3.8 Silicification

Silicification can occur during early or late diagenesis in the form of replacement or developmental varieties of quartz (Tucker 1981). Selective-replacement chalcedonic, length fast quartz at Oceana only replaces discrete layers within globular layered fossils. There is question to the processes controlling silicification and hence the importance of its presence is unknown. Discussed examples emphasise the character of nodular chert and bedded chert however the role of allochemical replacement in preserving delicate structures, such as at Oceana and within the State College Oolite of the Cambrian Mines Formation, Pennsylvania, are poorly constrained. Prothero & Schwab, (1996), considered the importance of fluctuations of the Carbonate Compensation Depth, CCD, with upwelling of silica-rich, abyssal-plain seawater resulting in massive deposition of radiolaria and diatoms. This is not the case at Oceana (20m max. palaeodepth), although it is likely silica was introduced through fault related structures during carbonate deposition. The close association, (co-genetic?), of non-ferroan dolomite and quartz presents an introductory point for understanding this problem.

3.9 Summary

The Moina Sandstone Formation in Zeehan, (Oceana), has an upper boundary with the overlain Gordon Group characterised by a conformable – disconformable separation with an interdigitating habit. The boundary is generally destroyed by faulting, decomposed by multi-generational, hydrothermally-driven mineralisation and thrust at low angle beneath the Moina Formation. Dominant compositions remain the most effective means of discerning the boundary, i.e. siliciclastic vs. carbonate. Upper Moina Formation calcareous sands near the boundary, described by Jack, (1960), suggest the possibility of a gradational association with overlain beds.

Four main depositional areas consisting of nine lithofacies are recognisable at Oceana. Sedimentation occurred in tropical latitudes, 23°C – 25°C, with similar modern analogues found at the Great Bahama Bank, Gulf of Mexico, and Abu Dhabi, the Persian Gulf. Gordon Group sediments are classified into three formations and five intraformational members beginning from the earliest Blackriveran. The Gordon Group in Zeehan is similar to the section at Mole Creek and dissimilar to the section in the Florentine Valley (Burrett 1995).

Subtidal to lagoonal sediments of the Ugbrook Formation drape the palaeosurface of Zeehan in association with sea-level transgression, consisting of calcarenite-dominant to biomicrite-dominant members (**Figure 16**). The Myrtle Formation consists of intertidal pale-grey dolomicrites with minor calcarenites and most other lithofacies, encompassing most depositional environments (**Figure 17**). Fifteen PACs in total have been recognised within the Myrtle Formation although structural elements have concealed the majority of these at Oceana (**Figure 18**).

The conformable Black Jacks Formation is overlain and represents dominant open-subtidal deposition. Regionally extensive peritidal members, (BJ1 & BJ 2), are locally absent and are disrupted by the siliciclastic Lords Siltstone Member during the Late Caradoc. The Lords event is associated with renewed uplift in the Tyennan region described as a short-lived epeirogenic event. Dominant subtidal deposition continues to the upper boundary with the Crotty Quartzite, with minor exceptions of a locally distributed upper peritidal member.

Intraformational breccias and breccio-conglomerates are the result of plastic deformed debris flows characterised by either local deformation with homogenous clast populations, or clast populations of several lithofacies. Oceana breccias contain clast types of various lithofacies and are typically not associated with boundary scouring or overlain normally graded calcareous sands. Boundaries are frequently intruded and mineralised although do show rapid transformation from deformed bedding to breccias. Brecciated sheets are variably deformed and typically show preserved bedding within the centre of the slump.

The carbonate clastics are likely to be associated with a combination of low-depositional and high-depositional margin processes. Low basin to slope deposition is evident in lagoonal sediments of the Ugbrook Formation (Burrett *pers. comm.*). High basin to slope deposition associated with an evolving escarpment, like Oceana Fault, probably dislodged loosely consolidated packages. Carbonate beds probably weakened and sheared along planes associated with coarser carbonate sediments and high allochemical components. Stylolitisation is absent and tecto-stylolitisation is poorly developed in biocalcarenite units.

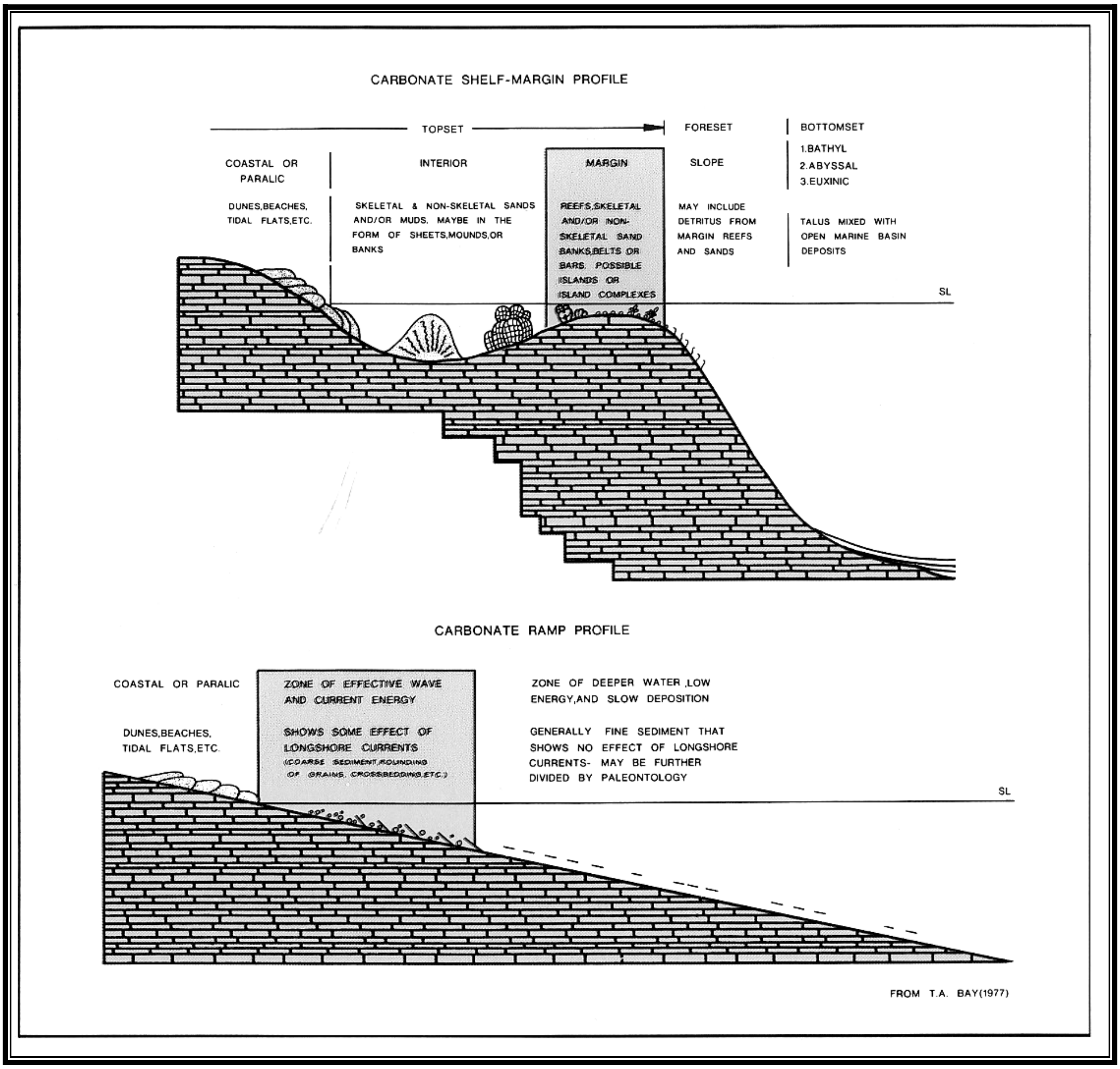


Figure 16: Bank-margin sands, (shaded), play an important part in geological models, whether deposition occurred over a shelf margin or a ramp profile, in these epeiric sea models the seaward, high-energy zone separates low-energy, deeper-water sediments from low-energy, shallow-water, lagoonal deposits (*Modified from* Halley *et al.* 1983).

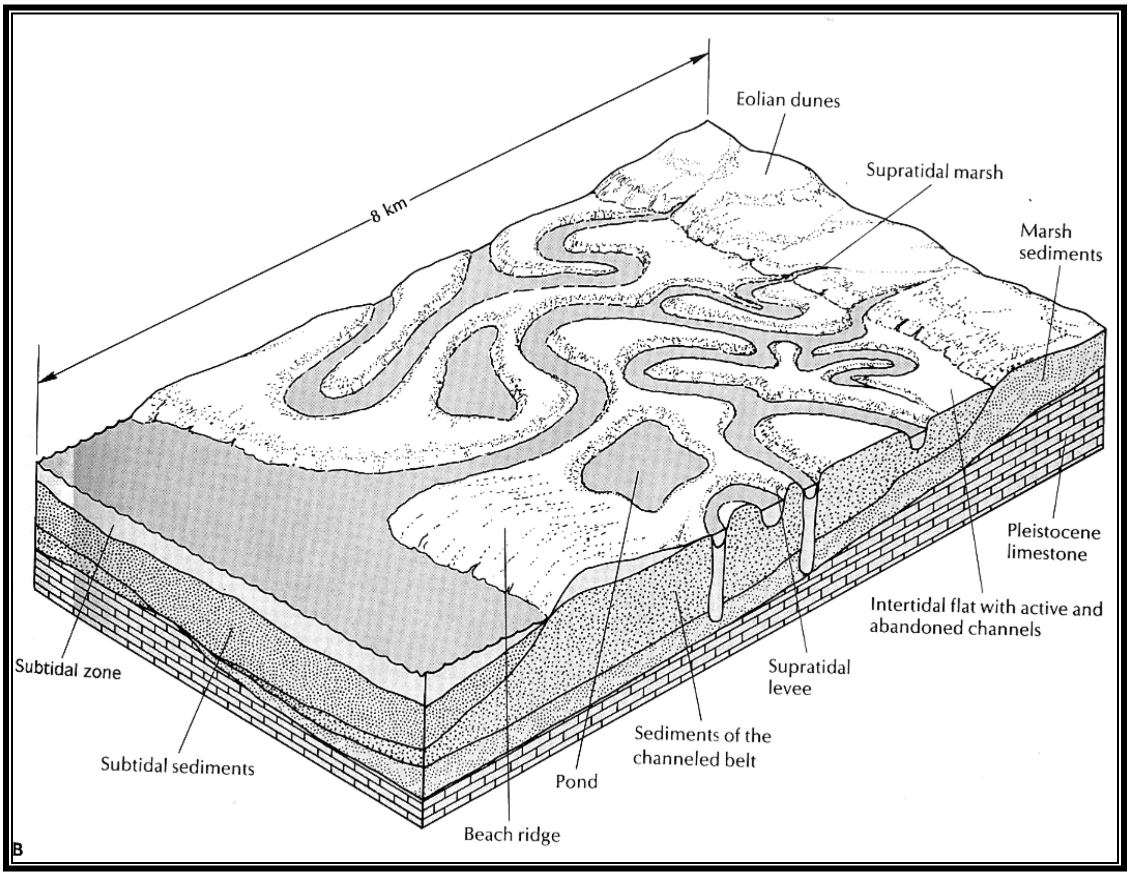


Figure 17: Major features of the peritidal environment (*from* Stanley 1989).

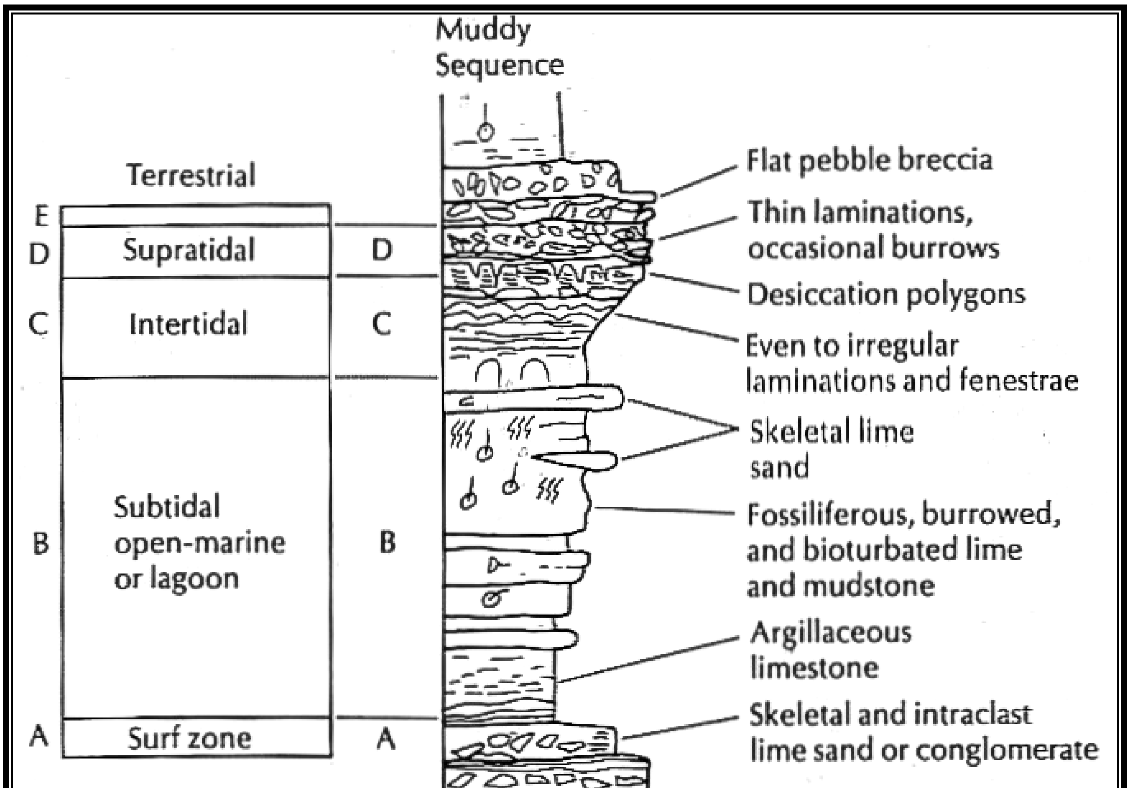


Figure 18: Hypothetical shallowing upward sequence on a low-energy carbonate shelf (*from* James 1984).

