure 6.7b). Very minor, finely disseminated galena, pyrite and sphalerite are present in the quartz.

Calcite

Coarse grained anhedral calcite is usually associated with quartz. The quartz often forms along the cleavage in the calcite suggesting deposition after the calcite. Many cavities show crustification banding, with calcite being deposited after quartz, which lines the cavities.

Sphalerite

Coarse grained browny-orange sphalerite is a relatively common ore mineral and is found as patches in calcite (Figure 6.5b) and in association with galena (Figure 6.5c). Galena, quartz and calcite replace the sphalerite. In places galena and quartz occur along cleavage in the sphalerite indicating deposition after the sphalerite (Figure 6.7c). Finer grained sphalerite (average 0.1 mm diameter) also occurs as disseminated blebs in a matrix of galena. Orientated "blades" of sphalerite (up to 0.6 mm in length) in galena occur in the same sample (Figure 6.7d). In places the sphalerite has clearly been deposited after quartz (Figure 6.7b).

Galena

Galena is the major sulphide, generally occurring as coarse grained patches in quartz (Figure 6.5a). A sample of the underlying massive archaeocyatha limestone contained small galena concentrations along veins and stylolites (Figure 6.6c). These veins (about 0.4 mm wide) contain quartz and calcite, and in places they widen and contain much coarser patches of galena. The veins cut across the stylolites, which contain quartz, clays and opaques. Crustification banding, which is commonly present, shows that order of deposition was quartz followed by calcite and then galena.

Dark laminated shale fragments and limestone fragments make up the blocks in the breccias. The shale fragments consist predominantly of quartz, mica and clays, with about 5% of fine grained opaques. In places the blocks contain patches of calcite and galena, which appear to be cavity fillings. Some of these cavities are lined with quartz and later filled with galena. Fine disseminated pyrite, galena and sphalerite have also been recognised.

Summary

The mineral textures and structures are comparable with other low temperature hydrothermal deposits such as the Upper Mississippi Valley deposits (Snyder, 1968). The order of deposition appears to have been quartz, then calcite, followed by sphalerite-galena, with quartz being deposited right through the paragenetic sequence.

CHAPTER 7.

FLUID INCLUSION STUDIES

7.1 INTRODUCTION

Fluid inclusion studies were undertaken on samples from Ediacara, Wirrealpa and the Western Flinders Ranges and Barritt's Mine and Pipeline Prospect from the Sellick Hill Area. Extensive studies were not possible due to lack of suitable transparent gangue material; the only suitable material was silica and dolomite from Ediacara, barite from the Wirrealpa Mine (1 sample) and silica from the Western Flinders Ranges (1 sample). Although only a few suitable inclusions could be found in Ediacara material the silica-galena veins gave consistent results for both composition and temperatures. Excellent inclusions were found in sphalerite, quartz and calcite from Barritt's Mine. Emphasis for the study was therefore placed on the silica samples from Ediacara and the sphalerite from Barritt's Mine.

7.2 METHOD OF STUDY

Forty five doubly polished plates averaging 0.15 mm in thickness and mounted with polyvinyl acetate, were prepared for fluid inclusion study. After initial examination to locate inclusions and determine their suitability, the plates were released in acetone and then cut up for use on the heating and freezing stage.

The equipment consisted of a Leitz Ortholux II POL-BK microscope fitted with Chaixmeca microthermometry apparatus for heating and freezing. A temperature range of -180° to $+600^{\circ}C$ was possible with the equipment. The homogenisation temperature for a primary fluid inclusion is the minimum temperature of formation of the host mineral, and when corrected for the pressure and salinity during crystallisation, is the true temperature of formation. Salinity data were obtained (when daughter minerals were not present) by determination of freezing point depression, the NaCl equivalent of the solution being the weight percent of pure NaCl in water which would give rise to the observed depression from the freezing point of pure water (Roedder, 1962, 1963).

7.3 PRIMARY AND SECONDARY INCLUSIONS

It is not possible for complete certainty in the distinction between primary and secondary inclusions, but according to Roedder (1967) the following criteria can be used to locate a suitable primary inclusion:-

(1) occurrence in euhedral crystals projecting into vughs.

(2) the inclusion must lie outside a plane of re-healed fractures.

(3) trapment of foreign daughter minerals.

(4) similar inclusions should contain the same major phases in approximately equal proportions.

(5) inclusions related to a former crystal shape or growth phenomenon (e.g., parallel to growth zoning or primary colour banding) are considered to be primary.

(6) inclusions parallel to a cleavage direction (or cutting across a crystal face, etc) are almost certainly secondary.

(7) isolated inclusions with no obvious planar arrangement are probably primary, particularly if large.

The last four criteria were the most useful in this study.

7.4 LIMITATION AND ASSUMPTIONS

There are several requirements which must be satisfied before the method of fluid inclusion thermometry can be applied rigorously.

(1) the fluid trapped upon sealing of the inclusion was a single homogeneous phase, and completely filled the cavity at the time of the deposition.

(2) there is no change in the volume of the cavity itself due to pressure, solution or precipitation.

(3) there is no addition or loss from the inclusion after sealing.

(4) the effects of pressure are insignificant or are known.

(5) primary inclusions can be distinguished from secondary inclusions.

7.5 FLUID INCLUSIONS - EDIACARA

Most studies were carried out on silica since this was the only gangue mineral of any significance. Of some 20 polished plates prepared only five contained any suitable inclusions. Coarse grained white dolomite was sufficiently abundant in two mineralised samples for polished plates to be prepared.

7.5.1 Silica

Inclusion of sulphides within silica are common (see Chapter 4). These can be in the form of disseminated solid inclusions, continuous and semi-continuous colloform banded material and sulphides outlining growth zoning in euhedral quartz. They are generally associated with primary zoning in silica and consequently the nature of the fluids in inclusion in silica are expected to be very similar to those from which sulphides precipitated.

A common feature of the samples is that they show colloform banding and contain many solid inclusions ranging in size from 10 to 50 micrometres. Many samples also show minute cavities lined with quartz crystals. Fluid inclusions are relatively rare and generally confined to clearer patches where the colloform banding is less pronounced. Two distinct types of inclusions can be recognised.

Type 1.

These inclusions are large, ranging from 20 to 40 micrometres in diameter and show a variable "vapour : liquid ratio" (Figure 7.1). It is suggested that these are formed by random exsolution of air dissolved in aqueous solutions (pers. comm., P. Ypma). Several large, completely gas filled inclusions are also present, probably indicating a trapping of air during crystal growth in near surface conditions (30° to 60°C). To test this theory the largest inclusion found (32/337) was crushed under the microscope. According to Roedder (1976) when inclusions are opened on the crushing stage and the gas bubble expands approximately 20 fold, this volume change would correspond to approximately 20 atmospheres pressure. On exposure to atmospheric pressure the vapour bubble showed no apparent increase or decrease in volume hence confirming near surface conditions (1 atmosphere pressure).

Type II

These inclusions show distinctly lower relief than Type I inclusions, are much smaller averaging 5 to 10 micrometres in diameter and have a constant "vapour : liquid ratio" (Figure 7.2). These inclusions are considered to be of primary origin. No daughter minerals have been observed in these inclusions.

7.5.2 Dolomite

Coarse grained white dolomite occurs in several samples in association with pyrite and/or galena as cavity filling or cement in collapse breccias. Fluid inclusions are relatively rare in these samples and range in size from 5 to 15 micrometres. Some are clearly of secondary origin as in 32/281 where inclusions can be seen cutting across crystal faces (Figure 7.3a) and others, presumably of primary origin, as in 33/179 (Figure 7.3b). These inclusions showed a constant "vapour : liquid ratio" and the vapour bubble is thought to consist dominantly of water vapour. If the carbon dioxide content of these were high, one would possibly expect either liquid carbon dioxide to form below 31°C or the formation of clathrate compound $CO_2.5\frac{3}{4}H_2O$ (carbon dioxide hydrate) on freezing (Roedder, 1972).

7.5.3 Homogenisation Temperatures and Salinities (Table 7.1)

Homogenisation temperatures on primary (Type II) inclusions in silica and primary fluid inclusions in dolomite, show a range of 159° to 199°C (Table 7.1), with homogenisation temperatures for dolomite lower than those for silica.

Salinities for Type I inclusions in silica are 3 to 6 equivalent weight percent NaCl. Salinities for Type II inclusions in silica and primary inclusions in dolomite range from 24 to 27 equivalent weight percent NaCl.

7.6 FLUID INCLUSIONS - WIRREALPA AND WESTERN FLINDERS RANGES

Barite, being the only gangue mineral at Wirrealpa, was used for fluid inclusion studies. However, very few inclusions were observed, possibly due to the cloudy nature of the barite. Several small (10 micrometres) two phase inclusions of probable primary origin were used for determinations.

Suitable material was similarly lacking from the Western Flinders Ranges samples. Rare small (5 micrometres) two phase primary inclusions were located in cloudy silica.

7.6.1 Homogenisation and Freezing Data

The range of homogenisation temperatures and salinities are given in Table 7.2 below.

TABLE 7.2

FLUID INCLUSION DATA
WIRREALPA AND W. FLINDERS RANGES

Sample No.	Location	Homogenisation T°C	Salinity (Wt % NaCl)
Barite - W 1	Wirrealpa	157 - 165	12%
Silica - G68/14	W. Flinders Rgs	132 - 143	25%

7.7 FLUID INCLUSIONS - SELLICK HILL AREA

7.7.1 Barritt's Mine

Sphalerite

Polished slabs of sphalerite provide excellent material for fluid inclusion studies because of the transparent nature of the sphalerite and the large size of some inclusions. The fluid inclusions are dominantly two phase inclusions ranging in size from less than 1 micrometre up to 100 micrometres, with most being in the 10 to 20 micrometres size range. Some of these are parallel to colour banding (Figure 7.4a) and hence are considered to be primary, whilst others occur in planes cutting across crystallographic directions and parallel to cleavage (Figure 7.4b).

Quartz

Clear euhedral coarse grained quartz contains only rare fluid inclusions. These are two phases inclusions ranging from 5 to 10 micrometres in diameter. The origin of these inclusions is problematical but they are possibly of primary origin (Roedder, 1967).

Calcite

Calcite contains many small (10 to 15 micrometres) two phase inclusions of probable secondary origin.

7.2.2 Pipeline Prospect

Calcite, the only gangue mineral, contains many inclusions most of which are two phase and of secondary origin (parallel to cleavage) (Figure 7.4c).

7.7.3 Sellick Hill Prospect

Many large two phase inclusions of probably primary origin are present in sphalerite. These inclusions are very similar to those found in sphalerite at Barritt's Mine.

7.7.4 Homogenisation Temperatures and Salinities (Table 7.3)

The range of homogenisation temperatures for sphalerite is 118° to 135°C. Temperatures from calcite and quartz, with one exception, also fitted into this range. The deposits show a narrow salinity range from 22.5 to 25 equivalent weight percent NaCl.

7.8 DISCUSSION

Fluid inclusions from Ediacara can be divided into 2 groups on the information that they provide:-

(a) Type II inclusions in silica and inclusions in dolomite. These indicate a temperature range of 159° to 199°C (uncorrected) and high salinities between 24 and 27 equivalent weight percent NaCl.

(b) Type I inclusions in silica that indicate near surface temperatures (30° to 60°C) and very low salinities (3 to 6 equivalent weight percent NaCl).

The Type II inclusions are thought to have been formed contemporaneously with the colloform silica and colloform sulphides. The Type I inclusions, which are most likely associated with quartz crystals lining minute vughs, must clearly have been formed after the colloform material and hence after the Type II inclusions. Textural evidence has indicated that the colloform banded material (sulphides and silica) crystallised before the euhedral forms (see Section 4.2.4) and it is therefore considered possible that the Type I inclusions are related to the deposition of the euhedral sulphides.

Data from the Wirrealpa Mine and the Western Flinders Ranges are similar, although the temperatures are slightly lower and the salinity of the Wirrealpa barite is only 12 equivalent weight percent NaCl. Data from sphalerite and gangue material from the Sellick Hill area are very uniform with uncorrected homogenisation temperatures ranging from 118° to 139°C and salinities between 23 and 25 equivalent weight percent NaCl.

Pressure corrections, which are needed because of the compressibility of the fluid, are greatest for inclusions with high homogenisation temperatures (Roedder, 1976) and can be ignored for homogenisation temperatures below 200°C. Although the solutions were saturated with respect to NaCl, the absence of any daughter minerals implies that ions other than Na and Cl are present (Roedder, 1976). Alternatively, by reference to Figure 5 of Takenouchi and Kennedy (1965) the absence of daughter minerals could confirm the relatively low homogenisation temperatures, since the figure shows that a saturated solution, if cooled from a high temperature, would crystallise salts.

The deposits are striking in their narrow range of salinities and moderately low homogenisation temperatures of the fluid inclusions. This suggests that they have formed from low temperature, high salinity fluids at low pressure. The generation of such highly saline brines could have taken place in several ways.

(1) A very late stage saline magmatic fluid evolved from a crystallising magma (magmatic hydrothermal). This is very unlikely, particularly for Ediacara, since no acid igneous intrusions are known in the vicinity. The much lower salinity of the Wirrealpa ore solutions could, however, be related to fluids emanating from the nearby diapir.

(2) Leaching of evaporites in the carbonate sequence or from underlying material. This leaching could be brought about by meteoric water or by connate and compaction fluids in the sediments. These low temperature hydrothermal fluids of sedimentary environments have been termed "stratafugic"

by Jackson and Beales (1967) to differentiate them from the true magmatic hydrothermal fluids. The relative importance of the two leaching agents (connate and meteroic water) is unclear and in fact the possibility of mixing of the two cannot be overlooked. Jackson and Beales (1967) have suggested the mixing of two fluids as a means of avoiding the serious problem of transporting lead and zinc with reduced sulphur in the same fluid at low temperature. They advocate that sulphur-deficient brines of deep circulation could have provided the metals (or reduced sulphur) with other brines supplying the reduced sulphur (or metals).

In the lower Cambrian carbonate of South Australia the source of the metals is considered to be the carbonate sequence (Chapters 3 and 5). The source of the reduced sulphur will be discussed in Chapter 8.

Evaporites have not been recognised in this study but the environment of deposition of the carbonate sediments would presumably favour development of them. Gypsum has been recognised from drilling in the carbonate sequence in the southern part of the Ediacara mineral field and quantities of barite in the vicinity of Black Eagle (Okill, 1972).

Comparison of fluid inclusion data with modern connate brine observations suggests that salinities of 25 to 30% NaCl may also be attained through membrane filtration with depths of 1 to 6 kilometres (Dickey, 1969). These depths however are greater than that for which there is evidence.

The connate brines would be heated by burial, but in areas with a normal geothermal gradient, temperatures of up to 200°C may be difficult to reconcile with the small burial depth indicated. However an abnormally high geothermal gradient as has been reported from some oil fields, could account for this problem. Alternatively, high brine flow rates could maintain elevated temperatures despite convective cooling, or regional geothermal gradients significantly above present gradients at the time of mineralisation are a possibility.

(3) Production of a chloride rich brine from sabkha sediments

The existence of a sabkha-type environment during the deposition of the host rocks at Ediacara has been proposed in Chapter 2. According to Bush (1970) the sabkha environment processes sea water such that the resulting brine is a sodium-calcium-magnesium-potassium chloride brine with very low sulphate concentration. Thus addition of material by the dissolution of evaporite deposits is not necessary to produce a brine similar to that indicated by fluid inclusion studies. These brines are also considered to be the solutions involved in the process of dolomitisation by seepage refluxion in sabkha environments (see Section 2.8), which may account for the strong relationship noted between dolomitisation and mineralisation in lower Cambrian carbonate sediments of South Australia.

Bush (1970) has also found a close association of sabkah-like deposits with Mississippi Valley-type ores, which coupled with the similarities between the chemical composition of fluid inclusions in the ores and sabkha brines, suggest a more than chance connection. The sabkha brine would seem to be an excellent leaching and transporting solution for lead and zinc as Barnes and Czamanske (1967) have shown lead and zinc can be carried in chloride rich solutions as chloride complexes. This ability is greatly reduced however if sulphur species are present in any appreciable amounts. The temperature of deposition (150° to 200°C) at Ediacara could be accounted for by the inorganic reduction of sulphate by hydrocarbons (Bush, 1970), which is a highly exothermic reaction and could raise the temperature of the fluids in a shallow environment.

A mechanism could therefore be proposed whereby compaction of sabkha sediments would expel brine which could then pass through a body of carbonate rock containing small amounts of metals. These metals, either in the form of sulphides or within the carbonate mineral lattices, would be leached from the rocks.

Obviously there must have been a much larger volume and weight of ore fluid than the resultant ore itself. The ore fluid therefore must not only be transported from the site of dissolution to the ore body, but many successive volumes must pass through the site of the ore body. The volumes that are needed may seem large, but when examined in geological terms they are not unreasonable. Roedder (1968) has calculated that to form the main ore body at Pine Point, the flow rates are low (less than 1 micrometre per second) and the quantity of flow is also reasonable (38 litres per minute), even when geologically small segments of time are assumed for ore deposition.

CHAPTER 8.

SULPHUR ISOTOPE STUDIES

8.1 INTRODUCTION

A sulphur isotope study was undertaken on the samples from the Ediacara mineral field, Wirrealpa Mine, the Western Flinders Ranges, Barritt's Mine, Pipeline Prospect and Sellick Hill Prospect.

The aims of this study are:

(1) To compare values between these areas with published data on other lead-zinc deposits in carbonate rocks.

(2) To ascertain the source of sulphur and mechanism of deposition.

(3) To compare temperature information with fluid inclusion data.

The sulphur species studied were mainly pyrite and galena, with some sphalerite and chalcopyrite from the Flinders Ranges and galena and sphalerite from the Sellick Hill area.

8.2 SAMPLING AND EXPERIMENTAL PROCEDURE

The simple mineralogy of the deposits meant that in many cases high purity sulphides could be extracted from the samples by means of a dental drill. In the deposits, other than Ediacara, sufficient coarse grained sulphide could usually be found to ensure no contamination from other sulphides or gangue. However, this was not so for most of the Ediacara samples because of the fine grain size of many samples. Some samples were sufficiently coarse to drill and others, where dolomite was the only contaminant, were washed with dilute acetic acid to remove the dolomite. The most difficult samples were those in which sulphides were intimately associated (e.g. 32/337). In this case the chemical separation procedure of Smith and Croxford (1973) was adopted.

Once samples had been prepared, a sufficient amount was weighed out (the amount ranged from 10 to 40 milligrams depending on the sulphide involved and was calculated on the basis of production of approximately 3.5cc of SO_2) with an excess of cupric oxide. This mixture was then burned in a previously evacuated furnace at 1200°C for approximately 10 minutes. The SO_2 produced was then purified using a method slightly modified (Seccombe, 1973) after

Dechow and Jensen (1965). Non-condensables were first removed over a liquid nitrogen trap, then water was extracted with a dry ice-acetone mixture, and finally CO_2 was removed by means of a slurry of liquid nitrogen and pentane. Yields of SO_2 were checked with a manometer and compared with calculated yields.

The ratio of $^{34}S/^{32}S$ of the sulphur dioxide was measured using a Micromass 602 mass spectrometer in the Glaciology Section of the Antarctic Division in Melbourne. The results are given in permil (‰) values defined as follows:-

$$\delta^{34}S\ (^{o}/_{oo}) = \frac{(^{34}S/^{32}S\ \text{sample} - {}^{34}S/^{32}S\ \text{standard}) \times 1000}{^{34}S/^{32}S\ \ \text{standard}}$$

The standard referred to is the troilite phase of the Canyon Diablo meteorite whose $^{34}S/^{32}S$ is 0.0450045, giving 0.00‰. Standards and repeats were run in each batch and a precision of 0.3‰ was established.

8.3 RESULTS

A total of 66 samples were analysed isotopically, 47 from the Flinders Ranges (41 Ediacara and 3 from both Wirrealpa and the Western Flinders Ranges) and 19 from the Sellick Hill Area (15 from Barritt's Mine and 2 from both the Pipeline Prospect and the Sellick Hill Prospect). All results are given in Tables 8.1, 8.2 and 8.3, and Figures 8.1 and 8.2.

8.4 SULPHUR ISOTOPE GEOTHERMOMETRY

8.4.1 Discussion

There is a systematic fractionation of ^{32}S and ^{34}S between co-existing sulphides under equilibrium conditions. This fractionation is temperature dependent and thus provides a potential geothermometer. Recent work (Grootenboer and Schwarcz, 1969; Kajiwara and Krouse, 1971; Czamanske and Rye, 1974; Rye, 1974; Rye and Ohmoto, 1974) has established the sulphur isotopic fractionations among important sulphur species.

These fractionation curves are based on experimental data and there are some differences between the curves produced by various workers. The galena-sphalerite pair has been found to be the most suitable due to relatively large differences in $\delta^{34}S$. Kajiwara and Krouse (1971) have shown that the heavy isotope ^{34}S is enriched in the sulphides in the following order - Pyrite > sphalerite ≃ pyrrhotite > chalcopyrite > galena, under equilibrium conditions.

In order that sulphur isotope determinations be successfully applied to geothermometry, suitability of samples is very necessary. The minerals should have been deposited contemporaneously and in equilibrium. However, this is very difficult to ascertain and in this work "coexisting" simply means the sulphides were in physical contact. Fortunately mineral pairs, and in particular the sphalerite-galena pair, often give isotopically determined temperatures that are compatible with other data, especially fluid inclusion temperatures, even though the minerals may not show evidence of having been deposited contemporaneously and in equilibrium. According to Rye and Ohmoto (1974) this indicates that they were deposited from solutions of uniform chemistry and temperature. Pyrite-galena pairs however, seldom give reliable temperatures according to Rye and Ohmoto (1974).

The temperatures obtained in this study have been derived from the relation:

$$1000 \ln \alpha_{x-y} = AT^{-2} \quad \text{(T in degrees Kelvin)}$$

A is an experimentally determined coefficient which varies depending on the species involved.

x and y are the 2 coexisting sulphide species.

$$\alpha = \text{fractionation factor} = \frac{(^{34}S/^{32}S)\ x}{(^{34}S/^{32}S)\ y}$$

e.g. if x and y are sphalerite and galena, then

$$\Delta\delta^{34}S_{sp-gn} = \delta^{34}S_{sp} - \delta^{34}S_{gn} \simeq 1000 \ln \alpha_{sp-gn}$$

$$\Delta\delta^{34}S_{sp-gn} = AT^{-2} \quad \text{where}$$

$A = 8.0 \times 10^5$ (Kajiwara and Krouse, 1971)

$A = 7.0 \times 10^5$ (Czamanske and Rye, 1974).

8.4.2 Temperatures

Ediacara Mineral Field

Only three samples containing coexisting sulphides were suitable for analysis. The results from these three samples are given below.

TABLE 8.4

Sample	$\delta^{34}Spy$	$\delta^{34}Sgn$	$\Delta\delta^{34}Spy\text{-}gn$	T°C [1]
33A/179	-11.46	-7.38		
33A/226.5	+1.3	-0.49	1.79	511
32 /327	+6.21	+3.83	2.38	407

1. Temperature according to experimentally determined relationship of Kajiwara and Krouse (1971).

The sample 33A/179 clearly indicates sulphur isotope disequilibrium since the $\delta^{34}S$ value for the pyrite is less than the value for the galena. This is confirmed by the other two samples, which give sulphur isotope temperatures of 400° to 500°C in comparison to homogenisation temperatures of 150° to 200°C for coexisting quartz and dolomite.

Rye (1974) has observed that sulphur isotope disequilibrium is common in low temperature deposits (below 200°C). Disequilibrium between sulphide pairs at low temperature has also been observed by Sasaki and Krouse (1969) at Pine Point, and by Pinckney and Rafter (1972) for the early mineralisation in the upper Mississippi Valley deposits. Rye and Ohmoto (1974) have suggested that deposits that show isotopic disequilibrium occur in shallow environments where boiling, mixing of fluids and redox reactions may occur.

Sellick Hill Area

Coexisting sulphides were found only at Barritt's Mine. Four sphalerite-galena pairs were analysed and the $\Delta\delta^{34}S$ value for each of these pairs, along with calculated temperatures, is given in Table 8.5.

TABLE 8.5

Sample	$\delta^{34}S$ sp	$\delta^{34}S$ gn	$\Delta\delta^{34}S$ sp-gn	T°C [1]	T°C [2]
$B2_1$	14.71	11.23	3.48	206	174
B3	15.7	12.74	2.96	247	213
$B3_1$	15.5	12.34	3.16	230	198
B4	13.59	11.46	2.13	340	300
Average of $B2_1$, B3, $B3_1$			3.20	228	195
Average of all Sp and Gn $\delta^{34}S$ values			3.33		

1. Temperature according to experimentally determined relationship of Kajiwara and Krouse (1971).

2. Temperature according to experimentally determined relationship of Czamanske and Rye (1974).

Three of the four values are in reasonable agreement. The other value (B4) can probably be ignored as the $\delta^{34}S$ value for the sphalerite is lower than the other three samples ($B2_1$, B3, $B3_1$). The reason for this is probably that the sphalerite was contaminated by galena. The average temperature measurements determined from sulphur isotopes for Barritt's Mine is 195°C (using the data of Czamanske and Rye, 1974). Uncorrected homogenisation temperatures for sphalerite ranged from 118° to 134°C, giving a discrepancy of 60° to 70°C between the two. Pressure corrections to the homogenisation temperatures, although small, would reduce this discrepancy slightly. According to Rye (1974), in the temperature range

200° to 370°C most of the corrected homogenisation temperatures are within 40°C of the data of Czamanske and Rye (1974) and that under the best circumstances an error of $\pm$ 20°C is inherent in the use of the sulphur isotope geothermometer. It appears that agreement between sulphur isotope temperatures and homogenisation temperatures is sufficient to indicate that the sulphides were in isotopic equilibrium.

8.5 DISCUSSION OF RESULTS

On the basis of the $\delta^{34}S$ values the deposits can be divided into two groups (Figure 8.1).

1. Ediacara, Wirrealpa and Western Flinders Ranges.

   These have a wide range of values from -12.5 to +8.6‰ with a mean of 0‰ .

2. Sellick Hill Area.

   These have a relatively narrow range (+11.0 to 15.8‰ , excluding the Sellick Hill Prospect) with a mean of 13‰ .

8.5.1 Ediacara

In general wide ranges in isotopic compositions can be explained in terms of fractionation as a function of mineral species, temperature, chemical environment or mixing of different sources of sulphur (Heyl, et al., 1974). Some possible sources of the sulphur are:-

(a) syngenetic sulphides

(b) sulphate - evaporite lenses

(c) connate - formational brine sulphate of sea water of evaporite origin

(d) organic sulphur

(e) magmatic sulphur

(f) volcanogenic sulphur

A wide spread of values clearly rules out magmatic sulphur, leaving sea water as the most likely ultimate source of sulphur. The large variation suggests that the original sulphur may have been syngenetic. However, the range by itself is not necessarily indicative of bacteriogenic sulphides (Rye and Ohmoto, 1974).

Schwarcz and Burnie (1973) have found that stratabound sulphide deposits associated with clastic marine sedimentary rocks display distributions of $\delta^{34}S$ values that are gradational between two main types. The first type shows a narrow distribution with a mode of 45 to 60% lighter than $\delta^{34}S$ of coeval seawater and the second a broad distribution centred around zero and ranging from 0 to 25% lighter than contemporaneous seawater sulphate. They have shown that there is a systematic relation between the type of $\delta^{34}S$ distribution and the type of depositional environment; the former type is associated with deep marine euxinic depositional environments, which are considered "open" to normal sea water with respect to sulphate reservoir, whereas the latter occur in sulphide deposits formed in shallow marine or brackish water nearshore depositional environments, considered to be "closed" with respect to replenishment of sulphate from the open sea.

This second type with a broad distribution centred around zero $\delta^{34}S$ shows broad similarities in both geological and isotopic characteristics with the Ediacara mineral field. Examples of this type include the Zambian Copper deposits (Dechow and Jensen, 1965) and the White Pine Copper Deposit (Burnie, et al., 1972). Comparison of the sulphur isotope data from the Zambian copperbelt with Ediacara and other deposits is given in Figure 8.2. Since the sulphur isotope data for Ediacara and the Zambian copperbelt show very similar characteristics it is worth comparing the geological features.

The stratabound copper deposits of Zambia are found in a series of clastic sediments ranging from conglomerate through sand and silt to carbonaceous shale deposited on a somewhat irregular surface of basement schists and gneisses. There is abundant evidence of current action and much of the ore is found in sedimentary rocks that were formed in a near-shore environment, presumably marine, gradational into brackish water conditions. Copper concentrations are strongly controlled by palaeogeographical trends (Dechow and Jensen, 1965). The Ediacara mineral field occurs in dominantly carbonate sediments but there is a strong tendency for the concentrations to be associated with the more clastic sandy dolomite. Although the Zambian ore deposits have been metamorphosed to varying degrees and some homogenisation of $\delta^{34}S$ values may have occurred, the weighted mean $\delta^{34}S$ value near 0‰ should still be characteristic of the original distribution. Schwarcz and Burnie (1973) account for sulphur distributions like those of Ediacara and Zambian deposits, by a model involving bacterial reduction of seawater sulphate in a "closed" system.

It is concluded that the sulphur at Ediacara was derived from syngenetic or perhaps diagenetic sulphides (Renfro, 1974) that were deposited by reaction of metallic ions and H_2S produced by bacterial reduction of sea water sulphate. The presence of probable syngenetic sulphides has been demonstrated at Ediacara and the $\delta^{34}S$ value of such sulphide (33A/366.5) is close to the mean for the deposit. This would mean that the original sulphides have been remobilised by very saline brines having temperatures of 150° to 200°C, as indicated by the fluid inclusion study, with the original distribution of the sulphur probably being preserved (although some fractionation may have taken place, particularly in breccias). However, it should be pointed out that the spread of values as observed now may be different from that of the original syngenetic or diagenetic sulphides. In other words the fact that the $\delta^{34}S$ value for the single sample of syngenetic sulphide (sample number 33A/366.5) is close to the mean of the deposit could indicate that the syngenetic sulphides were deposited with a narrow range about this value and that the present wide range is due to fractionation during the remobilisation stage. The $\delta^{34}S$ values for the Western Flinders Ranges samples (Table 8.2) possibly show similar characteristics to Ediacara. Since disseminated syngenetic sulphides have been recognised (Glover, 1968), it is suggested these are also the source of the sulphur. The $\delta^{34}S$ values for Wirrealpa sulphides show a very narrow range which may indicate a different source for the sulphur. However, only three samples from two small occurrences were analysed and these also fit in with the overall range of the Ediacara data.

8.5.2 Sellick Hill Area

The mineral occurrences in the Sellick Hill area show some differences in geological characteristics to the Ediacara mineral field, and this appears to be reflected in the sulphur isotope data. The data from the Sellick Hill area have much more in common with that from Mississippi Valley-type deposits, especially Pine Point and the upper Mississippi Valley (see Figure 8.2).

The Pine Point deposit has a mean $\delta^{34}S$ value of +20‰ (cf., Sellick Hill +13‰) and a very narrow range of $\delta^{34}S$ for galena (±3‰ variation) (Sasaki and Krouse, 1969). The mean value is similar to data for evaporitic anhydrite and sulphate of formation brines from strata of the same geological age. Sasaki and Krouse (1969) have, therefore, considered that the most plausible source of the Pine Point sulphur is the sea water sulphate, which was probably supplied in the form of connate brines or solutions from a nearby evaporite basin. If this is so then the sulphate must have been later reduced to sulphide with little isotopic fractionation. Sulphur in minor syngenetic or diagenetic sulphides in the surrounding rocks appears unrelated to the sulphur in the ore and returns widely scattered $\delta^{34}S$ values ranging from +9 to -19‰ which Sasaki and Krouse, (1969) have interpreted as normal biogenic sulphur. This sulphur is comparable in both range of sulphur isotope values and the proposed source of sulphur, with the Ediacara sulphides.

Hence it is considered that the source of sulphur in the Sellick Hill area is similar to that at Pine Point: sea water sulphate, either from sulphate evaporite lenses or from connate brines. However, syngenetic sulphides also cannot be overlooked as a possible source of the sulphur. It is quite possible that there is a mixed source for the sulphur coming from syngenetic sulphides and sulphate sulphur. This may account for the differences between the Sellick Hill Prospect and the other two mines (Table 8.3).

Since the ores occur as metal sulphides then the sulphate has to be converted to reduced sulphur at the same time producing only a small range of values. There are two ways by which this could be brought about:-

(a) Biological reduction

The temperature of ore deposition (around 130°C) suggests that organisms would not exist and therefore it would not be possible to transport the metals and sulphur in the same brine. On the other hand, if the metals and sulphur are carried in separate solutions then biological reduction of sulphate is possible in a cooler environment with later mixing to precipitate sulphides. However, the narrow range of $\delta^{34}S$ values would tend to rule out this method, since biological reduction should produce a wide range of values.

(b) Chemical reduction

Organic compounds (e.g., methane), if present in the brines, could slowly reduce the sulphate to H_2S which would then precipitate the metals (Barton, 1967). The metals may be present in the same brine or supplied from the mixing of brines.

In either case, to produce the small range of values, there must be little fractionation between coexisting sulphides or else homogenisation prior to the final emplacement as metal sulphides.

It is not known if any volcanic influence has supplied any sulphur; the nearest record of volcanics is in the lower Cambrian Heatherdale Shale at several localities about 120 kilometres from the Sellick Hill area. Sangster, (1976) considered that volcanogenic and sedimentary ores in marine rocks cannot be distinguished on the basis of the sulphur isotopes, since the marine conditions apparently would dominate over volcanic conditions and the overwhelming abundance of marine sulphate would be expressed in the isotopic composition of the sulphur.

8.6 PHYSICO-CHEMICAL CONSIDERATIONS

If the deposits have in fact derived their sulphur from sea water sulphate, then the isotopic composition of sulphur in such deposits should bear some relation to that of sea water sulphate sources, the $\delta^{34}S$ value of sea water sulphate of Cambrian age being +31(Sangster, 1976). There are two types of reactions producing sulphur isotope variation (Hoefs, 1973 and Thode, 1963) these being kinetic effects and chemical exchange reactions.

(1) Kinetic effect (non-equilibrium isotope effect)

This occurs, for example, during the bacterial reduction (by the anaerobic species Desulphovibrio desulphuricans) of sulphate to "light" H_2S which gives the greatest variations in the sulphur cycle.

Thode et al.,(1960), Feely and Kulp (1957), Vinogradov et al., (1962), Kaplan et al., (1963), Nakai and Jensen (1964) and others have found that in natural environments (shallow muds in association with oceans and lakes) enrichments occurred in ^{32}S from 15 to 62‰ for sulphides relative to sulphates. Laboratory experiments have demonstrated that during the reduction process, bacteria can produce fractionation up to 25‰. It must be pointed out that in nature sulphate is reduced to sulphide in two distinct situations, open and closed[1] sedimentary basins. In the open system the sulphate-reducing bacteria are in good contact with the infinite reservoir and the sulphate that they reduce is constantly replenished. In such circumstances the sulphide produced will have a constant δ^{34}S value relative to the sulphate reservoir. In a closed system the bacteria are in contact with only a limited amount of sulphate. In such cases the δ^{34}S values of the sulphides produced and of the residual sulphate depend on the extent of reaction of the available sulphate reservoir (Hoefs, 1973). Where closed situations are more closely approached greater isotopic fractionation occurs between the sulphate and the sulphide (Jensen, 1967).

Hence the sulphur isotope variation at Ediacara can be produced by the bacterial reduction of Cambrian sulphate of sea water origin in a closed system (this agrees with an earlier conclusion based on the comparison with Schwarcz and Burnie, 1973). During the remobilisation of the syngenetic sulphides, the spread of values has probably been maintained with fractionation between sulphides due to chemical exchange reactions. Neither stage of this two-stage process forming the Ediacara deposits is suitable for application of the quantitative approach of Ohmoto (1972). The first stage (bacterial reduction) is not amenable because kinetic factors and, hence,

[1] An open system refers to a basin with open circulation whereas a closed system refers to basins with restricted circulation.

sulphur isotope disequilibrium are involved (Rye and Ohmoto, 1974), and the second stage (remobilisation and deposition from saline brines) because sulphur isotope equilibrium between coexisting sulphides was apparently not achieved.

(2) Various chemical exchange reactions (equilibrium isotope effects)

This takes place, for example, between sulphates and sulphides on the one hand and between the sulphides themselves on the other, where there is a definite order of concentrating ^{34}S.

Where the temperature of ore deposition was sufficiently high for chemical (inorganic) reduction of sulphate to be the rate-controlling mechanism (as in the Sellick Hill area) then the ultimate sulphur isotope composition of the ore was determined by chemical factors, such as the proportions of oxidised and reduced sulphur species in solution, pH, temperature, and the isotopic composition of sulphur in the ore fluids ($\delta^{34}S_{\Sigma S}$ which was approximately +31‰).

If the coexisting sulphides have been deposited under equilibrium conditions, as has been suggested previously, then the data of Ohmoto (1972) can be applied. Figure 8.3 is adapted from Ohmoto (Figure 6, 1972) and approximates the conditions of ore precipitation at Sellick Hill (Barritt's Mine).

The homogenisation temperatures for sphalerite ranged from 118° 135°C. Figure 6 in Ohmoto (1972) has been adapted because $\delta^{34}S$ contours have been drawn for T = 150°C. Fluid inclusions have indicated that the pressure on ore fluids was low during mineralisation and therefore a maximum CO_2 pressure of one atmosphere, as used by Anderson (1973), is taken as an approximation only. For f_{O_2} = 1 atmosphere, PbS is stable below log $f_{O_2} = -48$ and is independent of pH. According to Holland (1965) the stability line for $PbS \rightleftharpoons PbSO_4$ is independent of f_{S_2} and therefore it is considered independent of the sulphur concentration. The value of the ionic strength (I) of the ore forming solutions is 1.0 for Figure 8.3. In the range of ionic strengths from 0.5 to 3.0 (2.5 to 15% weight NaCl) the positions of the $\delta^{34}S_i$ contours are only slightly affected by change in the ionic strengths of the fluids and hence the effect can be neglected (Ohmoto, 1972). The salinities at Sellick Hill are greater than 15% NaCl and hence have an ionic strength greater than 3.0 (up to 5.0), but it will be assumed that the effect will not be large enough to be considered. The $\delta^{34}S_i$ values for galena in Figure 8.3 are for $\delta^{34}S_{\Sigma S} \simeq +31‰$. The average $\delta^{34}S_{gn}$ is about +12‰, which indicates log f_{O_2} just below -48 and pH greater than 7 for the ore forming fluids. Using the isotopic enrichment factors of Ohmoto (Table 1, 1972) the proportions of oxidised and reduced sulphur species in the ore solutions can be calculated. For $\delta^{34}S = +31‰$ and $T = 150^{\circ}C$, the molecular proportion of reduced species is 0.64 and the molecular proportion of oxidised species is 0.36.

CHAPTER 9.

ORE GENESIS

9.1 EDIACARA MINERAL FIELD

9.1.1 Previous Theories

Broadhurst (1947) suggested that the Ediacara mineralisation was deposited from hydrothermal solutions that migrated up along fault zones and, that the breccias in which much of the mineralisation is located were due to faulting. Nixon (1962) focused attention on the stratiform nature of the mineralisation and the possible sedimentary nature of the breccias, leading him to classify the Ediacara mineral field as a Mississippi Valley-type deposit.

Thomson (1962) suggested a sedimentary exhalative origin for the metals at Ediacara, and indeed for the metals of the lower Cambrian of the Adelaide Geosyncline. He envisaged contemporaneous metal enrichment of sea water (and hence the sediments) from below by solutions or gases emanating along the basement fault lineaments, since Cambrian volcanic activity was in progress at this time at Truro (eastern Mt. Lofty Ranges) and other parts of Australia. Thomson (1965) also proposed an alternative hypothesis, which related the lower Cambrian lead mineralisation to the wide-spread Ordovician orogeny in South Australia. He considered that telethermal solutions rose along lineaments and deposited most of their lead in the overlying lower Cambrian sediments. In his study he sampled the lower Cambrian sediments over a wide area and the Gawler Range Volcanics. From this he concluded that the Gawler Range Volcanics could not have provided the metals for the sediments because of their low metal content and because no lead enrichment was found in the lower Cambrian in the western shelf area (Stuart Shelf). He did not consider that the Willyama Complex could have been the source area in a sedimentary origin of the mineralisation (see Section 5.2.1).

Nixon (1962) pointed out objections to the possibility of widespread exhalative enrichments along lineaments at Ediacara. These included the fact that no mineralisation occurs adjacent to the Gap Creek fault, remote from areas where mineralisation is known to occur, and there is no evidence of enrichment in other similarly orientated faults in either the dolomites or the Pound Quartzite.

Nixon believed that the metals were derived from solution through the precipitation of metal sulphides by H_2S generated by anaerobic bacteria, and that therefore some specific environment suitable for the existence of bacteria must have operated at the time. He favoured the contemporaneous deposition of sulphides with the other sedimentary components. This he considered would produce extremely fine grained sulphides, which due to "recrystallisation and post depositional movement", would produce the present form of the mineralisation.

Binks (1972) believed that the Ediacara Fault (Figure 1.2) may have acted as a major conduit for hydrothermal solutions, whether derived from the basement or intrusions, or from connate metal-bearing brines, which may have migrated up dip from the Adelaide Geosyncline. However, he did not consider whether the metals were deposited contemporaneously with sedimentation or after lithification.

9.1.2 Discussion

Since the Ediacara mineralisation is thought to have formed by a two stage process (see Section 8.5.1) it is appropriate to separate the discussion into two parts:-

A. Syngenetic Sulphides

The term syngenetic as used by the writer, includes sulphides deposited with the sediments as well as those deposited during the early stages of diagenesis. Any theory regarding the origin of the syngenetic lead mineralisation (see Section 4.2.1), must take into account the following:-

(1) The absence of intrusive igneous rocks as a possible source of ore solutions.

(2) The areal extent of mineralisation in lower Cambrian carbonate rocks of the Adelaide Geosyncline (Section 5.3.2).

(3) Penecontemporaneous or diagenetic dolomitisation of the carbonate host rocks (Section 2.8).

(4) A sabkha as an environmental model for the deposition of the host rocks (Section 2.8).

(5) The relationship of mineralisation to sedimentary environments - the Sandy Dolomite (sub-tidal to bar and channel) and the Laminated Dolomite (tidal flat) (Section 2.8).

(6) The stratabound nature of the mineralisation and the individual deposits (Chapter 3).

(7) The deposition of metals contemporaneously with sedimentation (Chapters 2, 3 and 4).

(8) Sulphur isotope characteristics (Sections 8.5.1 and 8.6).

Most of these points have been discussed previously, as indicated, but several require further discussion.

(3) There is no evidence to suggest that post-lithification dolomitisation occurred or that limestone-dolomite relationships are genetically related to sulphide mineralisation.

(7) The metals are thought to have been deposited contemporaneously with sedimentation from erosion of the Willyama Complex, although the possibility that the metals are of volcanic exhalative origin cannot be entirely ruled out (see Section 9.1.1). The metals are thought most likely to have been precipitated as sulphides by the reaction with H_2S produced by

the bacterial reduction of sea water sulphate. Some metal content may also have been incorporated into the carbonate structure, although electron microprobe studies were inconclusive since the metal contents of the carbonates were below the lower limits of detection (500 ppm). Davidson (1966) has suggested that algae, which are characteristic of evaporite sequences, have a high capacity for extracting lead from their environmental waters. Much of this metal content could later be removed by slowly migrating diagenetic brines or released to the pore solutions during dolomitisation, as suggested by Roberts (1973). Davidson (1966) has calculated that, for no more than 1 ppm lead released to the interstitial fluid, a 200 metre section of strata would yield 1000 tonnes per square kilometre.

Roberts (1973), in discussing the genesis of the Woodcutters Lead-Zinc Prospect, considered that lead and zinc would be concentrated in solution in an evaporitic environment (like that proposed for Ediacara) and eventually fixed in the sediments by co-precipitation with the precursors of dolomite. He considered that the dolomite was formed during diagenesis and that during dolomitisation the dolomite could not accommodate the lead and zinc associated with its precursors and hence these were released to the pore solutions. Thus the dolomitising fluid, which would be a highly saline brine, became a metal-bearing brine.

Renfro (1974) has suggested a diagenetic, rather than the traditional syngenetic, origin of the metals in stratiform sulphide deposits associated with evaporitic environments (e.g., Zambia, Kupferschiefer and McArthur River). He proposed that the metals were derived from terrestrial formation waters and that precipitation as metal sulphides took place when these solutions passed upward through buried, strongly reducing algal mats, charged with H_2S, on their way to the surface of evaporation. Details of Renfro's model have been compared with the model proposed for Ediacara without any real success, although the complex stratigraphy makes this difficult. However, it is thought that a syngenetic origin of the metals would be more likely in the light of other evidence (e.g., evidence of some syngenetic sulphides and the areal distribution of lead in lower Cambrian carbonates).

(8) Sulphur isotope studies have shown that the distribution of sulphur isotopes is comparable with the Zambian ore deposits, and that this distribution can be accounted for by the bacterial reduction of seawater sulphate in a closed system.

B. Epigenetic (Remobilised) Sulphides

The following points must be taken into account when considering the origin of the epigenetic sulphides:-

(1) The simple mineralogy. The only significant ore minerals are pyrite and galena, with minor to rare amounts of sphalerite, chalcopyrite, tetrahedrite, pearceite and marcasite. The major gangue minerals are silica (chalcedony and quartz) and dolomite with minor barite (Chapter 4).

(2) The mineralisation occurs as concentrations along stylolites, as cavity and vein-filling or as part of the matrix of dolomite breccias (Section 4.2).

(3) The lack of wall rock alteration. The only apparent wall rock alteration appears to be the dissolution of the carbonate host (Section 2.9). There is much evidence of post-depositional solution activity, in the form of stylolites, solution collapse breccias and stylobreccias. In many cases these features are mineralised and in places concentration of disseminated sulphides can clearly be ascribed to the solution activity. Some solution collapse breccias show blocks surrounded by mineralisation suggesting that the process of solution was concurrent with or just preceded mineralisation. The simplicity of the alteration, accompanying, or associated with, mineralisation indicates that the solutions were nearly in equilibrium with the carbonate host. The solutions moving through the dolomite had no effect, except to remove sufficient carbonate to make room for later ore and gangue mineralisation, with a slight excess of solution over ore deposition.

(4) Ore textures (e.g., colloform textures), show evidence of repeated episodical precipitation, at relatively low temperature (Section 4.3).

(5) Fluid inclusion studies indicate deposition from saline brines (24 to 27 equivalent weight per cent NaCl) at temperatures between 150° and 199°C (Section 7.5.3).

Any theory that accounts for the origin of the remobilised sulphides must be able to explain each of the following:-

1. Source of the ore solutions, sulphur and metals.
2. Transport mechanisms.
3. Reasons for deposition.

1. The sulphides were formed by remobilisation of fine grained disseminated sulphides of probable syngenetic origin by high saline brines. The origin of the sulphur and metals for these sulphides has already been discussed. The most likely methods of production of the brine would be by leaching of evaporites by connate waters or the processing of sea water in a sabkha environment (Section 7.8).

2. If saline brines were responsible for the remobilisation of the original fine grained sulphides, this means that both the sulphur and metal must have been transported in the same solution. Barnes (1967), Barnes and Czamanske (1967) and Czamanske and Rye (1974) believe that it is possible to transport both the reduced sulphur and the metal ions in the same solution if the solutions are neutral or slightly alkaline and contain a considerable amount (a few thousand ppm) of reduced sulphur. In this case the metals are carried as bisulphide complexes. Others (Anderson, 1973, 1975) maintain that it is not possible to transport both sufficient metal and sufficient reduced sulphur in solution at 100°C, to form an ore deposit.

3. Barnes and Czamanske (1967) have reviewed the causes of deposition, particularly from sulphide complexes. Changes in the physical environment of a solution, carrying metals as sulphide or chloride complexes, could include:

(a) cooling or heating

(b) dilution

(c) reaction with other solution or solids (neutralisation)

According to Barnes and Czamanske (1967), of the physical and chemical factors likely to cause deposition of sulphides, oxidation is the most effective, followed by decrease in pH, whereas dilution or decrease in temperature may cause no precipitation. This possibility has already been suggested by the sulphur isotope disequilibrium (Section 8.4.2), which is characteristic of shallow environments, where boiling, mixing of fluids and redox reactions may occur. The presence of colloform textures in the ore minerals suggest that initial precipitation was from solutions with a relatively high degree of supersaturation producing a large number of nucleii (Roedder, 1965). The mineralising process was not always constant and in equilibrium, as shown by crustification type banding and replacement of ore and gangue minerals.

9.1.3 Conclusions

1. During the deposition of the host rock carbonate sediments, terrestrial waters containing base metals in solution in trace amounts were being introduced into the shallow water environment. These metals were most likely derived from erosion of the Willyama Complex.

2. The metals entered the closed system of a tidal flat environment, where they were precipitated as sulphides, by the reaction of H_2S, produced by the bacterial reduction of sea-water sulphate. It is likely that some of the metal content would have also been incorporated into the carbonate mineral lattices.

3. The influx of metal into the depositional basin would have varied with seasonal change and would have been controlled by the rate and volume of discharge of land-derived waters into that basin.

4. An evaporation pan (sabkha) produced magnesium brines, which percolated downward and seaward dolomitising the sediments (seepage reflux).

5. This dolomitising fluid became a metal-bearing brine, by dissolution of disseminated syngenetic sulphides during the extensive solution activity in the host rocks. The solution activity, which provided a

suitable plumbing system for movement of the brines, most likely began during late diagenesis and has probably continued until present day.

6. The metal and sulphur bearing brines were neutral or slightly alkaline, the metals being carried as chloride or bisulphide complexes.

7. Sulphides were precipitated from the brines at temperatures of 160° to 200°C. Precipitation took place due to oxidation or a decrease in pH, and occurred over a long period of time. Deposition took place in stylolites, stylobreccias, solution collapse breccias and other permeable zones.

8. It is thought that a similar process would explain the origin of the sulphides in the Western Flinders Ranges. Schwarzback & Wopfner (1976) have also suggested a similar two stage process of mineralisation for the Puttapa Willemite deposits: an original sedimentary enrichment of zinc within certain dolomitised zones of a biocherm and subsequent concentration of willemite (and barite) by circulating supergene solutions along major fault zones.

9.2 SELLICK HILL AREA

9.2.1 Discussion

The following information must be taken into account when considering a possible origin of mineralisation in the Sellick Hill area (much of the information is from Barritt's Mine).

(1) The host rocks are limestone and hence mineralisation is not related to dolomitisation (Section 6.4).

(2) The mineralisation favours a particular stratigraphic position (the Fork Tree Limestone) but is quite clearly epigenetic in its present form (Section 6.4). The majority of the mineralisation is in the form of breccia fillings. The origin

of these breccias is obscure and could be ascribed to either tectonic or solution processes. It is thought that solution activity is more likely.

(3) The simple mineralogy (Section 6.4). The only ore minerals are galena and sphalerite with rare pyrite. The gangue minerals are calcite and quartz.

(4) The textures and mineralogy are typical of low temperature hydrothermal deposition (Section 6.4). Crustification banding is common, clearly indicating that numerous openings existed at the time of deposition.

(5) The lack of wall rock alteration. The dissolution of the limestone host may have been the only effect of the mineralising solutions.

(6) Fluid inclusion studies indicate deposition from highly saline brines (22 to 25 equivalent weight per cent NaCl) at temperatures between 118° and 139°C (Section 7.7.4).

(7) Sulphur isotope studies have indicated that the distribution of sulphur isotopes is comparable with the Pine Point and the Upper Mississippi Valley data. It is thought that the sulphur is of crustal origin either from evaporite lenses or from connate brines, the reduced sulphur being produced by biological or chemical reduction of the sulphate (Section 8.5.2). Deposition of the sulphides took place under equilibrium conditions and the ore fluids were neutral or slightly alkaline (Section 8.6).

Also any theory of ore genesis must be able to explain each of the following:-

(a) Source of the ore solutions, sulphur and metals

The most likely origin of the highly saline ore solutions was due to the leaching of evaporites by connate waters or by membrane filtration (see Section 7.8). These ore solutions may have been derived from the local carbonate sequence, from underlying formations, or from adjacent sedimentary basins. There is no evidence to suggest that the sulphur and the metals travelled in the same solution and hence they are considered most likely to have been transported in separate brines. Sulphur isotope studies have indicated that the most likely ultimate source of the sulphur was sea water sulphate (see Section 8.5.2), although syngenetic sulphides are a possibility.

The source of the metals was the local carbonate sequence and it is believed that these accumulated contemporaneously with sedimentation as suggested by the stratabound nature of the geochemical anomalies. It is not known definitely whether these metals were precipitated as sulphides, taken into the carbonate structure, or adsorbed onto clay minerals. However the shale fragments in the breccia at Barritt's Mine which contain approximately 0.1% lead, show evidence of fine disseminated sulphides.

(b) Transport mechanisms

If the metals and reduced sulphur were not transported in the same brine then there is no real problem since the metals would, presumably, be carried as chloride complexes.

(c) Reasons for Deposition

The metals were precipitated as sulphides at the site of deposition, due to mixing with reduced sulphur, supplied at the site. The reduced sulphur could have been produced by reducing some of the sulphate already in the brine (biologically or more likely chemically) or by addition of reduced sulphur to the brine by mixing with H_2S rich waters. It is suggested that both the metal and the H_2S must have been brought to the ore site slowly and for a long period of time.

9.2.2 Conclusions

1. During the deposition of the lower Cambrian carbonates, terrestrial waters containing base metals were introduced into the sedimentary basin. These metals may have been derived from erosion of the Willyama Complex or from contemporaneous volcanic activity. They were extracted from their environmental waters by calcareous algae, or adsorbed onto clays or precipitated as sulphides during periods of inter-tidal - supra-tidal development (e.g., as would have existed during the deposition of the lower member of the Fork Tree Limestone). This environment would also have favoured the development of evaporites.

2. Slowly migrating diagenetic brines, with salinities around 20 to 25 equivalent weight per cent NaCl and derived from the dissolution of evaporites or by membrane filtration, leached much of the metal content from the sequence.

3. These metal bearing brines were neutral or slightly alkaline, the metals being carried as chloride complexes.

4. Deposition of metal sulphides took place under equilibrium conditions at temperatures of 120° to 140°C, when the metal bearing brines encountered other subsurface brines containing reduced sulphur.

5. The reduced sulphur is of crustal origin, produced by the inorganic reduction of sea water sulphate in evaporite lenses or connate brines. The sulphur bearing brines could have been derived from the local sequence, from underlying formations or from adjacent sedimentary basins.

6. The depositional sites represent open spaces, produced by

tectonic or solution activity, where metal bearing brines and brines containing reduced sulphur intermixed for considerable lengths of time.

CHAPTER 10.

CONCLUSIONS

10.1 COMPARISON WITH MISSISSIPPI VALLEY-TYPE DEPOSITS

Few ore types have resulted in a more voluminous literature than the Mississippi Valley-type deposits. The characteristics of these have been extensively reviewed by many authors (see Ohle, 1959; Jackson and Beales, 1967; Snyder, 1968; Brown, 1970; Heyl et al., 1974; Beales and Onasick, 1970). Common characteristics are listed below for Mississippi Valley-type deposits and compared with the lower Cambrian Pb-Zn Deposits of South Australia.

MISSISSIPPI VALLEY-TYPE DEPOSITS	LOWER CAMBRIAN Pb-Zn DEPOSITS OF S.A.
1. Relatively simple mineralogy. Galena and/or sphalerite are the main ore minerals. Barite and fluorite are common. Pyrite is almost always present and chalcopyrite is usually minor, if present. Other minerals include calcite, dolomite and cryptocrystalline quartz.	1. Simple mineralogy. Galena is the only major ore mineral although minor sphalerite is present in the Sellick Hill area. Pyrite is common at Ediacara, but rare elsewhere. Chalcopyrite is conspicuous by its absence being found only in small amounts at Ediacara. Quartz and dolomite with rare barite constitute the gangue, but no fluorite has been recorded.
2. Very typically they occur in carbonate host rocks, - limestone or dolomite. The limestone is often dolomitised and fractured. The ore occurs in very shallow water carbonates and often the carbonate constitutes part of a reef.	2. All Pb-Zn deposits occur in shallow water carbonate host rocks, which are generally completely dolomitised. A sabkha (tidal flat) - type environment for the formation of the carbonates has been demonstrated at Ediacara and it is thought likely that this type of environment may have existed elsewhere (e.g., Western Flinders Ranges and Wirrealpa).
3. There is a general absence of igneous rocks as potential sources of ore solutions.	3. There are no known intrusive igneous rocks which might have provided potential ore solutions.

4. The ores have a low precious metal content, although silver is present in most districts, and is anomalous in a few. Sphalerite is relatively low in Fe. Co, Ni, Ag, Cu, Cd, In, Ge and Ga are often predominant as trace metals.	4. No detailed information on precious metal content is known, but silver is quite anomalous at Ediacara and small quantities of silver and gold have been reported from Wirrealpa.
5. The deposits are epigenetic in their present form and textures indicate that the dominant process of mineralisation was open-space fillings rather than replacement.	5. Most deposits are clearly epigenetic in their present form, although fine disseminated sulphides of probable syngenetic origin occur at several localities. Open space filling was clearly the dominant process of mineralisation.
6. Wall rock alteration is slight or absent, the main processes being dolomitisation, chertification and recrystallisation of the carbonate minerals (and this often preceded deposition of the ore). Sometimes there is so little alteration that it seems as though the introduction of the ore minerals themselves was the only effect.	6. Wall rock alteration is absent.
7. Stratigraphic evidence indicates the depth at which mineralisation occurred was quite shallow. In other words, pressure during mineralisation was low.	7. Mineralisation occurred at shallow depths.
8. They occur in most large sedimentary basins in all parts of the world, usually towards the edges of the basin, in unmetamorphosed and essentially tectonically undisturbed rocks.	8. The deposits occur around the margins and on shelf areas of the Adelaide Geosyncline in essentially unmetamorphosed rocks which have suffered only gentle deformation.
9. Solution activity, brecciation, slump, collapse and thinning are	9. Solution activity and brecciation are common, particularly at Ediacara,

commonly in evidence.	where solution activity has led to the development of stylolites, stylobreccias and finally solution collapse breccias.
10. Many ore bodies are stratabound in nature.	10. The deposits are clearly stratabound.
11. The ore bodies are usually related to positive structures. The structures themselves have many diverse origins; some are original sedimentary features (e.g., related to stratigraphic traps, reefs or breccias) and others are due to folding and faulting (in many places modified by solution and collapse).	11. The ore bodies are related to original sedimentary features (shallow to very shallow water environments favouring the penecontemporaneous formation of dolomite) and/or later structures produced by the effects of solution activity (stylolites, stylobreccias and solution collapse breccias). It can be demonstrated that Ediacara was the site of the most favourable sedimentary features (a sabkha) as well as the most intense solution activity. This may explain the occurrence of the largest known lead deposits at Ediacara.
12. Fluid inclusion data indicate that the ores were deposited from highly saline brines (salinities usually in excess of 20 equivalent weight per cent NaCl) and temperatures of ore deposition were about 200°C or less.	12. Fluid inclusion data indicate deposition from highly saline brines at temperatures between 120° and 200°C.
13. Sulphur isotope data indicate a crustal source for most of the sulphur in the sulphides.	13. Sulphur isotope data indicate a crustal source for the sulphur, either from syngenetic sulphides (which would have been formed by the reaction of metal ion with H_2S, produced by the bacterial reduction of sea water) or from sulphate in evaporite lenses or connate brines.

10.2 DISCUSSION

Current thought on the origin of the Mississippi Valley-type deposits has tended toward the possibility that many of them are derived as a result of diagenetic processes operating in sedimentary basins (see Beales and Jackson, 1966; Snyder, 1967; Davidson, 1966; Jackson and Beales, 1967). Most workers agree that there is essentially one deep seated aqueous source in sedimentary basins (connate water) and ores, oil and gas are seen as normal products of the diagenesis of a sedimentary pile, given suitable controlling conditions.

The concepts involved can be briefly outlined as follows. The metals were leached from sedimentary rock (either from basinal shales or by diagenetic release from host carbonates) and transported along zones of preferred permeability to the site of deposition. The metals were transported as metal chloride complexes by highly saline connate brines, such as might be derived from a sedimentary pile. Deposition of the metals as sulphides took place where and when the metal carrying brines encountered a reduced sulphur species, such as H_2S. Carbonate rock-forming environments, which are commonly evaporitic, serve as a source for H_2S, derived by the reduction of sea water sulphate. The Mississippi Valley-type ore bodies usually occur in shallow water carbonate rocks on basin margins or other positions that would lie in the paths of migrating basinal fluids.

This theory is not without its critics. Ohle (1976) has pointed out the difficulties in a complex plumbing system that requires separate "pipelines" for the metal-bearing brines and the H_2S-bearing waters. This is certainly the most significant criticism but Ohle (1976) has also pointed out other complications, such as the source of the sulphur, evidence of carbonate dissolution performed by the ore solutions, the over-simplification of the chemistry of postulated ore solutions and complex rather than simple mineralogies in parts of some districts.

In most respects the lower Cambrian lead and zinc deposits are directly comparable with the Mississippi Valley-type deposits. The only significant differences of the Ediacara mineral field are the significant silver content and the two-stage process for the origin of the mineralisation. Most workers would agree that the metals in Mississippi Valley-type deposits were derived from sedimentary rock rather than syngenetic sulphides. However at Ediacara the evidence strongly suggests that the metals were derived by the remobilisation of syngenetic sulphides. This theory requires both metals and reduced sulphur to be carried in the same solution, which means that the problem of a complex plumbing system would not apply at Ediacara.

Similar anomalous lead-zinc concentrations are known in the Precambrian Woocalla Dolomite on the Stuart Shelf (Thomas and Douch, 1971 and Johns, 1974). The Woocalla Dolomite consists of a series of black shales, dolomitic shales and dolomite and exhibits features of shallow water deposition, including cross bedding, oolites, ripple marks and laminations suggestive of stromatolites (Johns, 1974). The mineralisation consists of disseminated aggregates of pyrite, sphalerite, galena and chalcopyrite or concentrations along fractures or joints and the primary host rock appears to be a dolomitic shale rather than black shale (Thomas and Douch, 1971).

Johns (1974) suggested that there were four possible factors controlling the mineralisation in the Woocalla Dolomite, these being a positive structural feature with a flanking algal reef in a passive structural environment situated marginal to small partially enclosed basins, a disconformable contact providing favourable positions for introduced mineralisation and potential aquifers for ore fluids, the dolomite, and lastly basement fractures which would be potential zones of weakness through which mineralised solutions could have migrated. He considered that these controls would be effective whether the base metals were originally syngenetic or epigenetic. Clearly the mineralisation in the Woocalla Dolomite can be directly compared with the Ediacara mineral field and Mississippi Valley-type deposits.

In conclusion it is thought that the lower Cambrian and other similar lead-zinc deposits in the Adelaide Geosyncline can be explained as having been formed as a result of post depositional processes that would operate in any large sedimentary basin.

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APPENDIX

DETAILED GEOLOGICAL LOGS - EDIACARA

D.D.H. E33A/61

0 - 0.45m (00 - 1'6")	Kunkar rubble, pieces of grey dolomite
0.45 - 3.45m (1'6" - 11'6")	Grey dense stylolitic dolomite with coarse galena scattered through core between 0.45 - 1.8m (1'6" - 6'0"). Shows fracturing and occasional cavities. Partly weathered around 3m (10').
3.45 - 3.7m (11'6" - 12'3")	Slump breccia
3.70 - 8.25m (12'3" - 27'6")	Grey stylolitic dolomite. Galena at 4.2m (14'). Buff coloured in places. Dolomite is dense and fine grained.
8.25 - 10.3m (27'6" - 34'3")	Fine grained dense dolomite strongly weathered? along fracture planes (or stylolite planes). Weathering takes the form of well defined planes up to 1.5cm wide separating dolomite blocks. Zones consist of pink calcite, detrital quartz grains and small pieces of dolomite. These zones are probably due to solution activity. Archaeocyatha(?) at 9m (30').
10.3 - 11.2m (34'3" - 37'5")	Fine grained dense buff breccia showing preconsolidation slumping in places. Partially weathered.
11.2 - 13.2m (37'5" - 44')	Grey stylolitic dolomite. Stylolites give it a mottled appearance in places. At 11.7m (39') the dolomite becomes oolitic which possibly shows up original bedding.
13.2 - 13.35m (44' - 44'6")	A 15cm zone similar to the one at 8.25 - 10.3m (27'6" - 34'3") occurs.
13.35- 20.8m (44'6"- 69'4")	Fine grained massive crystalline grey dolomite. Variations in colour from grey to buff and the stylolitic nature give the rock a mottled appearance in places. In places slumping has occurred and cavities are scattered along the core. Archaeocyatha(?) at 19.5m (65').
20.8 - 20.85m (69'4" - 69'6")	Weathered dolomite

20.85 - 25.7m (69'6" - 85'7")	V. similar to before - fine grained stylolitic dolomite showing slumping and mottled in places. Galena occurs disseminated through the core. Cavities filled with silica and dolomite occur particularly after 22.8m (76').
25.7 - 28.9m (85'7" - 96'4")	Fine grained dense grey stylolitic crystalline dolomite mottled in places. Scattered galena becomes more abundant. Cavities frequent.
28.9 - 30.8m (96'4" - 102'8")	Dense grey strongly stylolitic mottled dolomite. The rock is so strongly stylolitic in places that it has the appearance of a breccia. Galena and iron oxides occur in stylolites around dolomite blocks. Occasional archaeocyatha(?).
30.8 - 34.2m (102'8" - 114')	Massive dense grey and buff coloured dolomite with scattered galena mainly along stylolites. Becomes more strongly stylolitic near 34.2m (114').
34.2 - 35.85m (114' - 119'7")	Dark grey to black slump(?) breccia composed of pieces of chert, jasper and dolomite fragments in a matrix of dark dolomite, galena pyrite and quartz. Stylolites are present around some of the blocks.
35.85 - 36.3m (119'7" - 121')	Dense fine grained pale grey stylolitic dolomite
36.3 - 36.5m (121' - 121'5")	Slump breccia as above with pyrite more abundant
36.5 - 37.4m (121'5" - 124'8")	Pale grey oolitic dolomite. Trace of galena along stylolites.
37.4 - 39.3m (124'8" - 131'0")	Massive fine grained mottled grey dolomite. Stylolites are present and from 38.3m (127'6") they become so abundant that the rock has a brecciated appearance. Galena, pyrite and silica occur in the stylolites.
39.3 - 44.4m (131'0" - 148'0")	Fine grained dense laminated dolomite. Some stylolites occur but not as frequent as before. Becomes more stylolitic around 43.5m (145').

44.4 - 48.8m (148' - 162'8")	Fine grained dense laminated dolomite with occasional slump zones. Very sparse galena along stylolites. Slump breccia zones (intraformational breccias) become more common after 47.3m (157'10").
48.8 - 53.4m (162'8"- 178'0")	Fine grained laminated grey dolomite. Galena and pyrite occur scattered along stylolites and coarser splashes in dolomite. Minor slump breccia zones occur towards 53.4m (178'). Stromatolites at 52.2m (174').
53.4 - 54m (178' - 180')	Collapse dolomite breccia. Dolomite blocks are mainly laminated and very porous and cement consists predominantly of galena and pyrite.
54.0 - 55.5m (180' - 185')	Laminated dolomite with strong development of stylolites - has a brecciated appearance in places. Disseminated galena and pyrite along stylolites.
55.5 - 58.7m (185' - 195'8")	Grey fine grained slumped dolomite. Stylolites abundant. Silica vein at 51m (190') bounded by stylolites.
58.7 - 65.6m (195'8" - 218'4")	Massive grey, strongly stylolitic dolomite shows slumping and has a brecciated appearance in places particularly 62.1m (207'). Galena and pyrite occur disseminated along stylolites in cavities and as splashes in the dolomite.
65.6 - 66.1m (218'4" - 220'4')	Laminated dark grey crystalline dolomite with disseminated galena.
66.1 - 67.9m (220'4" - 226'3")	Pseudobreccia as above with scattered galena and pyrite.
67.9 - 68.25m (226'3" - 227'6")	Laminated dark grey crystalline dolomite. Very thin veinlets (1mm) of galena in fractures and coarser patches of galena and pyrite occur in cavities.
68.25- 68.5m (227'6" - 228'4")	Laminated grey stylolitic dolomite.
68.5 - 84.1m (228'4" - 280'3")	Massive grey stylolitic dolomite with galena along stylolites. Dolomite shows slumping? in places and is a pseudobreccia (or collapse breccia) in places. At 76.2m (254') vugh filled with galena, pyrite and quartz crystals.

84.1 - 84.6m (280'3" - 282')	Silica vein. Silica shows colloform banding and has numerous vughs lined with quartz crystals. Patches of coarse grained galena and white dolomite.
84.6 - 85.5m (282'0" - 285'0")	Massive grey stylolitic dolomite.
85.5 - 85.8m (285'0" - 286'0")	Slump breccia with fine grained dark grey blocks in light matrix.
85.8 - 91.8m (286'0" - 306.0")	Massive fine grained grey stylolitic dolomite with disseminated galena.
91.8 - 92.4m (306'0" - 308'9")	Dolomite breccia (slump or collapse type?) Blocks of light grey laminated dolomite. One such block is cut by a vein containing galena and coarse grained white dolomite.
92.4 - 94.4m (308'9" - 314'8")	Oolitic stylolitic dolomite with disseminated galena and slumping.
94.4 - 95.4m (314'8" - 318'0")	Dolomite breccia probably of solution collapse origin. Blocks of laminated, massive and oolitic dolomite. Galena and pyrite occur in cement to blocks. Stylolites occur around the edges of some dolomite blocks. Blocks become very coarse at 95.1m (317') and also very sandy and porous.
95.4 - 101.7m (318'0" - 339'0")	Dolomite breccia (slump or collapse origin?). At 97.1m (323'6") the rock is very similar to 91.8 - 92.6m (306' - 389'). Rock is not as stylolitic as before and also much less mineralisation. The rock is sandy in places and a chert vein occurs between 100.5m and 101.4m (335'9" - 338').
101.7 - 108m (339'0" - 360'0")	Massive sandy light grey dolomite with large amount of galena between 103.8 - 104m (346' - 346'10") in a silica vein? Bedding is evident in places. Slumping occurs at 106.5 - 106.8m (355' - 356'). Oolites occur after 106.8m (356').

108.0 - 111.2m (360'0" - 370'8")	Dolomite breccia of solution collapse origin. The rock is very distinctive around 109.8m (366') and shows good evidence of solution. The dolomite is bleached and brecciated, and the cavities filled mainly by detrital quartz. Galena occurs scattered throughout the rock in the cement and along stylolites. At 110.6m (368'6") a thin silica vein occurs containing galena and pyrite.
111.2 - 114.9m (370'8" - 383'0")	Massive sandy light grey dolomite. The rock is very stylolitic from 101.3 - 111.9m (371'-373') giving the rock a pseudobreccia appearance but the stylolites become much less frequent after this mineralisation occurs along stylolites (eg. 113.1m (377')). Bedding is evident at 114m (380').
114.9 - 116.4m (383'0" - 388'0")	Dolomite showing preconsolidation slumping.
116.4 - 117.9m (388'0" - 393'0")	Fine grained oolitic grey dolomite. Becomes sandy near 117.9m (393'). Slumping in places.
117.9 - 118.8m (393'0" - 396'0")	Dolomite as 114.9 - 116.4m (383 - 388') showing slumping and evidence of solution.
118.8 - 120.0m (396'0" - 400'0")	Massive light grey dolomite with disseminated galena and pyrite mineralisation.
120.0 - 120.6m (400'0" - 402'0")	Oolitic dolomite with galena and pyrite.
120.6 - 123.3m (402'0" - 411'0")	Dense fine grained grey sandy dolomite.
123.3 - 124.9m (411'0" - 416'4")	Very sandy grey dolomite with galena and pyrite scattered along stylolites. Bedding evident.
124.9 - 125.0m (416'4" - 416'8")	Weathered oolitic vughy dolomite.
125.0 - 125.6m (416'8" - 418'8")	Grey vughy dolomite with galena and pyrite in vughs and along stylolites. The abundance of stylolites give the rock a pseudobreccia appearance with pyrite as cement. The rock is weathered and very porous.
125.6 - 127.7m (418'8" - 425'6")	Sandy and oolitic dolomite with scattered galena and pyrite mineralisation.

127.7 - 128.3m (425'6" - 427'6")	Sandy oolitic dolomite. The oolites are coarse grained and very abundant (50%). Pyrite occurs as cement around oolites.
128.3 - 130.2m (427'6" - 434'0")	Grey massive stylolitic dolomite, sandy and oolitic in places with disseminated pyrite and galena along stylolites. Shows slumping at 129.9 - 130.2m (433 - 434').
130.2 - 133.2m (434'0" - 444'0")	Massive pale grey, sandy, well bedded dolomite with scattered galena and pyrite. Stylolites present.
133.2 - 133.8m (444'0" - 446'0")	Laminated grey dolomite with thin shale layers.
133.8 - 135.6m (446'0" - 452'0")	Massive grey, sandy, bedded dolomite with pyrite and galena along stylolites.
135.6 - 135.9m (452'0" - 453'0")	Coarse grained, sandy, oolitic dolomite grit, with pyrite.
135.9 - 149.9m (453'0" - 499'8")	Interbedded shales, dolomitic shales and sandstone.
149.9 - 153.0m (499'8" - 510'0")	Worm Burrow Beds.
153.0 - 155.3m (510'0" - 517'8")	Pound Sandstone.

END OF HOLE.

D.D.H E32/61

0 - 8.4m (0 - 28'2")	Massive mottled (light and dark grey) fine grained stylolitic dolomite with cavities along the length of the core. Stylolites particularly common around 2.1-2.4m (7'-8'). Possible archaeocyatha?. Cavities common at 6.9-7.2m (23'-24') and are lined with quartz from 7.8-8.1m (26'-27'). Oolitic at 8.4m (28').
8.4 - 9.3m (28'2" - 31'0")	Sharp boundary (solution contact) between dark grey oolitic dolomite and underlying mottled light buff dolomite. Dolomite is vughy and often partly filled with coarse grained white dolomite.
9.3 - 10.8m (31'0" - 36'0")	Dark grey very stylolitic dolomite.
10.8 - 14.0m (36'0" - 46'6")	Massive fine grained grey stylolitic dolomite.
14.0 - 18.7m (46'6" - 62'3")	Massive fine grained dark grey stylolitic dolomite. Cavities 15.9m (53') and laminations14.4m (48') and in places the rock shows a pseudobreccia appearance due to solution activity(?) e.g. 15m (50'). The rock becomes mottled at 17.7m (59').
18.7 - 19.2m (62'3" - 64'0")	Dark grey crystalline dolomite with many cavities.
19.2 - 22.3m (64'0" - 74'3")	Massive buff mottled dolomite with a slight purple tint.
22.3 - 22.7m (74'3" - 75'9")	Very distinct reddish coloured massive dolomite.
22.7 - 24.3m (75'9" - 81'0")	Mottled grey stylolitic dolomite, vughy in places.
24.3 - 24.8m (81'0" - 82'6")	Buff grey dolomite with bedding evident.
24.8 - 25.5m (82'6" - 85'0")	Dolomite breccia consisting of buff and dark grey blocks in a light matrix.
25.5 - 25.7m (85'0" - 85'6")	Dark grey dolomite.

25.7 - 26.0m (85'6" - 86'6")	Dolomite breccia consisting of a large proportion of silica fragments. A probable slump type breccia. Vugh filled with galena.
26.0 - 26.2m (86'6" - 87'3")	Massive buff dolomite.
26.2 - 26.4m (87'3" - 88'0")	Dolomite slump breccia as above. Stylolitic.
26.4 - 30.3m (88'0" - 101'0")	Massive fine grained buff dolomite. The rock is well fractured with white coarser grained dolomite often occurring along fractures.
30.3 - 32.1m (101'0" - 107'0")	Pale buff laminated dolomite, well fractured in places.
32.1 - 32.4m (107'0" - 108'0")	Very distinctive dolomite breccia consisting of pale buff dolomite blocks in a black matrix. Probably a solution collapse type breccia.
32.4 - 38.9m (108'0" - 129'6")	Pale buff laminated dolomite as before. Slumping is evident forming intraformational breccias about 2-4cm thick.
38.9 - 40.5m (129'6" - 135'0")	Slump dolomite breccia in laminated dolomite. Blocks of massive dolomite also occur.
40.5 - 40.8m (135'0" - 136'0")	Buff laminated dolomite as above.
40.8 - 43.4m (136'0" - 144'6")	Slump type? dolomite breccia as above. Very stylolitic and vughy around 42.6m (142').
43.4 - 46.5m (144'6" - 155'0")	Buff laminated dolomite as before.
46.5 - 48.1m (155'0" - 160'4")	Slump type dolomite breccia in laminated dolomite. Contains large fragments of laminated dolomite as at 47.1m (157'). Galena occurs at 47.4m (156'). Chert vein at 47.9m (159'6"). At 47.7m (157') the same black cement as at 32.1m (107') occurs.
48.1 - 49.0m (160'4" - 163'3")	Buff laminated dolomite. At 48.2m (160'6") a 2cm thick clastic dyke (of dolomite breccia as before) cuts across the laminated dolomite. This is clearly a solution phenomenon and is probably an extension of the breccia above. Hence the earlier breccias may simply be due to solution.

49.0 - 54.6m (163'3" - 182'0")	Slump type dolomite breccia in laminated dolomite as above. This breccia is very well cemented (as are the earlier ones). Coarse grained galena occurs in splashes between 51.2m (170'6") and 51.7m (172'). The rock is very siliceous around 52.3m (174') and a pink silica vein occurs between 52.7m (175'6") and 52.8m (176'). Very porous and stylolitic at 53.7m (179') with galena.
54.6 55.5m (182'0" - 185'0")	Buff laminated dolomite.
55.5 - 56.7m (185'0" - 189'0")	Buff slump(?) type dolomite breccia.
56.7 - 58.0m (189'0" - 193'3")	Grey buff laminated dolomite with considerable galena along stylolites at 58m (193'3").
58.0 - 59.0m (193'3" - 196'6")	Grey and buff massive dolomite.
59.0 - 59.1m (196'6" - 197'0")	Buff dolomite breccia.
59.1 - 62.3m (197'0" - 207'6")	Massive grey stylolitic dolomite. In places the dolomite has a brecciated appearance.
62.3 - 63.0m (207'6" - 210'0")	As above but the rock is more weathered and there is a marked increase in stylolites and galena. Near 63m (210') the rock becomes quite sandy.
63.0 - 68.1m (210'0" - 227'0")	Grey fine grained massive stylolitic dolomite with galena disseminated through the core and along fractures. Very stylolitic and siliceous around 66.9-67.5m (223'-225').
68.1 - 68.3m (227'0" - 227'9")	Buff laminated dolomite.
68.3 - 73.7m (227'9" - 245'6")	Massive fine grained buff-grey stylolitic dolomite with scattered galena along stylolites. Pyrite occurs at 69.9m (233'). The rock becomes very oolitic at 72.6m (242').
73.7 - 77.0m (245'6" - 256'8")	Slump type(?) dolomite breccia with large blocks of light grey dolomite and smaller blocks of darker grey dolomite. Towards 75m (250') the rock becomes vughy with more galena and pyrite (could be more of a solution type breccia).

77.0 - 78.0m (256'8" - 260'0")	Dolomite breccia with blocks of mainly light grey dolomite in a pyrite rich cement. No galena obvious.
78.0 - 80.3m (260'0" - 267'6")	Massive grey stylolitic dolomite with scattered galena.
80.3 - 80.5m (267'6" - 268'2")	Dolomite breccia.
80.5 - 81.5m (268'2" - 271'6")	Massive grey stylolitic dolomite as before. The rock is oolitic at 81.3m (271').
81.5 - 82.5m (271'6" - 275'0")	Stylolitic slump type breccia.
82.5 - 84.6m (275'0" - 282'0")	Buff grey stylolitic silty(?) dolomite (pseudobreccia?). The rock is porous and strongly mineralised.
84.6 - 91.1m (282'0" - 303'6")	Buff grey stylolitic dolomite breccia of probable solution activity, particularly after 86.5m (288'). The rock then consists of blocks of light-dark grey massive dolomite of very variable size in a matrix of finer dolomite and silica. The silica forms pods (up to 2cm in diameter) and veins (up to 4cm wide) and contains abundant galena in it.
91.1 - 98.1m (303'0" - 327'0")	Massive light grey crystalline dolomite, sandy in places and containing minor stylolites.
98.1 - 99.3m (327'0" - 331'0")	Buff sandy and oolitic dolomite breccia with large amount of pyrite.
99.3 - 100.8m (331'0" - 336'0")	Massive stylolitic dolomite.
100.8 - 101.5m (336'0" - 338'3")	Pale grey dolomite breccia which is very strongly mineralised. The rock consists of blocks of pale dolomite in a matrix of mainly galena, pyrite and silica. Most likely due to solution activity.
101.5 - 102.5m (338'3" - 341'8")	Buff-grey stylolitic dolomite rich in galena lined with quartz and galena at 102m (340').
102.5 - 102.8m (341'8" - 342'9")	Very oolitic buff grey dolomite.

102.8 - 111.1m (342'9" - 370'3")	Grey dolomite, sandy and oolitic in places with no apparent stylolites or mineralisation. Around 106.8m (356') the dolomite is mottled light and dark grey and galena occurs along stylolites. The rock is very oolitic around 109.3m (364'3") and 109.6-109.8m (365'4"-365'10").
111.1 - 118.4m (370'3" - 394'6")	Buff-grey sandy dolomite. Oolitic with pyrite at 112.4m (374'9").
118.4 - 121.5m (394'6" - 405'0")	Very oolitic grey dolomite. Bedding evident at 120.3m (401').
121.5 - 125.7m (405'0" - 419'0")	Light-grey sandy dolomite, oolitic in places with bedding evident.
125.7 - 134.8m (419'0" - 449'3")	Off white-grey dolomitic siltstones with fine laminations of darker shale.
134.8 - 137.7m (449'3" - 459'0")	WORM BURROW BEDS - Greeny-grey mottled sandstone.
137.7 - 138.8m (459'0" - 462'9")	Pound Sandstone.

END OF HOLE.

TABLE 2.1

DISTRIBUTION OF GEOLOGICAL FEATURES AND ENVIRONMENTAL INTERPRETATION - CARBONATE EVIRONMENTS.