Plate set 1

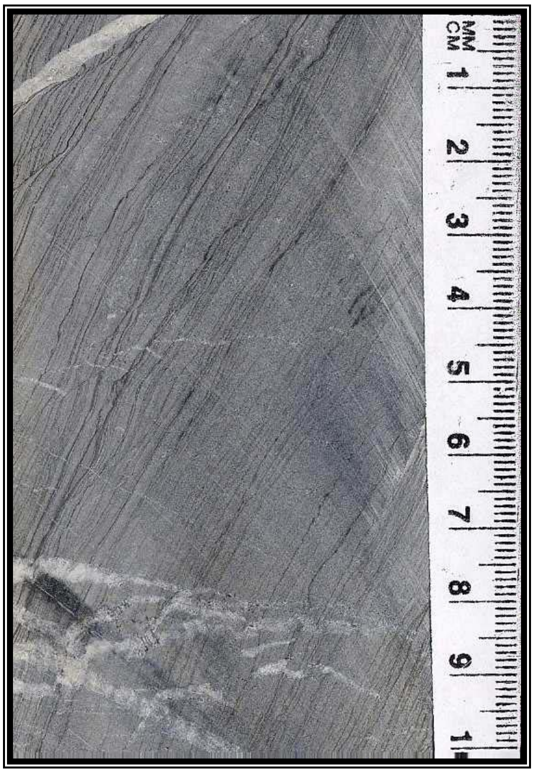
1 – A: Core sample of lithofacies 2; pale-grey micrite, with irregular fenestrae composing 10% of total volume. Thin seams of dolomite are strewn pervasively through the sample.

1 – B: Core sample of lithofacies 2; pale grey micrite, finely laminated with argillaceous micrite or mudstone, minor cross-bedding and ripple marks.

1 – C: Core sample of lithofacies 2; pale grey micrite, bioturbated and worm burrows are filled with mudstone or argillaceous micrite.

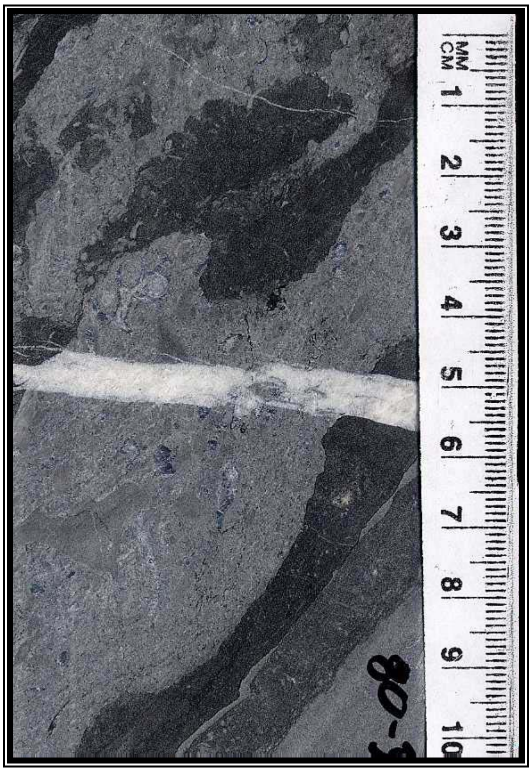
1 – D: Core sample of lithofacies 3; bio-sparite, representing mechanical effects of storm swells on carbonate systems. Allochem debris accumulates into shoals or lenticular deposits and are rapidly overlain by semi-bouyant sediment, resulting in deformation of underlain beds, i.e. flame structures, load casts, *et cetera.*

A



B

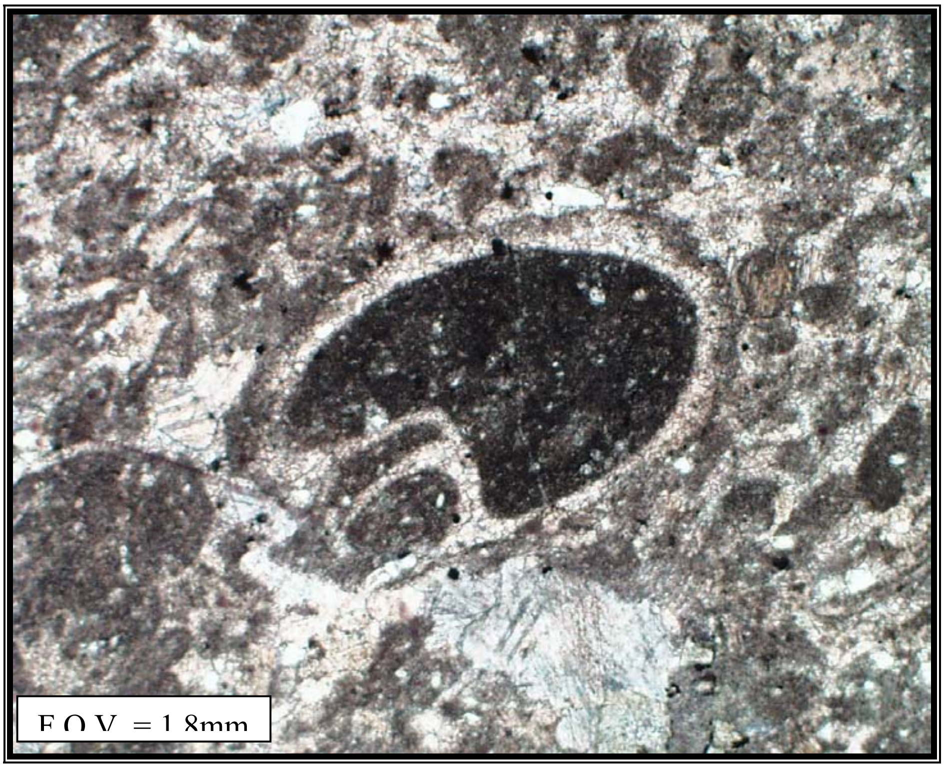
C



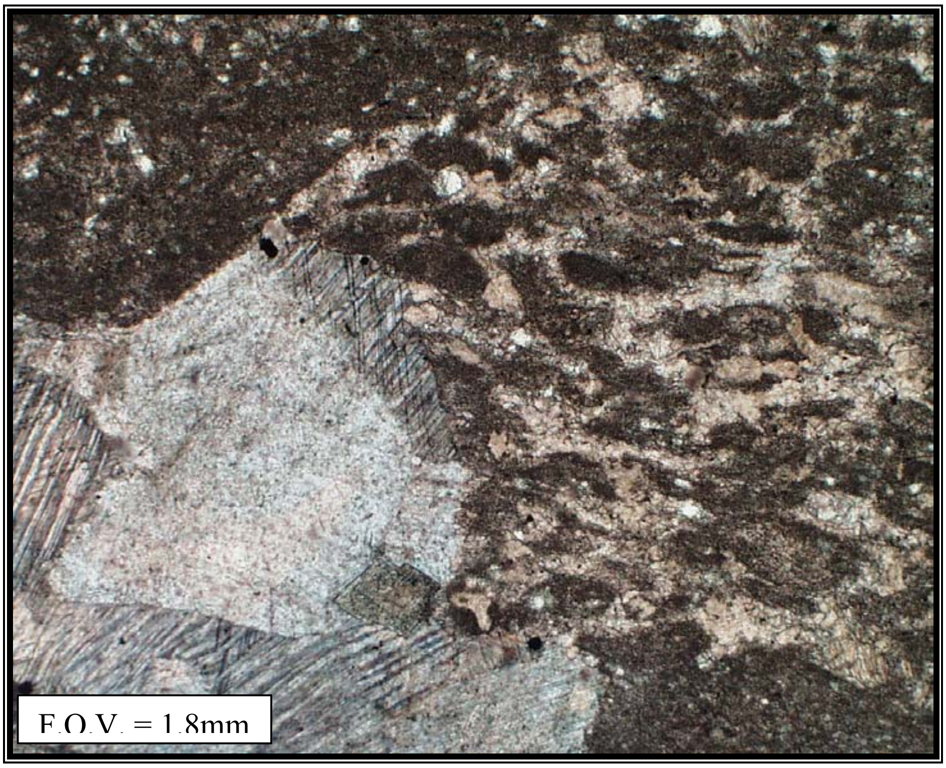
D

1 – E: Photomicrograph of lithofacies 3; typical pel-biosparite. Large gastropod chamber filled with micrite, dissolution vugh (lower right) filled with ferroan calcite. Lack of a cement fringe on the gastropod shell suggests one sparry generation of drusy calcite.

1 – F: Photomicrograph of lithofacies 3; typical stained pel-biosparite, dominated by micrite intraclasts and peloids. Dissolution vugh filled with calcite (red) and progressively accommodating ferroan calcite (blue) species.



E



F

1 – G: Core sample of lithofacies 4; biocalcarenite shoals with interbeds of mudstone or argillaceous dolomicrite (Neudert 1994)

1 – H: Core sample of lithofacies 4; coarse laminated biocalcarenite intermixed with grey micrite, and interbedded with argillaceous micrite and mudstone. Core section represents transition from shallow open subtidal conditions to shallow protected subtidal conditions.

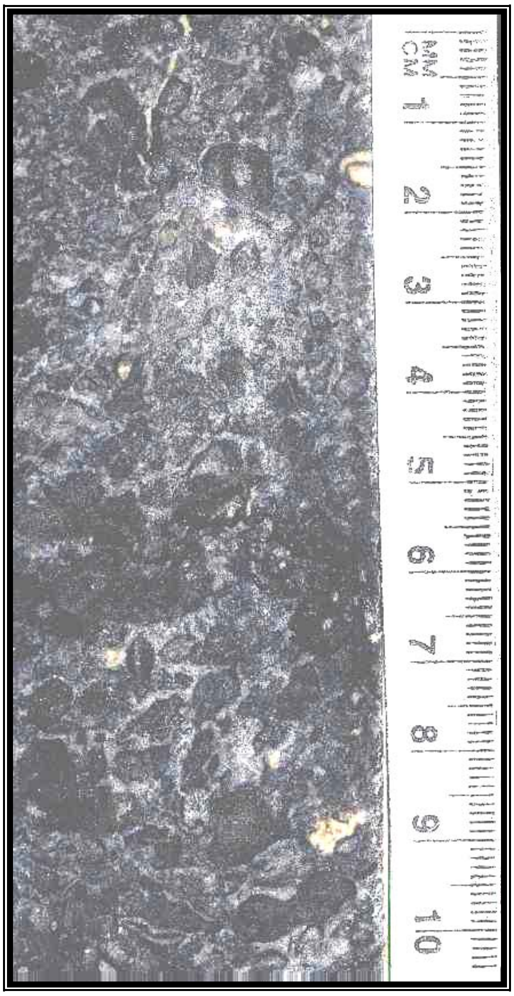
1 – I: Core sample of lithofacies 4; massive to coarse bedded and shoaled bio-calcarenite with dispersed mud component bioturbated and infilled by orthochem-rich calcarenite.

1 – J: Core sample of lithofacies 5; medium to fine bedded and shoaled onco-biomicrite with oncolytic argillaceous dolomicrite interbeds. Micritic matrix is dominantly recrystallised to sparite, chaotic arrangement of allochems.

G

H

I



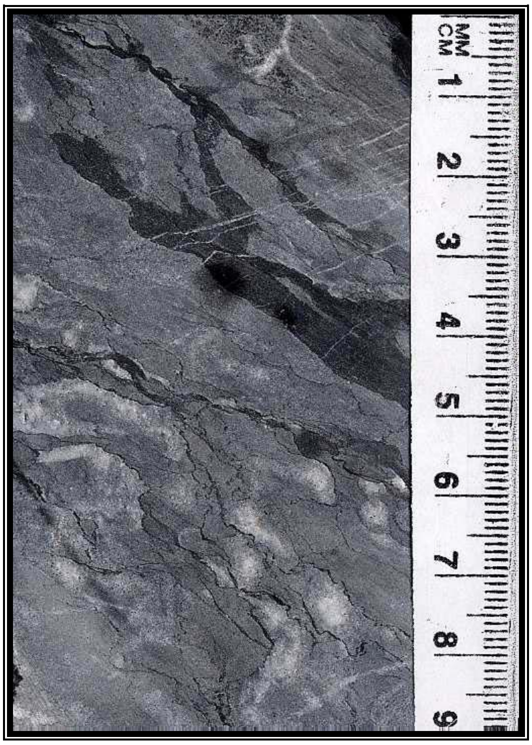
J

1 - K: Core sample of lithofacies 6; dark-grey dolomicrite with stromatoporoid debris interbedded with argillaceous dolomicrite. Wispy character to beds is indicative of a shallow, protected subtidal depositional environment.