(Based on criteria of LaPorte, 1969, and Thomson & Thomasson, 1969)

	Tidal flat-lagoon. Poor circulation. Highly variable environment.	High and low energy sub-tidal. Good circulation. Stable except for variable water agitation.	Open shallow shelf. Highly stable environment with good circulation. Low terrigenous influx.	Open shallow shelf. Low energy variations caused by periodic terrigenous influx.
LITHOLOGIES	Pellets & Intraclasts Early Dolomite	Sparite		Terrigenous Mud
STRUCTURES	Erosional Surfaces Irregular Laminations Vertical Burrows	Cross-Stratification Oolites		
PALAEONTOLOGY	Algal Structures			
ENVIRONMENTS IMPLIED FOR UNITS AT EDIACARA	Worm Burrow Beds Laminated Dolomite Massive Dolomite	Sandy Dolomite	Transition Shales	

TABLE 3.1a

SUMMARY OF DIAMOND DRILL HOLE DATA - EDIACARA MINERAL FIELD

Hole No.	Most Significant Intersections Interval (metres)	Pb %	Cu ppm.	Zn ppm.	Ag ppm.	Summary of lead assay data for other intersections (in metres)
IP1	-	-	-	-	-	75.8 - 76.0 av 0.0156%
IP2	225.0 - 243	0.085	475	150	2.5	-
1-12	-	-	-	-	-	-
2-11	-	-	-	-	-	-
3-6	34.8 - 42	0.025	0.2%	200	1	-
E1	-	-	-	-	-	No Assays
E2	31.5 - 32.4	0.97	200	100	11	0 - 54.0 av 0.105%
E3	1.8 - 3.6	1.43	12.4%	0.28%	205	1.8 - 91.7 av 0.062%
E4	-	-	-	-	-	0 - 59.0 av 0.0035%
E5	34.5 - 42.3	0.91	100	50	110	-
	52.8 - 57	1.02	700	100	28	-
E6	0 - 39	1.56	100	100	20	7 - 11.5 av 7.72%
E7	57.0 - 87	1.32	0.18%	600	4	40.5 - 90.0 av 0.88%
E8	-	-	-	-	-	0 - 53.4 av 0.007%
E9	-	-	-	-	-	0 - 74.6 av 0.06%
E10	56.1 - 74.1	0.97	0.15%	800	17	-
E11	-	-	-	-	-	0 - 70.2 av 0.018%
E12	-	-	-	-	-	0 - 93.6 av 0.0079%
E13	15.6 - 30	0.83	50	100	6	22.8 - 24.0 av 2.63%
E14	6.0 - 34.5	1.92	40	70	24	-
E15	24.0 - 54	1.04	n.d.	n.d.	n.d.	-
E17	30.0 - 33	1.07	n.d.	n.d.	n.d.	-
	48.0 - 51	1.03	n.d.	n.d.	n.d.	-
E18	4.5 - 9	0.98	1.81%	n.d.	n.d.	-
E19	6.3 - 10.2	0.20	2.78%	n.d.	n.d.	0 - 15.6 av 0.084%
E20	6.0 - 6.6	0.94	0.58%	0.37%	n.d.	0 - 16.0 av 0.50%
E21	-	-	-	-	-	0 - 115.5 av 0.09%
E22	-	-	-	-	-	0 - 59.7 av 0.11%
E23	0 - 21	0.88	100	200	10	-
E24	-	-	-	-	-	0 - 285.6 av 0.097%
E31	-	-	-	-	-	0 - 106.0 av 0.14%
E32	81.0 - 103.5	0.91	300	700	50	97.5 - 103.6 av 2.2%
E33A	93.0 - 114	1.03	40	50	14	0 - 155.3 av 0.27%
E34	135.0 - 153	0.91	50	200	6	171 - 174.0 av 1.95%
	168.0 - 177	1.07	300	90	24	-
E35	9.0 - 24	1.23	70	300	3	0 - 106.0 av 0.25%
E39	153.6 - 162.6	0.83	400	700	20	0 - 207.6 av 0.17%
E40	-	-	-	-	-	-
E41	207.0 - 228	0.72	n.d.	n.d.	4	208.7 - 210.0 av 1.05%
E42-45	-	-	-	-	-	No Assays
E46	109.5 - 111	0.35	n.d.	n.d.	99	0 - 136.8 av 0.02%
E47	42.0 - 44.7	n.d.	0.38%	n.d.	n.d.	-
E48-50	-	-	-	-	-	No Assays

n.d. = not determined

Analysis by Australian Mineral Development Laboratories

TABLE 3.1b

SUMMARY OF GEOLOGICAL LOGS - EDIACARA MINERAL FIELD

(Depths in metres)

HOLE NO.	MASSIVE DOLOMITE	LAMINATED DOLOMITE	SANDY DOLOMITE	TRANSITION SHALES	WORM BURROW BEDS	POUND QUARTZITE	TOTAL DEPTH
IP1						0 -185.7	185.7
IP2	0-174?	174? -225.0	-	225.0-248.4	248.4-250.2	250.2-256.0	256.0
1-12	0- ?	? -119.0	-	119.0-127.5	127.5-130.5	130.5-142.6	142.6
2-11	0- ?	? - 92.8					92.8
3-6	0- 34.8	-	-	34.8- 40.0			40.0
E1	Cainozoic sediments only						
E2	0- 52.5?						
E3		0 - 4.5?	4.5- 35.4	35.4- 53.5	53.5- 57.0	57.0- 91.6	91.6
E4		0 - 10.5?	10.5- 45.6	45.6- 59.5	59.5- 63.0	63.0- 78.7	78.7
E5			0 - 68.4	68.4- 92.5	92.5- 95.5	95.5-100.2	100.2
E6	0- 6.0	-	6.0- 46.2	46.2- 57.4	57.4- 59.8	59.8- 64.9	64.9
E7	0- ?	? - 43.0	-	43.0- 94.0	-		94.0
E8	0- ?	? - 27.3	-	27.3- 40.0	40.0- 43.0	43.0- 54.4	54.5
E9		0 - 5.1	-	5.1- 50.0	50.0- 52.0	52.0- 74.8	74.8
E10	0- ?	? - 56.2	-	56.2- 74.2			74.2
E11	0- 70.3						70.3
E12	0- 92.8	-	-	92.8- 93.6			93.6
E13	0- 7.5	-	7.5- 40.9	40.9- 50.0			50.0
E14			0 - 47.1				47.1
E15		0 - 17.1?	17.1- 67.5				67.5
E17		0 - 21.0?	21.0- 66.3				66.3
E18	?						
E19	?						
E20	?						
E21	0-155.8?						155.8
E22		0 - 7.5?	7.5- 40.8	40.8- 57.3	57.3- 60.0		60.0
E23			0 - 40.5	40.5- 58.2	58.2- 60.3	60.3- 75.3	75.3
E24	0-179.1	179.1-255.3	-	255.3-280.0	280.0-283.8	283.8-285.6	285.6
E31	0- 17.1	17.1- 43.8	43.8-103.8	103.8-106.2			106.2
E32	0- 33.6	33.6- 90.3	90.3-123.6	123.6-134.7	134.7-137.7	137.7-138.9	138.9
E33A	0- 39.3	39.3- 96.0	96.0-136.0	136.0-150.0	150.0-153.0	153.0-155.4	155.4
E34	0- 48.0	48.0-154.8	154.8-187.8	187.8-203.4	203.4-206.4	206.4-207.0	207.0
E35		?0 - 50.1	50.1- 81.0	81.0- 92.4	92.4- 94.2	94.2- 97.9	97.9
E39	0- 91.5	91.5-160.0	160.0-183.0	183.0-200.7	200.7-203.7	203.7-207.3	207.3
E40	0- 27.3	27.3-112.5	112.5-135.0	135.0-145.8			145.8
E41-44	?						
E45	0- 55.0	55.0-123.4	-	123.4-151.4	151.4-154.2	154.2-170.0	170.0
E46	0- 26.1	26.1- 93.6	-	93.6-130.2	130.2-132.0	132.0-136.8	136.8
E47	0- 33.9	33.9- 72.3	-	72.3-102.0	102.0-105.0	105.0-111.6	111.6
E48-50	?						

TABLE 5.1

NOMENCLATURE AND ROCK UNIT CORRELATION OF LOWER CAMBRIAN SEDIMENTS IN THE ADELAIDE GEOSYNCLINE

(Correlation after Daily et al., 1976)

SELLICK HILL AREA (Abele & McGowran, 1959, Daily et al., 1976)		EDIACARA (Nixon, 1962)	FLINDERS RANGES (Daily, 1956) (Dalgarno, 1964)		
					Billy Creek Formation
Carrickalinga Head Formation					
NORMANVILLE GROUP	Heatherdale Shale		HAWKER GROUP		Oraparinna Shale
	Fork Tree Limestone				Bunkers Sandstone
	Sellick Hill Formation	Top Not Exposed		Wilka-Willina	Parara Limestone
	Disconformity	Disconformity??		Disconformity	Disconformity
	Wangkonda Formation	Ajax Limestone		Limestone	Wirrapowie Limestone
					Woodendinna Limestone
	Mt. Terrible Formation	Parachilna Formation		Parachilna Formation	

TABLE 7.1

FLUID INCLUSION DATA - EDIACARA

Sample No.	Mineral	Type of Inclusion P = Primary S = Secondary	Homogenisation Behavior		Freezing Data	
			No. of Determinations	$T^{o}C.$	$T^{o}C.$	Salinity wt% NaCl
32/289	Silica	PII	5	193-199	-23.2	24
32/289	Silica	PI			- 1.1	3
32/337	Silica	PII	6	181-193	-24.4	24.5
32/337	Silica	PI			- 2.1	5
33A/368.5	Silica	PII	2	182-188	-25.4	25
33A/368.5	Silica	PI			- 2.4	5
33A/377	Silica	PII	4	175-190	-24.9	25
33A/377	Silica	PI			- 1.6	4
10/174	Silica	PII	3	187-189	-28.7	27
10/174	Silica	PI			- 3.1	6
32/281	Dolomite	S	2	187-196	-24.6	25
33A/179	Dolomite	P	3	159-162	-26.9	26

TABLE 7.3

FLUID INCLUSION DATA - SELLICK HILL AREA

Sample No.	Mineral	Type of Inclusion P = Primary S = Secondary	Homogenisation Behavior		Freezing Data	
			No. of Determinations	T°C	T°C.	wt% NaCl
B1	Sphalerite	P	2	135	-19.6	22.5
	Quartz	P?	4	135-139	-23.0	24.0
B2	Sphalerite	P	5	118-133	-22.7	24.0
	Calcite	S?	4	133-137	-21.8	23.5
$B3_1$	Sphalerite	P	2	126	-22.0	23.5
P1	Calcite	S?	4	134-143	-24.6	25.0
$P2_1$	Calcite	S?	3	137	-20.9	23.0
S	Sphalerite	P	3	126-135	-20.4	23.0

B = Barritts Mine   P = Pipeline Prospect   S = Sellick Hill Prospect

TABLE 8.1

$\delta^{34}S$ VALUES - EDIACARA

SAMPLE	$\delta^{34}S$‰		DESCRIPTION
	PYRITE	GALENA	
			HOLE E33A
33A/3		+8.23	Coarse splashes of galena in massive fine grained stylolitic dolomite.
33A/179	-11.46	-7.38	Pyrite and galena occur as matrix with minor white dolomite in solution collapse breccia.
33A/226.5	+1.3	-0.49	Coarse grained euhedral pyrite & galena occur as veinlets & vugh fillings, in laminated grey crystalline dolomite.
33A/237		-2.0	Galena & pyrite occur as fine grained concentration along stylolites. Sampled from coarse grained galena.
33A/253		-3.15	Galena occurs as fine grained disseminations through stylolitic dolomite and concentrated along stylolites. Very similar to 33A/237.
33A/282		+5.42	Galena occurs as disseminations in a silica vein. Textural evidence suggests repeated episodical precipitation of galena & silica.
33A/304		+1.45	Fine grained massive stylolitic dolomite with much disseminated galena. Some galena is also concentrated along stylolites.
33A/318	-3.78	-1.82	Galena & pyrite occur disseminated through the matrix of a dolomite breccia and along stylolites.
33A/346		-2.17	Relatively large percentage of galena disseminated through a silica vein.
33A/366.5		-3.5	Very fine grained sulphide (mainly galena?) disseminated through sandy dolomite which has been modified by solution activity.
33A/372		-2.24	Sandy stylolitic dolomite containing fine grained disseminated galena and concentrations along stylolites.
33A/383.5	+6.16		Coarse grained galena and white dolomite occur as cavity & fracture fillings in massive dolomite.
33A/426	+8.59		Pyrite as cement to oolites in coarse oolitic dolomite.

TABLE 8.1 (Cont.)

SAMPLE	$\delta^{34}S$‰ PYRITE	GALENA	DESCRIPTION
			HOLE E32
32/86		+5.87	Coarse grained galena occurs in dolomite breccia.
32/201		-0.09	Splashes of galena in massive stylolitic dolomite.
32/241		+0.78	As above.
32/257	-1.27		Dolomite breccia consisting of blocks of light grey dolomite in a pyrite rich cement.
32/260	-2.20		As above.
32/282		+0.11	Coarse grained galena & white dolomite occur in a cavity or fracture filling (probably associated with stylolites). The dolomite is quite rich in galena which seems to be concentrated along or near stylolites.
32/292		+3.36	Dolomite breccia (solution origin), the cement consisting predominantly of silica with galena disseminated through it.
32/327	+6.21	+3.83	Galena and pyrite occur closely associated as concentrations along stylolites. Some very fine sulphide also is disseminated through the sandy dolomite.
32/337	-1.83	+3.62 +5.66 sp. +7.00 cpy.	Colloform pyrite, galena, chalcopyrite sphalerite & silica occur as cement to dolomite blocks in a dolomite breccia.
32/356		+2.41	Sandy dolomite containing coarse grained patches of galena along stylolites. Very fine grained sulphides also occur through the dolomite.
			OTHER HOLES
5/151		+1.49	Finely disseminated galena in sandy dolomite.
6/74.5		-1.73	Disseminated galena in massive stylolitic dolomite.
14/68		-0.52	Splashes of galena in massive dolomite.
14/110		-2.48	Galena occurs in vughs in massive dolomite.
17/102		-7.40	Galena occurs concentrated along stylolites & as splashes in stylolitic dolomite breccia.

TABLE 8.1 (Cont.)

SAMPLE	δ^{34}S ‰		DESCRIPTION
	PYRITE	GALENA	
			OTHER HOLES (CONT.)
17/173.5		-2.07	Splashes of galena in massive stylolitic dolomite.
17/169		-0.19	Galena concentrated along stylolites.
41/692	-12.53		Dolomite breccia with pyrite a major component of the cement.
41/738	-11.4		As above.
SG		+1.13	Minor galena in oxidized ore from Greenwood's Workings.

TABLE 8.2

$\delta^{34}S$ VALUES - WIRREALPA & WESTERN FLINDERS RANGES

SAMPLE	$\delta^{34}S$ ‰ PYRITE	$\delta^{34}S$ ‰ GALENA	DESCRIPTION
			WIRREALPA MINE
W1		+7.43	Coarse grained galena, partly oxidized, in fractured limestone.
W2		+8.19	Galena occurs as irregular splashes in massive stylolitic crystalline limestone.
W3		+7.25	Massive coarse grained galena rimmed by barite.
			WESTERN FLINDERS RANGES
G68/4		+6.33	Galena occurs as fine to coarse disseminated blebs in a porous dolomite.
G68/12		+4.06	Coarse grained galena irregularly distributed through silica.
G68/14		-5.88	Irregular coarse grained splashes of galena in silica

TABLE 8.3

δ^{34}S VALUES - SELLICK HILL AREA

SAMPLE	δ^{34}S‰		DESCRIPTION
	GALENA	SPHALERITE	
			BARRITTS MINE
B1	+12.15		Coarse grained galena & euhedral quartz as cement to porous limestone blocks in breccia
B2		+15.77	Coarse grained sphalerite calcite & quartz making the matrix of a breccia.
B3	+12.74	+15.7	Closely associated & intergrown galena & sphalerite, calcite & quartz as cement in breccia.
B2_1	+11.23	+14.71	As above - Sphalerite & galena coexisting
	+12.05	+11.6	Non coexisting sphalerite and galena
B3_1	+12.34	+15.50	Galena occurs as cavity fillings in blocks & sphalerite in cement of breccia.
B4	+11.46	+13.59	Finely intergrown galena & sphalerite in cement of breccia.
B5	+11.91		Coarse grained galena in cement in breccia.
B6	+12.04		Patches of coarse grained galena occur in thin quartz-calcite veinlets in archaeocyatha limestone.
B7	+12.24		
			PIPELINE PROSPECT
P1	+11.0		Breccia containing various limestone blocks in a matrix of coarse grained galena and calcite.
P2_1	+11.1		
			SELLICK HILL PROSPECT
S1	+18.1	+23.8	Recrystallized archaeocyatha limestone with splashes of coarse grained galena & sphalerite.

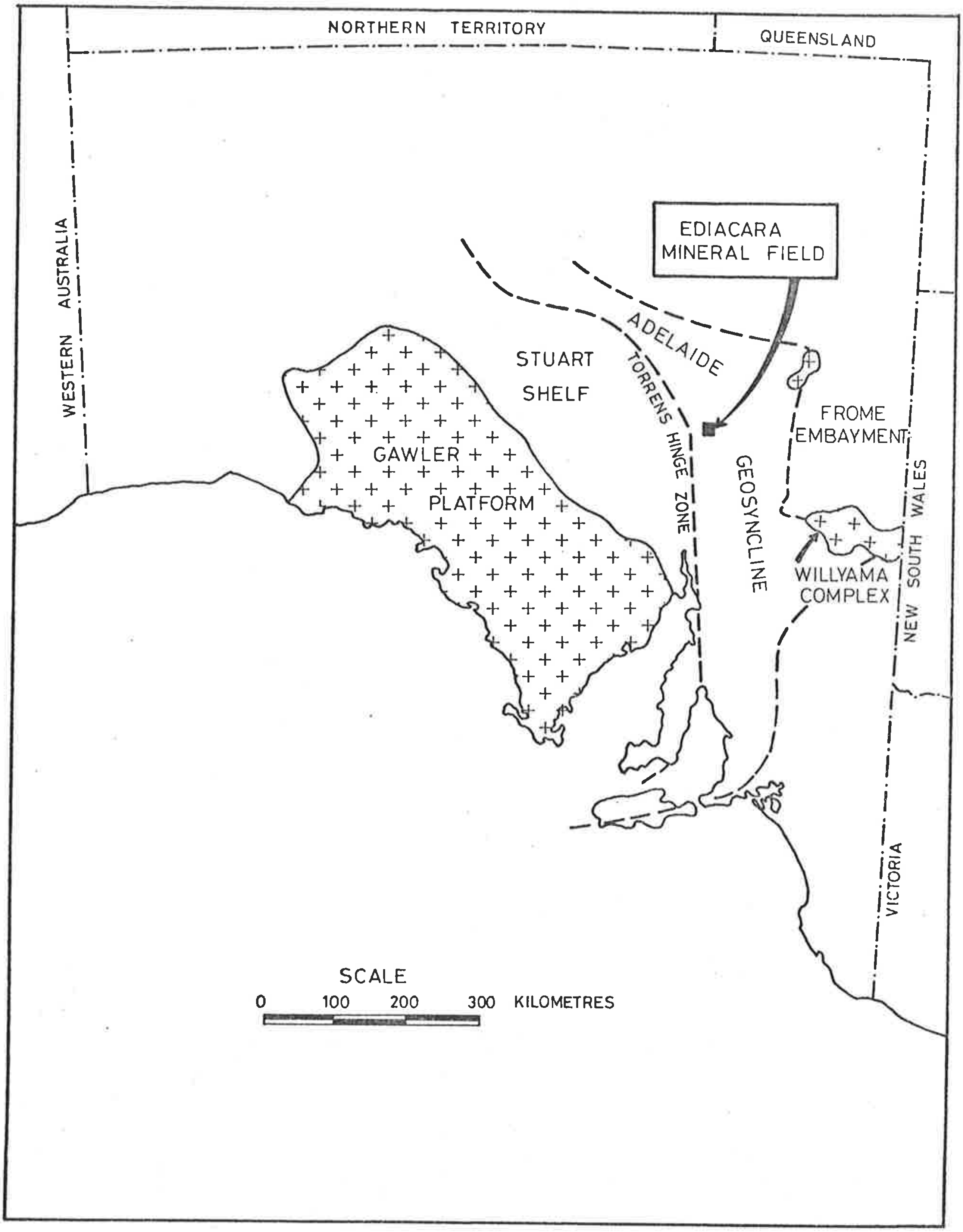


FIGURE 1.1 LOCATION OF EDIACARA MINERAL FIELD AND REGIONAL SETTING (After Thomson, 1969)

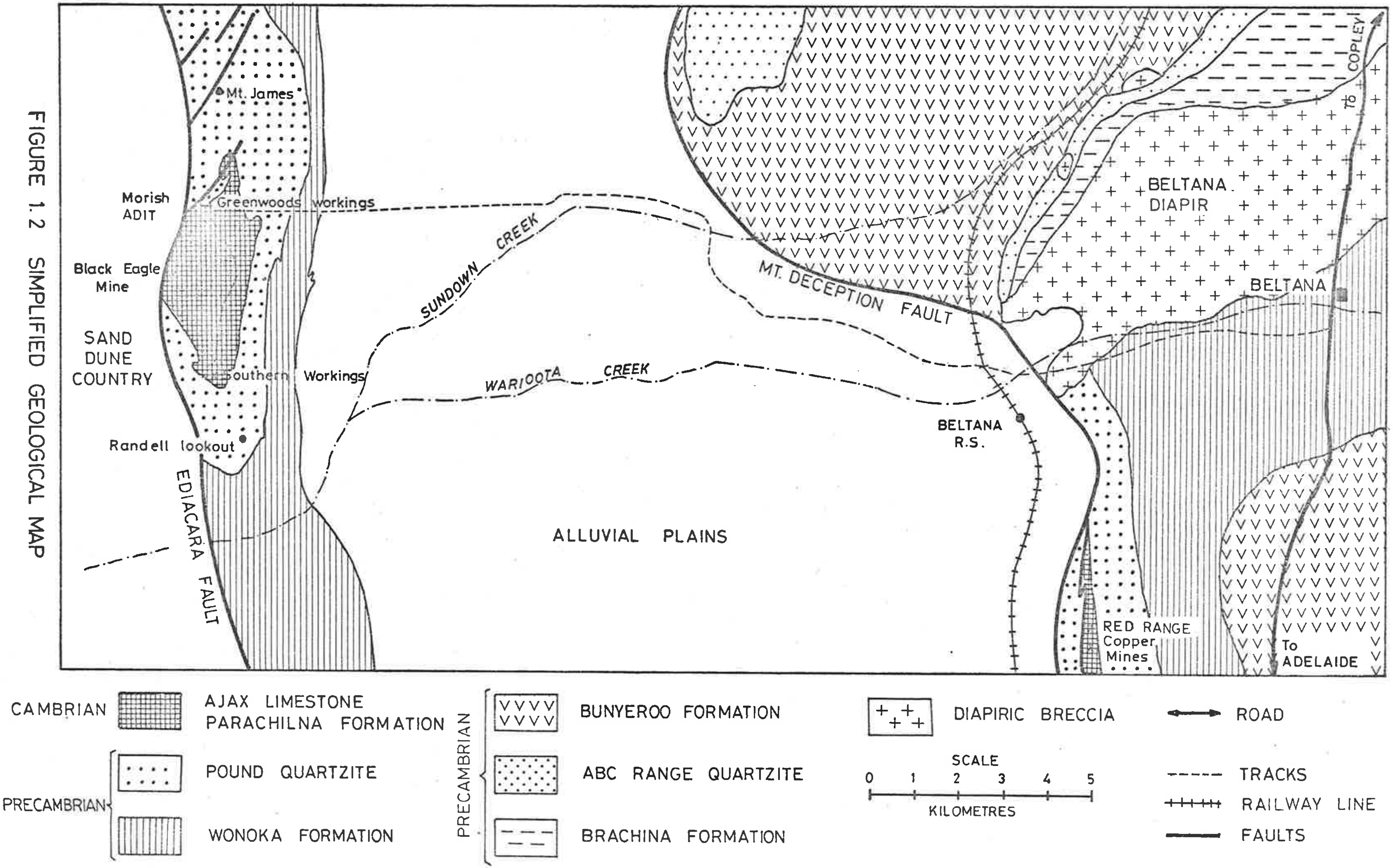
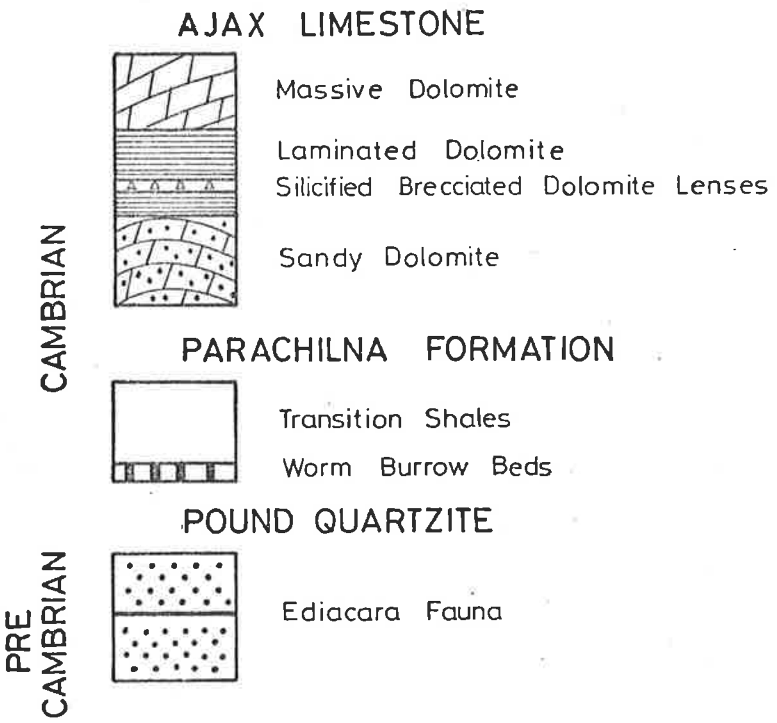


FIGURE 1.2 SIMPLIFIED GEOLOGICAL MAP

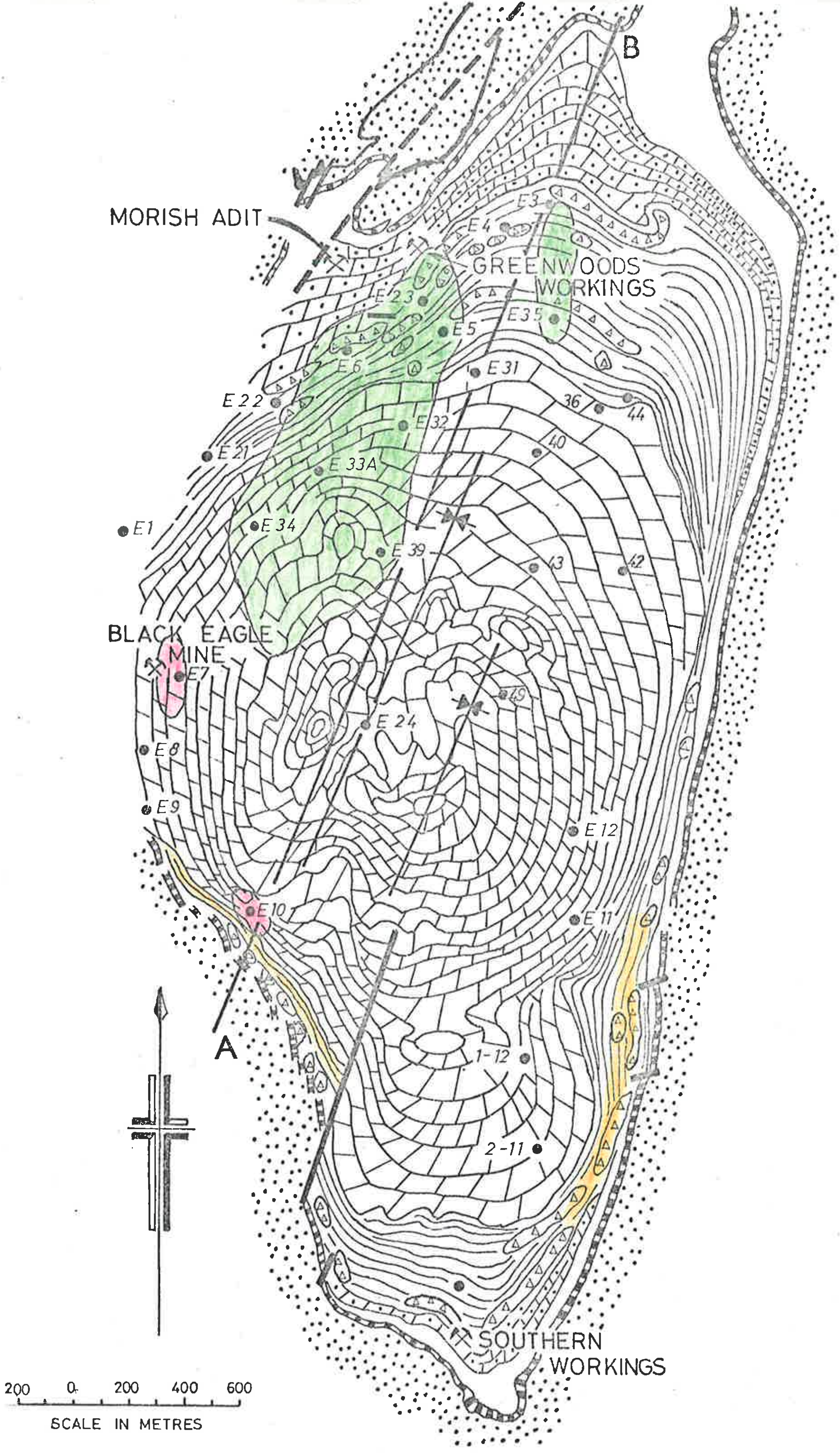
FIGURE 1.3

GEOLOGY OF THE EDIACARA MINERAL FIELD
(Compiled from Nixon, 1962, and Johns, 1972)

LEGEND



Syncline	✕
Fault	—
Diamond Drill Holes	● 48
Areas of Manganiferous - iron Gossan	🟨
Extent of Mineralisation in Ajax Limestone (Laminated Dolomite and Sandy Dolomite) + 0.5% Pb	🟩
Extend of Mineralisation in Parachilna Formation (from drill holes)	🟥



GEOLOGY OF THE EDIACARA MINERAL FIELD
(Compiled from Nixon, 1962 and Johns, 1972)

FIGURE 2.1

a. Finely crystalline sandy (intraclastic) dolomite showing stratification. Horizontal stylolite in centre of specimen.

33A/352 Sandy Dolomite

b. Medium crystalline sandy intraclastic dolomite showing horizontal stylolites. A stylolite marks the contact with massive finely crystalline dolomite.

33A/383.5 Sandy Dolomite

c. Laminated dolomite breccia.

33A/307 Laminated Dolomite

d. Contact between solution collapse breccia and finely crystalline (intraclastic?) dolomite.

33A/179 Laminated Dolomite

FIGURE 2.1

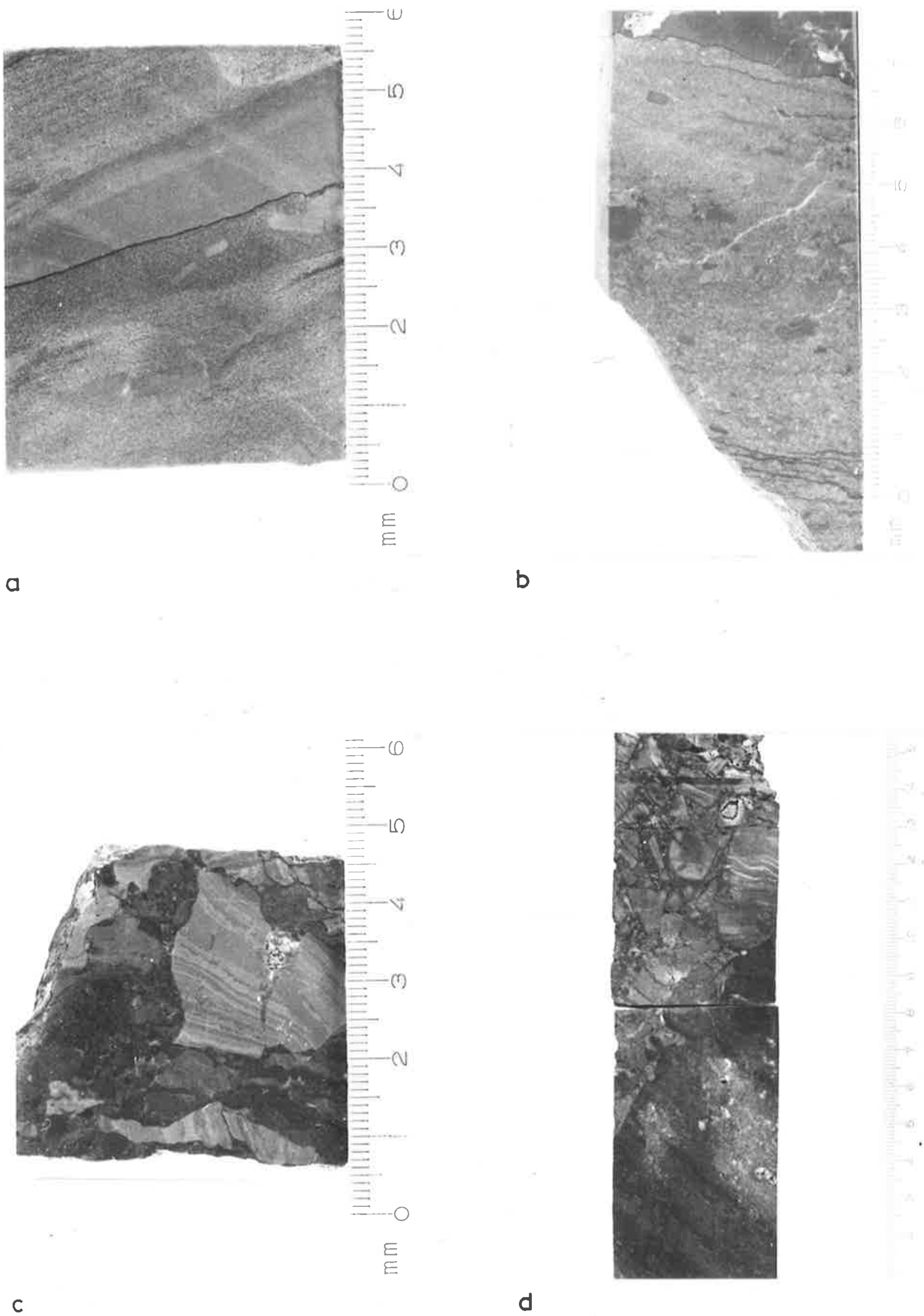


FIGURE 2.2

a. Dolomite breccia of probable sedimentary origin.

33A/285 Laminated Dolomite

b. Dolomite breccia of probable sedimentary origin, showing effects of solution activity (producing a stylobreccia).

33A/207 Laminated Dolomite

c. Solution collapse breccia.

32/107 Massive Dolomite

d. Solution breccia filling fracture in laminated dolomite.

32/160.5 Laminated Dolomite

FIGURE 2.2

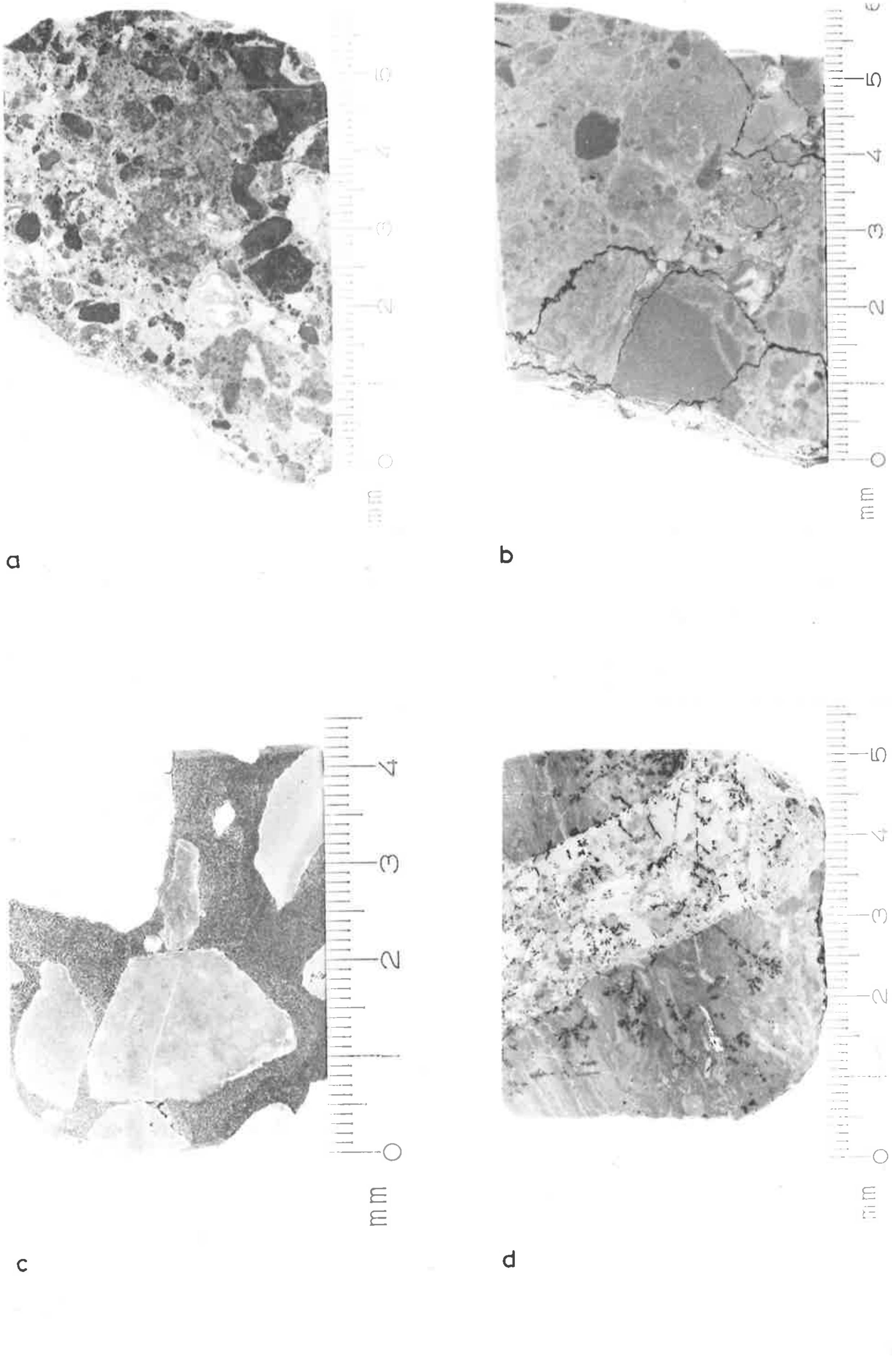


FIGURE 2.3

a. Chert vein in Laminated Dolomite.

33A/159

b,c,d. Examples of breccias in Massive Dolomite.

b.	33A/116	
c.	33A/121	Possible slumping is present
d.	32/86	Slumping is evident

FIGURE 2.3

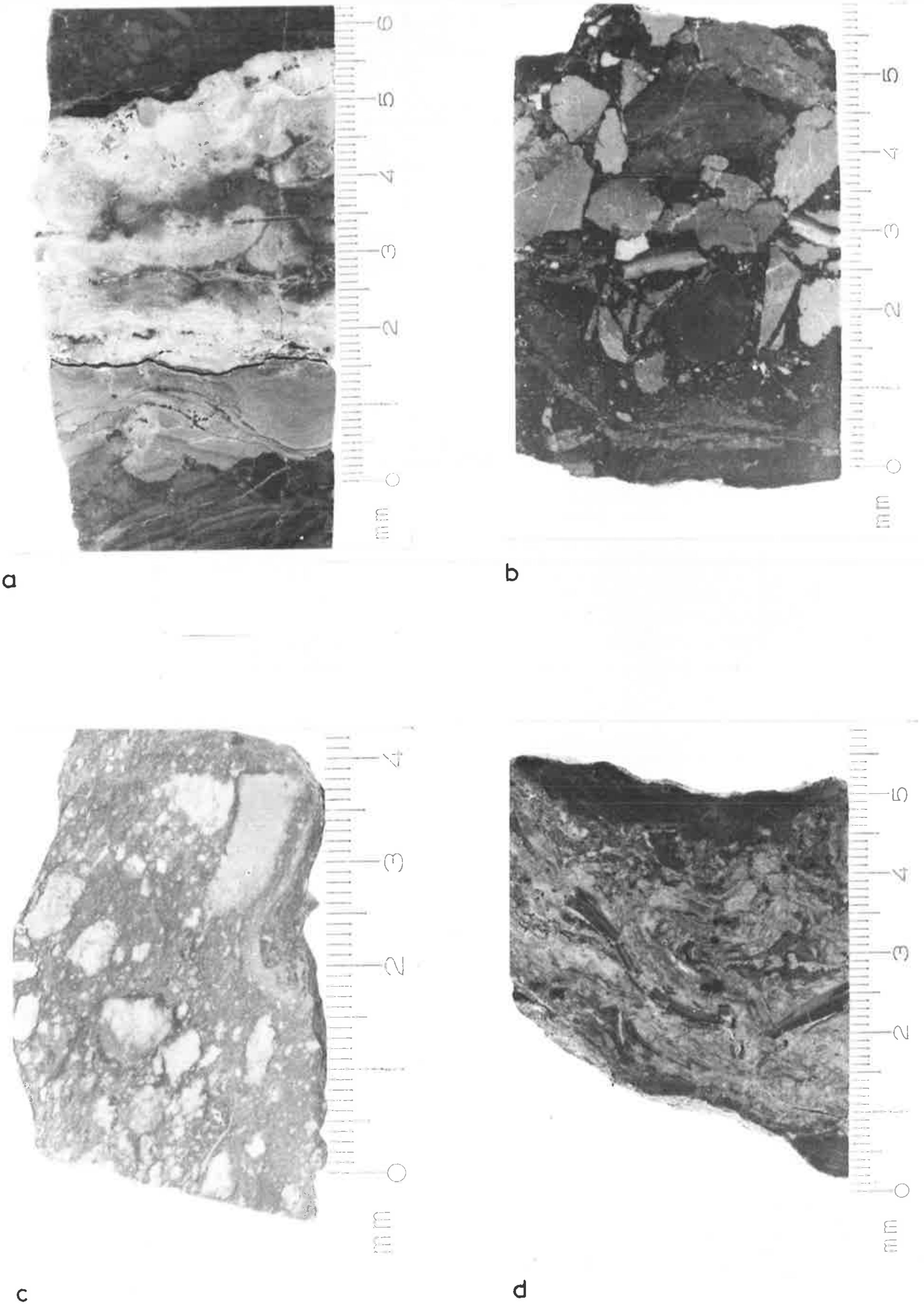


FIGURE 2.4

a. Finely crystalline, laminated dolomite.

33A/141 Laminated Dolomite

b. Light coloured, finely crystalline, intraclastic dolomite and dark coloured, finely crystalline dolomite, containing oolitic zones. A stylolite marks the contact between these two lithologies which are indicative of a subtidal environment.

32/28 Massive Dolomite

c. Dolomite breccia containing abundant spheroidal pyrite in the cement. The pyrite is coated in places by chalcedony.

32/260 Transmitted Light

d. Oolites showing fine, concentric growth structure. Very fine grained opaques conform, in places, to this concentric growth structure. Hence these opaques are syngenetic.

33A/ 426 Transmitted Light

FIGURE 2.4

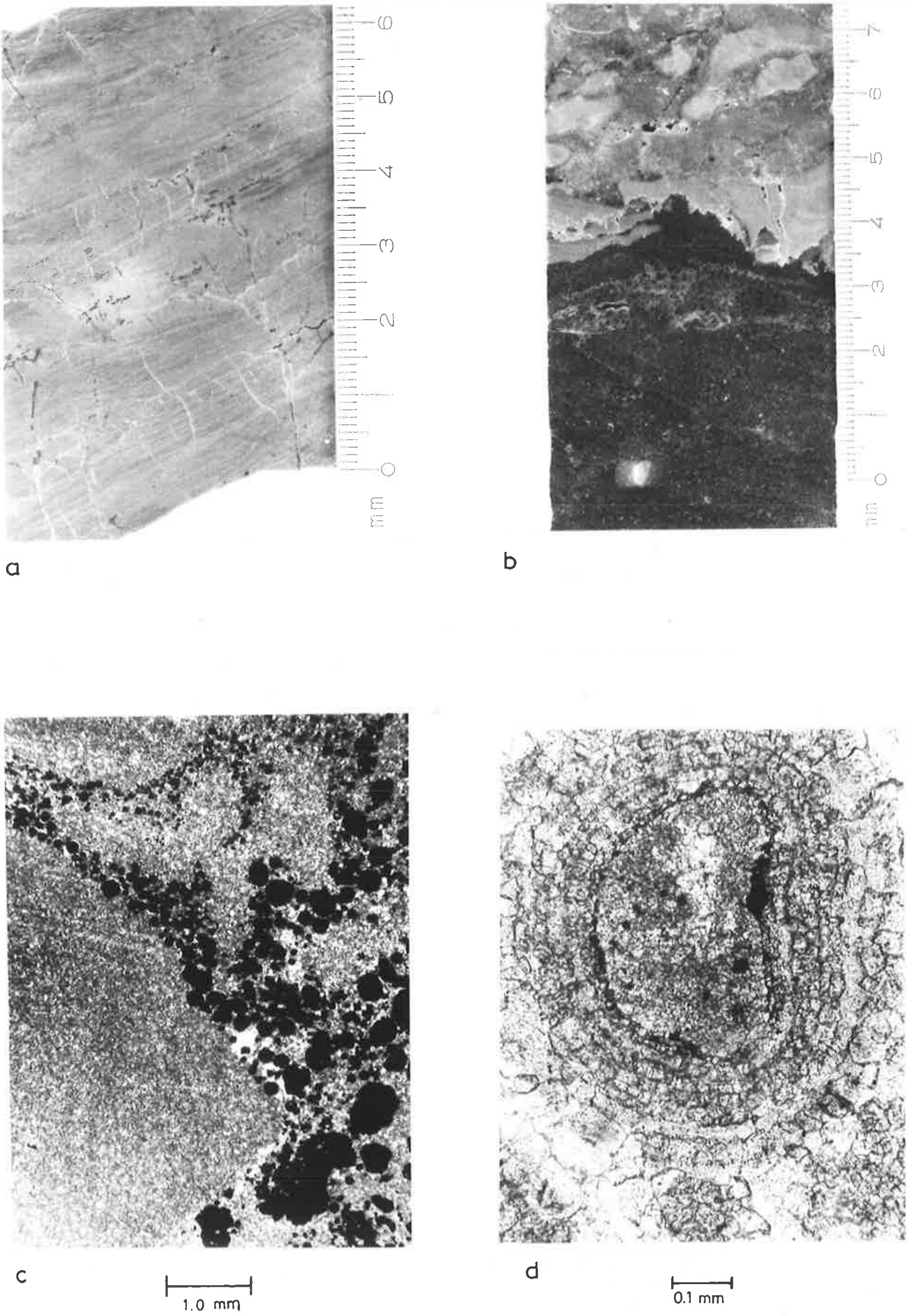


FIGURE 2.5

Small Divisions on scale represent mm.

a. Solution affected dolomite, producing a stylobreccia.

33A/131 Laminated Dolomite

b: Solution collapse breccia in sandy dolomite. Distinct dolomite types can be recognised

A_1 - Represents original sandy dolomite. Dark colour due to abundance of very fine grained opaques (mainly sulphides). Grainsize 0.003mm.

A_2 - "Bleached" zone due to removal of fine grained opaques.

B - Coarser grained dolomite (0.01 to 0.05mm) precipitated during solution activity.

C - Clear, coarse grained dolomite associated with mineralisation along stylolites.

33A/366.5 Sandy Dolomite

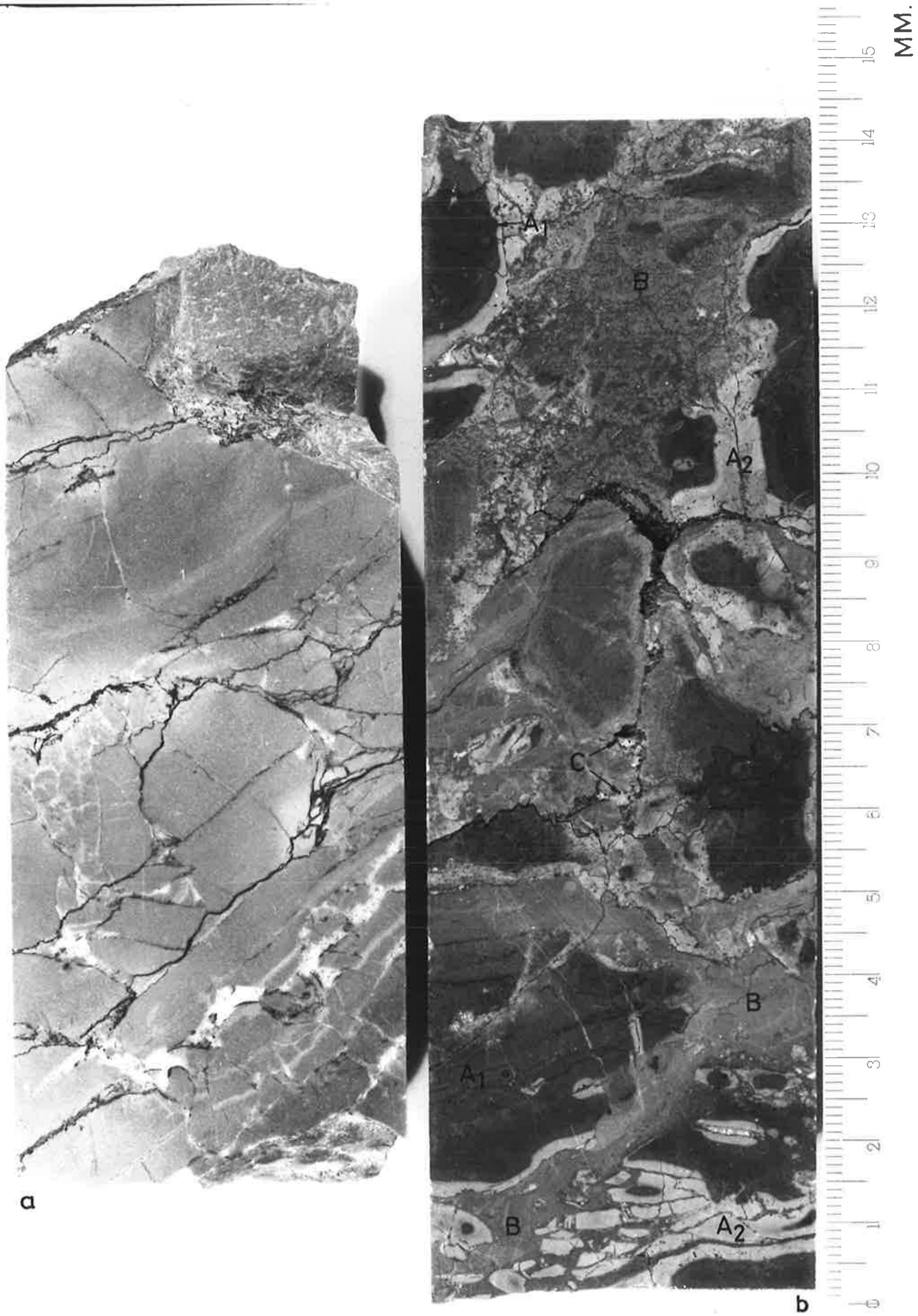


FIGURE 2.5

FIGURE 2.6

a. Medium crystalline, sandy, intraclastic (oolitic) dolomite.

33A/383.5 Transmitted Light

b. Sandy, intraclastic dolomite.

32/410 Transmitted Light

c. Laminated dolomite breccia - stylobreccia.

33A/314 Transmitted Light

d. Finely crystalline, laminated dolomite, containing finely disseminated opaques (sulphides - probably galena & pyrite).

32/157 Transmitted Light

FIGURE 2.6

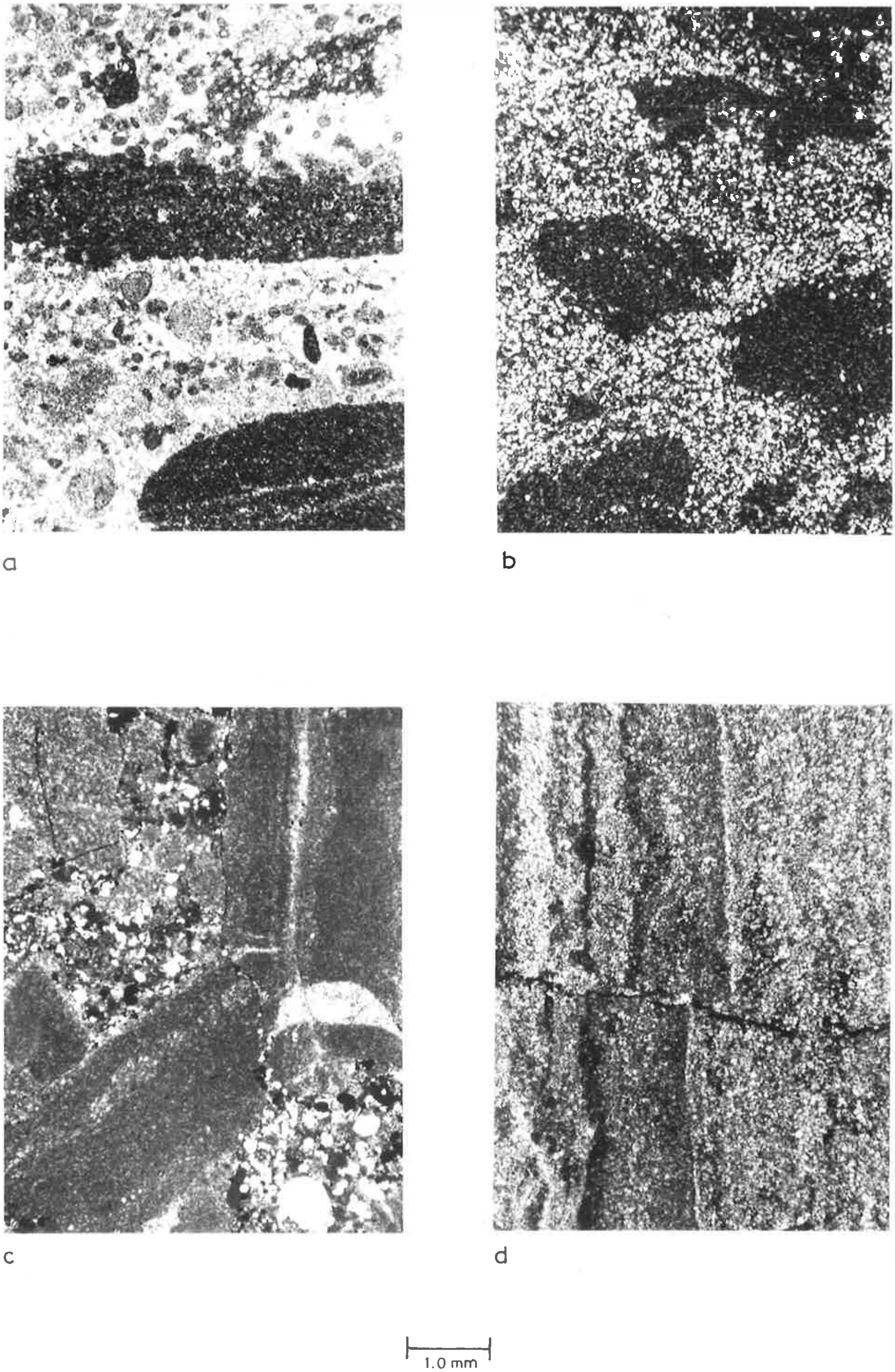


FIGURE 2.7

a. Finely crystalline dolomite containing an interconnecting network of stylolites. The stylolites contain concentrations of opaques (mainly sulphides), detrital quartz and clays. The stylolites give the rock a brecciated appearance in hand specimen (stylobreccia).

33A/304 Laminated Dolomite

b. As above, but containing fragments of darker and finer grained dolomite, probably due to solutional activity - stylobreccia.

32/197 Laminated Dolomite

c. Stylolite marking the contact between darker and lighter dolomite in Figure 2.7b. The grain size difference is clearly visible.

32/197 Transmitted Light

d. Finely crystalline, oolitic dolomite. A horizontal type stylolite clearly shows the concentration of sulphides and detrital quartz by solutional activity.

33A/39 Massive Dolomite

Figure 2.7

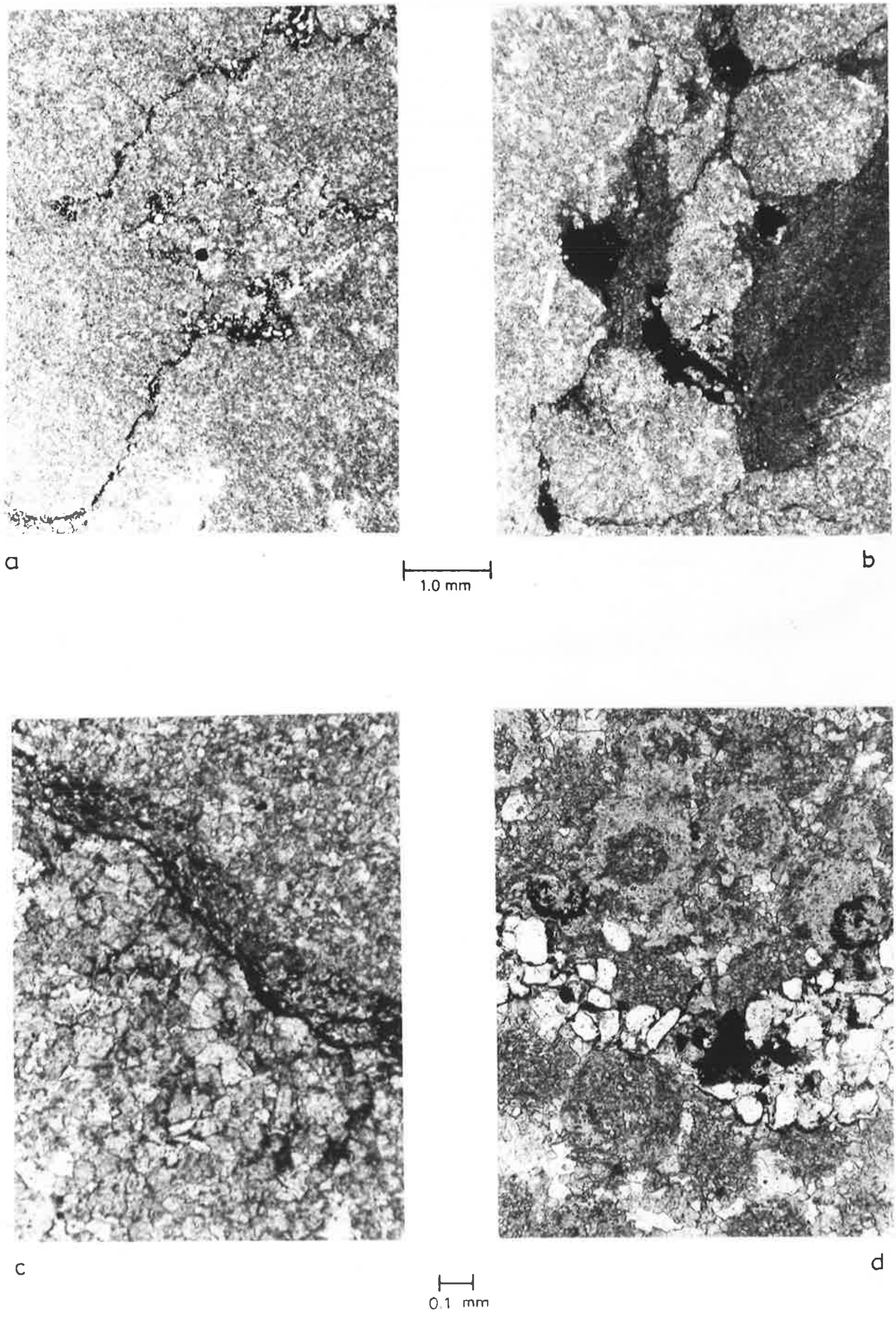
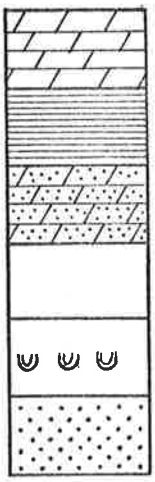


FIGURE 2.8

GENERALISED SECTIONS - EDIACARA
D.D.H. E32 AND E33A.

(BASED ON CRITERIA OF LAPORTE, 1969, AND THOMSON AND THOMASSON, 1969).

LEGEND



Massive, finely crystalline dolomite
- shows slumping and stylolitic

Laminated dolomite
- occasional breccias

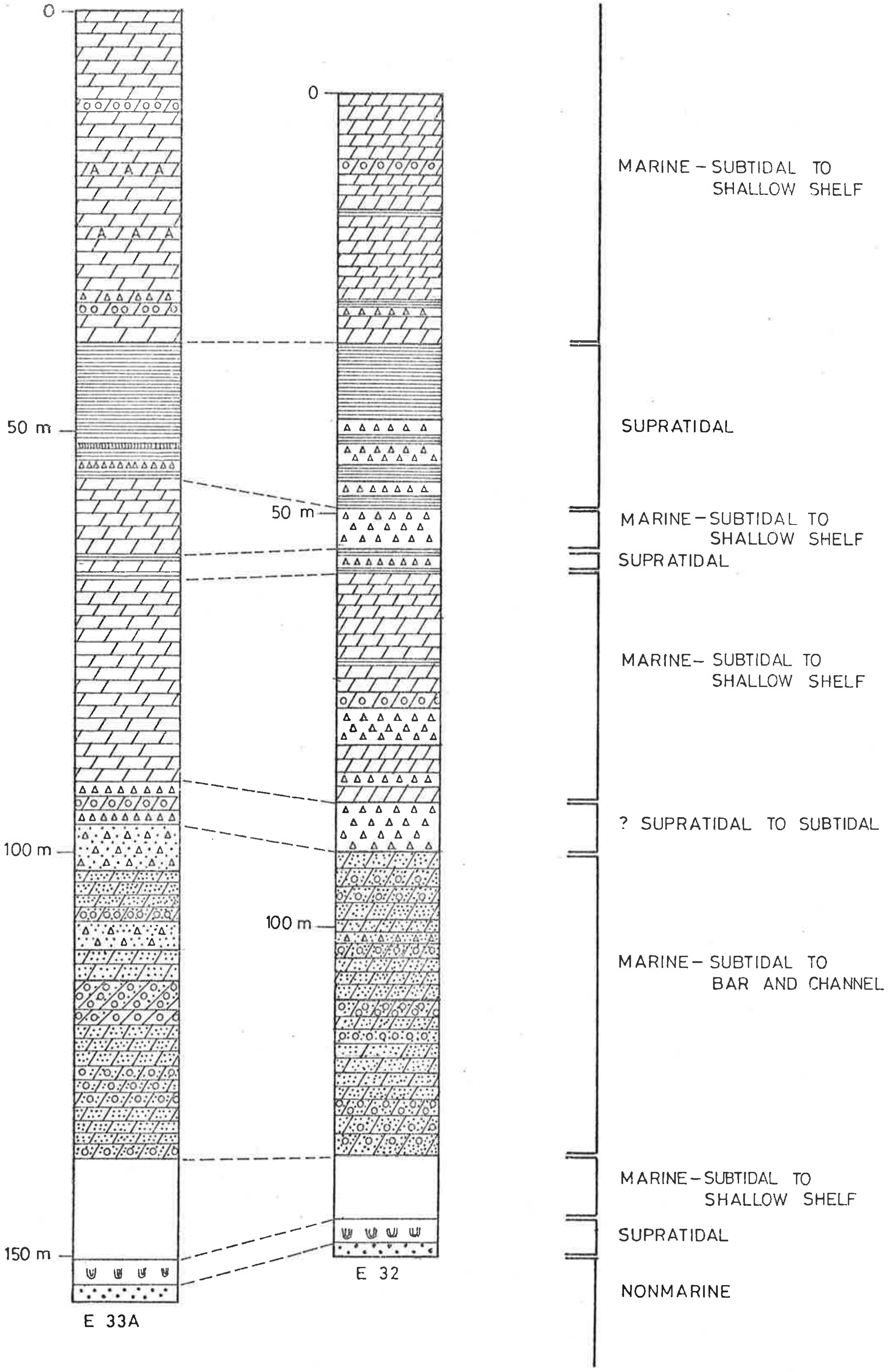
Sandy, finely crystalline dolomite
- cross bedded oolitic & stylolitic in parts

Transition Shales

Worm Burrow Beds

Pound Quartzite

oooooooooo	Oolitic
ΔΔΔΔΔΔΔΔ	Breccia
AAAAAAA	Archaeocyatha
〰〰〰	Stromatolite


0
50 m
100 m
150 m
E 33A
0
50 m
100 m
E 32
MARINE – SUBTIDAL TO SHALLOW SHELF
SUPRATIDAL
MARINE – SUBTIDAL TO SHALLOW SHELF
SUPRATIDAL
MARINE – SUBTIDAL TO SHALLOW SHELF
? SUPRATIDAL TO SUBTIDAL
MARINE – SUBTIDAL TO BAR AND CHANNEL
MARINE – SUBTIDAL TO SHALLOW SHELF
SUPRATIDAL
NONMARINE

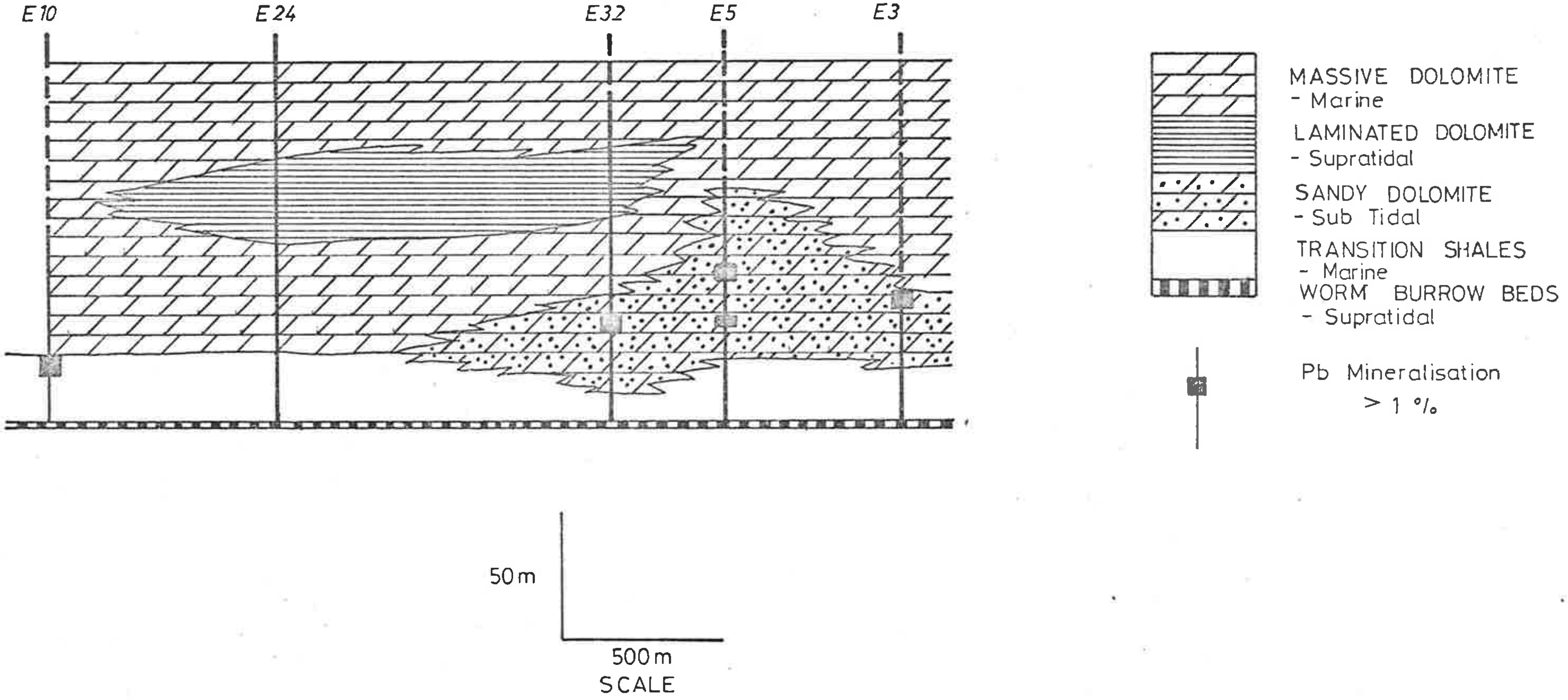
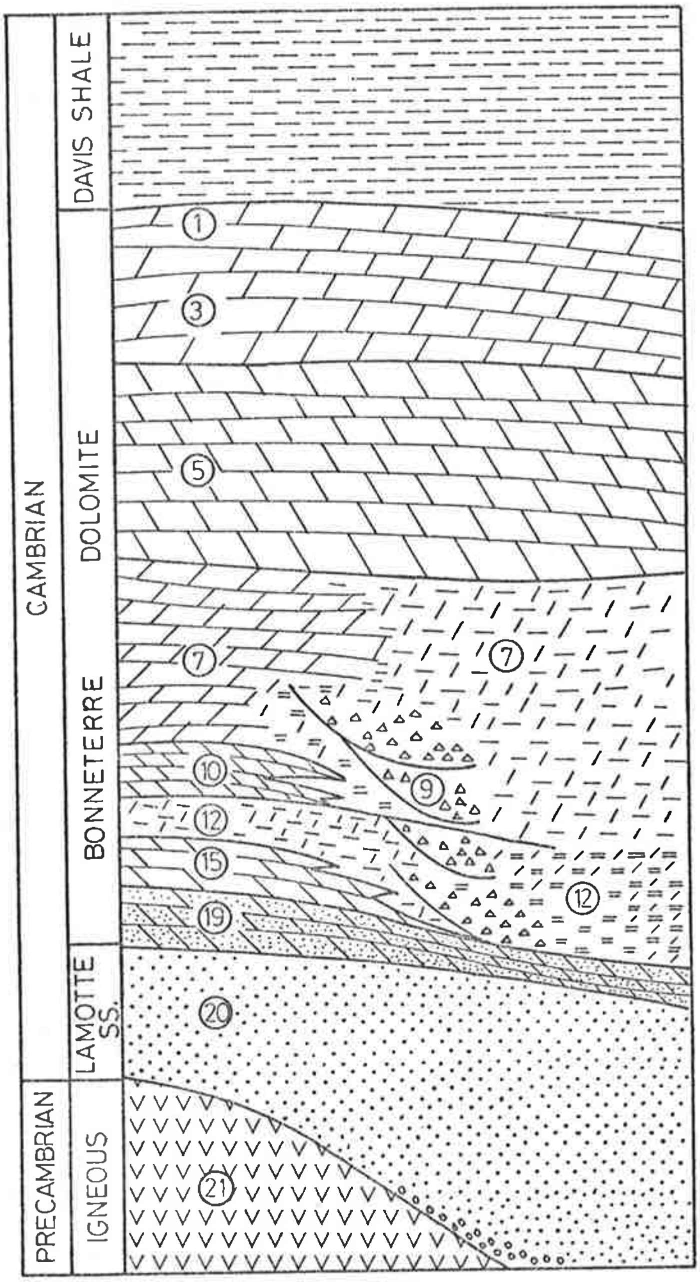


FIGURE 2.9

DIAGRAMMATIC CROSS SECTION - EDIACARA

(along line A-B in figure 1.3)



1. Dense grey dolomite

3. Mottled blue and white dolomite & chocolate brown dolomite

5. Thick bedded tan and brown oolitic dolomite

7. Main algal reef zone. Commonly thick massive reef throughout on ridge structures. Some thin and scattered reefs. Non reef rock is generally thin, wavy bedded, fine grained, gray or tan dolomite.

9. Breccias

10. Thick, fine-grained, even bedded tan dolomite on southwest side of district. Coarse-grained, lenticular tan dolomite over ridge structures. Thin or absent between ridges.

12. Thin, wavy bedded, fine-grained and spotted dolomite, contains black shale partings. Algal beds common at base. Thin over ridges.

15. Light coloured, coarsely crystalline. Often glauconitic. Frequently thick over ridges.

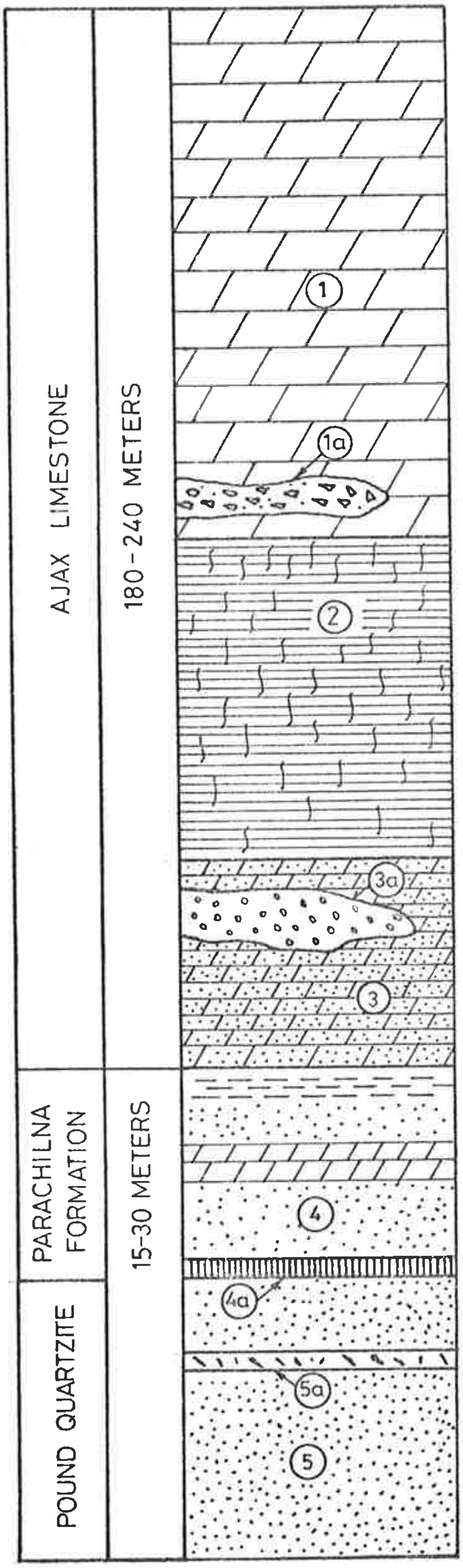
16. Brown compact dolomite. Algal mat, sometimes with digitate columns. Usually found at 15/19 contact.

19. Tan or gray sandy dolomite. Thickens to form ridges.

20. Sandstone with occasional siltstone beds. Poorly cemented in upper part. Thin dolomitic beds in upper part. Residual igneous boulders at base.

21. Precambrian, volcanics and granite

FIGURE 2.10 GENERALIZED STRATIGRAPHIC SEQUENCE SOUTHEAST MISSOURI LEAD DISTRICT
(After Snyder, Odell, 1958)



1 Massive crystalline light-dark grey dolomites with cherty layers. Archaeocyatha near top and styolites

1a Dolomite breccia near bottom

2 Laminated algal dolomites. Fine grained buff-grey coloured dense dolomites with occasional thin sedimentary breccia zones (often mineralized) Some breccia zones up to tens of feet common.

3 Sandy cross bedded dolomite interbedded with fine grained dense dolomites and oolitic dolomites

3a Layers of dolomite breccia up to several feet thick

4 Interbedded dolomitic shales, silts, sandstones and dolomite

4a Worm burrow bed. Gritty sandstone with clayey or chloritic matrix

5a Ediacara Fossil Horizon Cross bedded, slumped, flaggy, laminated quartzite

5 Pound Quartzite White sandstone

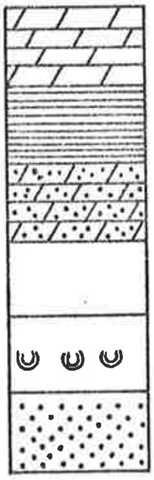
FIGURE 2.11 GENERALIZED STRATIGRAPHIC SECTION - EDIACARA

FIGURE 3.1

SUMMARISED GEOCHEMICAL AND GEOLOGICAL LOGS FOR SELECTED DRILL HOLES

(Analyses by AMDEL for the South Australian Department of Mines)