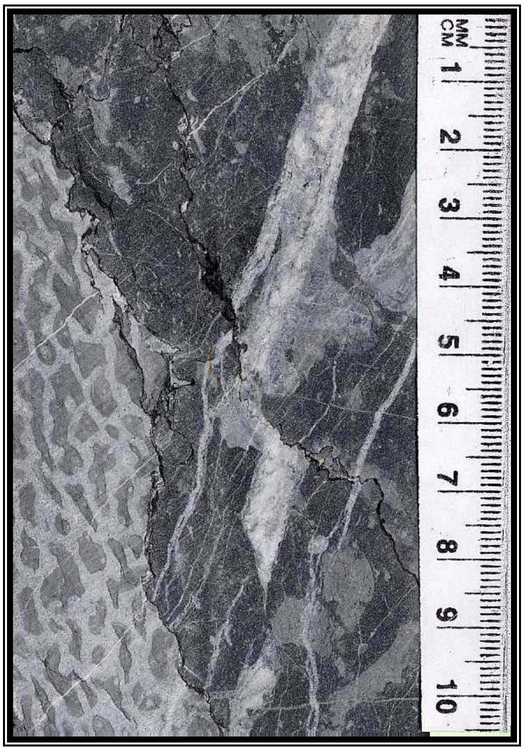
1 - L: Core sample of lithofacies 6; Heavily stylolitised and calcite veined dark-grey bio-micrite with crinoidal debris and large coral.

1 - M: Core sample of lithofacies 7; Brachiopod packed mudstone interrupting argillaceous dolomicrite bed, interbedded with dark-grey dolomicrite.

1 - N: Core sample of lithofacies 7: Fossiliferous bryozoan and crinoidal, massive, argillaceous dolomicrite.



K



L

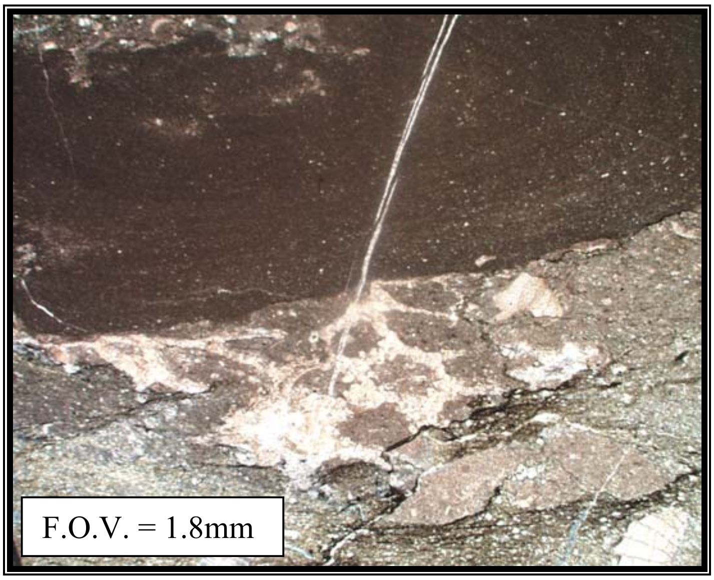
M

N

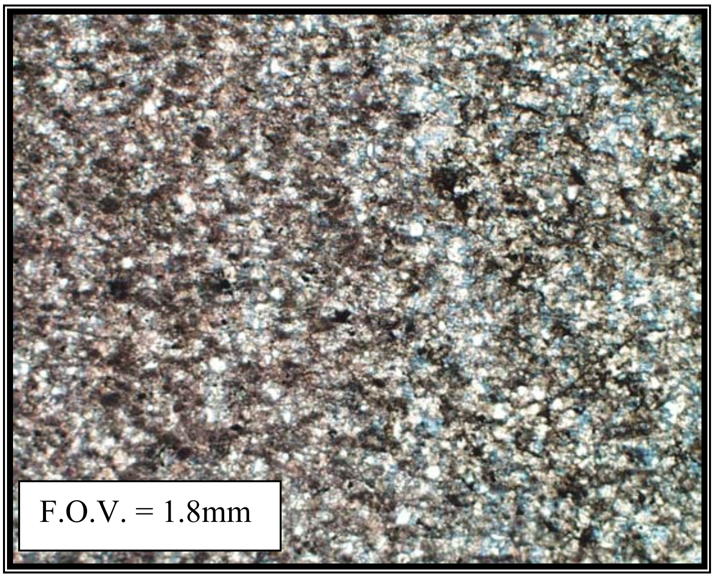
1 - O: Photomicrograph of lithofacies 5; Large concentric oncolite with interior micrite supported by argillaceous dolomicrite.

1 - P: Photomicrograph of lithofacies 6; carbonate stained typical micrite (red) to dolomicrite (blue) boundary occurring sharply within a micrite bed.

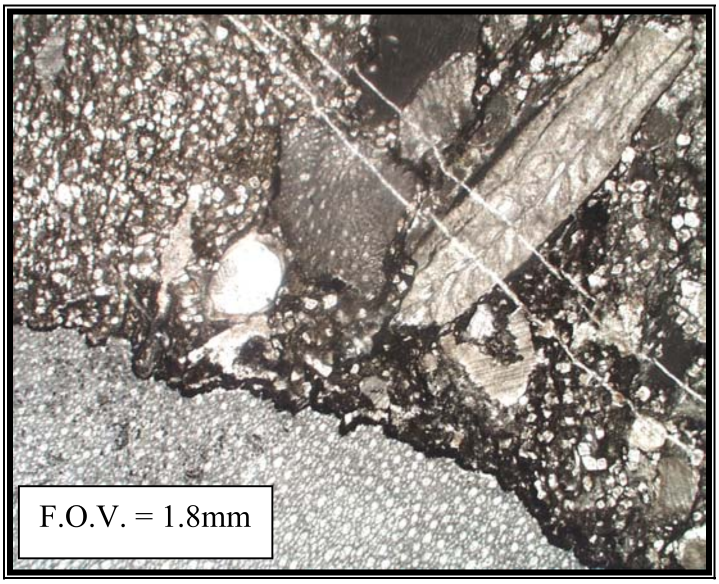
1 - Q: Photomicrograph of lithofacies 7; Argillaceous dolomicrite packed with several species of calcareous algae and other unknown species.



O



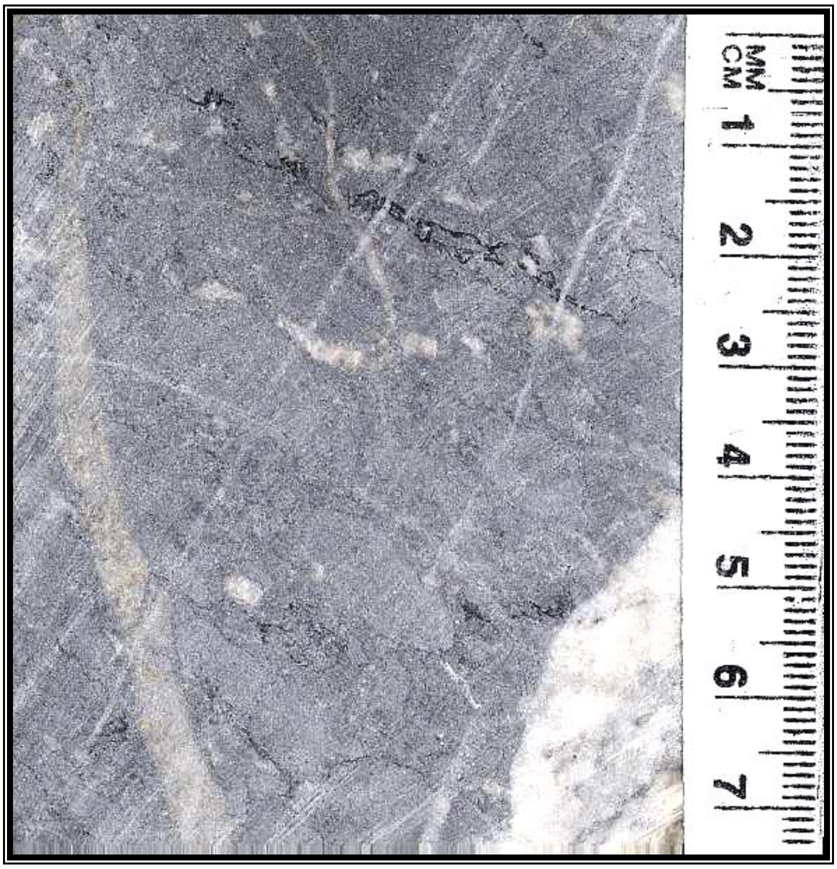
P



Q

1 - R: Core sample of lithofacies 8; well-developed nodular limestone in protected lagoonal lithofacies, orthochemical-rich nodules supported by mud-rich dark-grey dolomicrite. This sample is unfossiliferous however other samples can include barren and packed examples of several lithofacies.

1 - S: Core sample of lithofacies 9: This sample is probably secondary dolomite however the composition is similar to typical dolomites at Oceana.



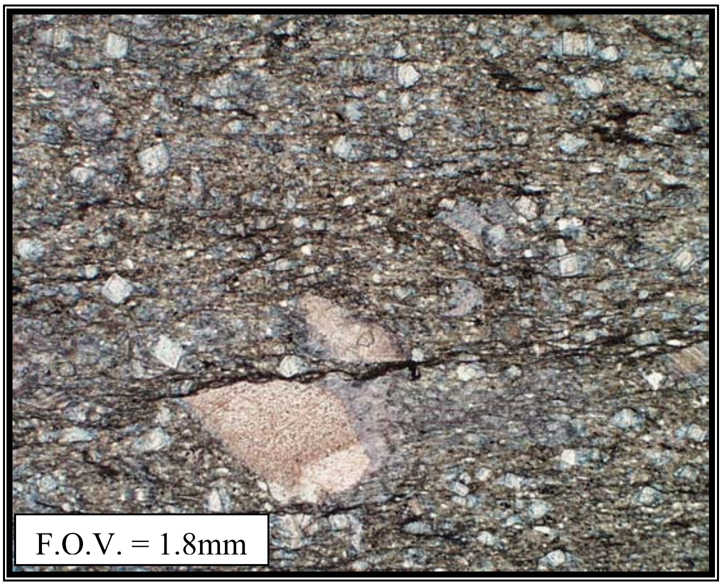
R

S

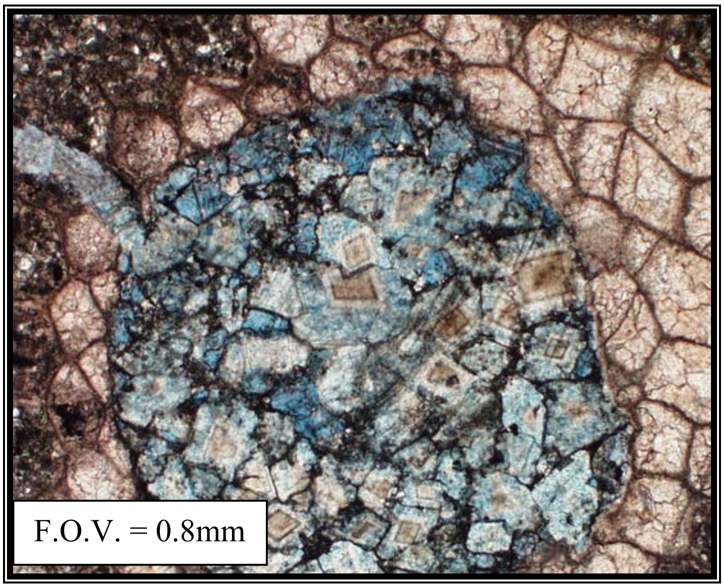
1 - T: Photomicrograph of lithofacies 9; argillaceous-rich micrite (black) with sparry calcite vugh fill, replaced by ferroan dolomitic compositions. Purple envelope of ferroan calcite is the result of dolomitisation process

1 - U: Photomicrograph of lithofacies 9; dark grey dolomicrite with large bryozoan, bryozoan cavity filled by ferroan zoned dolomite, dolomitic fluids have not affected drusy calcite replaced fossil indicating a probable late- or post-diagenetric phase

1 – V: Photomicrograph of intraformational breccia; pel-bio-micrite debris within argillaceous dolomicrite matrix. Sparry material is unaffected by mineralisation of zoned dolomite suggesting varied origins. Micrite clast has sharp abraded edges.