LEGEND



Massive finely crystalline dolomite
shows slumping and styolitic

Laminated dolomite
occasional breccias

Sandy, finely crystalline dolomite
cross bedded oolitic and styolitic in parts

Transition Shales

Worm Burrow Beds

Pound Quartzite

oooooooo	Oolitic
ΔΔΔΔΔΔΔΔ	Breccia
AAAAAAA	Archaeocyatha
▬▬▬▬	Stromatolite

Vertical Scale ______Depth in metres

Horizontal Scale ____Metal Content in %

————	Lead
– – – – – –	Copper
—·—·—	Zinc

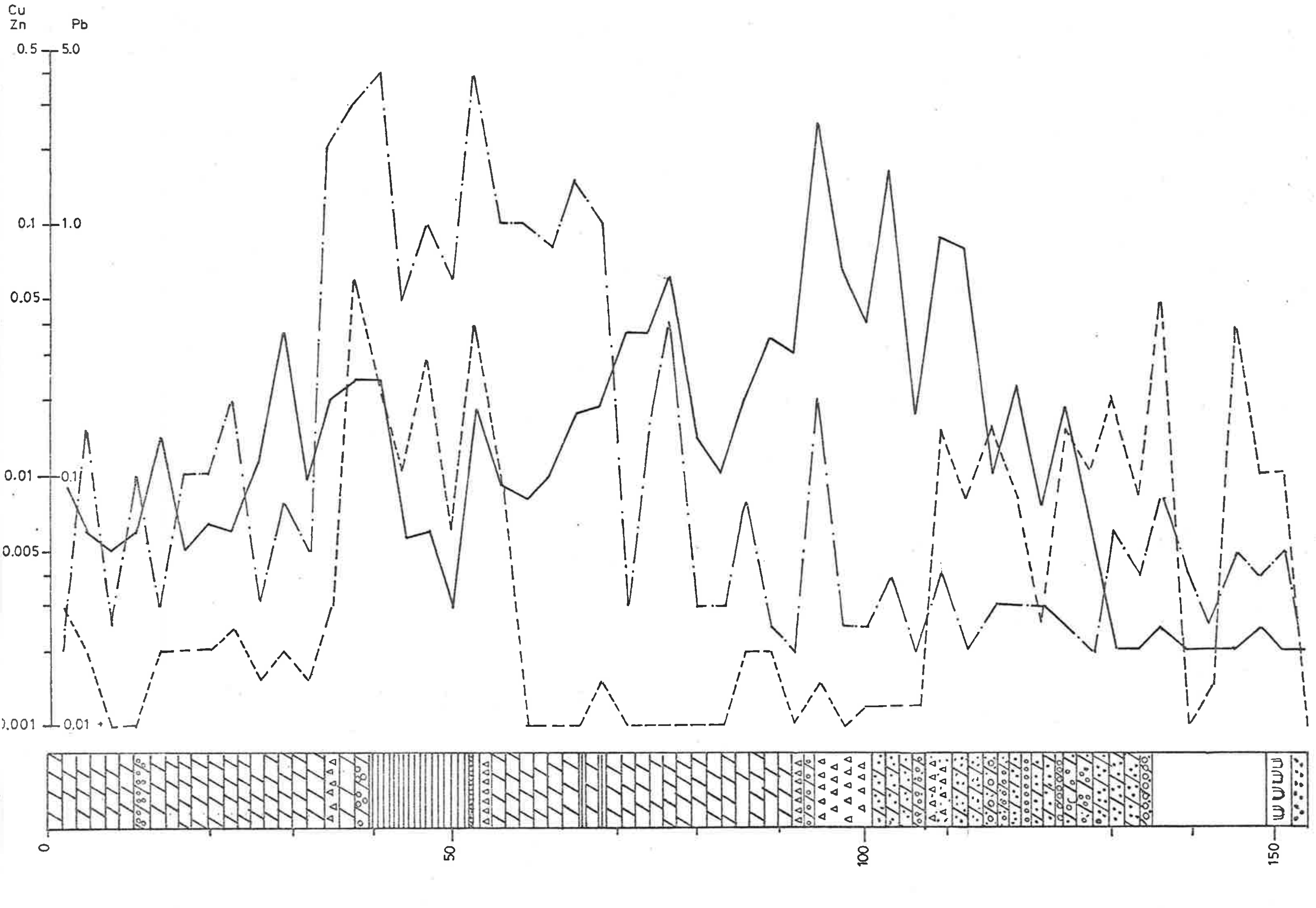


FIGURE 3.1a
D.D.H. E 33a

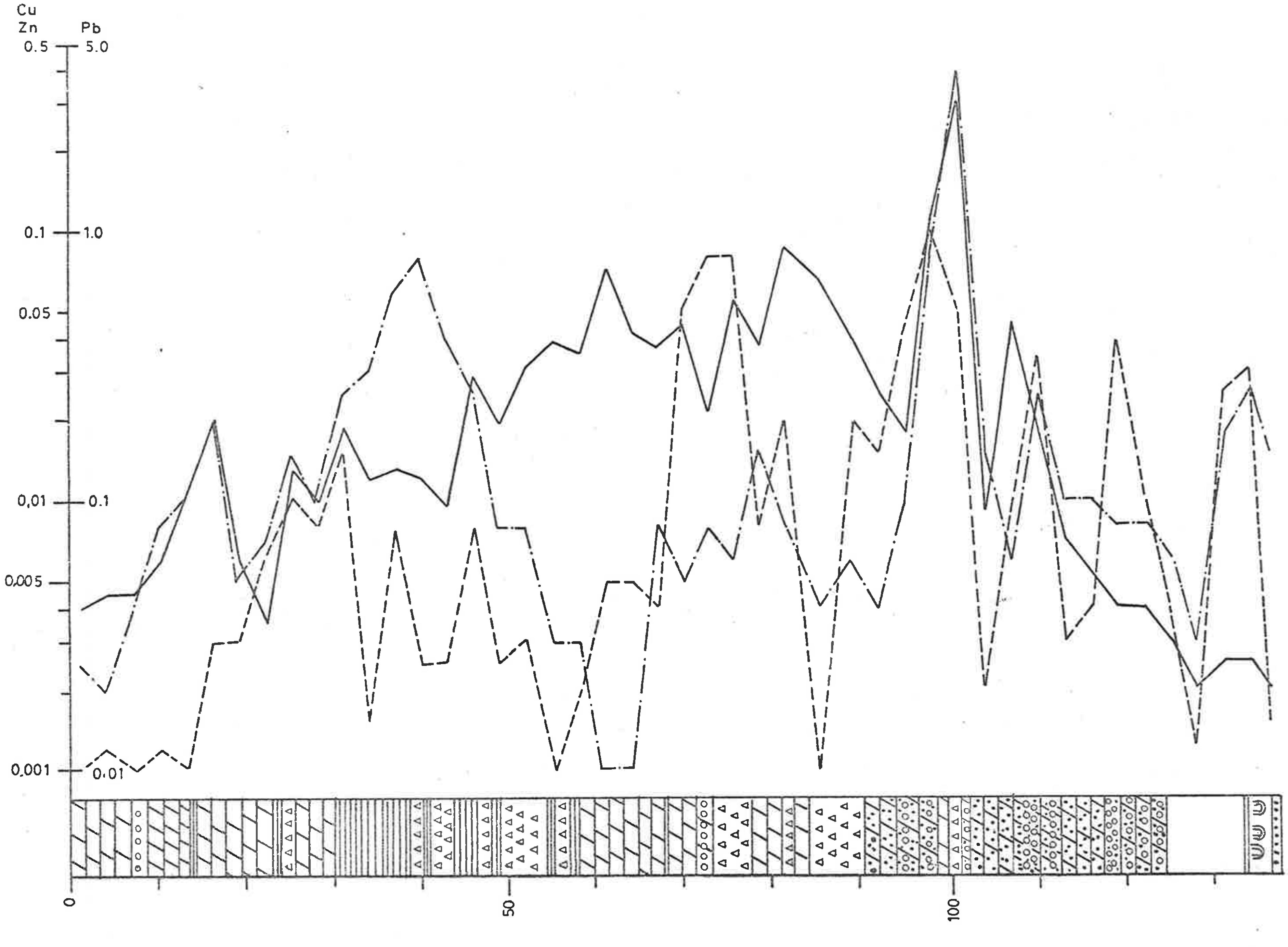


FIGURE 3.1b
D.D.H. E 32

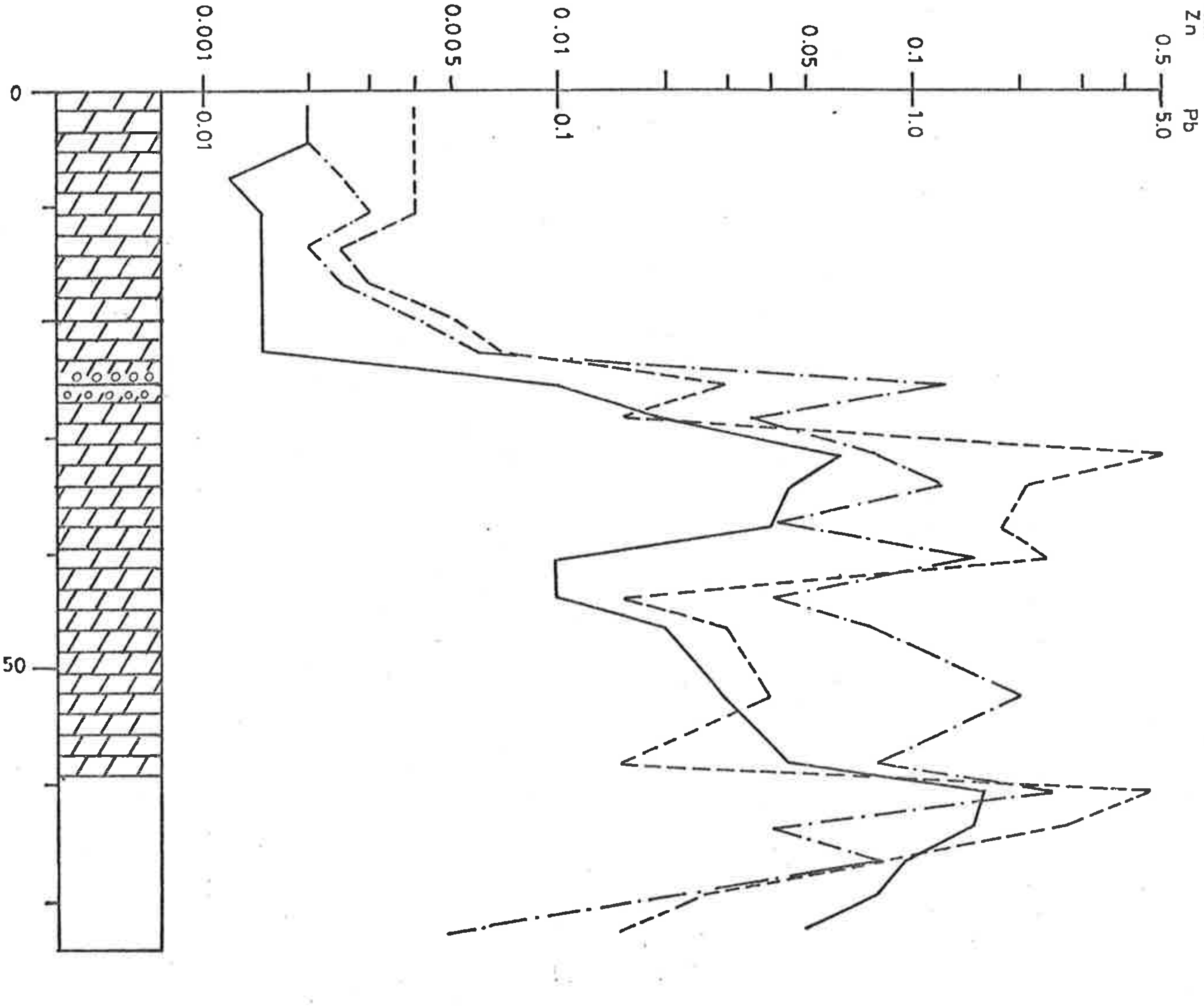


FIGURE 3.1c
D.D.H. E10

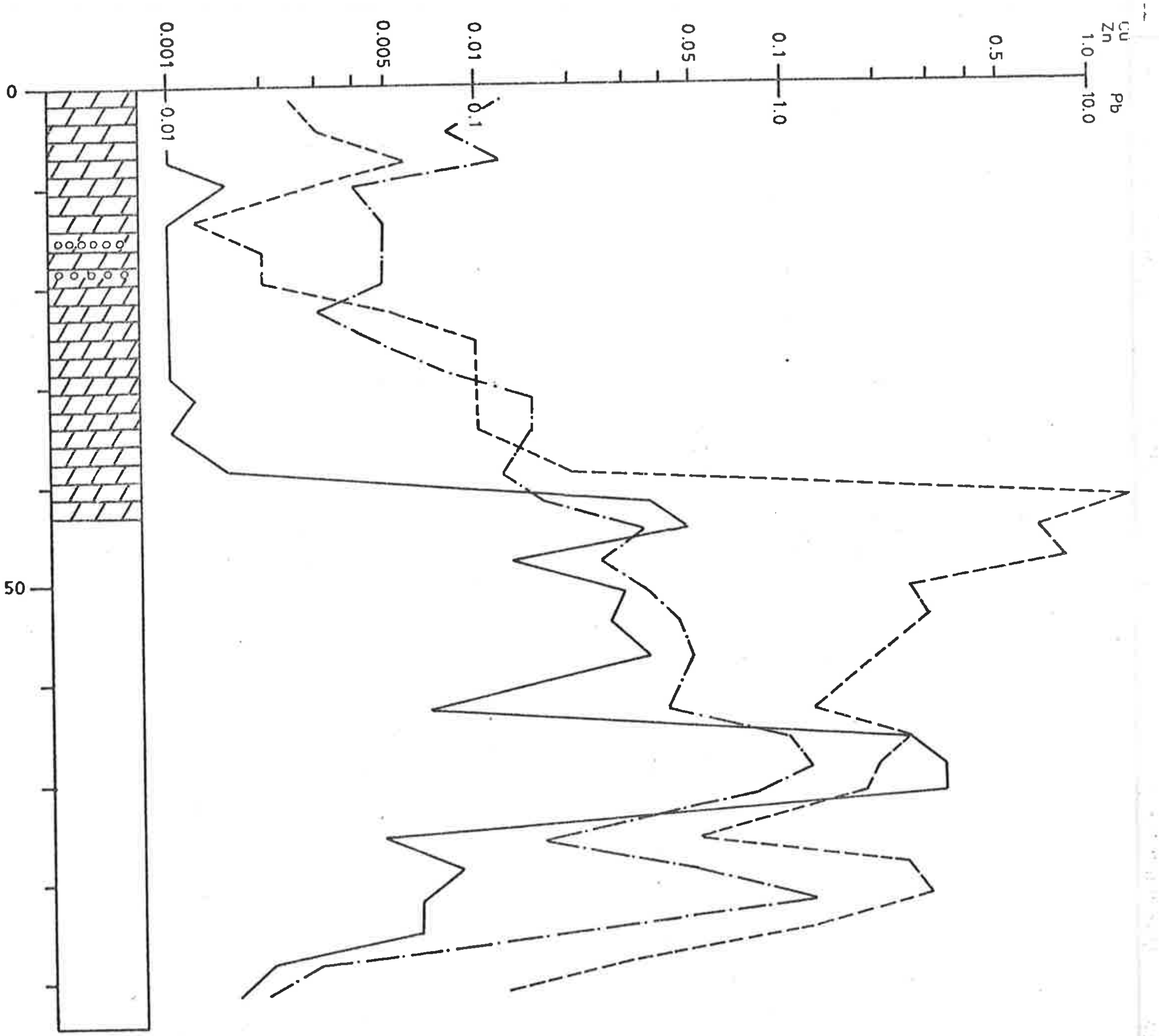


FIGURE 3.1d
D.D.H. E7

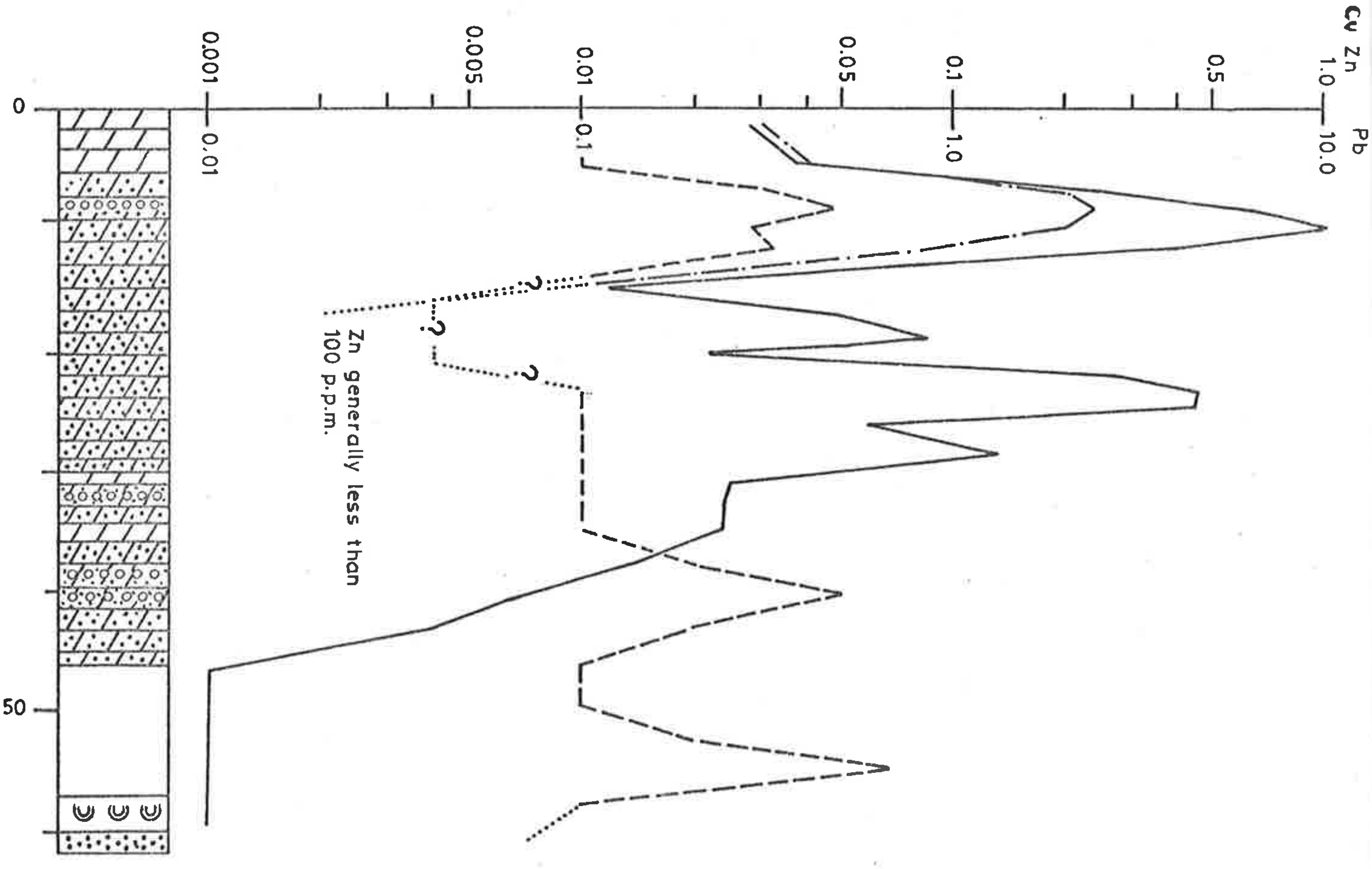


FIGURE 3.1e
D.D.H. E6

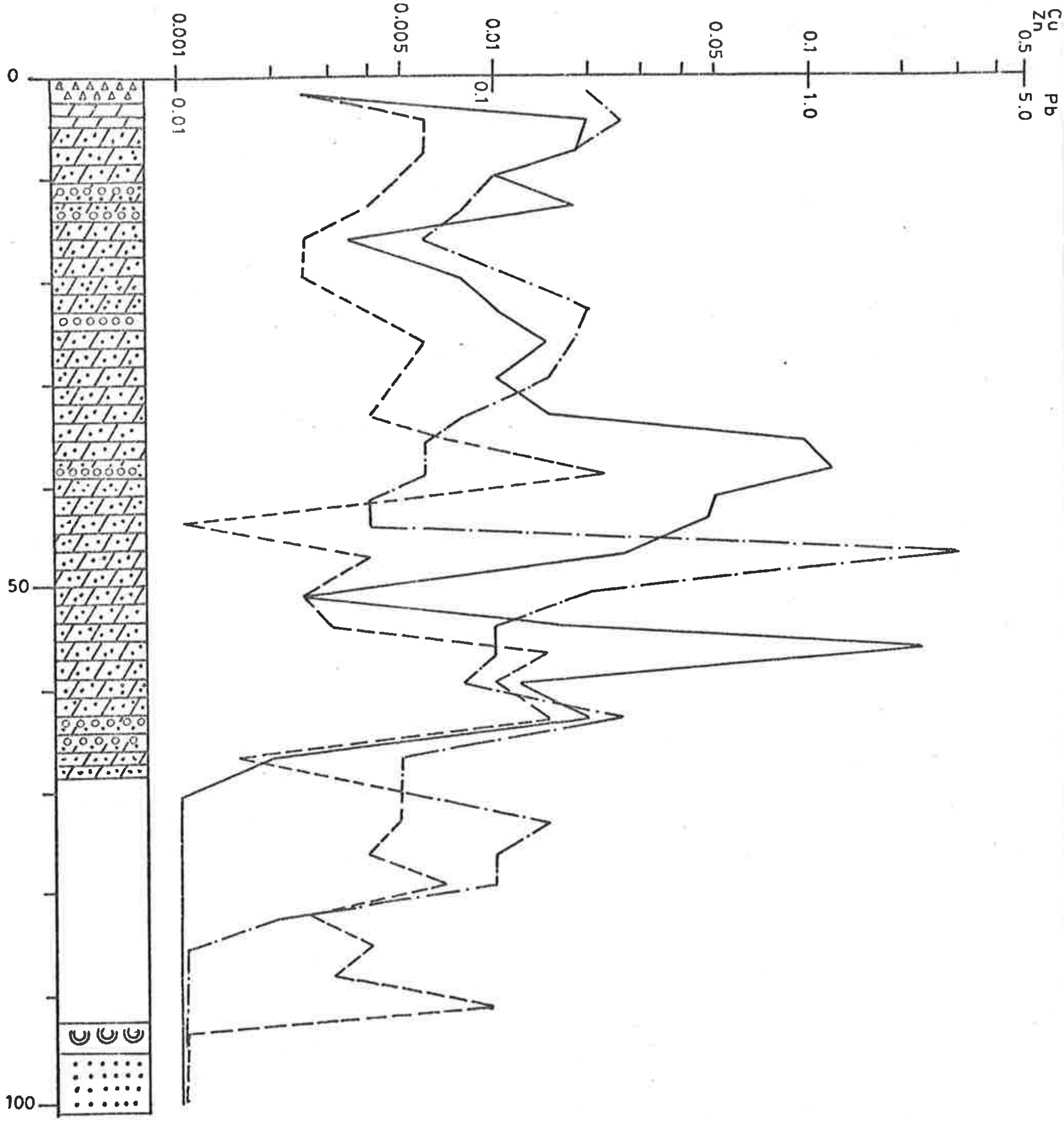


FIGURE 3.1f
D.D.H. E5

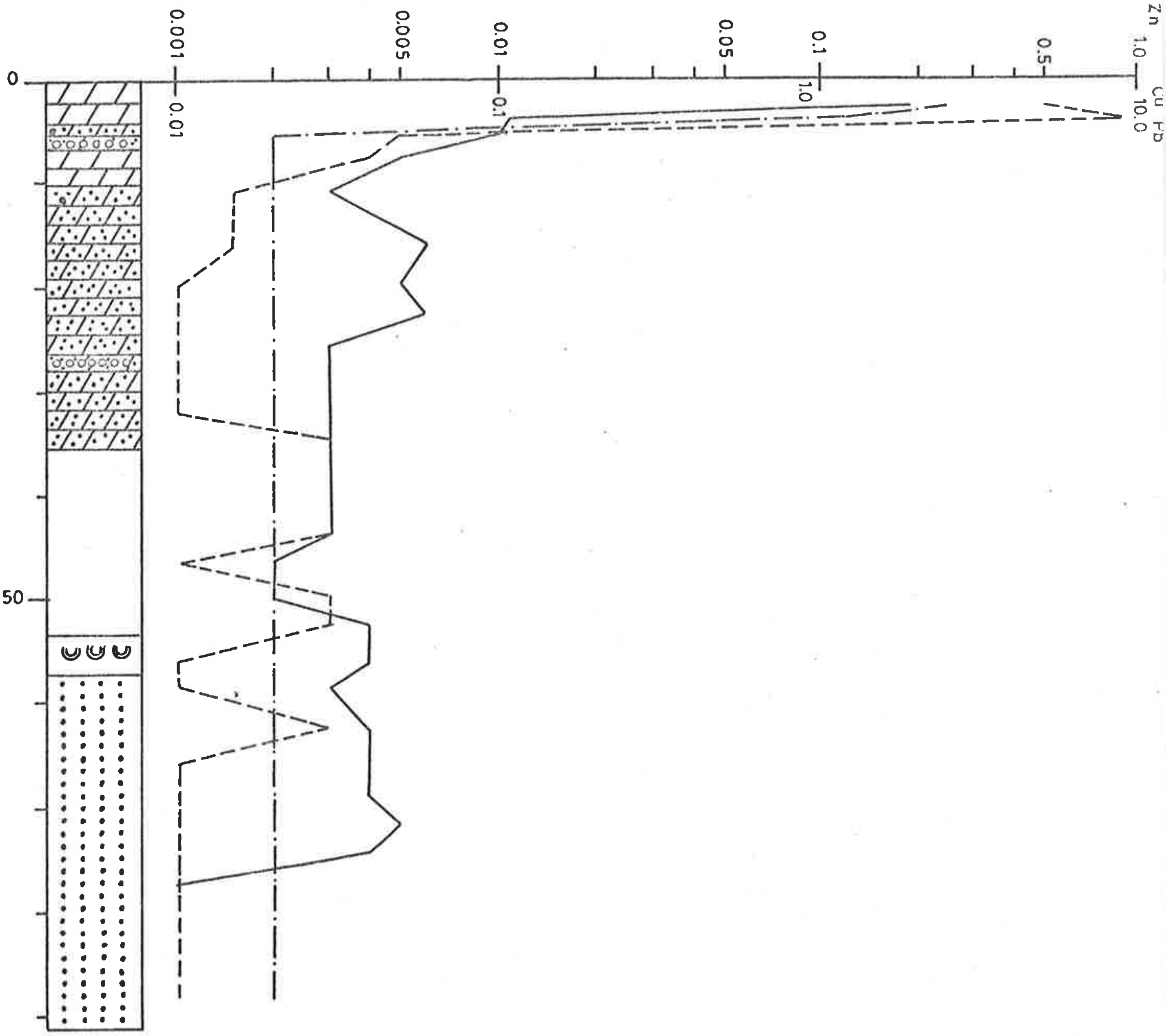


FIGURE 3.1g
D.D.H. E3

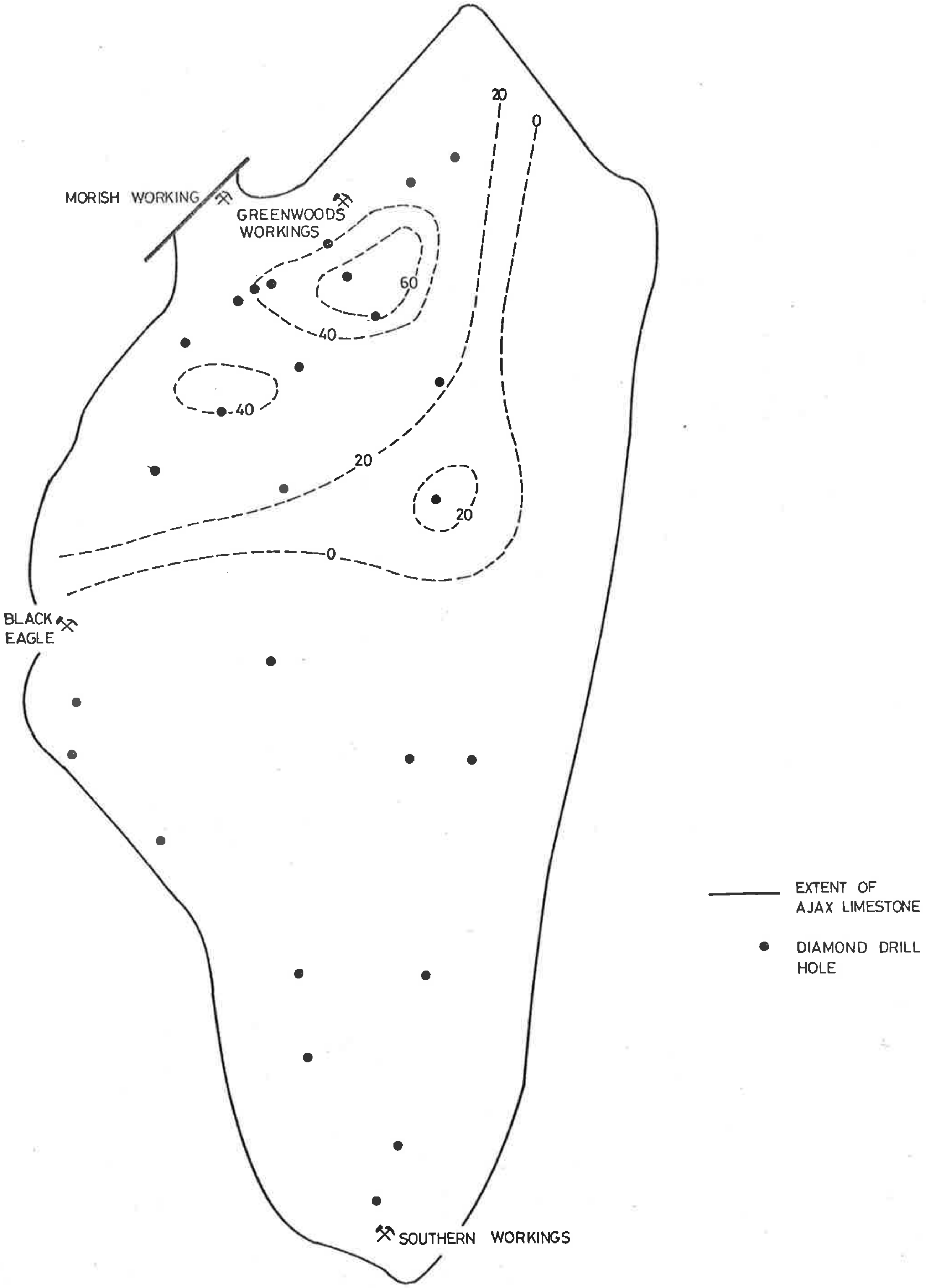


FIGURE 3.2 ISOPACH OF THE SANDY CROSS BEDDED DOLOMITE
(Contour Interval 20 metres)

FIGURE 4.1

a. Patches of galena scattered through finely crystalline, sandy dolomite, and thin seams of galena along stylolites.

33A/371.5	Sandy Dolomite

b. Oolitic dolomite containing coarse patches of pyrite, which cements the oolites. Stylolite in top of specimen is parallel to bedding.

33A/426	Sandy Dolomite

c. Concentration of spheroidal pyrite in sandy dolomite. Sulphides are also concentrated along the stylolite in the upper part of the specimen.

32/327	Sandy Dolomite

d. Mineralisation along veins and fractures as cavity fillings in laminated dolomite.

33A/226.5	Laminated Dolomite

FIGURE 4.1

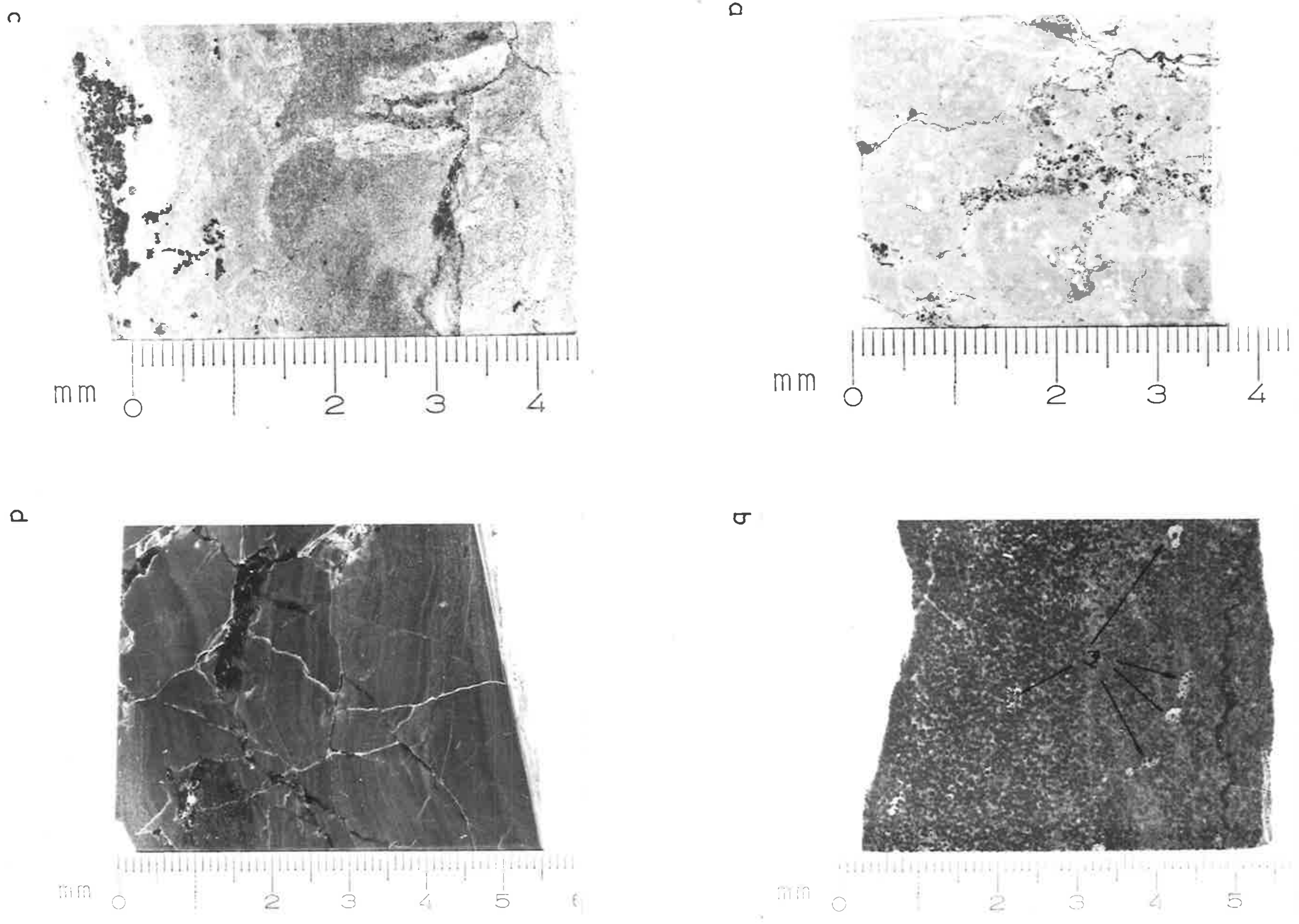


FIGURE 4.2

a. Mottled, sandy dolomite. Dark areas contain larger proportion of opaques than lighter, "bleached" areas. Notice association of stylolites with lighter areas. Galena and pyrite are concentrated along stylolites and as cavity fillings (bottom half of specimen).

32/356 Sandy Dolomite

b. As above, but showing in more detail, relationship between mineralised stylolites and veins and "bleached" zones in dolomite.

33A/366.5 Sandy Dolomite Bar scale is 1.0 cm.

c. Coarse grained dolomite, partially replaced by silica in a vein.

33A/282 Laminated Dolomite

d. Silica vein containing disseminated galena. The contacts of the vein with the dolomite can be seen in the top and bottom of the specimen. A stylolite occurs along the bottom contact.

32/292 Laminated Dolomite

FIGURE 4.2

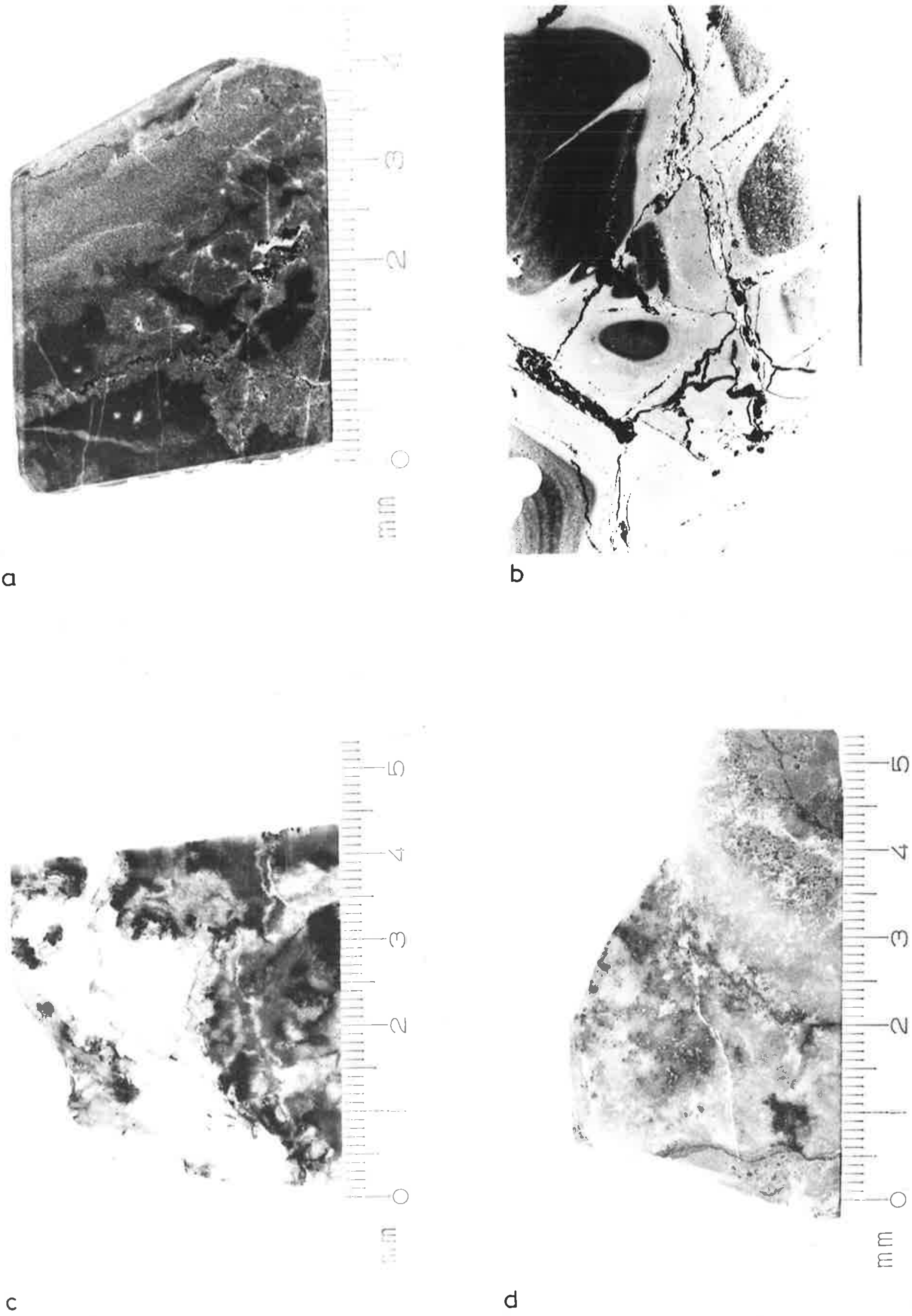


FIGURE 4.3

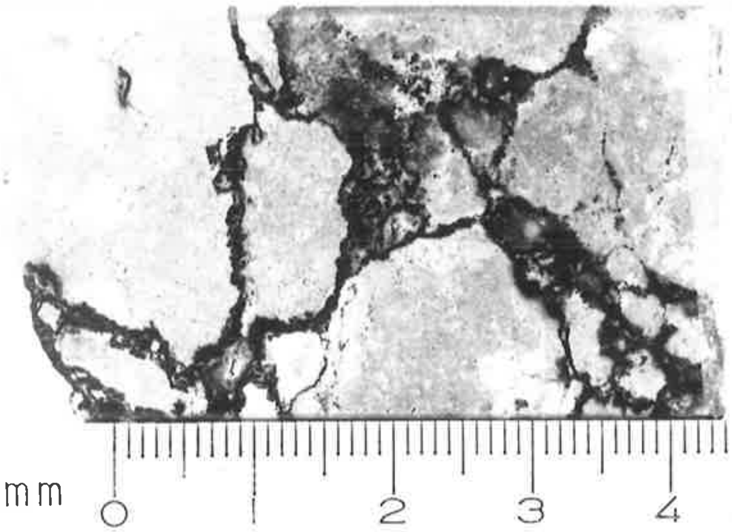
a. Dolomite breccia (stylobreccia). The matrix consists of sulphides and silica (mainly chalcedony). The matrix could be concentrations along stylolites, rather than true breccia filling.

32/337 Sandy Dolomite

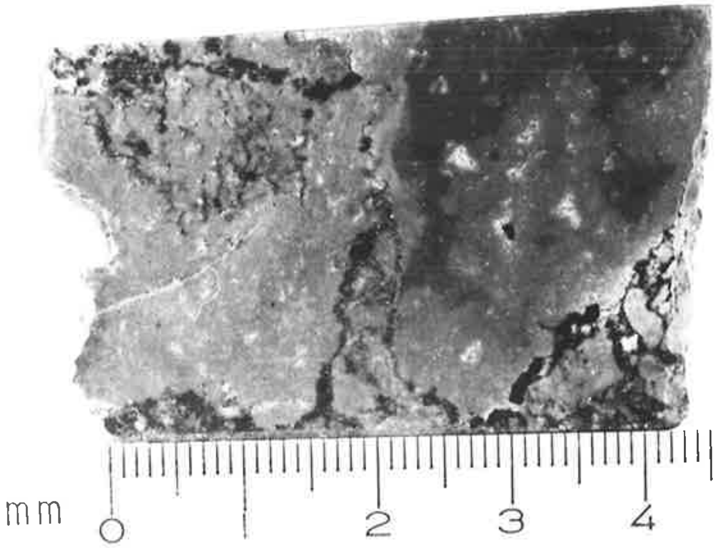
b. As above. Evidence for stylolites much more convincing in this sample. Note the dolomite has a similar "bleached" appearance as in Figures 4.2a and 4.2b.

32/388 Sandy Dolomite

FIGURE 4.3



a



b

FIGURE 4.4

a. Dolomite breccia. Fragments of laminated and massive dolomite in a pyrite rich matrix.

32/257 Laminated Dolomite

b. Dolomite breccia (stylobreccia) containing a wide variety of fragments (oolitic, laminated and massive dolomite and siliceous fragments). Sparse pyrite and galena occur in the matrix. Stylolites are present along the edges of dolomite fragments (dark specks less than 1.0mm are pyrite or galena).

33A/318 Laminated Dolomite

c. Collapse type dolomite breccia. Dolomite fragments are cemented by coarse pyrite, galena and minor dolomite.

33A/179 Laminated Dolomite

d. Sparse galena and pyrite mineralisation in the cement of a dolomite breccia (stylobreccia). Note minor sulphides along laminations in the largest dolomite block, suggestive of syngenetic origin.

33A/314 Laminated Dolomite

FIGURE 4.4

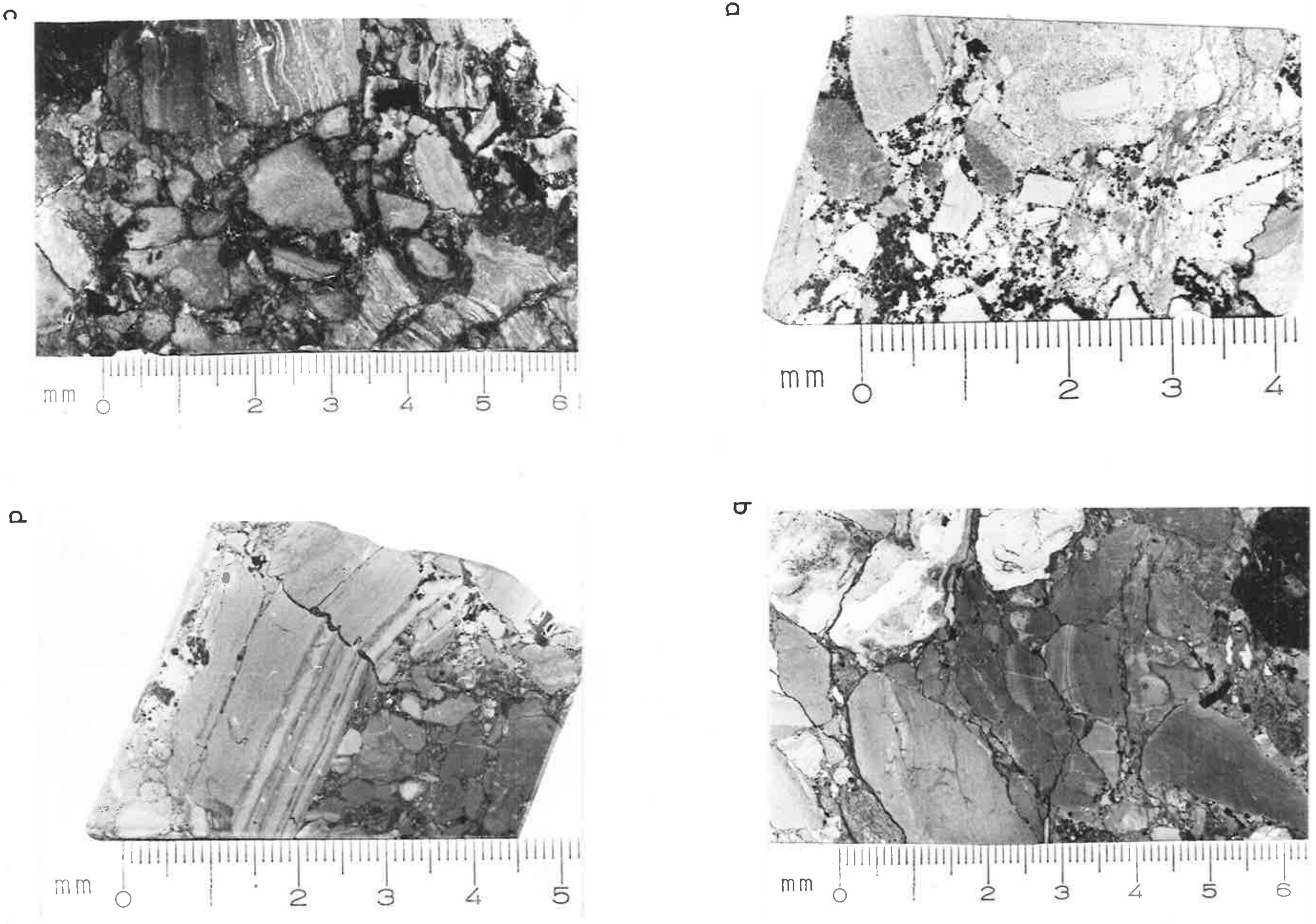


FIGURE 4.5

a. Cavity lined with galena, with later barite infilling.

33A/371.5 Transmitted Light

b. Coarse grained euhedral quartz containing many liquid and solid inclusions.

33A/371.5 Transmitted Light

c. Galena and quartz occurring along a stylolite. Quartz occurs as both equant and elongate crystals.

33A/371.5 Transmitted Light

d. Fine grained sulphides concentrated along a stylolite. Some coarser patches of galena, as cavity fillings, can be seen.