T



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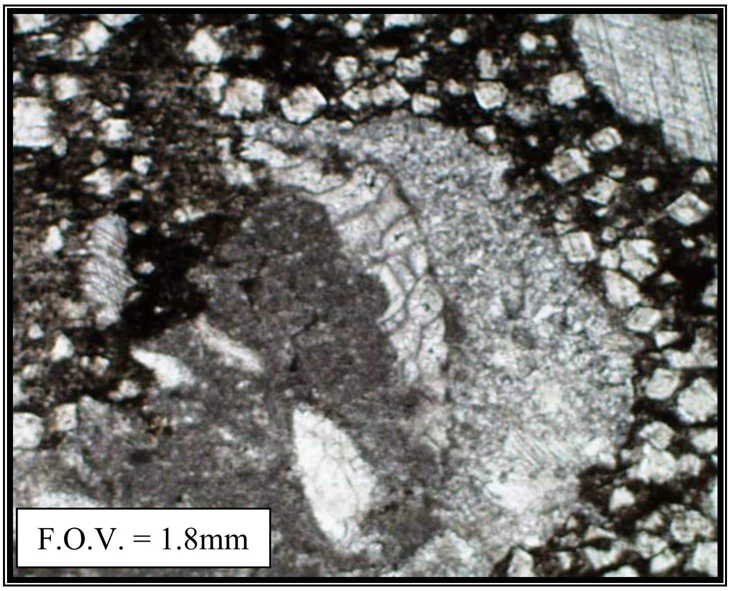
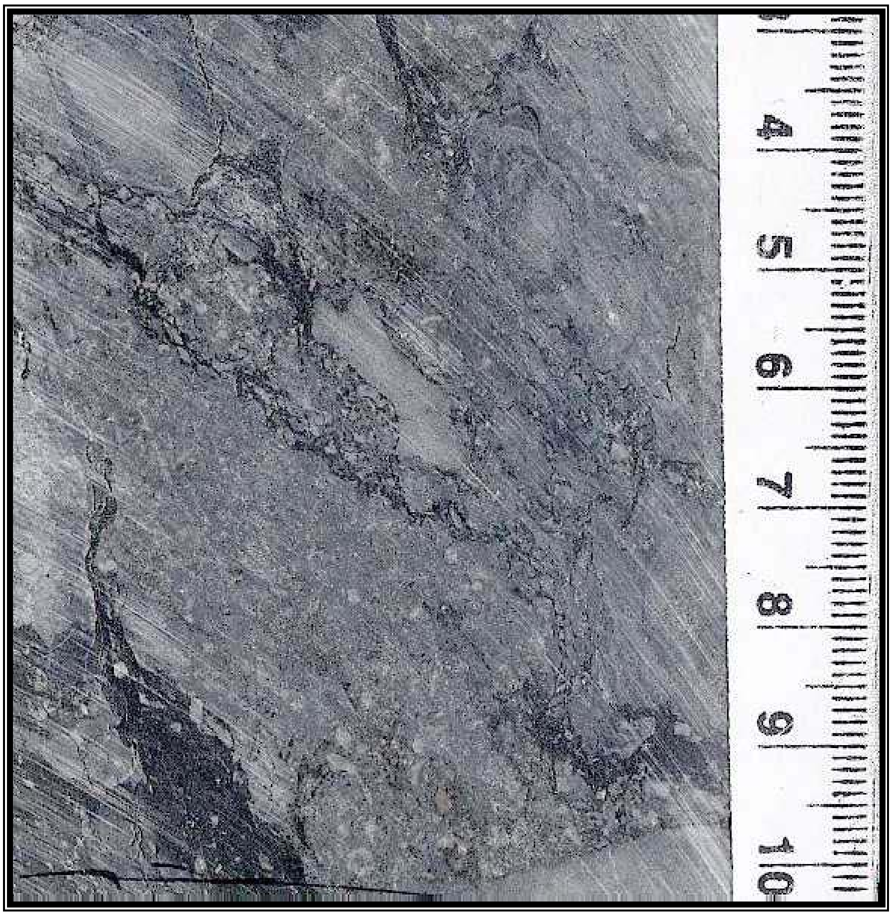


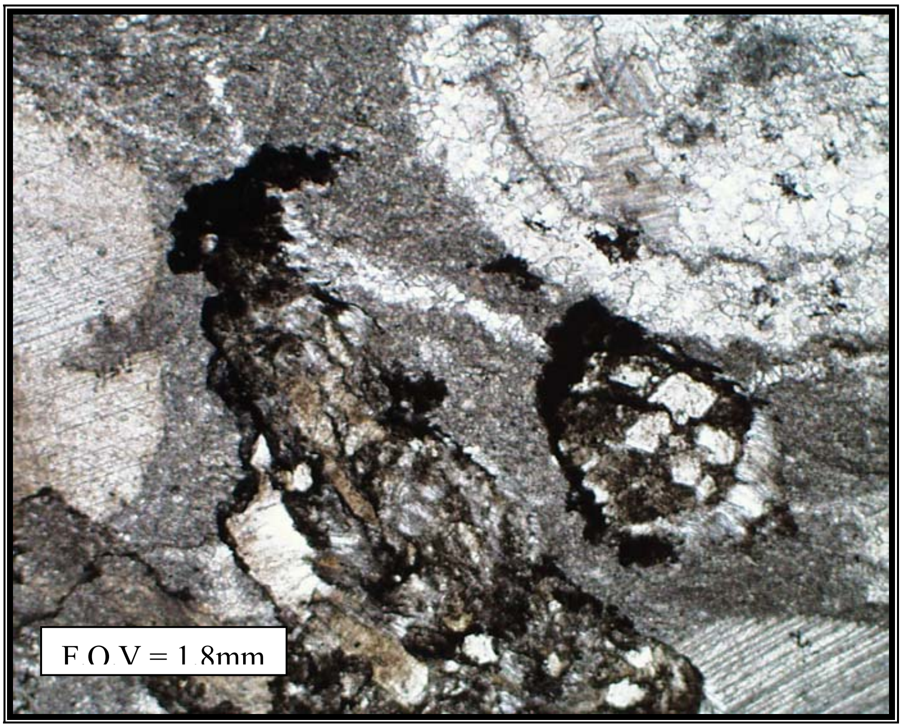
V

1 - W: Core sample of intraformational breccia; clasts of crino-biomicrite supporting argillaceous dolomicrite matrix.

1 - X: Photomicrograph of intraformational breccia; debris of aqrgillaceous dolomicrite bed intraclastic within clast of pel-bio-sparite.



W



X

Mineralisation: textures and geochemistry 4

4.1 *Introduction*

Oceana can be structurally divided into two zones that contain stratabound mineralisation and a combination of stratabound and discordant mineralisation within Exploration Lease 20/2002-(Oceana). The exploration history is included as **Appendix A**. Mine and petrographic descriptions are based on commercial reporting by Cordery, (1998), Jones, (1978), and Jack, (1960), with supplemental classification by academic authors.

Core is generally in good condition from South Oceana Fault and decreases in quality and recovery in holes closer to Oceana Fault. Core produced by BHN/S, and subsequently Zeehan Mines, is of a poor quality, is heavily oxidised and was poorly catalogued when submitted to the Mineral Resources of Tasmania. Oceana mine and the immediate vicinity were locally gridded during initial operations which has been maintained to present day (**Figure 1**).

Mineralisation types consist of -:

Type A: Vein-hosted fault-bound, discordant, epi-genetic, massive and disseminated ore to a depth greater than 200m between Oceana Fault - Mine Fault and Mine Fault - South Oceana Fault (semi-mined, unbottomed).

Type B: Carbonate-hosted stratabound massive ore from 200m to greater than 380m depth south of South Oceana Fault and possibly beyond South Oceana (Semi-mined).

Type C: Supergene enrichment of lateritic pug and clay extending into dominant fault zones, (not-mined).

Type D: Fault-bound carbonate-hosted epi-genetic massive ore to an unknown depth associated with the Moina Sandstone and Gordon Group boundary.

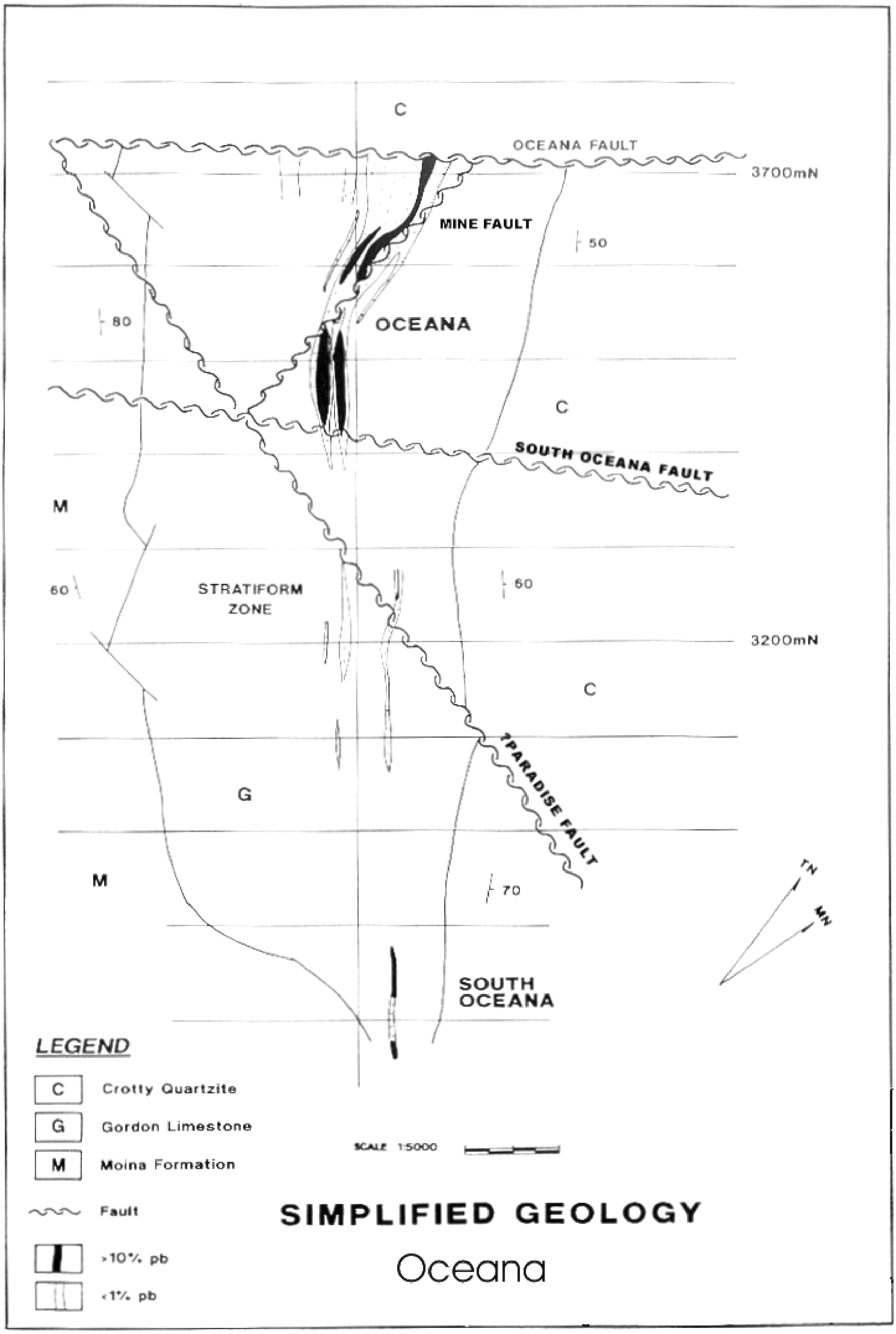


Figure 1: Simplified geology of Oceana with dominant structural features and surface projection of mineralisation (*Modified from* Quayle 1992).

Oceana Mine has been classified into Northern and Southern Zones, (Oceana to Mine Fault; Mine to South Oceana Fault), by Jack, (1960), and was reclassified after further drilling, (Jones 1978), into a Northern Zone, consisting of Northern and Southern Blocks from Jack, (1960), and the Southern Zone, extending from South Oceana to Paradise Fault (Northern Block), and from Paradise Fault through to South Oceana workings (Southern Block). The local grid and subsequent sections incorporating drill hole locations produced by various companies is included as **Appendix C**.

4.2 *Local and structural setting of Mineralisation*

4.2.1 Northern Zone

The Northern Zone comprises the Northern Block, Oceana Fault to Mine Fault (Northern Zone of Jack, 1960), and the Southern Block, Mine Fault to South Oceana Fault. The Northern Block is adjacent to the northeast-southwest Oceana Fault, which is considered to have produced ~700m of apparent dextral transcurrent offset, (Saxon 1995). Both blocks are triangular in shape and each extend up to 150m along strike. Discordant coarsely crystalline galena-siderite veins with minor pyrite, sphalerite and rare chalcopyrite, boulangerite, bournonite and other Sb sulpho-salts, characterise ore in the Northern Zone. Vein mineralogy is dominated by gangue calcite to siderite and dolomite with minor quartz (Jack 1960). Ellis, (1984), described the isolated occurrence of a very fine chalcopyrite vein in a polished section of sphalerite, as evidence for the existence of chalcopyrite.