33A/304 Transmitted Light

FIGURE 4.5

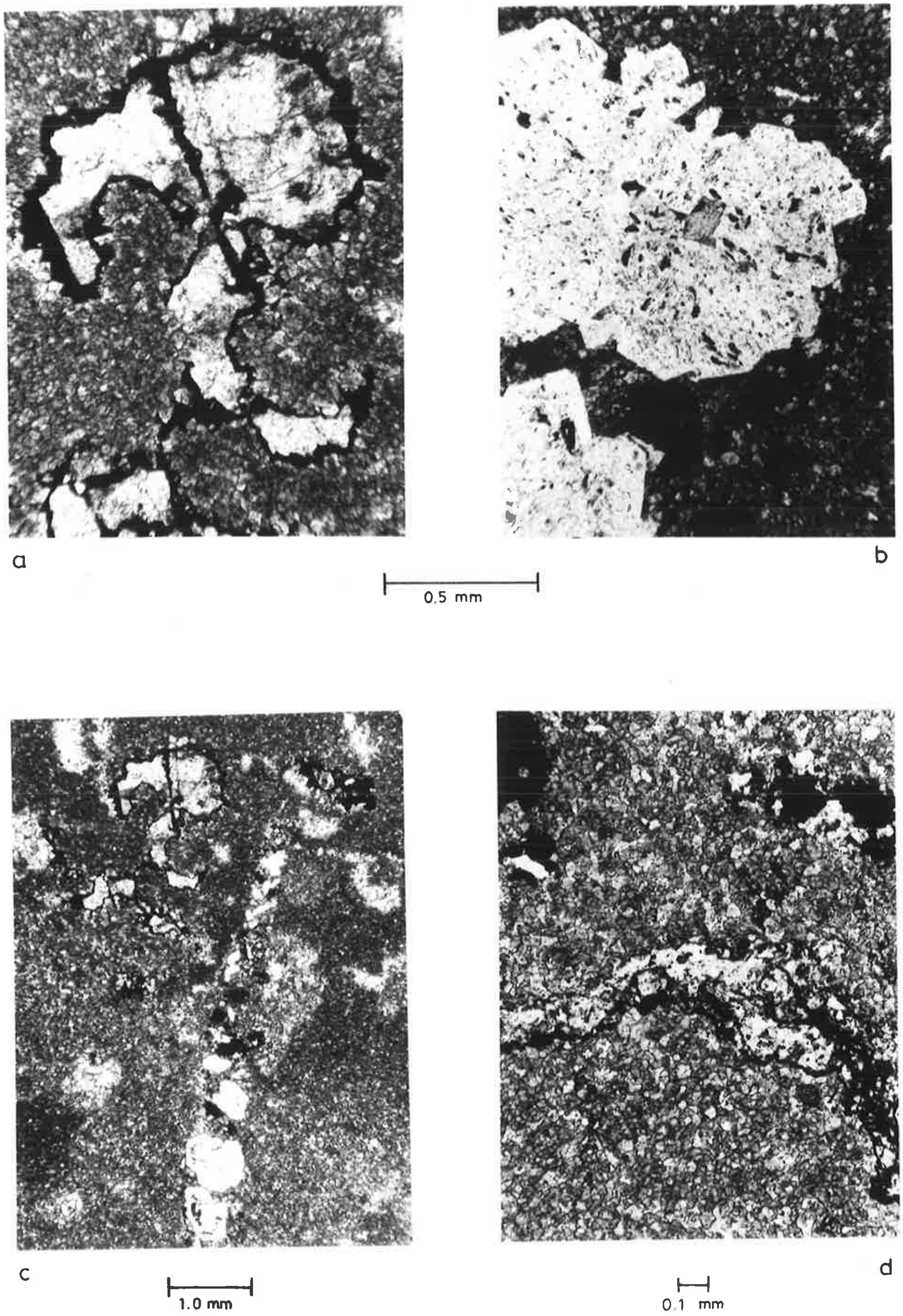


FIGURE 4.6

a. Euhedral pyrite crystals in a matrix of galena. Dolomite rhombs are also present in the galena matrix. Pyrite is possibly being replaced by galena.

33A/226.5 Reflected Light

b. Exsolution rods and blades of pearceite ($Ag_{16}As_{2}S_{11}$) in galena.

33A/226.5 Reflected Light

c. Coarse patches of sulphides and dolomite, filling a cavity, which tapers out to a stylolitic seam.

33A/226.5 Transmitted Light

FIGURE 4.6

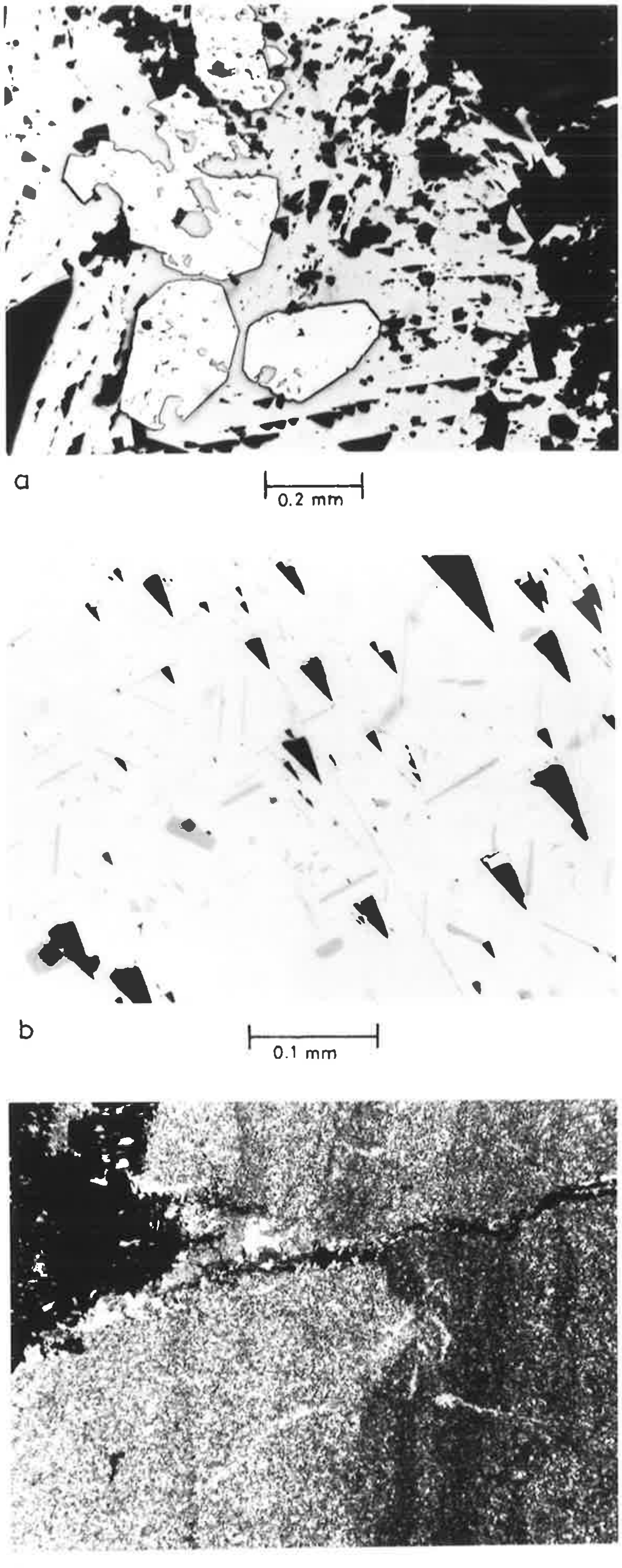


FIGURE 4.7

a. Framboidal pyrite in silica.

33A/366.5 Reflected Light

b. Coarse grained, euhedral pyrite and framboidal pyrite.

33A/366.5 Reflected Light

c. Contact between lighter (bleached) and darker zones, showing large concentration of opaques in darker zone.

33A/366.5 Transmitted Light

d. Sulphides concentrated along a stylolite and filling cavities around oolites.

32/356 Transmitted Light

FIGURE 4.7

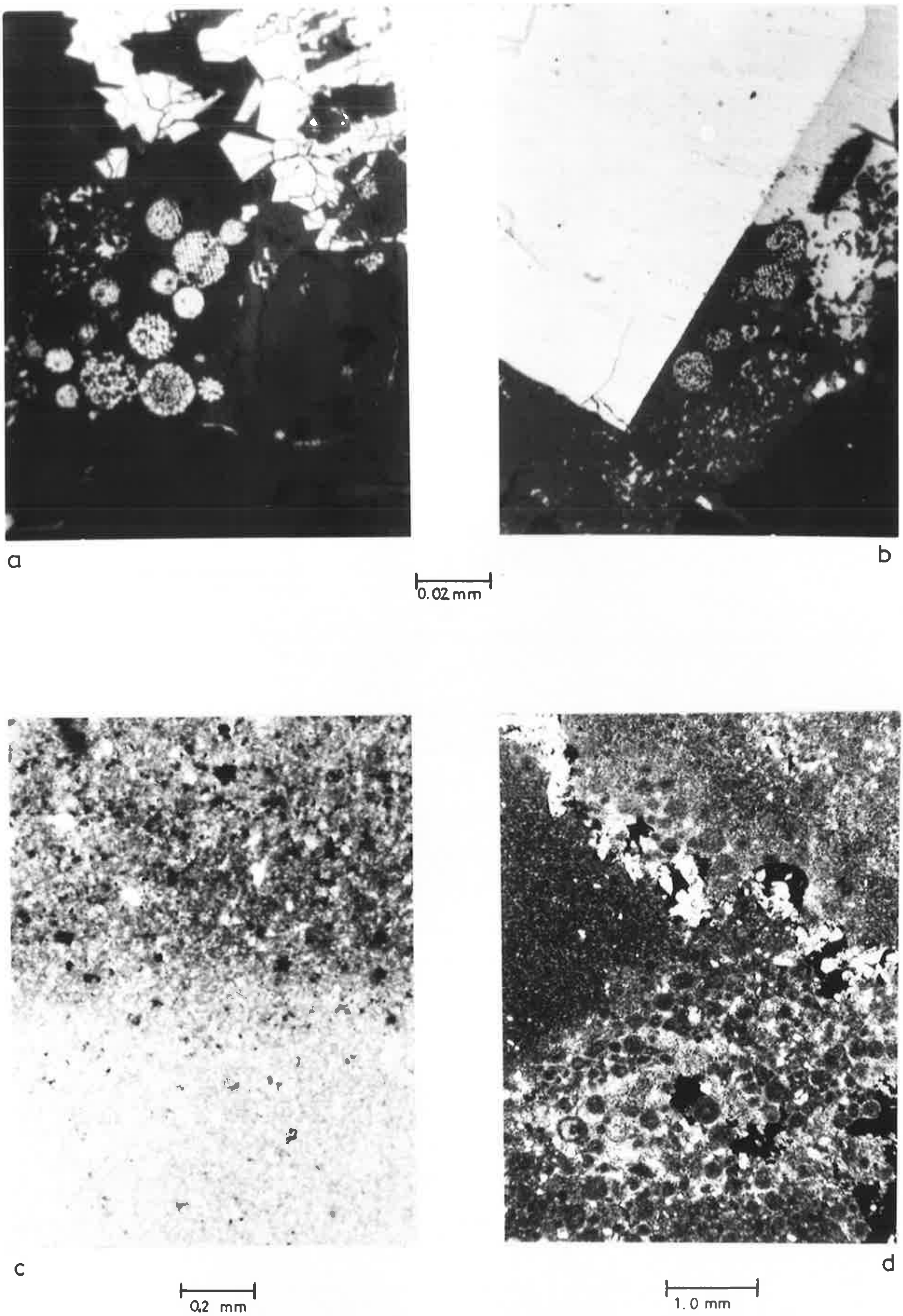


FIGURE 4.8

a. Two forms of silica
   (i) euhedral quartz with growth zoning marked by bands of sulphides (top and bottom of photo).
   (ii) Microcrystalline silica containing framboidal sulphide (galena) (centre of photo).

33A/282 Transmitted, plane polarised light

b. Same field of view as Fig 4.8a, in transmitted, crossed polarised light.

33A/282

c. Colloform banded silica.

33A/377 Transmitted, plane polarised light

d. As above, showing large interlocking and radiating grains.

33A/377 Transmitted, crossed polarised light

FIGURE 4.8

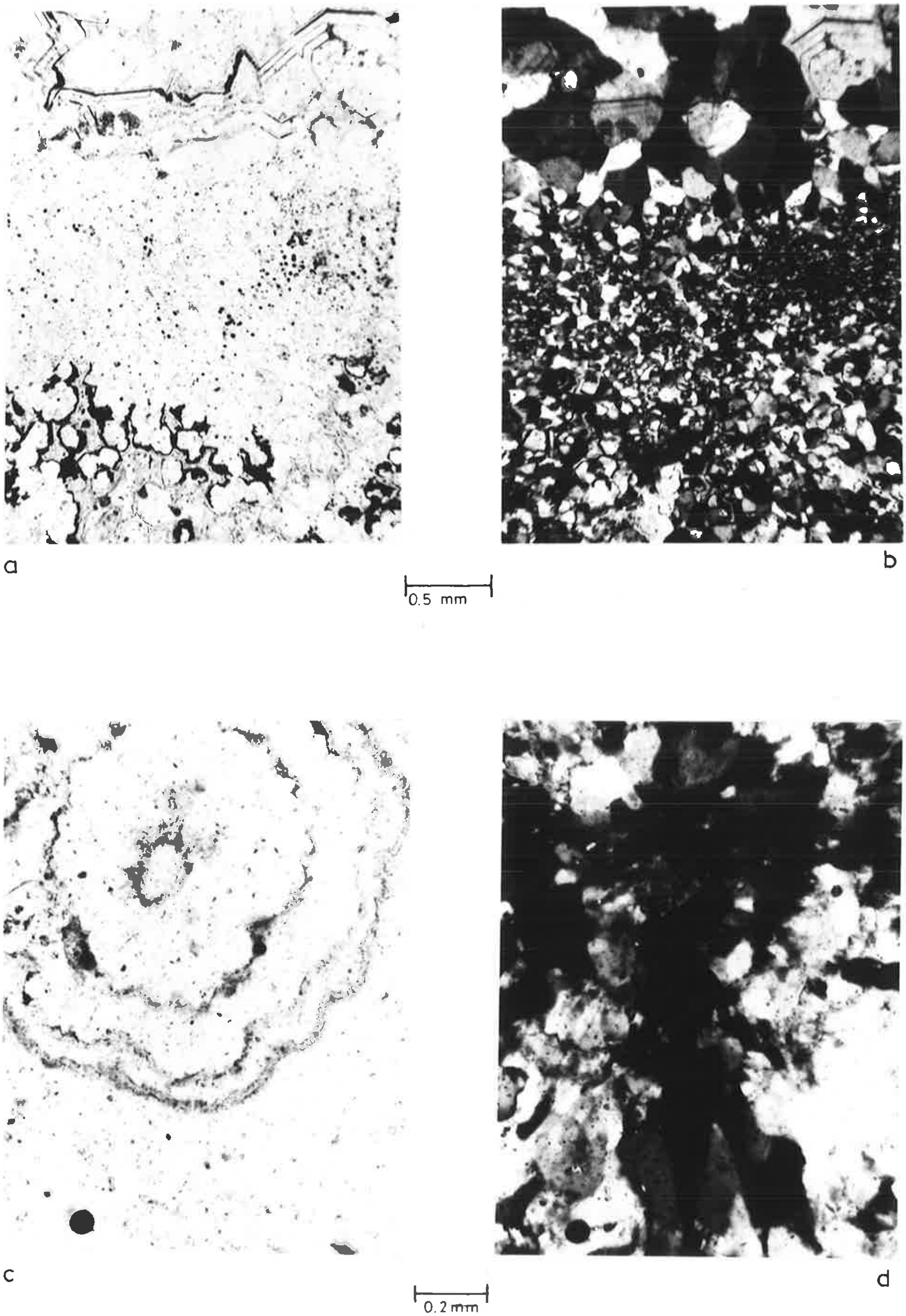


FIGURE 4.9

a. Abundance of prehnite inclusions in silica showing strong alignment.

33/377 Transmitted Light

b. Blebs of galena and corroded dolomite rhombs in colloform banded silica.

32/292 Transmitted Light

c. Corroded dolomite rhomb in colloform silica and galena. Note also colloform banded galena (in bottom of photo).

32/289 Transmitted Light

d. Fine grained dolomite filling cavities around euhedral and growth zoned quartz.

32/292 Transmitted Light

FIGURE 4.9

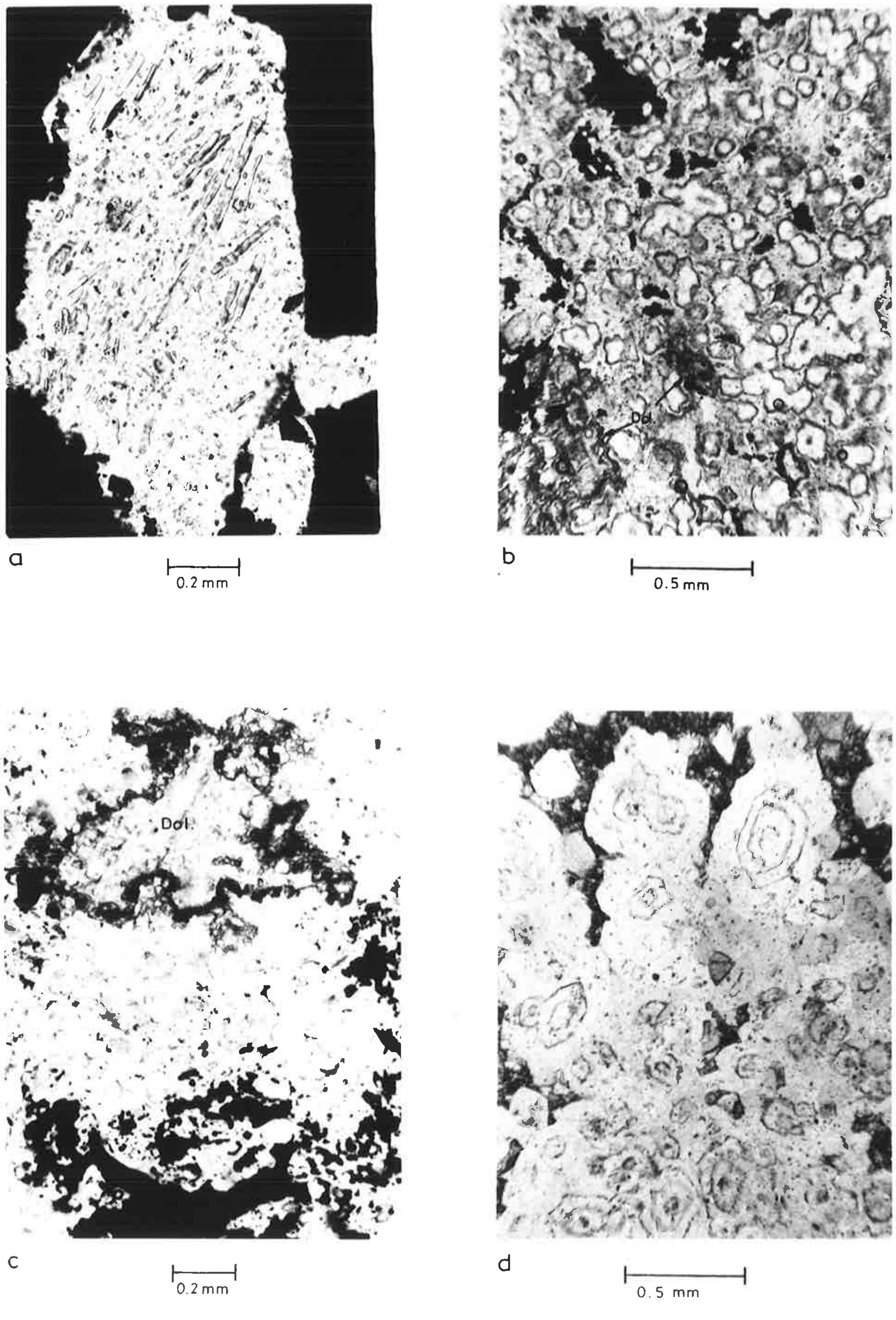


FIGURE 4.10

a. Colloform banded barite in silica.

33A/317 Transmitted Light

b. Galena and barite filling open space around euhedral quartz. The barite was clearly deposited after galena.

33A/377 Transmitted Light

c. Intricately banded silica, with the opaque (galena) conforming to the colloform outlines.

32/289 Transmitted Light

FIGURE 4.10

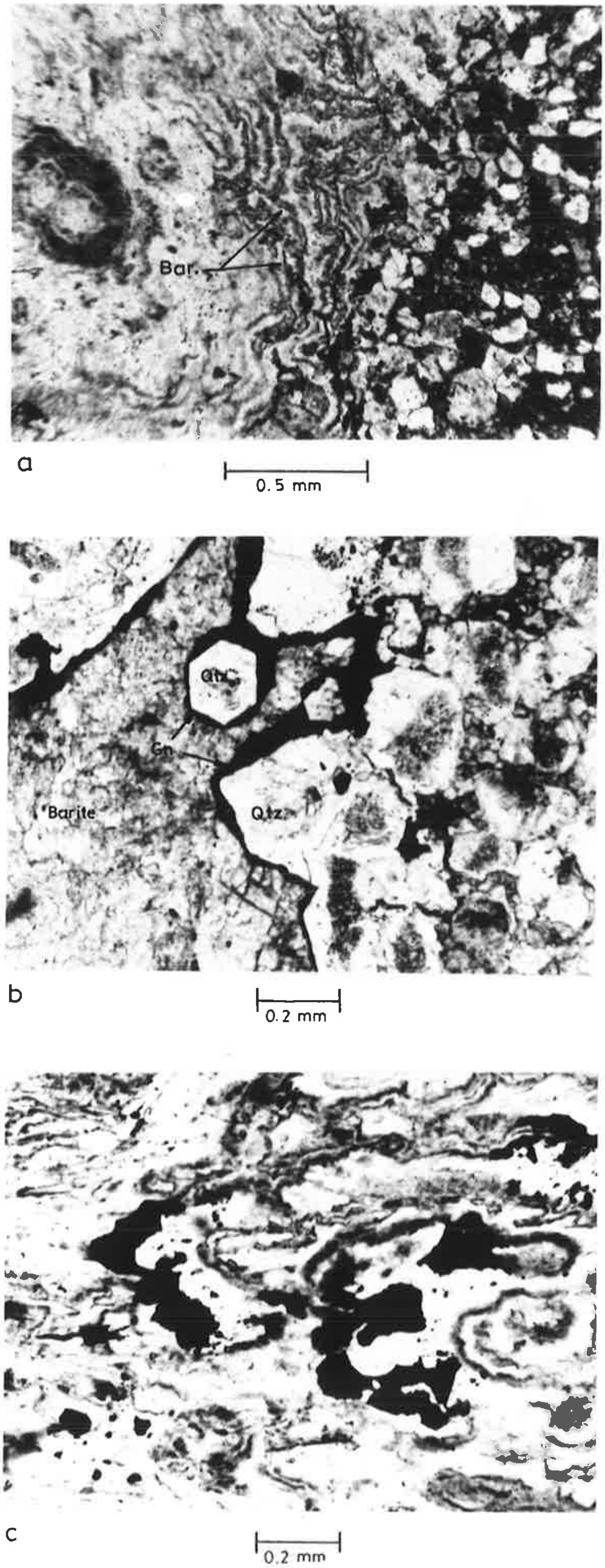


FIGURE 4.11

a. Euhedral and colloform sulphides in a matrix of galena and sphalerite. Euhedral pyrite is fractured and filled with chalcopyrite and sphalerite.

32/337 Reflected Light

b. Euhedral pyrite developed around colloform sulphides (pyrite and chalcopyrite).

32/337 Reflected Light

galena - blue white
pyrite - cream
chalcopyrite - yellow
sphalerite - medium grey
gangue - black

FIGURE 4.11

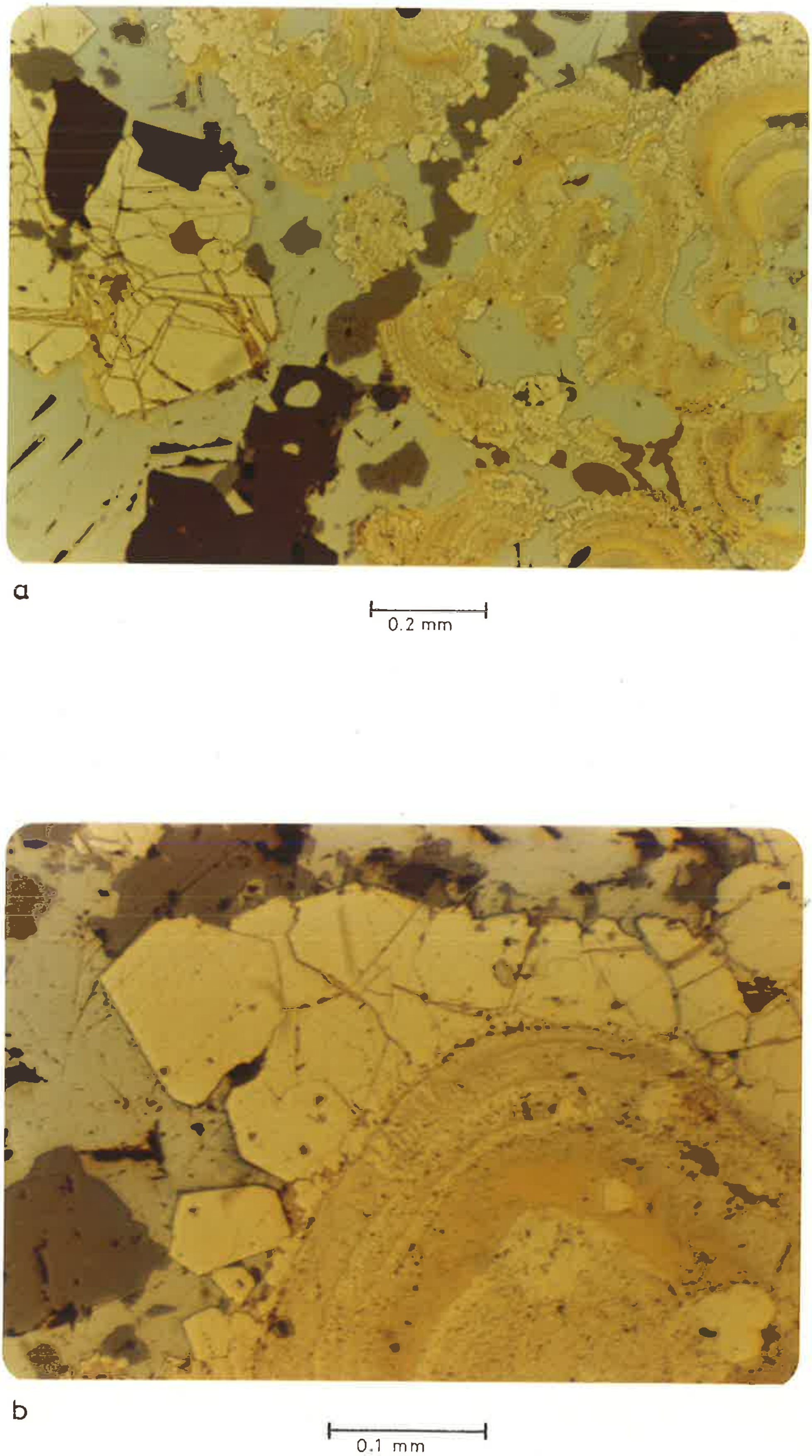


FIGURE 4.12

a. A large euhedral pyrite grain growing through very delicately colloform banded pyrite and chalcopyrite.

32/337 Reflected Light

b. Colloform and euhedral sulphides in a matrix of galena and sphalerite. Notice the abrupt termination of the colloform bands, indicating corrosion by later solutions.

32/337 Reflected Light

galena - blue white
pyrite - cream
chalcopyrite - yellow
sphalerite - medium grey
gangue - black

FIGURE 4.12

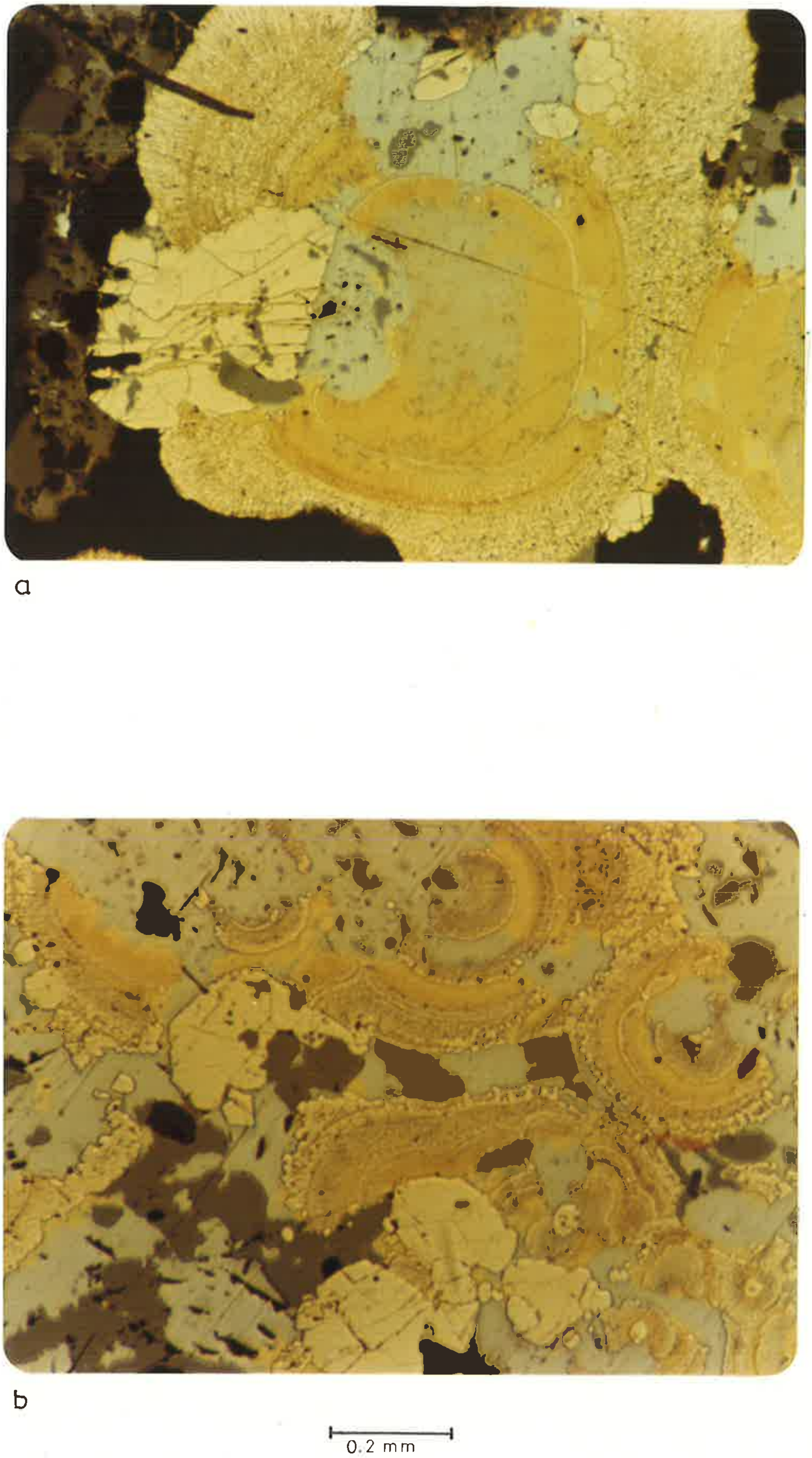


FIGURE 4.13

a. A thin stylolitic seam containing colloform and euhedral sulphides (py and cpy) in a matrix of galena, sphalerite and tetrahedrite (lighter grey than sphalerite). Blebs of sphalerite also occur scattered through the dolomite. Note the oolitic-like texture developed in places.

32/337 Reflected Light

b. Very well developed colloform pyrite and chalcopyrite, with minor euhedral pyrite, in a matrix of galena and sphalerite. The discontinuous nature of the colloform bands is very apparent. Some pyrite bands consist of euhedral crystals.

32/337 Reflected Light

galena - blue white
pyrite - cream
chalcopyrite - yellow
sphalerite - medium grey
gangue - black

FIGURE 4.13

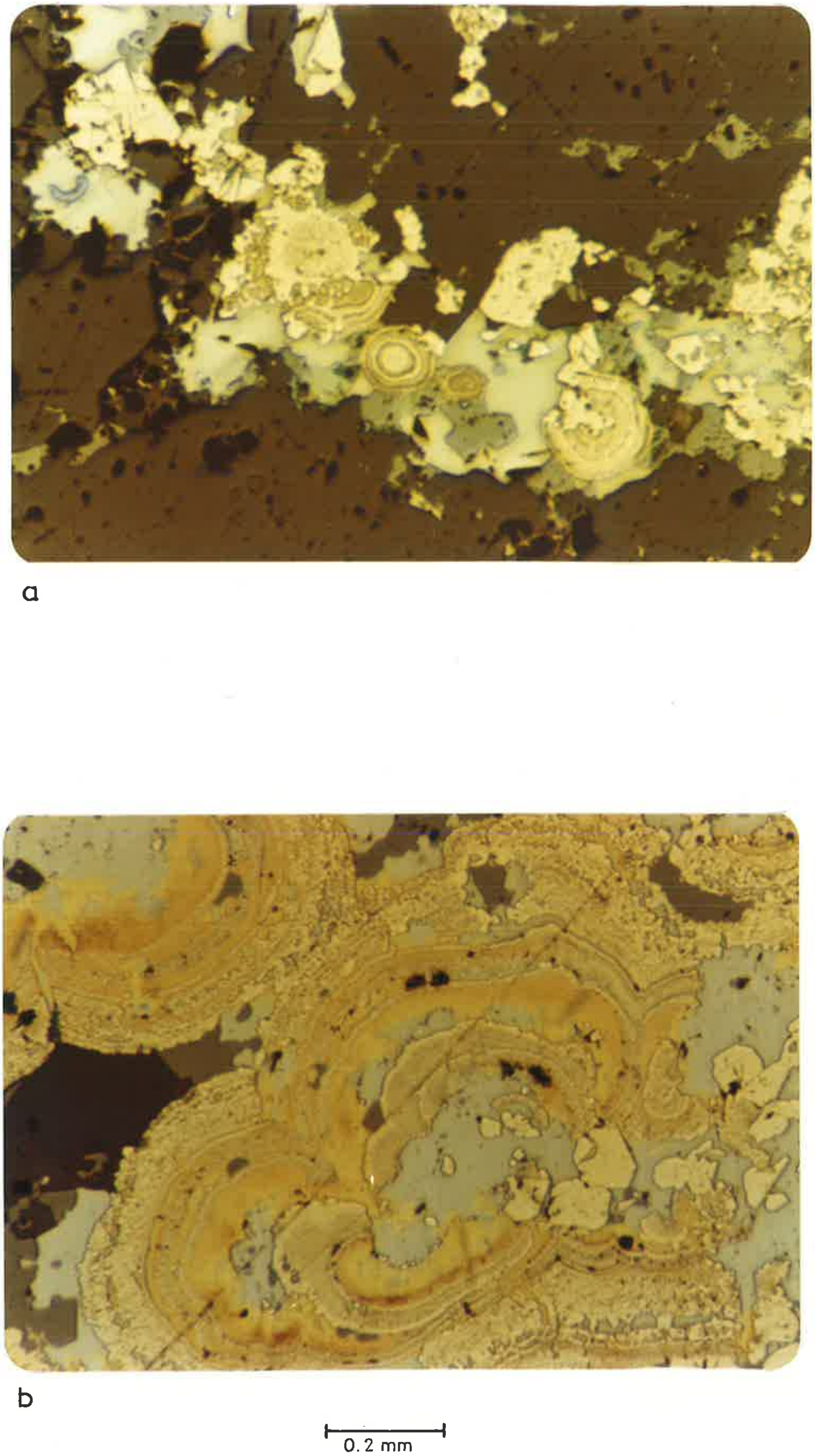


FIGURE 4.14

a. Colloform silica, with bands of galena and sphalerite.

32/337 Transmitted Light

b. Colloform pyrite, coated by silica, forming around dolomite blocks.

32/257 Transmitted Light

c. Colloform sphalerite and galena filling cavities. Galena white; sphalerite light grey.

33A/116 Reflected Light

d. Colloform sphalerite in galena.

33A/116 Reflected Light

FIGURE 4.14

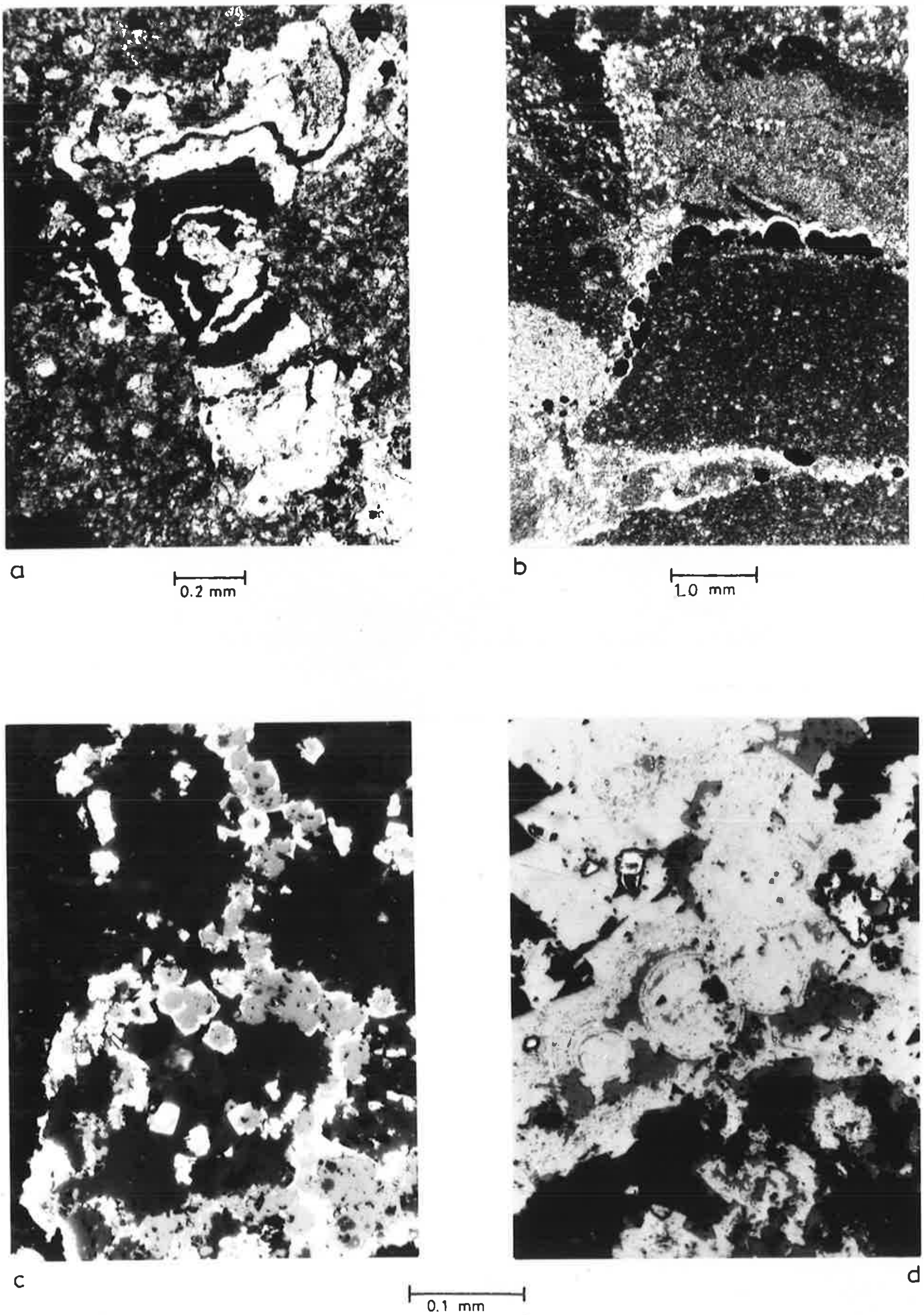


FIGURE 4.15

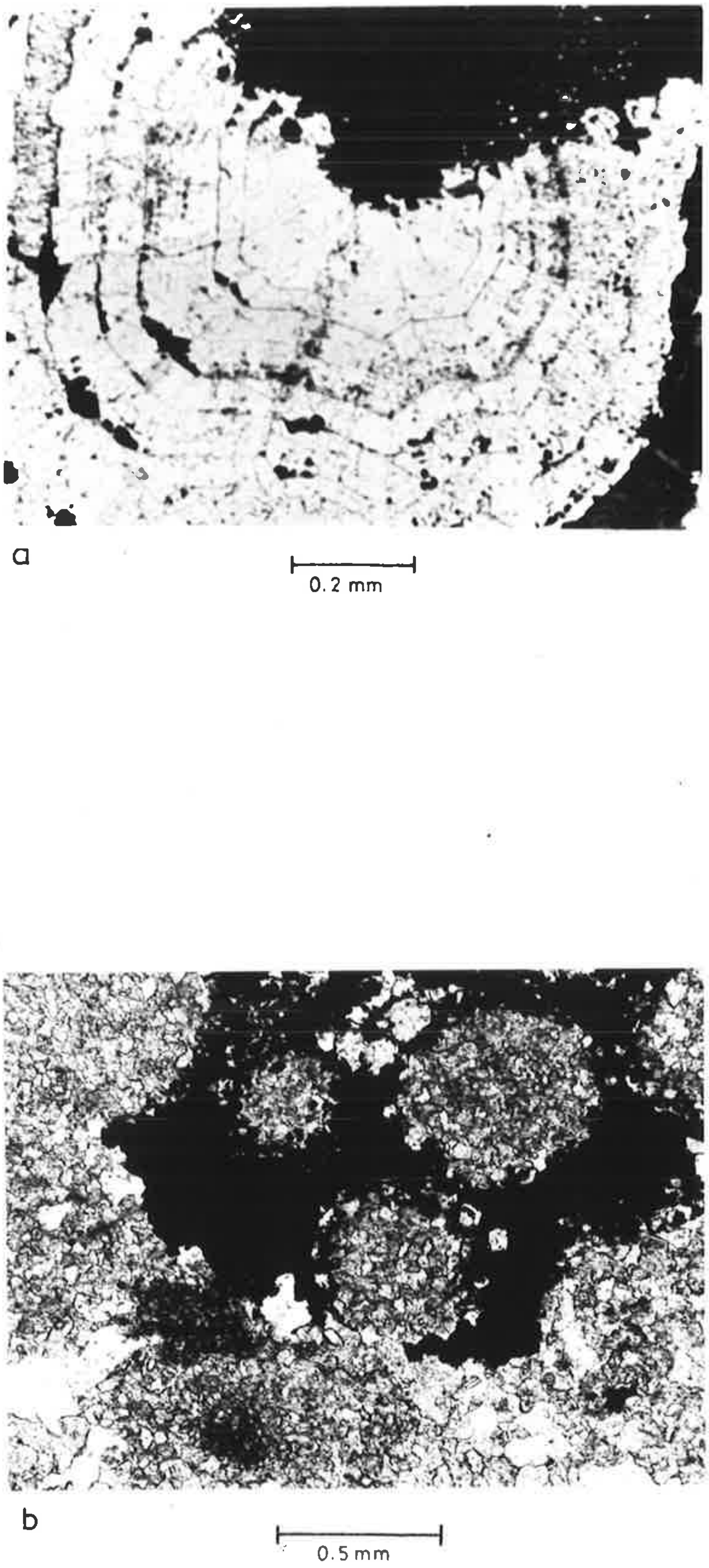
a. Coarse grained pyrite showing growth zoning.