Jack, (1960), and Blissett, (1962), described ore occurring in two prominent shears striking northwest 330° and dipping 85° northeast. Lenses rarely exceed ~3m in thickness, with exceptions to ~11m thick tensional shear replacements of crushed rock, positioned 2m to 5m apart (Taylor 1983). Irregular to stockwork vein systems associated with faults and fractures strike northwest with sub-vertical northeast dip. Massive crystalline calcite and iron-carbonate veins cut stylolites, inundate porous lithologies and dissolution vughs, and replace orthochemical-rich beds.

A northeast-southwest trending fault terminates the Gordon Group in the north end of the Austral Valley; this structure parallels the Oceana Fault, and may have generated mineralisation equivalent to the cross-cutting style at Oceana (Jones 1978).

4.2.2 Southern Zone

Mineralisation in the Northern Zone occurs in two prominent, vertical shears parallel to bedding dipping northeast, known as the eastern and western lenses (Jack 1960). These lenses become dominated by replacement textures to the south and continue to South Oceana within intraformational breccias. The western lens is thinner and has a true width of 0.75m to 3.0m. It has a strike length of at least 450m. The eastern lens occurs up to 6m in true thickness, with limited strike extent of 300m and dip extent of 180m (Taylor 1983). The ore bodies persist from South Oceana Fault and are displaced within 200m by a formerly unnamed fault. In this thesis the unnamed fault will be named the Paradise Fault.

Drilling at South Oceana (OP1), and Pyramid (OP3) intersected both stratabound lenses, however they thin to the southeast and poorly assay for base metals. Middle column stratabound ore lenses, similar at Oceana, re-develop at Greives Siding and occur in other locations around Zeehan, suggesting this feature is common to the Gordon Group in Zeehan, (Glover 1995; Akerman 1998).

4.2.3 Fault Zone

The fault zone represents two varied types of mineralisation with a likely association. Type E mineralisation was described as a pug clay overburden blanket that may extend to depths of 70 and 120m adjacent to Oceana Fault and others (Jack 1960). Aircore sampling by Cordery, (1998), suggests surface metal depletion and supergene enrichment to similar depths. Secondary enrichment is locally coincident with ore sulphides and provides a regional geochemical halo to mineralisation. Secondary cerrusite and minor hemimorphite are associated with manganiferous, iron-rich gossan and pug. Samples of the Oceana Lode Gossan, cited by Cordery, (1998), contained a high concentration of Mn with background levels of Ba, As, Sn and W, and no significant Au or Cu. The sample average, (four samples), returned 8%Pb, 1.8%Zn, 85g/t Ag, 235ppm Cu, <0.008ppm Au, 35%Fe, 5.3%Mn, 75ppm Ba, 6ppm As, 20ppm Sn, and 4ppm W.

Recent reporting of drilling projects at South Oceana and Pyramid Mines note the existence of Limonite, goethite, and relict massive sulphide, associated with the lower faulted boundary of the Gordon Group, Type D, (Saxon 1995; Cordery 1998). Significant intersections by DDH-OP1 and DDH-OP3 are considered a feasible inclusion to the ore reserve at Oceana, even though metal decomposition is evidently advanced. Regional geophysical analysis broadly outlines this feature (**Appendix E**)

4.3 Northern Zone (Type A)

4.3.1 Introduction

The Northern Zone of Oceana, Type A, is bound by the Oceana, Mine and South Oceana Faults (Jack 1960). Petrography is dominated by gangue calcium- to iron-carbonate which hosts ore-grade sphalerite, galena and rare chalcopyrite. Paragenetic studies and ore petrography have to include previous descriptions from Jack, (1960), and Jones, (1978), due to poor core conditions and outcrop.

Mineralisation is thought to be associated with Oceana Fault, which is implied from the general thinning of veins, ore lenses and tectonic breccias away from the structure. Ore is described to occur in two prominent shear zones characterised by massive crystalline calcite supporting wall-rock breccia. Sphalerite typically occurs near vein contacts as overgrowths, stringers or as replacement mineralisation. Discrete stringers are typically strewn throughout carbonate veins connected by thin seams of bituminous or siliceous compositions. .Sphalerite occurs independently of, and associated with galena as euhedral disseminations and rarely with chalcopyrite. Pyrite gangue is rare to absent in replacement and vein compositions, with the latter showing consistency to the investigations of Sn-bearing granite-related Fe zonation by Both and Williams, (1968).

4.3.2 Petrography of the Northern Zone

There are three distinct sphalerite varieties in the Northern Zone based on colour variations. Although mineral colours are generally not scientifically substantiative they do show evidence of either variable compositional phases, and possibly generations, or at least relative mineralising processes. Honey-brown sphalerites are hosted by massive crystalline ankerite to siderite as stringers. Pink sphalerite is typically disseminated or associated with thin irregular veins of sideritic composition. Red sphalerite typically replaces orthochemical components in micritic beds as massive sulphide. The Northern Zone has been mined to 195m depth (No. 6 level), and is proposed to thin with depth to the east. Depending on the extension of this mineralisation it is possible the ore lens connects with the lower boundary of the Gordon Gp, and hence, combined resources of Type A and D mineralisation.

Dolomitisation is texturally destructive adjacent to Oceana Fault and obscures any available correlations between Northern Zone drill holes. Carbonate gangue minerals occur as massive, vug- and open space-fill and discordant, irregular fracture-fill veins. Galena from the western lode of the Northern Zone was noticeably sheared which indicates mineralisation occurred before the main phase of the Tabberabberan Orogeny during the Early Devonian (Burrett *et al.* 1984; Williams 1968).

4.3.2.1 Type A

Sphalerite

Sphalerite occurs as massive and disseminated euhedral to subhedral crystals ranging from <1mm to 4mm diameter. The composition of sphalerite can be loosely defined at a macroscopic scale by the colour variation, (Klein & Hurlbut 1993) i.e. honey-brown sphalerite (Cd-rich) and pink sphalerite (Fe- & Cd-rich). Honey-brown sphalerite typically precedes siderite and galena, and occurs as euhedral to subhedral replacement and disseminated crystals. Pink sphalerite is dominantly disseminated or coarse crystalline, hosted by sideritic veins. There is a common association of pink and honey-brown sphalerite preceding galena and pyrite mineralisation, which may suggest similar geneses from evolving fluids or variable generations. Red sphalerite occurs as stringers of massive, euhedral crystals. In thin section, the stringer material is partly quartz and isotropic material that has been massively inundated by siderite. Highest assays reported by Amoco M.A.C. (ZT Project) drilling yielded 5.6%Zn to 36.9%Pb in ZT-82-13 at 280m and 11%Zn to 2.56%Pb in ZT-80-8 at 166m.

Galena

Galena occurs as massive-veined, disseminated, vug-fill and massive euhedral to trace crystals and blebs in host calcite, ankerite and siderite veins. Galena is dominantly associated with honey-brown sphalerite and siderite as intercrystalline infill. Galena mineralisation is associated with violent fracturing of sphalerite replaced wall-rock, however galena is rarely a replacement sulphide itself. Galena has a minor association with pink sphalerite however examples are commonly intraclastic. Galena was observed independent of sphalerite in zones of 'stripey' ore and as minor isolated blebs, <5mm, in post-ore calcite veins. Highest assays reported by Amoco M.A.C. (ZT Project) yield 36.9% Pb in ZT-82-13 at 280m. Silver reaches trace amounts of 400g/t in ZT-82-13 at 280m.

Pyrite

Pyrite is not abundantly associated with ore minerals and occurs as isolated and aggregated euhedral and subhedral framboids from trace amounts to 3mm width. Clusters and isolated micro-scopic framboids have sparsely mineralised vein host-rocks and vein boundaries. Pyrite generations are described in more detail in the Type C section.

Hydrothermal Carbonates

Calcite, ankerite and siderite are massive-crystalline and occur as open-space-fill, vug-fill and fracture veins. Compositions range from dominant calcite with minor ankerite, to subordinate calcite and ankerite with siderite, and minor calcite and ankerite with siderite. Vughs typically have massive selvage of honey siderite, which is infilled by white siderite. Vugs are isolated and compose ~2% of viewed core, of which, few examples contained bituminous films, (<1mm thick). Massive spar composes 40% of total hydrothermal carbonate gangue in the northern zone. The spar generations fracture wall-rocks and overprint all other gangue phases. Siderite 1 and 2 are additionally fractured by spar generations and stylolitisation.

Chalcopyrite

Chalcopyrite was observed as the presence of malachite in ZT-82-13 to 100m depth, (Jones 1978), and findings of a chalcopyrite vein within sphalerite, in polished section (Ellis 1984). Assays reveal trace Cu to 230ppm at 280m (ZT-82-13), coincident with massive sulphide minerals. Chalcopyrite 'disease' in sphalerite is considered more likely to form by the process of replacement than by exsolution, (Deer *et al.* 1995), and is probably related to epigenetic processes.

Manganese Minerals

Reported drill core assays by Jones, (1978), yielded compositions up to 7.0%Mn associated with fault zones and arenaceous sediments, and trace amounts in carbonaceous sediments. Ore zones are characterised geochemically at Oceana by a Mn halo (Taylor 1983). Associated manganiferous compositions such as pyrolusite or rhodochrosite, are typically absent. This aspect of Oceana is intriguing, raising the question of where the manganese came from, and may be settled one day.

4.4 *Southern Zone (Type B)*

4.4.1 Introduction

The zone consists of two stratabound lenses, western and eastern, exceeding 200m depth, 300m strike and 180m depth, 450m strike length, respectively. Mineralisation occurs at the top and base of both intraformational breccia units as massive-and stringer-style, veins and replacement. Much thinner intraformational breccia beds were identified in core at South Oceana, correlated to the western lens, and the bed assayed moderately for Zn, Pb and Ag (Akerman 1998).

4.4.2 Petrography of the Southern Zone

The southern zone is characterised by higher zinc ratios and dominantly occurs as replacement lenses in the centre of the limestone column. The western lens shows a marked asymmetrical zonation of basal lead, succeeded by siderite (Jones 1988).

4.4.2.1 Type B

Sphalerite

Sphalerite crystals and stringers are characterised by euhedral to subhedral disseminated and replacement red, honey-brown and pink forms, similar to the Northern Zone. Complete and partial replacement of orthochemical-rich beds by honey brown sphalerite can be seen at a macroscopic scale as coarse to fine crystalline mineralisation. Red massive sphalerite and fine, pink crystalline sphalerite occurrences are hosted by massive siderite > ankerite > calcite veins and vug-fill. Coarse crystalline honey brown sphalerite replaces orthochemical-rich beds and is fractured by massive vein-like galena, 5-50cm thick. Mineralisation is characteristically pyrite poor, which is preferable to the mineral market of today, with minor Fe-disease bands in red specimens at a microscopic level.

Galena

Massive veined galena occurrences were assayed by Jones, (1983), resulting in examples such as 29% Pb and 10% Zn in ZT-80-4 at 252m. Galena occurrences are disseminated, massive crystalline ‘vein-like’, vug-fill and fine replacement but are prominent as massive, pure galena veins up to 50cms in thickness, associated with the ‘eastern’ lens. Taylor, (1983), emphasised the presence of thinly bedded shale and stratiform galena in ZT-80-4 at the base of the western lens. Fine bedded dolomicrite and argillaceous dolomicrite pass into thinly-bedded argillaceous dolomicrite and layered galena and siderite. Syngenetic deformational textures were reported to affect the sediments and the replacement galena. These textures were not identified in this study which does not necessarily mean they do not exist.

Pyrite

Pyrite occurs as coarse crystalline to trace amount disseminated, replacement and fracture-controlled euhedral to subhedral crystals with little framboidal growth. Disseminated examples are commonly restricted to argillaceous dolomicrite beds or scattered randomly in hydrothermal siderite. Replacement pyrite occurs in discrete bio-dolomicrite and bio-sparite bands replacing the sparry mould of fossils. Fracture controlled pyrite occurs as blebs and aggregates along vein contacts.

Early syn-sedimentary pyrite, (Type 1), occurs with argillaceous dolomicrite beds and appears to pre-date some dolomitisation. Clusters and disseminated framboids are disturbed and cut by zoned dolomite associated with syn-sedimentary dolomitisation. Electron microprobe analysis by Peace, (1995 – CAMECA SX50), supports a probable syn-sedimentary origin.

Syn-diagenetic pyrite, (Type 2), is assumed from the occurrence of euhedral cubes along stylolites and a co-eval relationship with diagenetic dolomitisation. This phase of pyrite can also be considered to occur in early diagenetic calcite-rich veins. A variant to this form occurs as massive forms replacing sparry calcite allochems.

A third generation of pyrite was classified by Peace, (1995), using the electron microprobe, occurring as small blebs within zoned sphalerite crystals, (10μm diameter). The samples were observed to replace sphalerite 2, (pink sphalerite), and to display a 'stripe' texture illustrating infill by siderite B. It was suggested therefore that this phase of pyrite mineralised prior to cementation by siderite B (Peace 1995).

The final phase of pyrite is observed to overprint all mineralisation associated with the Devonian epi-genetic phases. Massive and framboidal examples rarely occur in quartz-rich veins and indicate siderite as the dominant gange iron phase. Examples are associated with the latest overprint veins, wall-rock dessemination and stylolites.