33A/179 Reflected Light

b. Pyrite filling possible voids around oolites. The pyrite appears to be replacing the dolomite.

33A/426 Transmitted Light

FIGURE 4.15



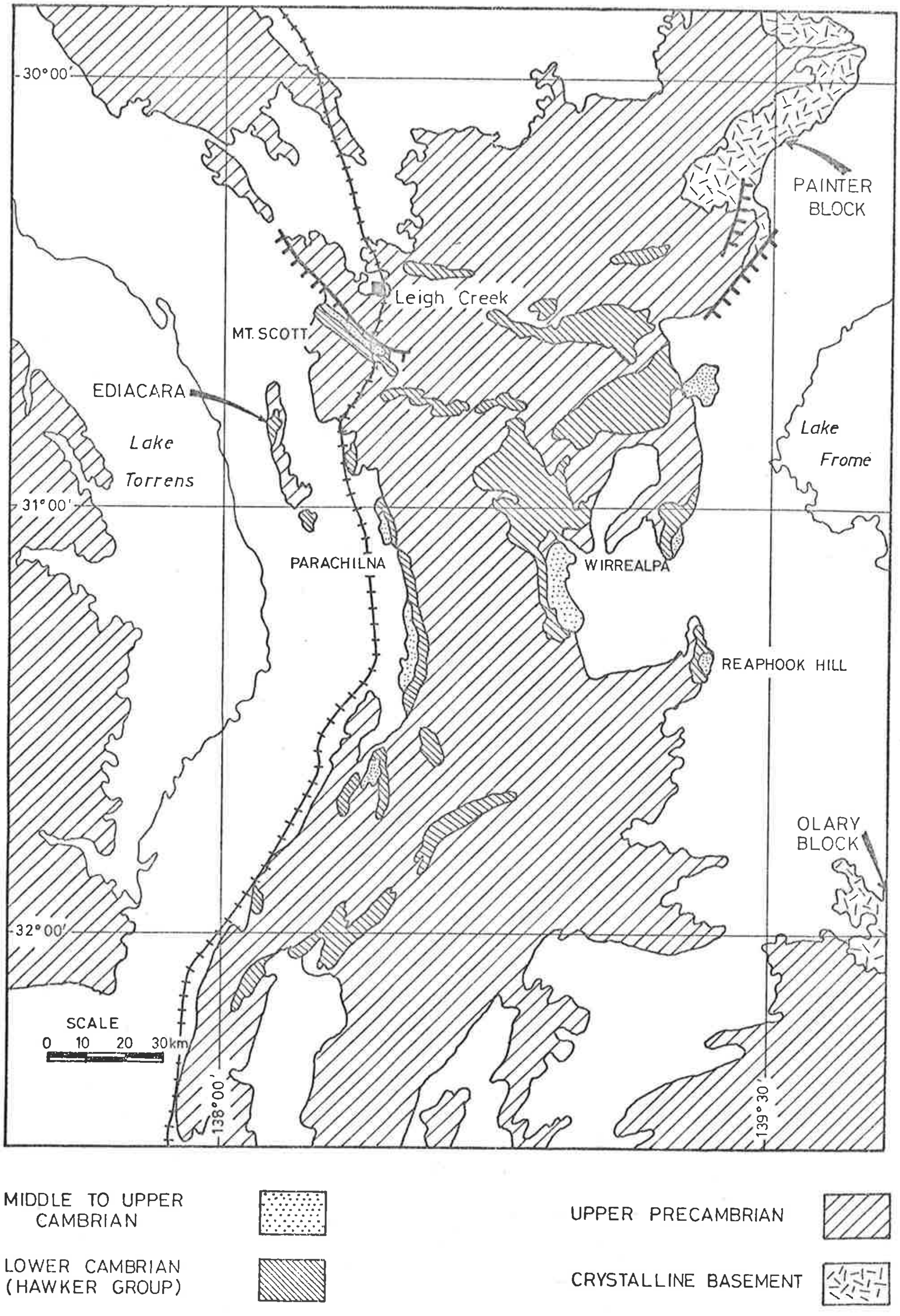


FIGURE 5.1 CAMBRIAN SEDIMENTS IN THE ADELAIDE GEOSYNCLINE (After Wopfner, 1968)

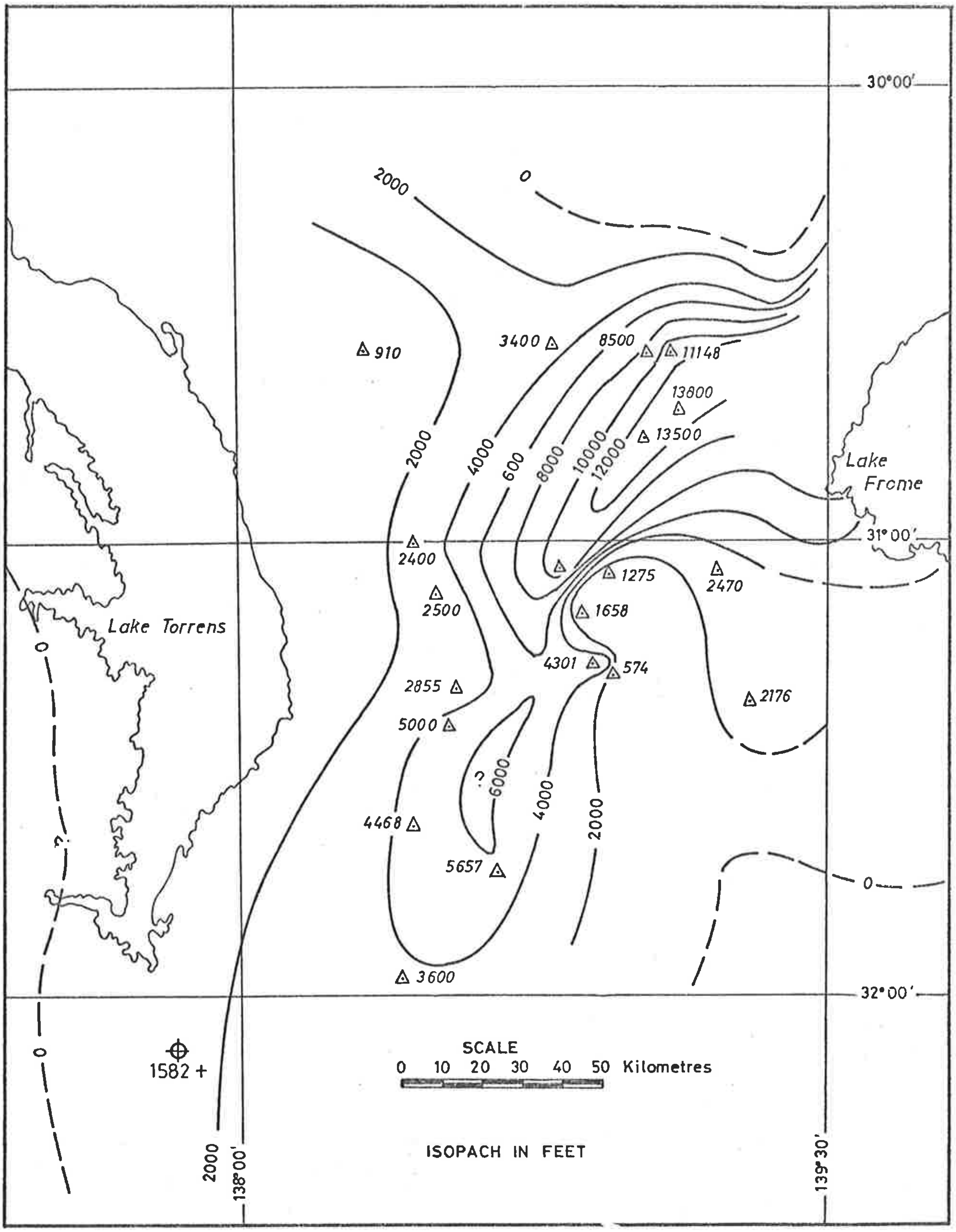


FIGURE 5.2 – ISOPACH MAP OF HAWKER GROUP – LOWER CAMBRIAN
(After Wopfner, 1968)

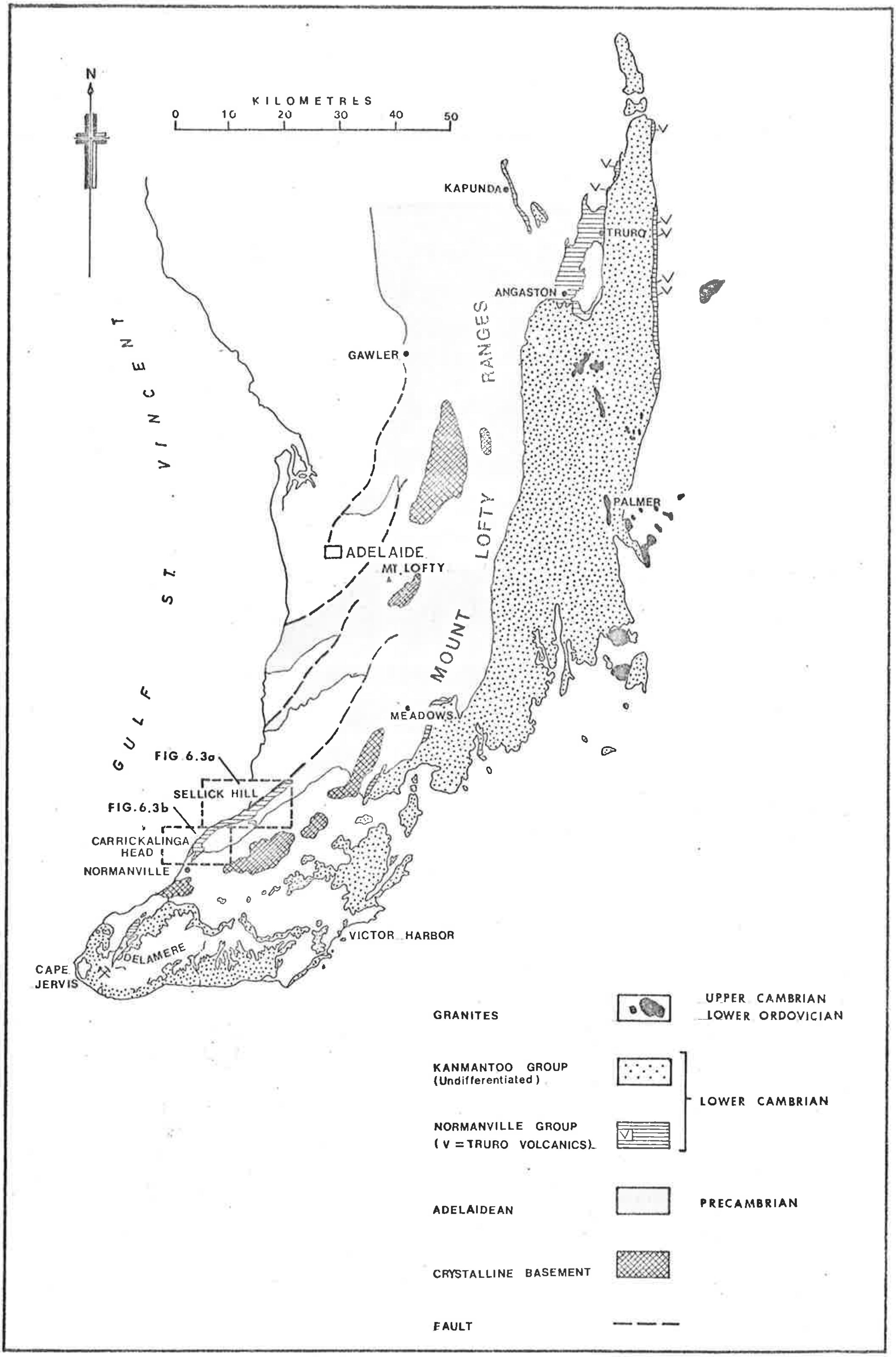


FIGURE 5.3 THE DISTRIBUTION OF THE NORMANVILLE GROUP SEDIMENTS
(After Daily, Firman, Forbes & Lindsay, 1976)

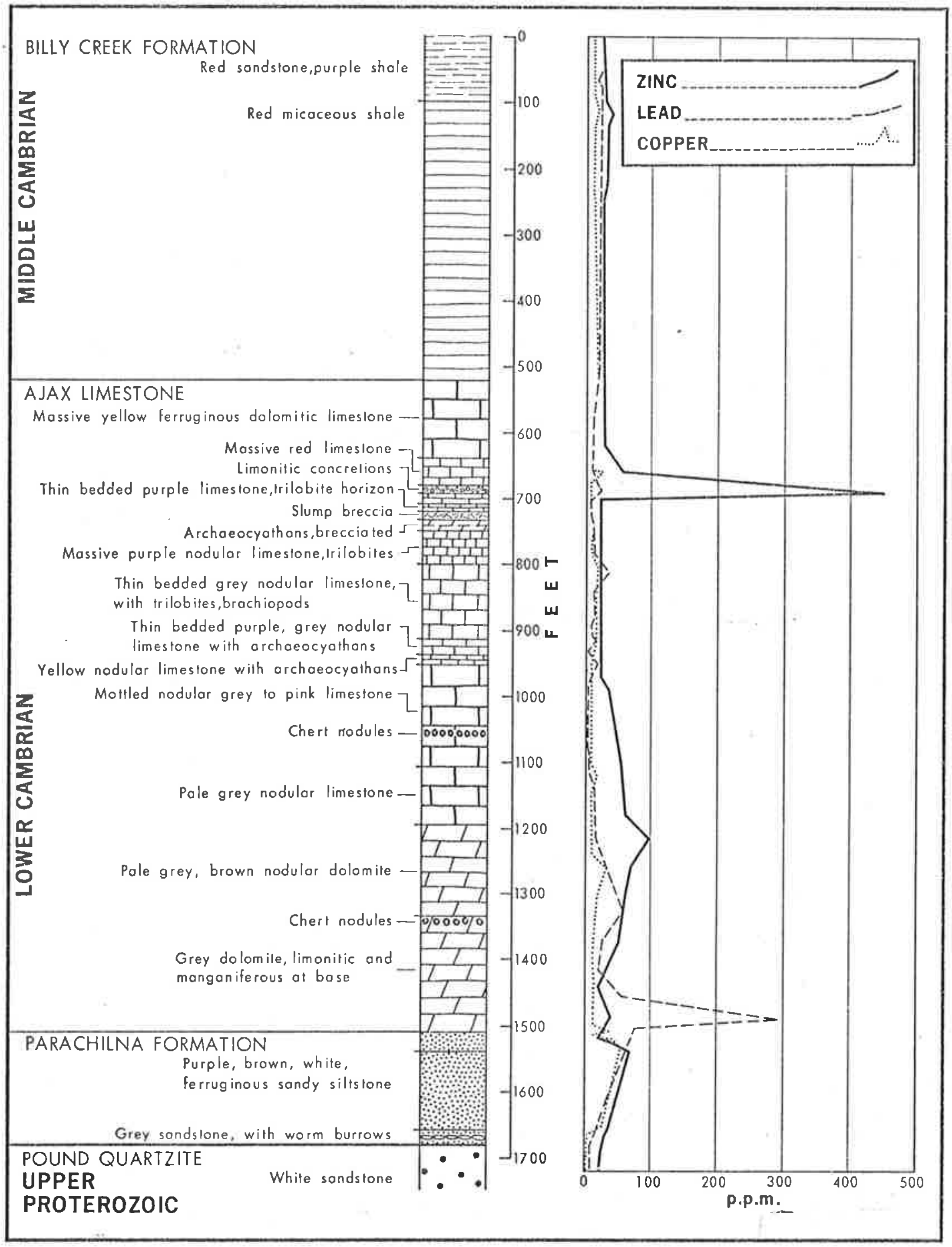


FIGURE 5.4 MOUNT SCOTT, GEOCHEMICAL SECTION (from Johns, 1972)

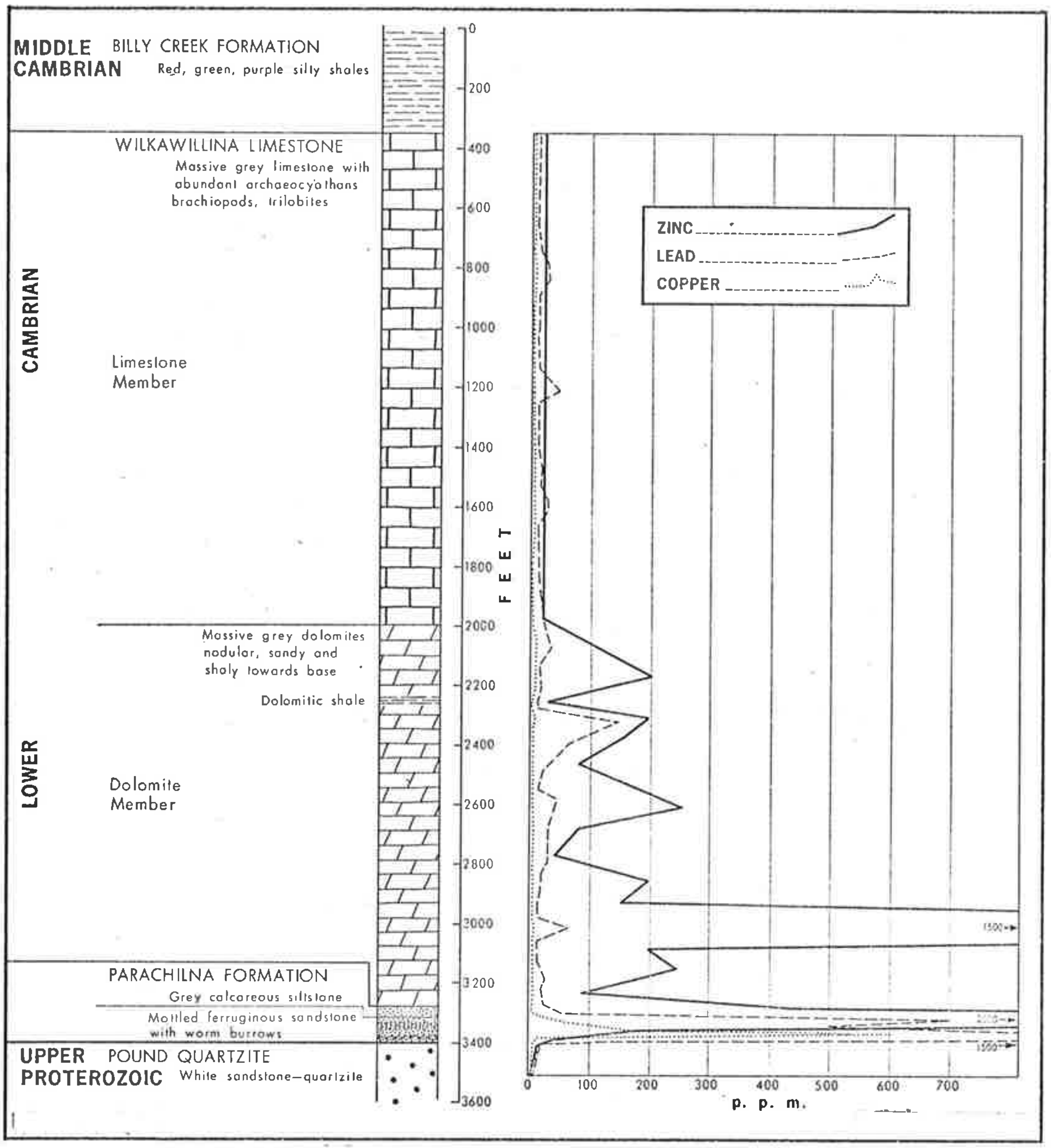


FIGURE 5.5 BRACHINA GORGE, GEOCHEMICAL SECTION (from Johns, 1972)

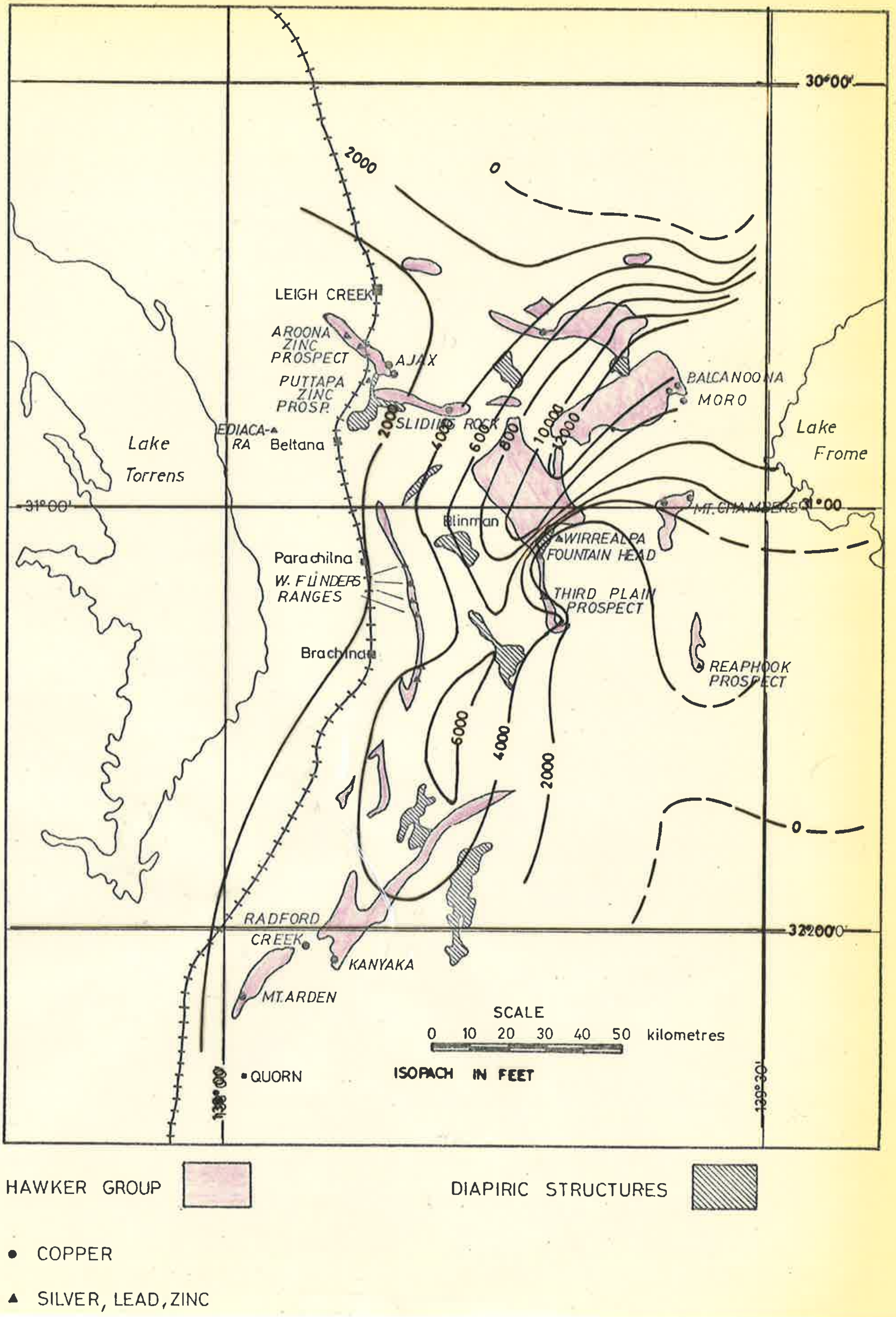
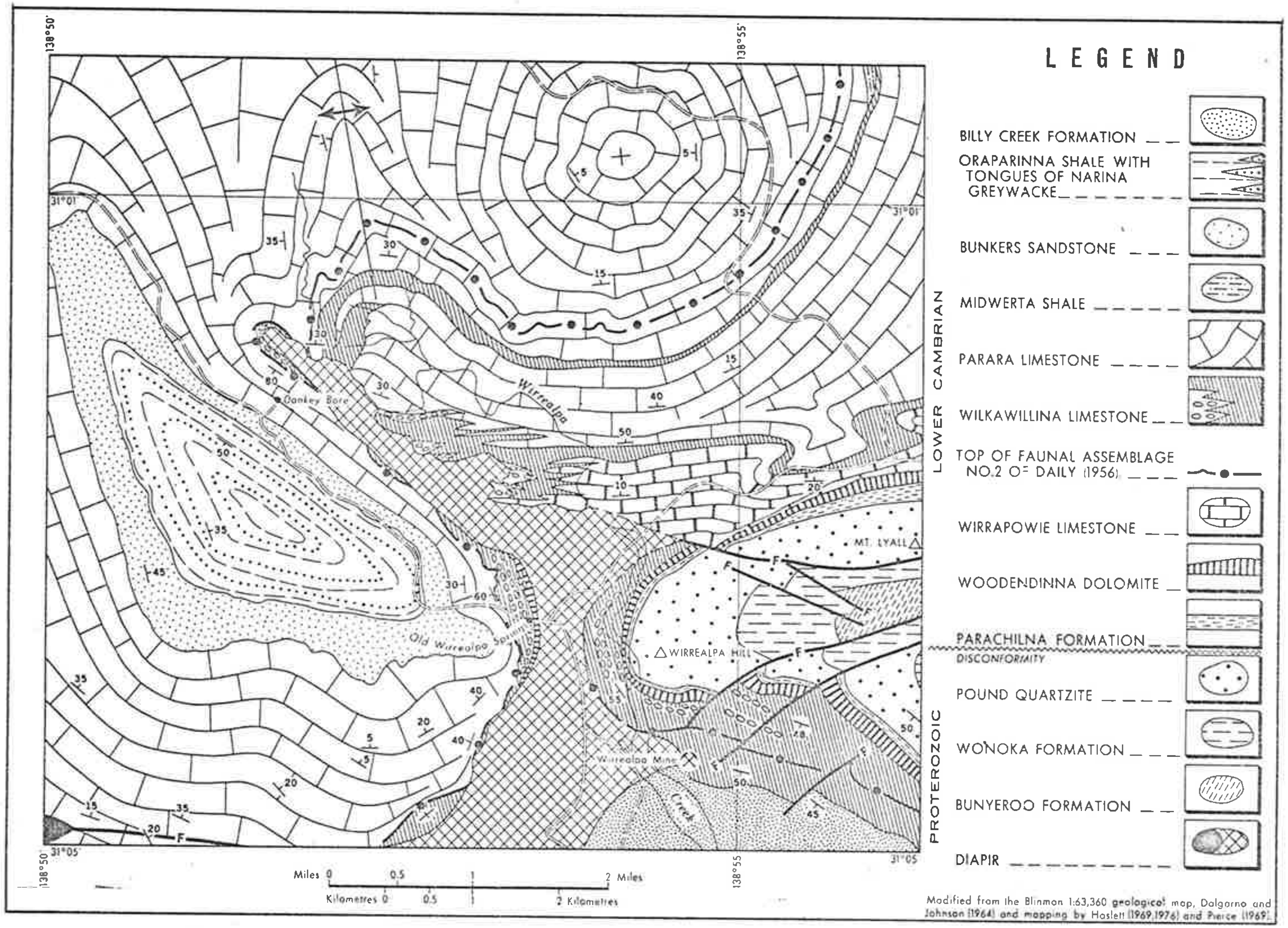


FIGURE 5.6 Cu, Pb & Zn MINERALISATION IN LOWER CAMBRIAN SEDIMENTS (After Johns, 1971)



Modified from the Blinman 1:63,360 geological map, Dalgarno and Johnson (1964) and mapping by Haslett (1969,1976) and Pierce (1969).

FIGURE 6.1 GEOLOGY IN THE VICINITY OF THE WIRREALPA MINE (from DAILY, 1976)

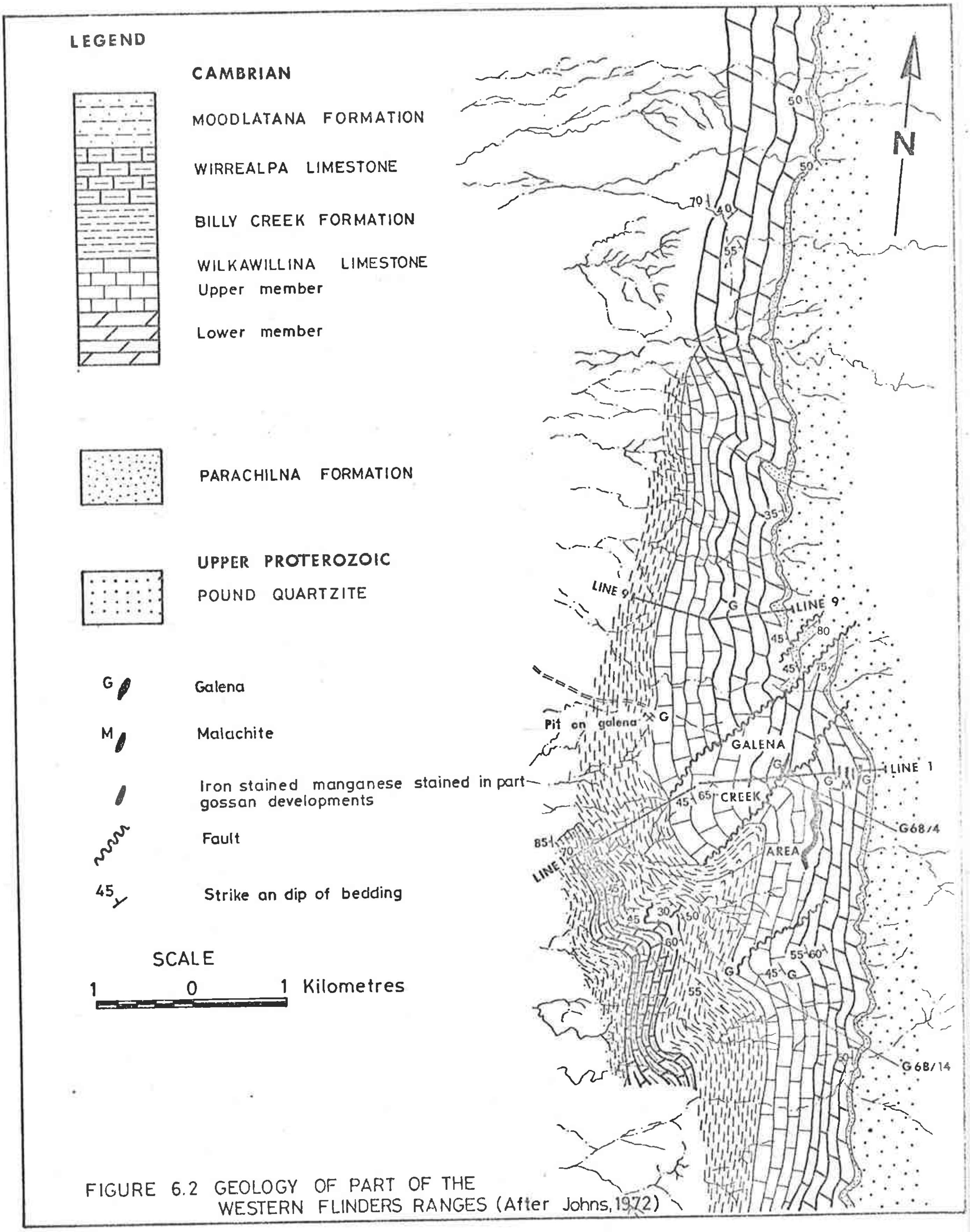


FIGURE 6.2 GEOLOGY OF PART OF THE WESTERN FLINDERS RANGES (After Johns, 1972)

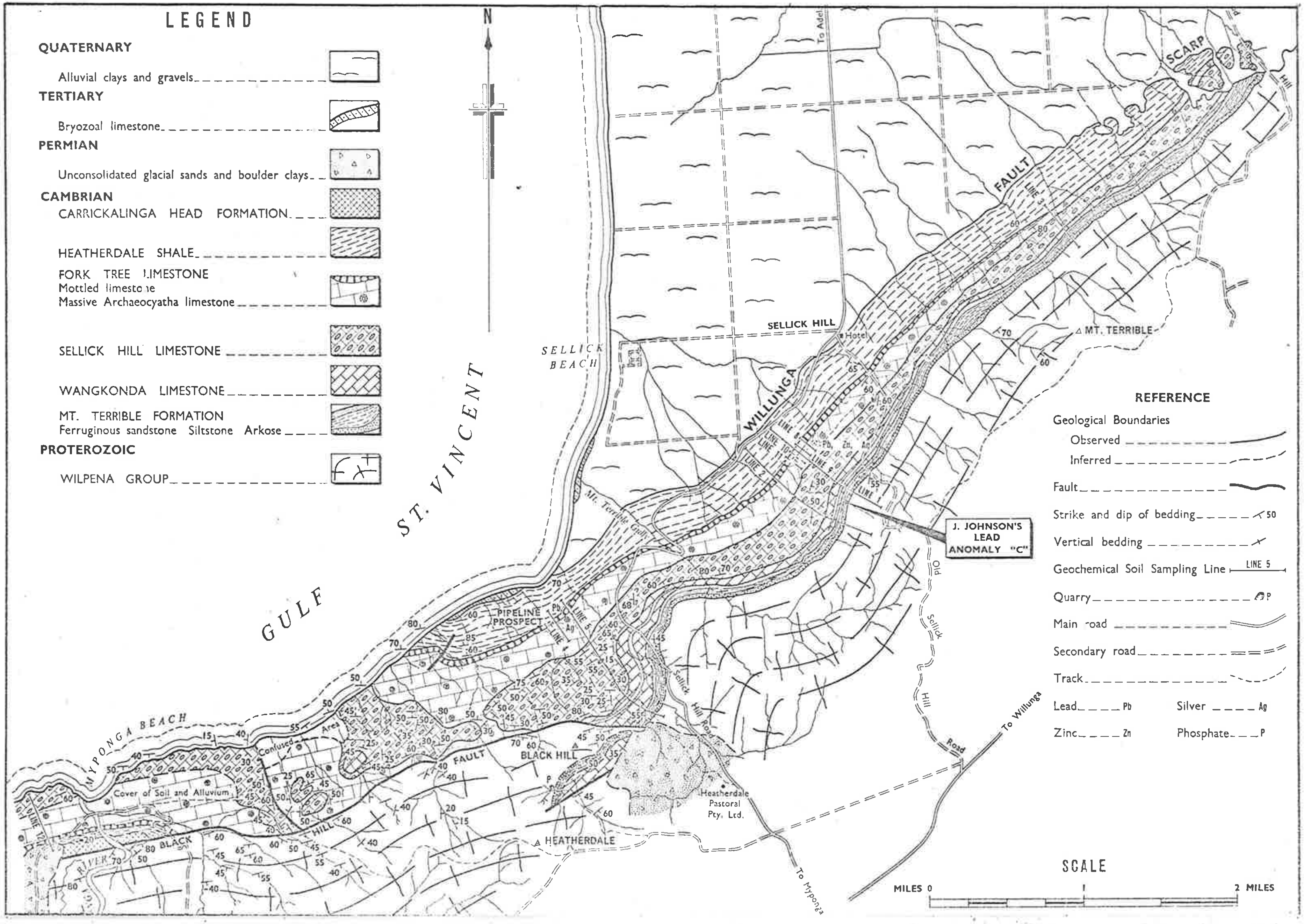


FIGURE 6.3a GEOLOGY OF THE SELLICK HILL AREA (from Wright, 1968b)

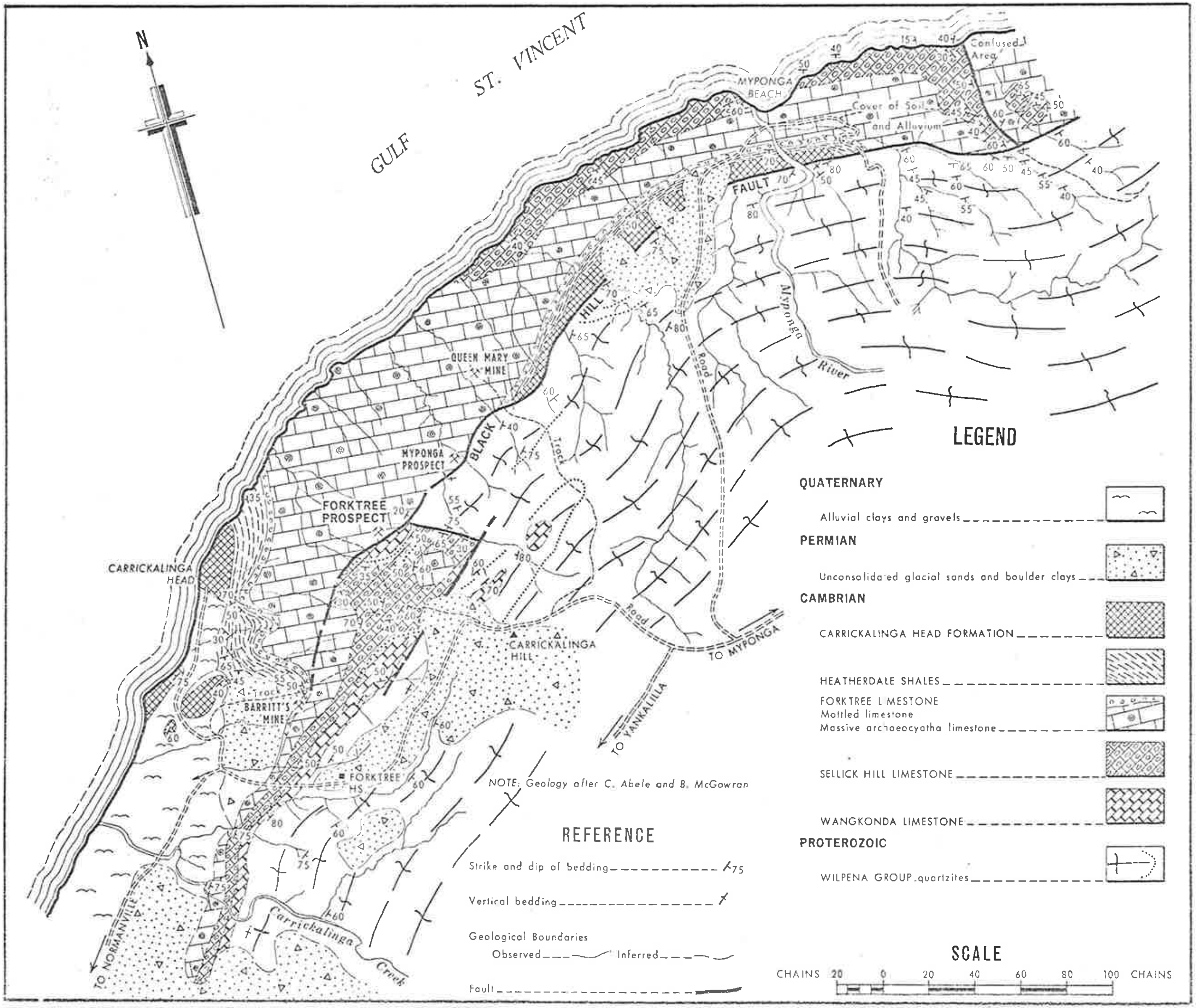


FIGURE 6.3b GEOLOGY OF THE SELLICK HILL AREA (from Wright, 1968b)

FIGURE 6.4

a. Coarse grained galena, coated with barite, in brecciated dolomitic limestone.

Wirrealpa Mine.

b. Lens of coarse grained galena (Gn) and calcite, showing contact with mottled limestone. Fragments of the limestone are visible in the lens.

Pipeline Prospect.

FIGURE 6.4

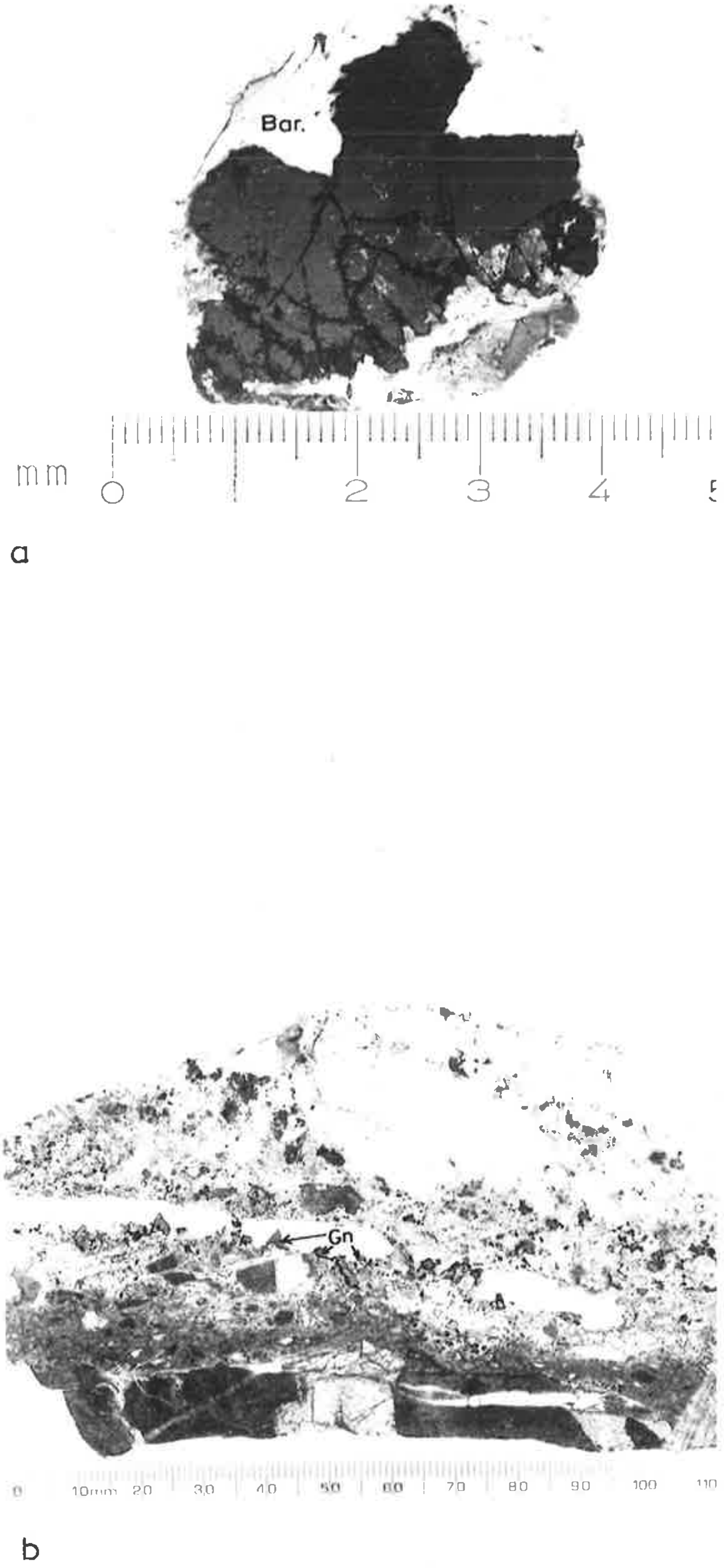


FIGURE 6.5

a. Coarse grained galena (Gn) & euhedral quartz cementing blocks of porous limestone. Numerous cavities present.