Hydrothermal Carbonates

Hydrothermal carbonates at Oceana are typically siderite-rich and occur as carbonate-replacement and fracture-fill, vein masses and stockwork. Massive siderite is commonly orange, (oxidised), or pale cream to white with occasional carbonaceous or bituminous inter-crystalline material. Silicified mudstone-rich dolomitic host bands remain within hydrothermal carbonates, while host orthochemical components are engulfed or washed away. Two generations infill karst vugs consisting of brown, dog tooth spar siderite and massive white siderite, which are cut by calcite-rich veins. Thin section analysis shows massive influxes of calcite associated with dedolomitisation and brecciation of siderite replaced wall-rock lithologies (dolomicrite). The dominant calcite phases fracture siderite 2, and suggest a clear association with post-lithification regional kinematics. Siderite 2 is characterised by a sweeping extinction and a common association with ore sulphides.

Honey brown sphalerite precedes red siderite, siderite 1, carbonate-replacement. Siderite 1 replaces and infills host material not mineralised by sphalerite, and is itself overgrown by pyrite and siderite 2. The western ore lens is characterised by vug-fill and replacement siderite, which indicates fluids were intruded into lithified sediments.

4.5 Fault Zone (Type C & Type D)

4.5.1 Introduction

The Fault Zone is considered to comprise the lower boundary of the Gordon Group, which was mineralised during the Benambran or the Tabberabberan Orogenies, and the supergene overburden pug clay, which is obviously associated with regional structures. Numerous regional and local structures exist in the area inhibiting a compilation of a complete stratigraphic sequence at Oceana. Recent re-drilling at Pyramid, (DDH-OP3), has shown that the Gordon Group does not thin as much as expected and has been thrust beneath the Moina Formation ~20m west in a structural illusion (Leaman 1993). Assay of goethite and pug clay from the lower boundary returned low values of Zn, Pb and Ag (Akerman 1998).

4.5.2 Mineral petrography of the Fault Zone

4.5.2.1 Type E

The reported manganiferous currusite gossan by Jack, (1960), provides a valuable supergene indicator of mineralisation in the decomposed pug overburden. The pug is reported as a massive decomposed blanket enveloped by Cambrian and Silurian siliciclastics with much higher induration. Preliminary open-cut designs extend to 70m depth adjacent to Oceana Fault, which discharges 11.4 megalitres of water per day (Ingham 1988 Cyprus). Pug clay is massive, banded and mottled crimson red, brown, black, orange and green deposits with disseminated blebs of crystalline galena and minor sphalerite. Widespread aircore sampling to 10m depth with assays by Saxon, (1995), yielded 2369ppm Zn, 461ppm Pb and <1ppm Ag above Type C ore.

4.5.2.2 Type F

Exploration conducted by Saxon, (1995), for Pasminco Exploration on the Oceana Project determined lensing out of stratbound ore to the south, and massive goethite with 5% quartz spherules in its place. Assay of this zone by Saxon, (1995), yielded 200ppm Pb and 2036ppm Zn averaging 11.9m along the boundary with the Moina Sandstone. Structural analysis of the Zeehan region by Pitt, (1962), proposed regional scale, thrust dis-aggregation, competence-fractures associated throughout the Wurawina Supergroup and the middle Gordon Group. This boundary structure possibly extends at depth to Oceana Fault, in the north, and continues dipping northeast (note Geophysics Ch).

The Zeehan Carbonate project conducted by CRA Explration proposed five target concepts for carbonate-hosted Zn deposits in the Gordon Group (Grieves Siding, Mariposa, Professor Range, Firewood Siding, Sunny Corner, Myrtle, Pyramid, Oceana, Austral Creek and Black Jacks), (Parkinson 1994). Of the five target concepts, two targets were the lower and upper boundaries. Most aforementioned mines in Zeehan are prospective for and associated with <1m to >50m of massive sulphide with hydrothermal carbonate, or supergene-enriched, carbonaceous or ferruginous clays or pug. The upper and lower boundaries were drilled during the Pasminco Zeehan Project, (OP1 & 3), which revealed a lower and upper ferruginous or carbonaceous clay zone associated with massive goethite. At Oceana, the upper boundary was unmineralised, slightly silicified or coincident with kaolinised clay.

4.6 Petrography of Oceana

4.6.1 Sphalerite

Sphalerite 1

Sphalerite 1 is the most abundant sulphide reaching a size of 5mm with a honey brown colour. Euhedral and subhedral masses occur replacing orthochemical components of bedded and massive Gordon Group strata. Few examples of crystals occur with veins in the Southern Zone and tend to be intraclastic.

This type of sphalerite was observed replacing limestones and preceding fracture and infill by galena and calcite, respectively. The replacement bands followed distortions of the bed giving the appearance of stratiform mineralisation. Sphalerite 1 ranges in colour from amber to honey brown to yellow. The finer the crystal size generally equates to the darker the appearance. This is not to be confused with findings of Williams, (1968), who observed sphalerite to darken with increasing FeO content, which Roedder and Dwornik, (1968), entirely disagree with.

Ellis, (1984), characterised this phase by the presence of chromatic bands which were used as marker horizons for unravelling the ore formation sequence by McLimans *et al.*, (1980), and Eldridge *et al.*, (1983). Bands were concentric around cores of opaque or carbonaceous cores, which implied the crystal grew from a nucleus, although microprobe analysis illustrated no difference in composition (Ellis 1984). The presence of two cleavages, characteristic of dolomite, indicated a probable replacement origin in some crystals.

Sphalerite 2

Sphalerite 2 is red in colour occurring as isolated euhedra supported by massive crystalline calcite, ankerite or siderite. Examples are commonly associated with bituminous stringers within calcite breccia zones. Overprint relationships indicate that sphalerite probably preceded or was penecontemporaneous with mineralisation of siderite 2 as was silicification, due to fracturing and dissolution by sideritic fluids. Ellis, (1984), defined this generation of sphalerite as free of distinct chromatic banding and considerably fractured.

Sphalerite 3

This generation of sphalerite was visibly absent at Oceana from logged core. Examples cited by Peace, (1995), at Austral and by Ellis, (1984), at Z-25 & Z-28. This type was reported to occur in the dolomitic micrite beds stratigraphically above the major zones of mineralisation. Examples are very small, rounded blebs with a distinct red-brown colour and isotropism in thin-section. Some examples were observed within stylolites and indicate a possible relationship with carbonate dissolution to accumulation, as in similar observations for pyrite (Ellis 1984).

Peace, (1995), described similar generations at Austral as showing distinct clear and orange-coloured growth bands with typically small fragments of opaque organic material. Crystals are generally clustered and replace siderite 2. Incorporated organic matter suggests mineralisation was dominantly carbonate replacement (Peace 1995). Both mentioned authors note the cloudy appearance of sphalerite cores, however at 500x magnification they contain abundant tightly packed fluid inclusions.

4.6.2 Galena

Galena is characterised by massive vein-like and disseminated occurrences throughout the Oceana prospect. Examples north of Mine Fault occur up to 1m thick and up to 13 metres thick south of Mine Fault, in the Northern Zone. Examples in the Southern Zone are similar in occurrence with additional replacement textures. Galena veins or zones are thickest in the eastern lens, reaching up to 50cms thickness. Taylor, (1983), described stratiform galena 'beds' showing soft sediment deformation in units at the base of the western lens. Although subsequent authors have chosen to disregard this feature it will not be settled until further drilling programs are implemented, and must be included. An alternative explanation of this feature may be similar to examples in MVT deposits of co-genetic carbonate-replacement of easily accessible lithologies. Fluids would have inundated susceptible lithologies and could have replaced along beds, preserving soft sediment deformation and producing pseudo-stratiform mineralisation. Argillaceous dolomicrite beds were resistive to the replacement process (Taylor 1983).

Galena infills siderite 2, fractures sphalerite 1 and sphalerite 2, and is encrusted by later stage calcite. Ellis, (1984), described regions of ore where galena blebs coalesced to form a matrix with rounded residuals of sphalerite (atoll textures). Later calcite-rich veins generally contain randomly dispersed galena blebs throughout. Vein-hosted galena is typically engulfed by fluids and is characterised by absent replacement textures. This would suggest two mineralising episodes of galena, which describes an original influx of lead that is overprinted by Devonian galena. Homogenous populations observed by Gulson *et al.*, (1987), may contradict this however calcite-related galena is rare in occurrence and may not have been sampled.

4.6.3 Chalcopyrite

The presence of chalcopyrite has been substantiated by observations north of Mine Fault, (Jack 1960), minor assay, a single report of malachite, (Jones 1978), and as occurring as disseminates in veins and fractures with galena cutting sphalerite, dolomite and siderite, or as disease within sphalerite (Ellis 1984). Vein and fracture occurrences were evident in this study, in accordance with findings of Ellis, (1984). Ellis, (1984), suggested an explanation similar to one Eldridge *et al.*, (1983), based on the Kuroko deposit, which was due to the late paragenetic nature of the chalcopyrite, metals replace FeS compounds in sphalerite by the reaction:

$$\{ Zn_{(0.95)}Fe_{(0.05)} + 0.048\ Cu^{+} + 0.048\ H_2S = 0.952\ (Zn_{(0.998)}Fe_{(0.002)}S) + 0.048\ H^{+} + 0.024\ H^{2} \}$$ may include replacement of ZnS.

4.6.4 Pyrite

Four phases of pyrite were observed at Oceana. The first two phases are clearly syn-diagenetic and are associated with dolomitic and argillaceous dolomicrite horizons.

The first hydrothermal phase was noted by Peace, (1995), as disease and intercrystalline euhedra with sphalerite. Examples are considered to pre-date siderite 2 mineralisation. A final phase of pyrite occurs in veins cross-cutting all other features at Oceana.

4.6.5 Dolomite

The many phases of dolomite at Oceana can be broadly divided into diagenetic types, mineralisation-related types and post-mineralisation types. Diagenetic generations are typically fine grained and form irregular patches throughout the limestone host. Late-stage diagenetic fluids are typically enriched in iron and result in the precipitation of ferroan dolomite. Large, zoned, isolated, euhedral, ferroan rhombs are indicative of steady-state conditions over a considerable period of time.

Co-genetic dolomite and mineralisation phases were classified into fine- and coarse-grained varieties by Ellis, (1984). Fine-grained dolomites are coincident with the alteration envelope of lodes. Coarse-grained dolomites were found in one location from the Northern Zone adjacent to the Oceana Fault, (Ellis 1984), occurring as vug-fill with siderite, sphalerite and galena. Both types are consistent with halo envelopes of stratabound deposits and occur in other mineralised parts of the Gordon Group in the Zeehan region. Post-ore dolomite is coincident with faults possibly associated with Tabberabberan movements or likely post-Carboniferous kinematics.

4.6.6 Hydrothermal carbonates

Diagenetic sparry calcite is ubiquitous in the lagoonal sediments of the Ugbrook and Myrtle Formations. Siderite 1 is dominantly associated with the Southern Zone occurring as fine grained, <1mm, replacements of orthochemical-rich beds, i.e. micrites. Siderite 1 in the western lens replaces most other components, including isolated sand grains in micrite units, with remnant bituminous films representing argillaceous beds.

Siderite 2 occurs as massive crystalline comb textured, vug-fill and open space fill with a pale brown to grey colour. Examples line dissolution cavities in the host and are surpassed by cream white siderite 3. Siderite 2 can be recognised by the sweeping extinction, similar in habit to saddle dolomite.

Siderite 3 is cream white and was only observed to overprint siderite 2 examples. Compositions infill the centre of vugs, over comb-textured siderite 2, and as thin veins cross-cutting and fracturing ore generations and other hydrothermal generations. This type is rarely observed at Oceana and is generally subordinate to sparry calcite in occurrence. Hydrothermal calcite generations overprint all episodes of siderite mineralisation.

4.6.7 Quartz

Detrital quartz comprises a considerable proportion of carbonate sediments in most formations present at Oceana. Evidence for hydrothermal silicification is rare although has been documented at Oceana and other localities, such as at the upper boundary and in some vein compositions. At Oceana, evidence occurs as two styles probably representing the same phase. In the host limestone, globular stromatoporoid layers are alternatively replaced by quartz and late diagenetic to early-ore dolomite. In the mineralisation phases euhedral quartz crystals have infilled replacement sphalerite and the argillaceous components of the host lithology. This implies siliceous fluids were involved early into the onset of mineralisation. Massive calcite spar overprints and disrupts quartzose lithologies indicating the occurrence of a different, later, hydrothermal episode.

4.7 Paragenesis

A paragenetic scheme can be constructed for the Southern Zone. Paragenetic textures are important in understanding typical overprint relationships characteristic to the deposit.

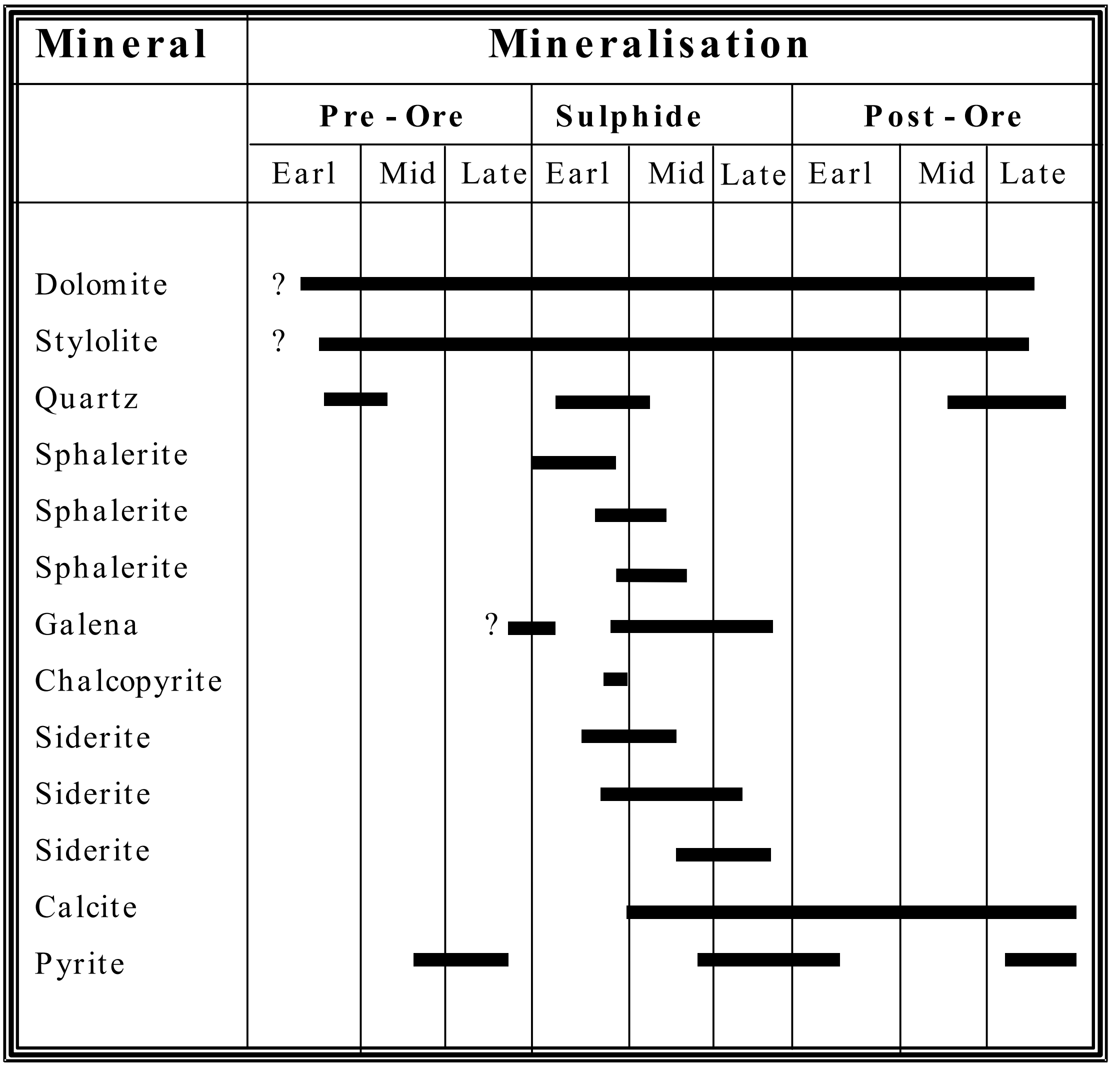


Figure 2: Paragenetic construction of the Southern Zone at Oceana.

4.8 Weathering Products

Prolonged intense weathering of ore minerals proximal to Oceana Fault has resulted in the formation of a weathered, pug-clay blanket extending to at least 70m depth. Supergene enrichment of this blanket was considered during the 1978 tenement, based on reporting of the gossan composition, and has been substantiated with aircore and wacker sampling during the 1995 tenement.

The ore occurrences are characterised by an intense stain associated with oxidation of Fe-rich minerals, i.e. siderite. The stain pervades minimally into the host-rock and represents a zone of groundwater channelling. Due to high water fluxes, this zone has degraded to limonite, with relict ore sulphides, and ultimately goethite. Supergene textures include cubic and dendritic boxwork which indicate substantial remobilisation and oxidation. The basal boundary of the Gordon Group at South Oceana is characterised by massive goethite with cavity-fill quartz spherules, which provide little indication of parent mineral compositions. Sampling of the boundary at other locations around Zeehan, i.e. Grieves Siding and Mariposa, typify silicification, massive limonite, goethite, ore sulphides and accelerated decomposition.

4.9 Geochemistry

Oceana mineralogy has been intensely surveyed during the course of the exploration history (refer **Appendix A**). Many experimental methods have been tested and have resulted in a valuable array of methods that are appropriate for relatively small carbonate-hosted deposits of this type. This section is included for the purpose of compiling existing data, with their positive or negative implications, and further analysing the Southern Zone for trace elements associated with zinc ore minerals. Samples were collected at 20m intervals over the length of the core, with focused sampling of 10m intervals when obviously coincident with ore minerals. The reason for this approach to sampling is due to restricted spectral analysis by Amoco M.A.C., i.e. Cu, Pb, Zn and Ag, and the piecemeal approach to analysis by Pasminco, i.e. 20 element analysis of the ore zone. The ore lens intersected by ZT-80-4 is considered to provide a valuable aspect of mineralisation for the Southern Zone and is, more importantly, easy to cross-reference to preceding authors investigations.

4.9.1 Cathodoluminescence

Cathodoluminescence was previously considered for use on the carbonates which include the main activators (Mn2+ & Pb2+ ions) and the main quenchers (Fe2+, Ni2+ & Co2+ ions). Peace, (1995), intended to use the method for petrographic analysis of the paragenetic relationships, however the pervasive high concentrations of Fe2+ ions acted to quench most of the luminescence.

4.9.2 Electron Microprobe

Carbonate analysis of vein carbonates from the Northern Zone, (ZT-79-2 @ 144.5m), and ore analysis of sphalerites from the Northern Zone, (ZT-82-11 @57m), and the Southern Zone, (ZT-82-10A @ 76.7m), was undertaken by Peace, (1995). The first two phases of siderite associated with mineralisation were revealed to be impure and virtually identical in chemical composition. The third type of siderite was chemically more distinct than the preceding phases and was associated with Zn compositions to 10 wt.% within siderite (Appendix G).

Sphalerite was sampled by Peace, (1995), for the purpose of identifying silver content, which was proposed by Ellis, (1984), to average 1.3 wt.% in galena. Microprobe analysis revealed poor to below detection-limit amounts of silver averaging 0.94 wt.% in detectable samples.

4.9.3 XRF analysis

A pilot study into the systematic geochemistry of the Southern Zone was performed on 25 samples collected from DDH ZT-80-4. Samples were analysed by X-ray fluorescence, using a Philips PW – 1480 X-ray Fluorescence spectrometer at the University of Tasmania. Major element analysis was carried out on fusion disc samples, and trace element analysis on pressed powder pills. DDH ZT-80-4 was chosen for sampling because of good recoveries and conditions, and can be compared to the western lens intersected in ZT-80-7. Samples were collected with no bias towards the ore zone to assess the success of grab sampling at fixed intervals. This method will result in lower than expected ore values.

Previous data was recorded from ZT-82-10A by Jones, (1978). Sampled sections of both drill holes provide a valuable measure of the eastern ore lens, however, assays consisted of a four-element survey based on findings of Both and Williams (1968). Data from ZT-80-4 provides a more complete picture for elemental variations.

In an attempt to further understand the ore body selected portions of ZT-80-7 and OP2 were re-analysed using AAS for the elements Cu, Pb, Zn, Ag, Fe, Mn, Co, Ni, Bi, Cd, Mo, V and Mg, XRF for Ba, W and Sn, and Vapour Hydride AAS for As, Hg, Sb, Se and Te, (Saxon 1995), (**Appendix G**). Background values for the ore zone are :

Element	xBackground	Element	xBackground
Cu	25	Pb	2000
Zn	400	Ag	30
Fe	7	Mn	20
Ni	5	Cd	60
Hg	50	Sb	30

Zn, Pb, Cd, Mn and Hg define the ore halo (Saxon, (1995). Anomalous values and halo extent are:

Element	Anomalous Cutoff Value (ppm)	Distance from Ore (true)
Zn	200	12m
Pb	60	9m
Cd	3	8m
Mn	590	6m
Hg	0.03	10m

Results indicated enriched alteration values local to the ore zone with no significant extensions into host rocks or similar stratigraphic horizons Newly acquired data from ZT-80-4 will provide values of the eastern lens from the same stratigraphic position in ZT-82-10A at a different location.

Element suites were based on previous studies, which included suites relevant to previous genetic model aspects, such as Irish-type or MVT model deposits. Some examples of MVT sphalerite are known to include high trace concentrations of germanium in addition to known occurrences of cadmium. Sphalerite is generally associated with gallium, germanium and indium, which have close relationships with aluminium. Antimony was selected for assay, in support of mercury to observe the extent of the role Devonian fluids played on mineralisation. Antimony is broadly dispersed in distal, granite-related hydrothermal vein systems, so results may indicate proximity within vertical and outward zonation of typical west Tasmanian tin-granitoid districts summarised by Large, (1989).

Rao, (1989), described the Gordon Limestone at Mole Creek characterised by low trace amounts of Mn, moderate Na and high Sr concentrations. When compared to modern aragonitic carbonates, concentrations were significantly depleted in Sr and Na and moderately enriched in Mn. These patterns are attributed to diagenetic processes. Ti, Rb and K were positively correlated with clay minerals illite, kaolinite and montmorillonite. The positive correlation between Rb and K is probably related to substitution of Rb for K in illite (Rao 1989).

4.9.3.1 XRF Results

Whole rock data obtained by XRF at the University of Tasmania is included, as **Appendix D - 3.** A number of trace elements are below detection limits. These include U, W, Bi, Se, Na and Ge. Downhole element variations in ZT-80-4 are plotted in **Appendix D - 4**.

Ore zone samples can be identified by the highest enrichments of Pb. Ore is characterised in these examples by massive crystalline siderite, pug mudstone and breccia replacement, respectively with depth. Zn enrichment is coincident with ore zones, however, porous calcarenites near mineralised intraformational breccias show considerable enrichment also. Broadly spaced indiscriminate sampling has shown that alteration enrichments are evident to ~10m with minor enrichments to ~15m.

Data was sorted according to dominant associations into silicate, carbonate and sulphide components (**Appendix D – 5**) . Silicate components were dominantly Si, Ti and Al. Elements that show a systematic distribution with silicate components include K, Y, Rb, Ni, Cd, Sb and to a lesser extent, Ga and Th. These distributions can be broadly grouped into categorical fields defined by the achieved levels of enrichment. Groups represented within the silicate component include K, Rb, Si, Ti, Al, and Y; Ni, Sb and Cd; and Ga and Th.

Carbonate components are represented by Ca, Fe, Mn and Mg. Broad groups consist of Fe and Mn, and Ca and Mg. Both groups are characterised by similar trends. The final sulphide group consists of S, Ni, Cu, As, Pb and Zn, which can be grouped into S, Ni and As, and Pb, Zn and Cu.

4.9.3.2 XRF discussion

Ore zones are characterised by elevated Fe and Mn. Wide spaced sampling distinguishes the ore zones using these elements. Pb and Zn spikes are generally homogenous with minor fluctuations near surface, probably related to supergene enrichment. Pb values are of a greater magnitude than Zn with the exception of enriched Zn in coarse-grained lithofacies. Ca has a negative spike at similar depths to Pb, Zn, Fe and Mn enrichment suggesting they were expelled as a result of the mineralising process.

The most important aspect of this data is the demonstration of similarities observed in silicate component elements. Plots show these elements occur in proportion to each other and the significant enrichment in the heavily veined and tectonically brecciated upper section of ZT-80-4. These elements are far less enriched near the ore zones and indicate the possibility of two dominant mineralising occurrences. Si, Al, Ti, K, Rb, Y and, to a lesser extent Ga, are homogenous and indicate a probable association with granite-related hydrothermal fluids.

Scatterplots of Ca, Mg and Fe indicate dolomite and ankerite, as the dominant hydrothermal gangue phases. Dolomites have high Ca:Mg ratios which may be attributable to Fe replacement of the Mg component. Ankerites are also generally Ca-rich and show minor excursions to sideritic compositions.

Geochemical evaluation of the Gordon Group at Mole Creek indicates that Mn is considerably enriched in the ore zone. Rb and Ti may be hosted in clay minerals which are present at Oceana. Clay minerals are associated with fault zones and porous units, and are related to hydrothermal activity associated with intrusion of the Heemskirk Granite or a later episode.

4.10 Zn Number

The zinc number was developed as an exploration guide to assess for blind volcanogenic massive sulphide deposits in the Cambrian Mt Read Volcanic Belt, western Tasmania (Large & Huston 1986; Huston & Large 1987). Large and Huston, (1986), noticed consistencies in zinc ratios, means and the standard deviation in these deposits and illustrated this in a frequency histogram. Supplemental data of well-known Devonian related deposit ratios were compared and showed a variation to the restricted ratios of the Cambrian stratiform deposits (**Figure 3**). The Zinc number is an invaluable geochemical technique for screening deposits for further prospectivity (Large 1989).

Zinc ratios are possibly controlled by four major factors, including the relative concentrations of lead and zinc in the source rocks, the mechanisms of metal solution from the source rocks, the saturation-non-saturation of base metals and overall chemistry of metal bearing species, and the efficiency of metal deposition. The controlling factor on using this index is concentrations must be greater than 200ppm (Huston and Large 1987).