B_1 Barritt's Mine.

b. Coarse grained calcite with minor quartz and sphalerite (Sp) cementing dark laminated shale blocks.

B_2 Barritt's Mine.

c. Coarse patch of galena and sphalerite in euhedral quartz and calcite. Growth zoning is present in the quartz, in the lower right.

B_2 Barritt's Mine.

FIGURE 6.5

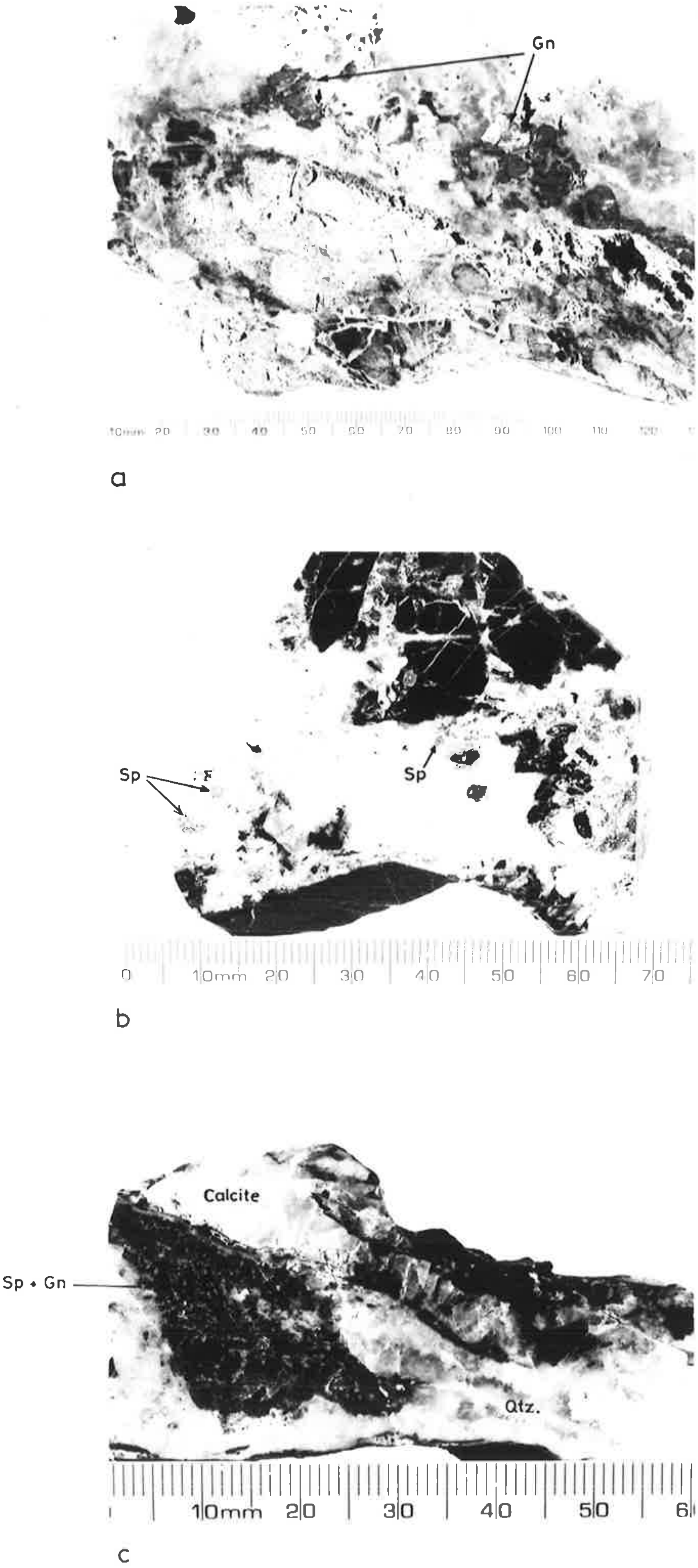

Gn
Gn
10mm 20 30 40 50 60 70 80 90 100 110 120
a
Sp
Sp
0 10mm 20 30 40 50 60 70
b
Calcite
Sp + Gn
Qtz.
10mm 20 30 40 50 6
c

FIGURE 6.6

a. A matrix of predominantly quartz, with minor calcite and galena (Gn) cementing dark shale fragments. The quartz crystals form a comb structure around the fragments in places (bottom of photo).

B_4 Barritt's Mine.

b. As above. Cement also contains sphalerite and shale block in upper left contains blebs of sulphide.

B_5 Barritt's Mine.

c. Archaeocyatha limestone containing galena along veins and stylolites.

B_6 Barritt's Mine.

FIGURE 6.6

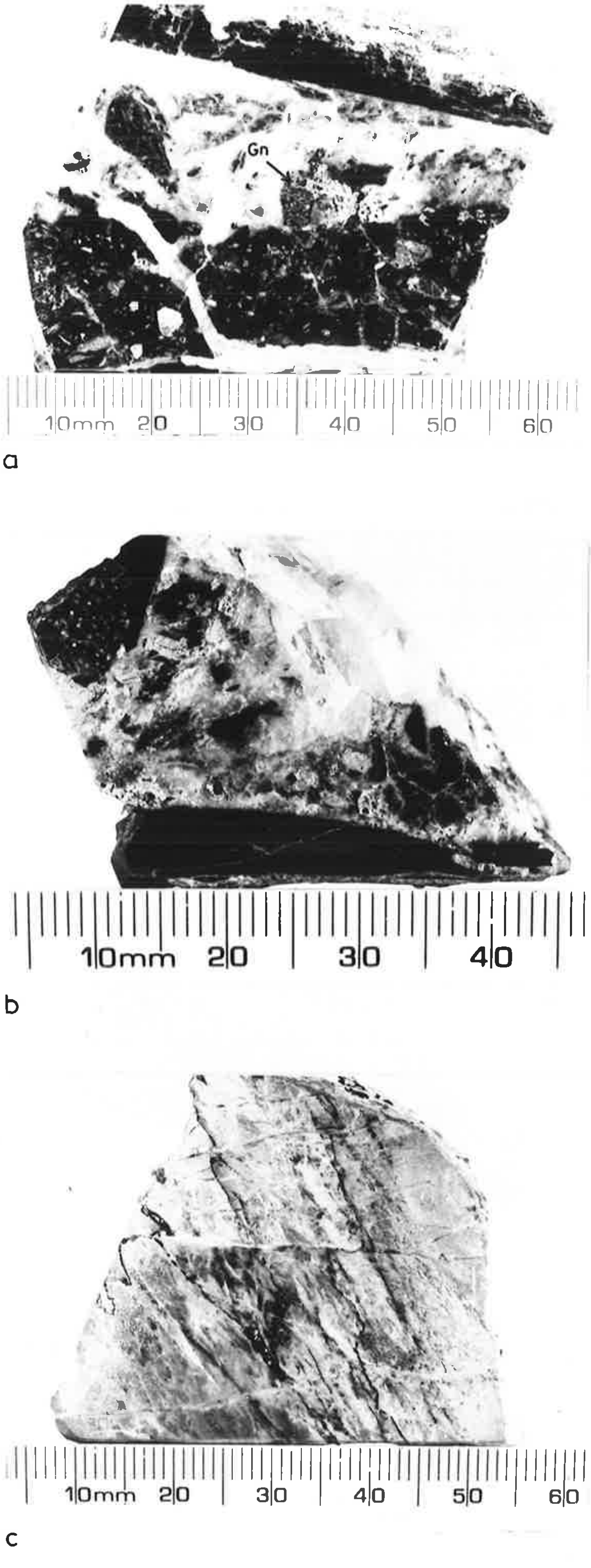


FIGURE 6.7

a. Framboidal pyrite in sphalerite. This is part of a large euhedral pyrite grain.

S_3 Reflected Light

b. Coating of elongate quartz crystals on a shale fragment, with later sphalerite being deposited on the quartz.

B_3 Reflected Light

c. Galena and quartz replacing? sphalerite along cleavage.

B_3 Reflected Light

d. "Blades" of sphalerite orientated in galena.

B_3 Reflected Light

FIGURE 6.7

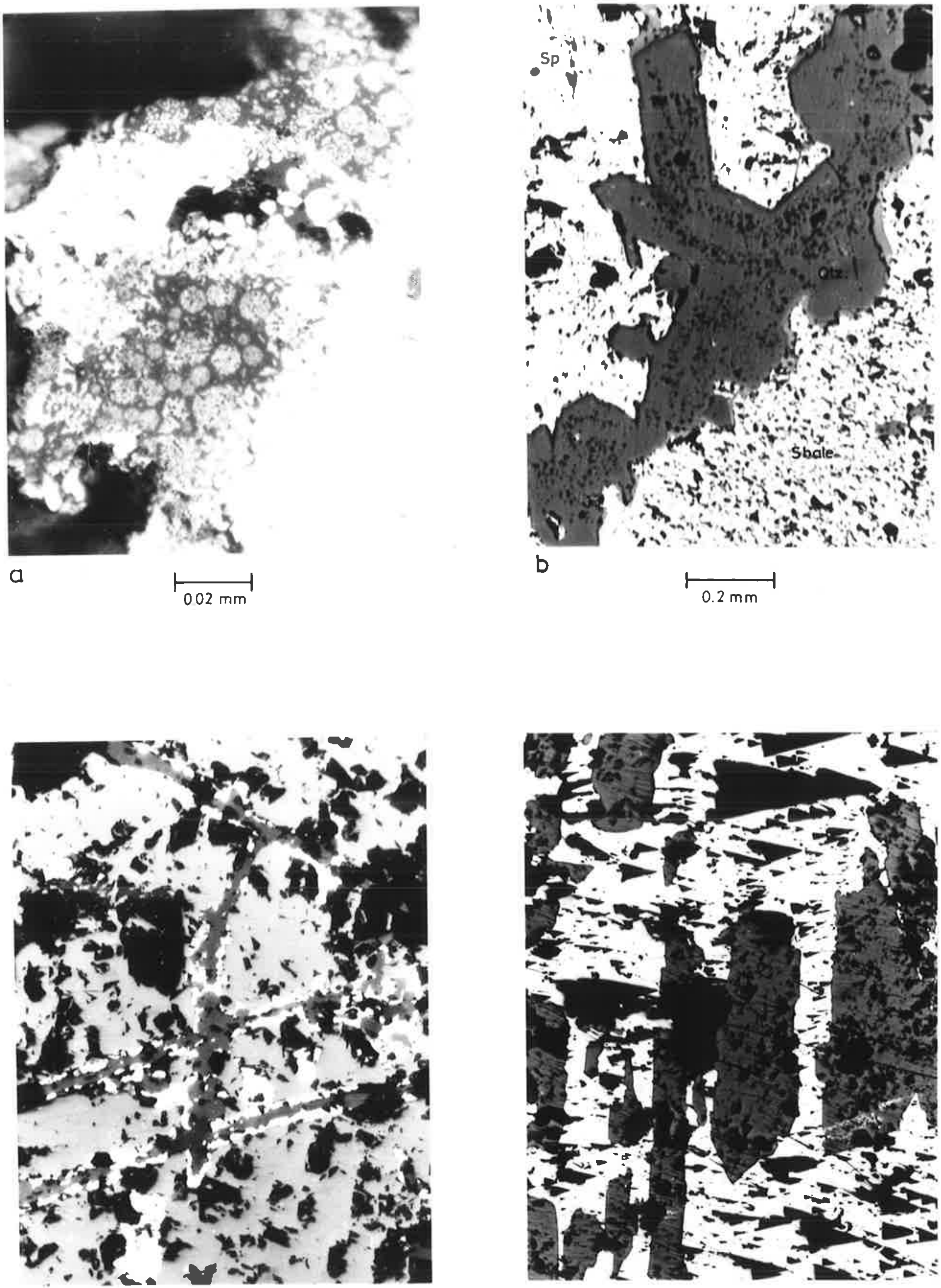


FIGURE 7.1

EXAMPLES OF TYPE 1 INCLUSIONS IN SILICA - EDIACARA

These are large two phase inclusions showing a variable "vapour : liquid ratio". Many solid inclusions (with very low relief) and disseminated inclusions of sulphides are present.

a. 32/337

b. 32/337

c. 32/337

d. 32/289

FIGURE 7.1

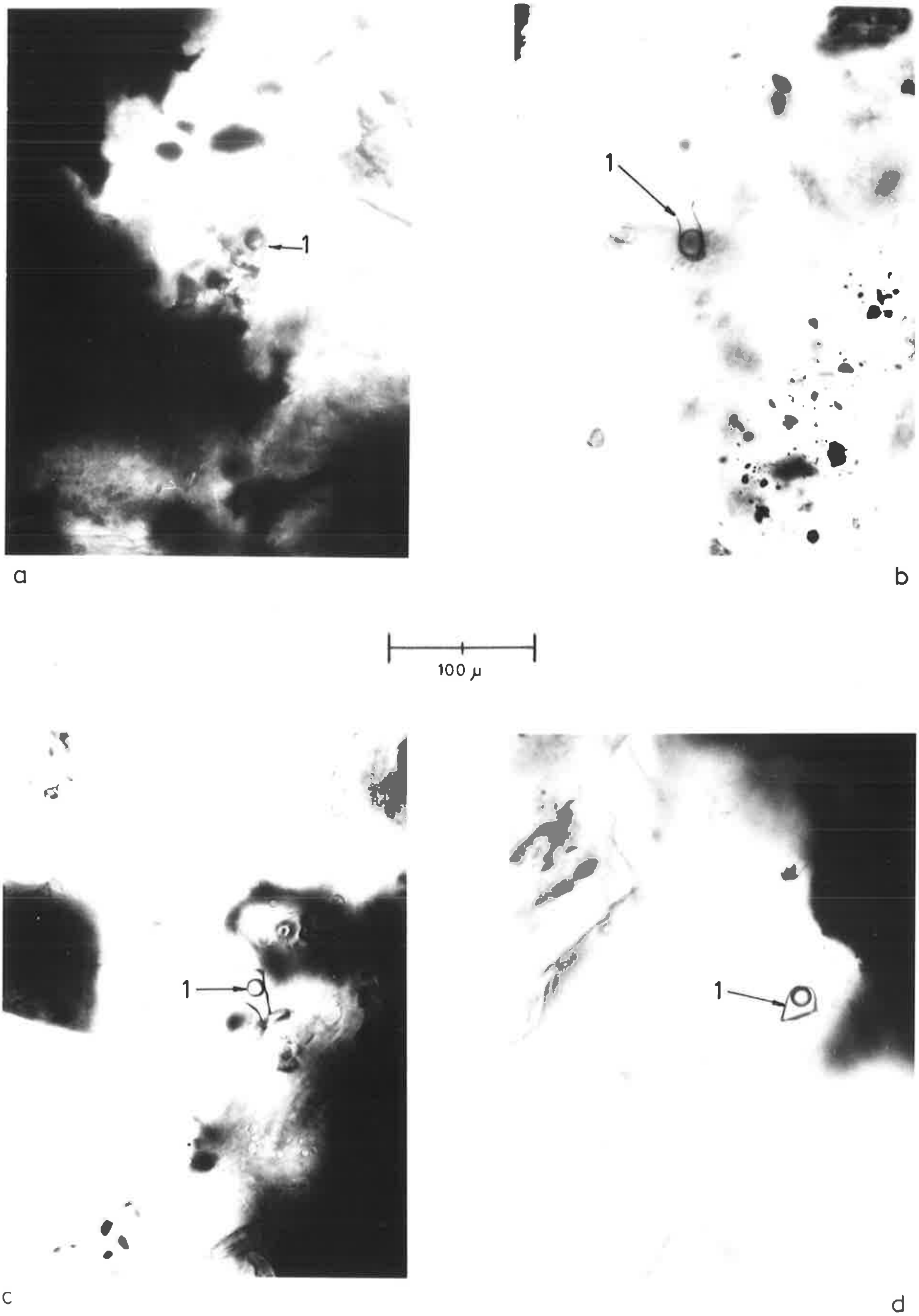


FIGURE 7.2

EXAMPLES OF TYPE II INCLUSION IN SILICA - EDIACARA

a. One prominent Type II inclusion (2). Also shown are several large, completely gas filled inclusions (a) and solid inclusions (b).

32/337

b. Many Type II inclusions (2), showing a constant "vapour:liquid ratio".

10/174

c. One prominent Type II inclusion (2), with several solid inclusions, including sulphides.

32/289

d. Type II inclusions (2) in silica.

Figure 7.2

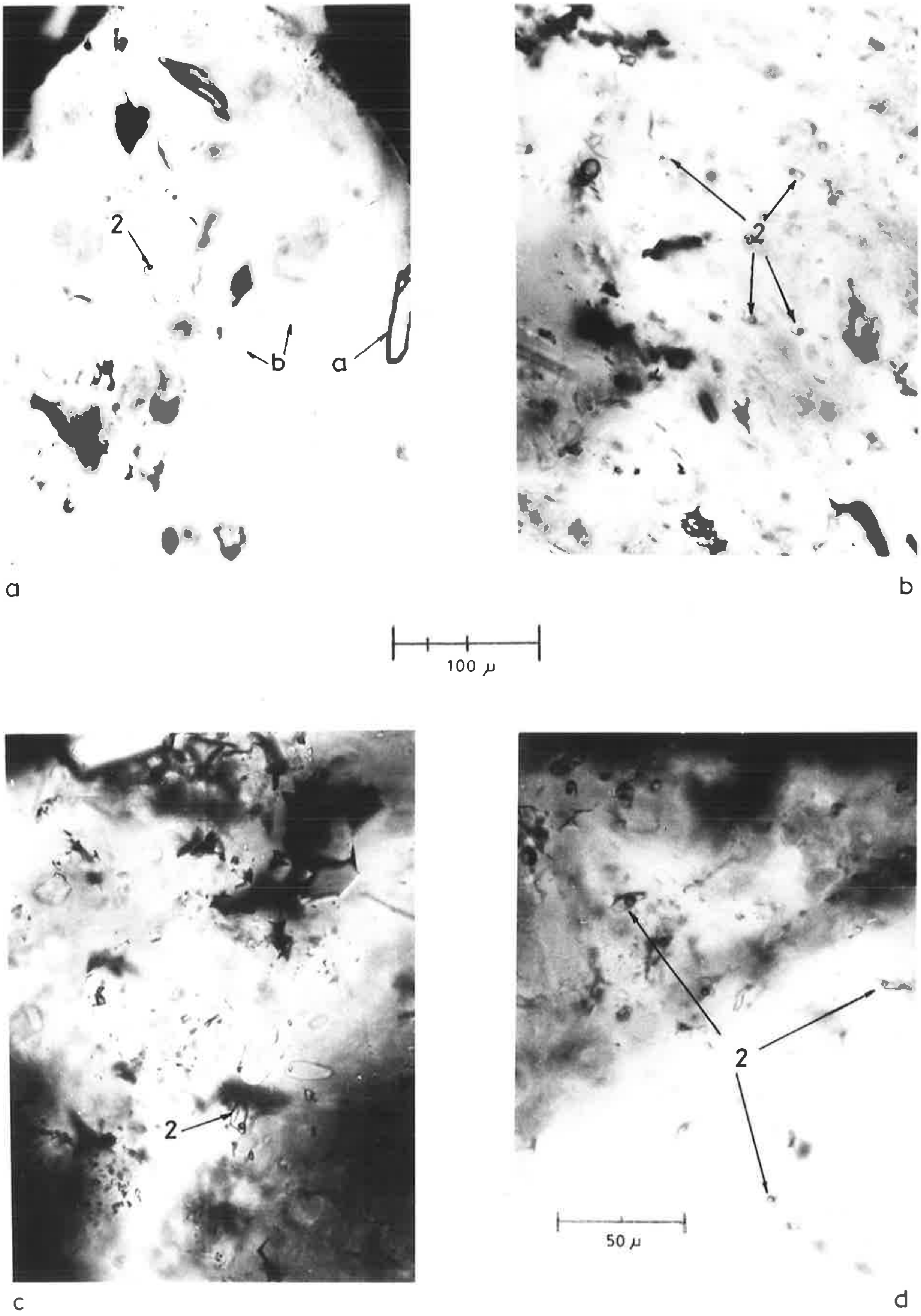


FIGURE 7.3

EXAMPLES OF INCLUSIONS IN DOLOMITE - EDIACARA

a. Secondary two phase inclusions cutting across crystal faces in dolomite.

32/281

b. Rare primary two phase inclusion in dolomite.

33A/179

FIGURE 7.3

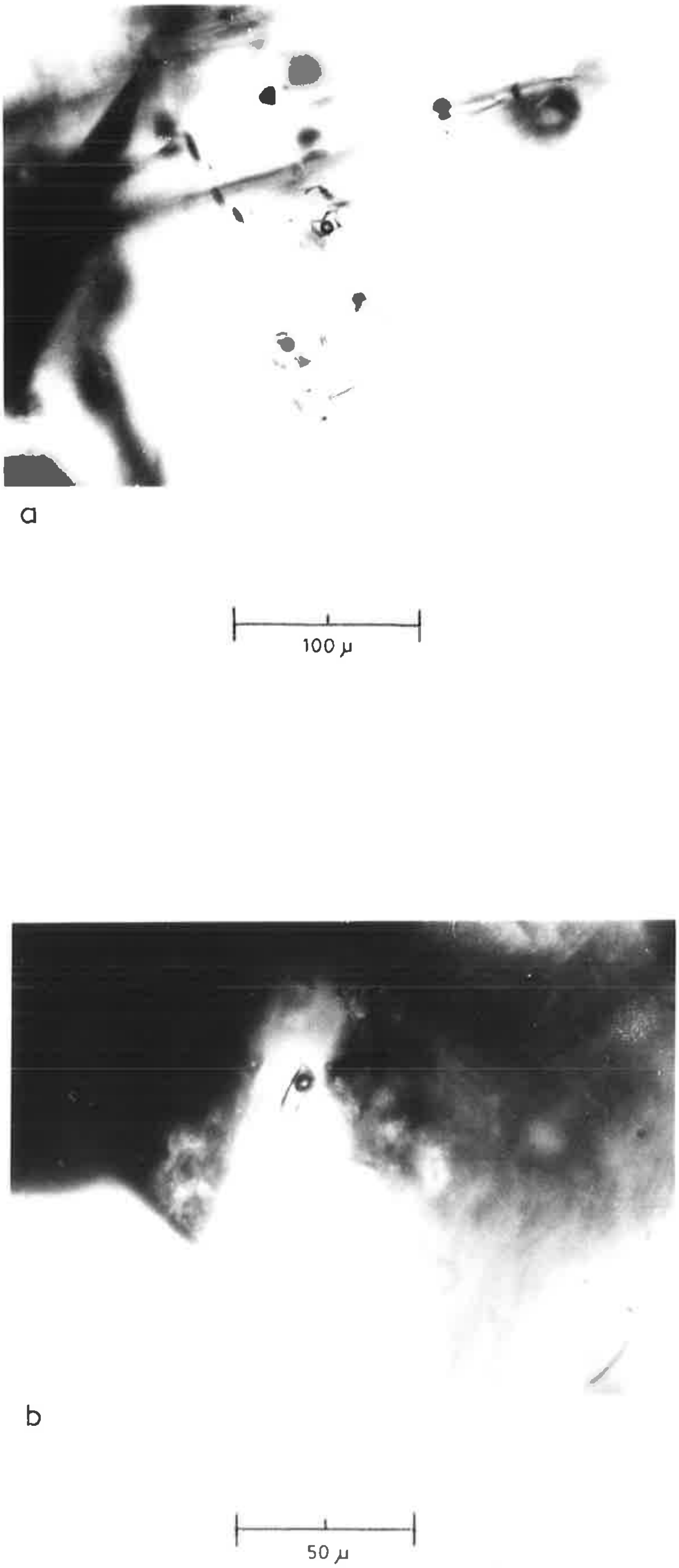


FIGURE 7.4

EXAMPLES OF FLUID INCLUSIONS - SELLICK HILL AREA

a. Large two phase inclusions parallel to colour banding in sphalerite (primary inclusions).

B_2 Barritt's Mine

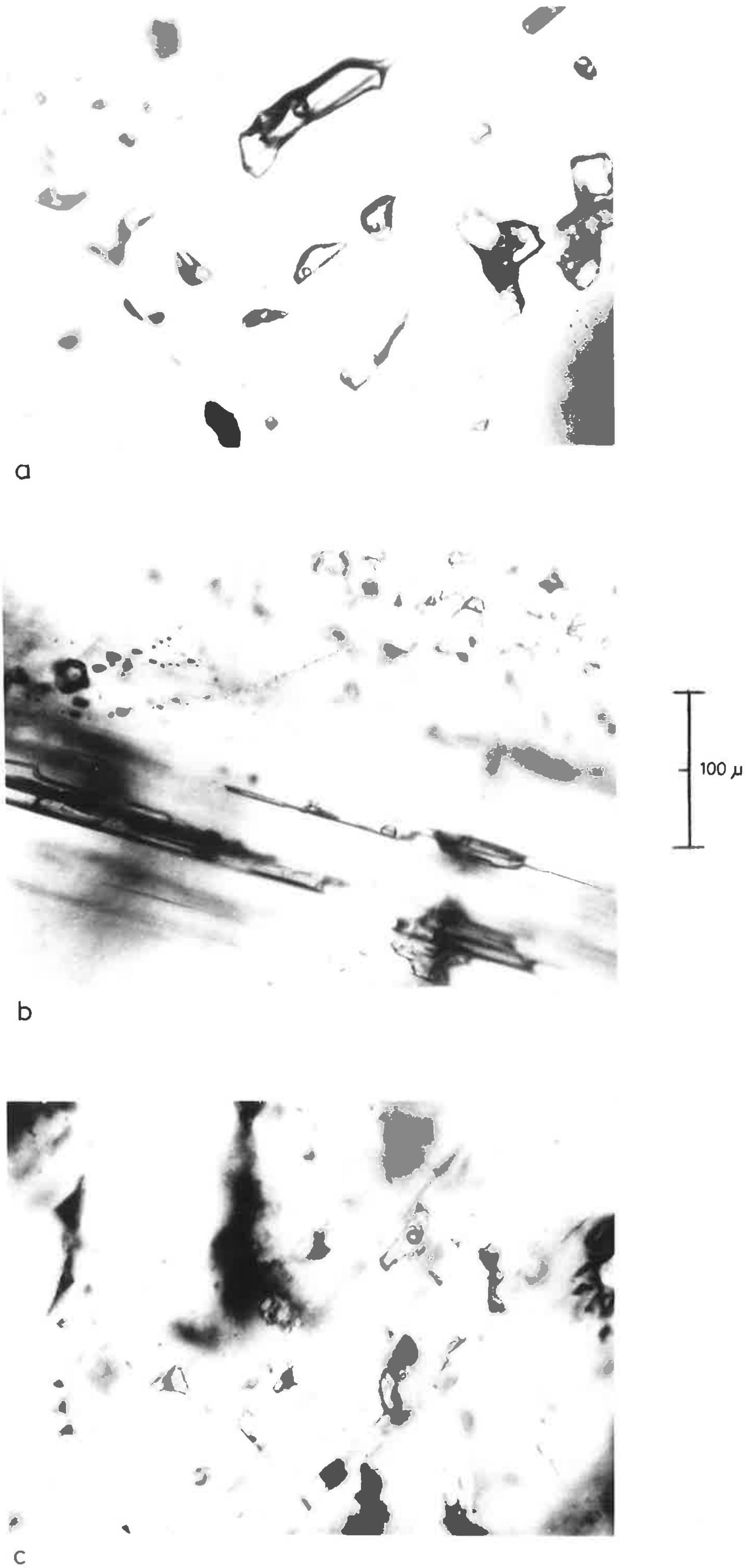
b. Elongate two phase inclusions along cleavage in sphalerite (secondary inclusions).

B_2 Barritt's Mine

c. Two phase inclusions along cleavage in calcite (secondary inclusions).

P_1 Pipeline Prospect

FIGURE 7.4



E. Ediacara - Breccias & Veins

D. Ediacara - Disseminations & Stylolites

C. Ediacara - Pyrite

B. Ediacara - Galena

A. All Samples
(Ediacara and other
localities)

■ Ediacara

◪ Sellick Hill

☒ Wirrealpa and W. Flinders
Ranges

FIGURE 8.1 SUMMARY OF SULPHUR ISOTOPE RESULTS

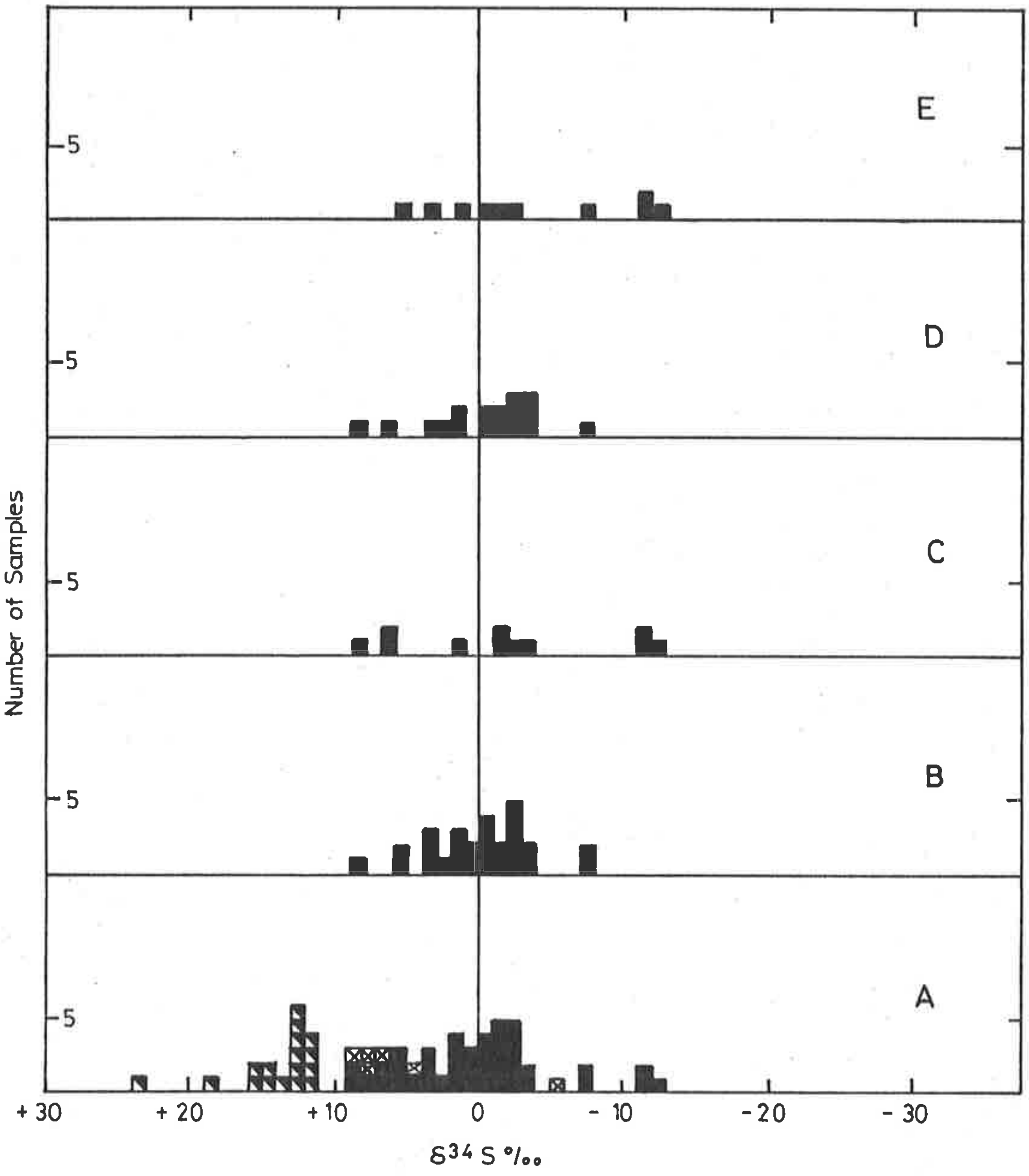


FIGURE 8.1 SUMMARY OF SULPHUR ISOTOPE RESULTS

G. Upper Mississippi Valley District (Pinckney & Rafter, 1972;
Ault & Kulp, 1960)

F. Irish Base Metal Mines (Greig et al; 1971)

E. Northern Pennines (Solomon, Rafter & Dunham; 1971)

D. Pine Point (Sasaki & Krouse; 1969)

C. S.E. Missouri District (Ault & Kulp; 1960)

B. Zambia Copperbelt (Dechow & Jensen; 1965)

A. This Study - all values below +10 are from the Flinders Ranges.
all values above +10 are from the Sellick Hill area.

FIGURE 8.2 COMPARISON OF SULPHUR ISOTOPE DATA FROM THIS STUDY WITH PUBLISHED INFORMATION

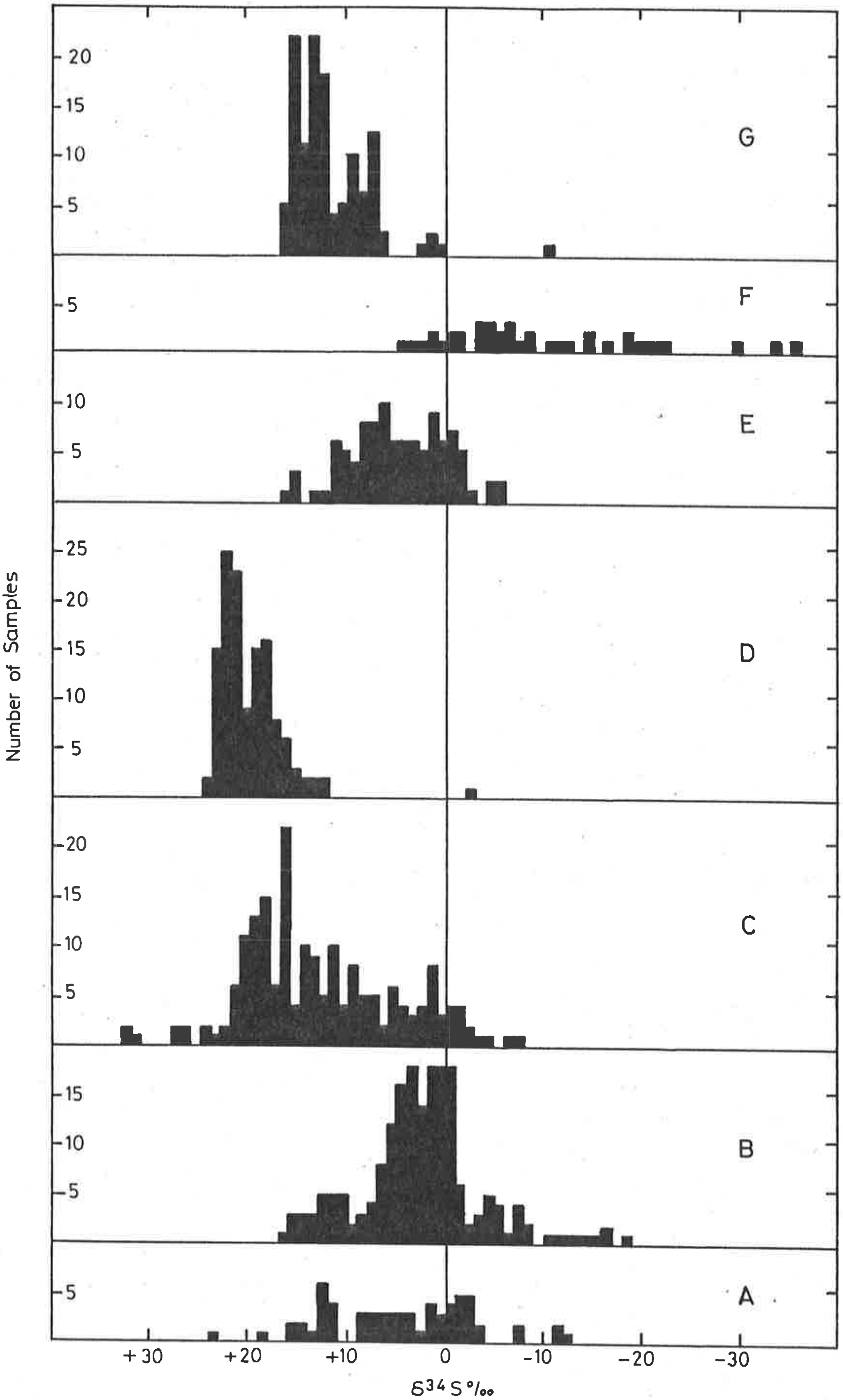


FIGURE 8.2 COMPARISON OF SULPHUR ISOTOPE DATA FROM THIS STUDY WITH PUBLISHED INFORMATION.

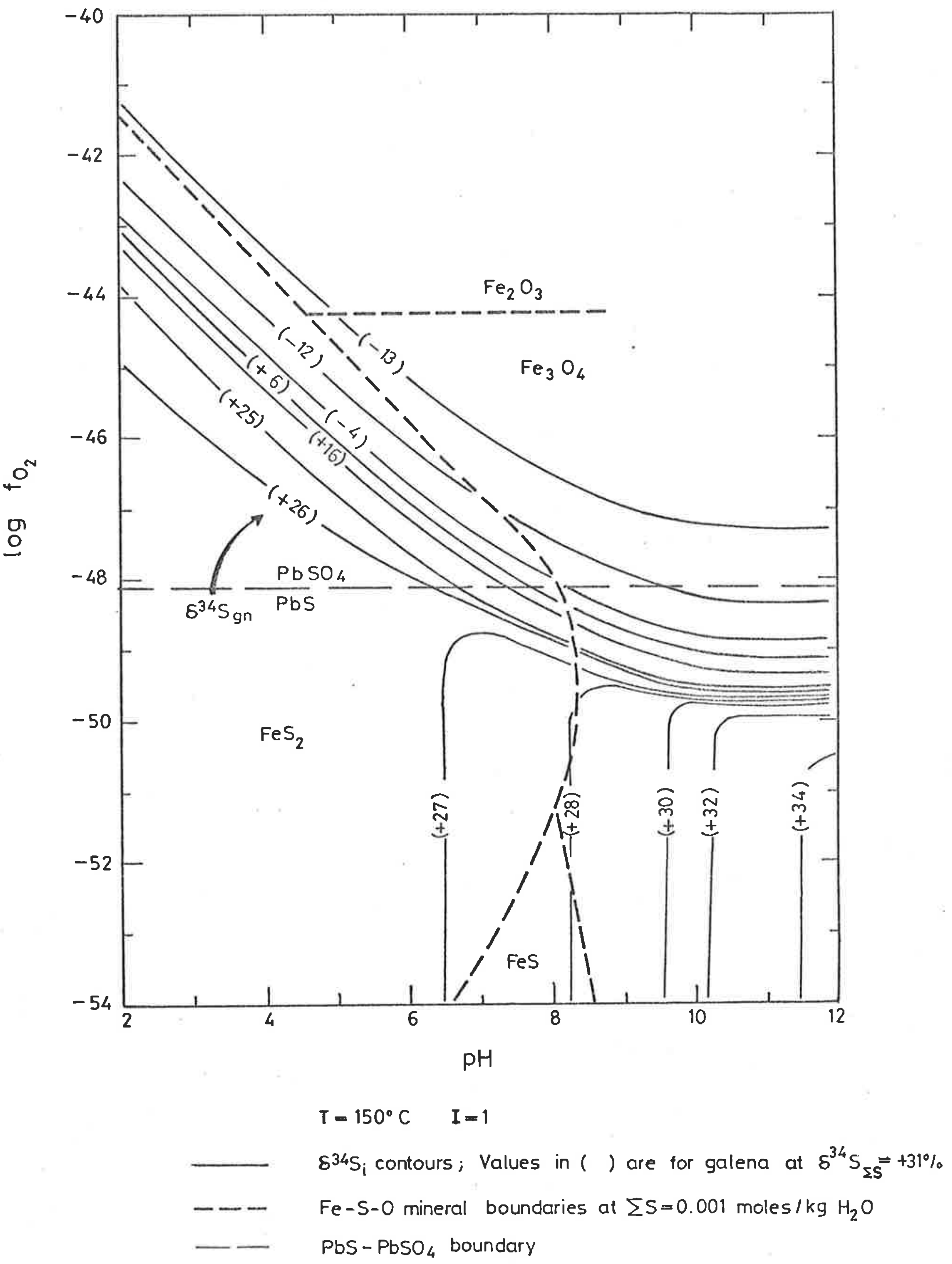


FIGURE 8.3 (Adapted from Ohmoto, 1972)