Zinc numbers at Oceana were grouped into an entire deposit array and a Southern Zone array. This approach to data sorting was based on the obvious textural differences between the areas. Acquired data was sourced from Jack, (1960), for the Northern Zone, and Jones, (1980), from the western lens of the Southern Zone. A combination of values from the western and eastern lenses will provide a broad representation of Southern Zone mineralisation.

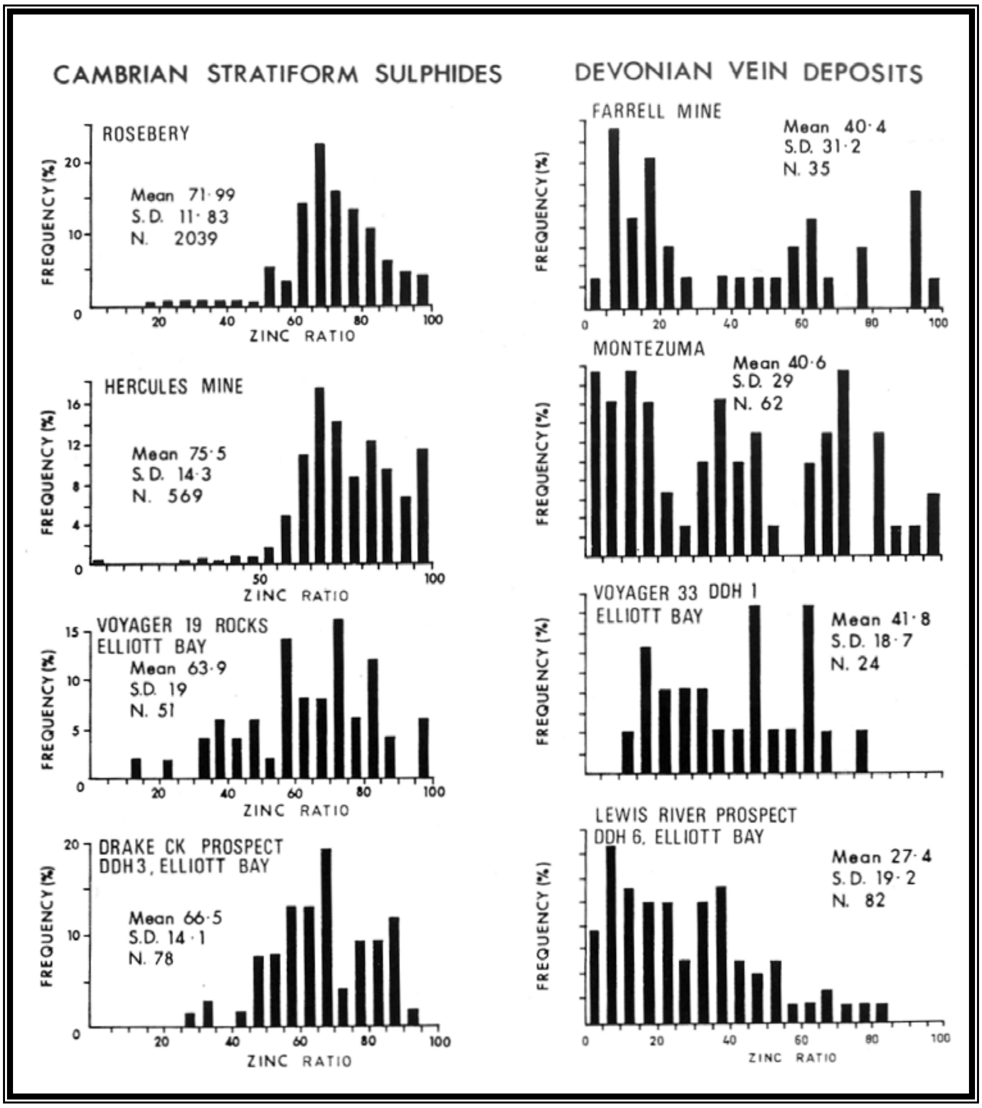


Figure 3: Zinc ratio histograms for Cambrian and Devonian style mineralisation and prospects, western Tasmania (*from* Large 1989).

Zinc Number Results

Frequency histogram plots of the Zn number, (mass ratio), in the Northern Zone have a mean of 29.46 and a Standard Deviation of 25.99 (**Figure 4**). Frequency plots indicate ratios are consistent in shape to Devonian frequency plots. Zinc numbers are consistently below 50 and indicate the Northern Zone is a lead-rich deposit with Devonian characteristics.

The Southern Zone plot is considerably different and is characterised by a mean of 45.70, and a Standard Deviation of 26.94 (**Figure 5**). Frequency histograms are consistent in shape to Cambrian stratiform sulphides which are typically zinc-rich. Large Standard Deviation values from both styles of mineralisation is no doubt related to mixing and remobilisation of the metals.

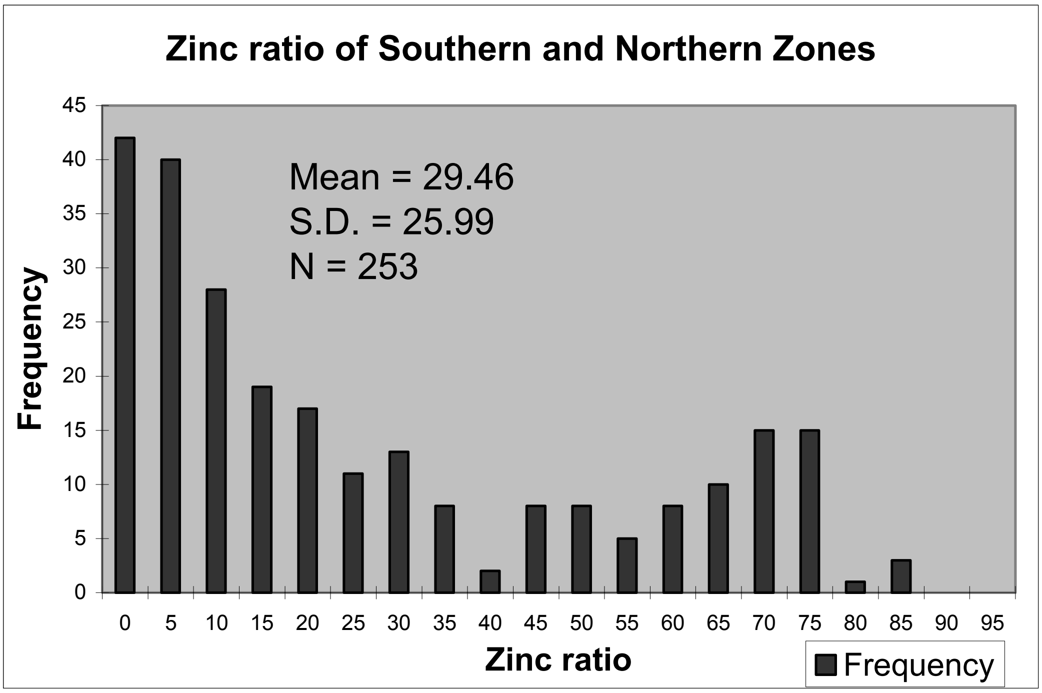


Figure 4: Statistics of the zinc number, (100xZn/(Zn+Pb), from the Northern and Southern Zones at Oceana.

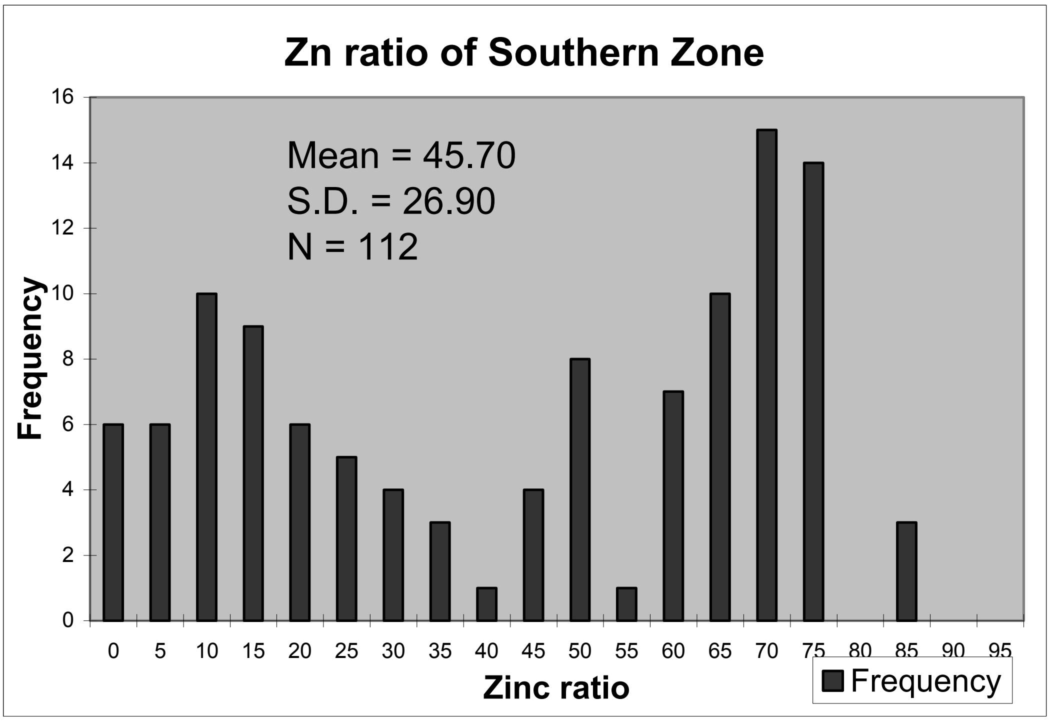


Figure 5: Statistics of the zinc number, (100xZn/(Zn+Pb), from the Southern Zone at Oceana.

4.11 Discussion

The Southern Ore Zone has been a region of genetic contention for decades, ranging from epi-genetic, (Jack 1960, Ellis 1984, Peace 1995), to syn-genetic (Roxburgh & Jones 1980, Taylor 1983) development. Authors who emphasised epigenetic processes generally discounted the sedimentary associations describing them as lithofacies characteristic of a well-advanced platform. Authors, who favoured syngenetic mineralisation, involving a combination of both styles, have described the sediments hosting the ore as debris flows. Neither of these descriptions are satisfactory because the sediments formed in a ramp to mini-platform where lithofacies development is restricted, and the ore hosting sediments were associated with slumping during deposition and diagenesis. Syn-diagenetic tectonism is evident from the presence of Oceana Fault, the Lords Siltstone and intraformational breccias, which are temporally associated with the Benambran Orogeny of eastern Victoria.

4.11.1 Northern Zone

The Northern Zone is characterised by massive carbonate replacement and discordant vein and breccia zones. Fault breccias are associated with wall rock fracturing and clasts are supported by massive crystalline hydrothermal carbonates. Infill of cavities and vugs by the hydrothermal carbonates implies sedimentary lithification before intrusion of the fluids, whereby dissolution probably resulted.

Post-kinematic episodes after mineralisation of galena are represented by a distinct cleavage which is noticeably bent, (Ellis 1984), and the presence of extensive kinking from the western lens at Oceana (Lyall 1966). The former case was substantiated by Burrett, (1984), as probably occurring from the Early Devonian. Some mineralisation at Oceana is displaced by low angle thrust faults, *De*D_4, which suggests an age similar to intrusion of the Heemskirk Granite. Later calcite-rich, pyrite-bearing veins are probably associated with late stage fluids circulating from the parent Heemskirk Granite pluton or a later stage of hydrothermal activity.

The northern zone replaces the stratigraphic equivalent as in the southern zone and hence, could have a similar origin (Ellis 1984). The two prominent shears described by Jack, (1960), may or may not be associated with the replacement lenses and this will not be further clarified due to exhaustion of the reserve. The zinc ratio properties of the Northern and Southern Zones indicate Devonian characteristic values. This implies mineralisation during the Devonian was overwhelming in proportion to during the Ordovician.

4.11.2 Southern Zone

The Southern Zone is characterised by epigenetic carbonate replacement lenses that formed during diagenesis. Replacement textures are fractured by discordant mineralisation and precede stylolitisation for the majority. Two modal populations occur in the eastern lens of the Southern Zone. Ore zone proximal Fe and Mn defines an alteration halo up to 15m from the deposit. Other enrichments are associated with discordant parts of mineralisation associated with kaolinisation. The kaolinisation process has resulted in significant enrichment of Ti, Rb and Al amongst others, and may provide a compositional vector to ore.

Zinc number frequencies from the Southern Zone are consistent with frequencies from Cambrian stratiform sulphide deposits such as Rosebery, Hercules and Elliott Bay. The large deviation compared to Cambrian deposits indicates lead-rich regions or pods characterise the ore zones, which are probably related to Devonian mineralising solutions.

4.11.3 Fault Zone

The pug overburden can be considered as a component to the resource. Significant development at depth related to water discharge is evidence for the presence of supergene enrichment processes. A significant question remains as to the minor to absent proportions of manganiferous minerals compared to extensive supergene halo and gossan enrichments. The manganese would be partly derived from sideritic and ankeritic gangue however this doesn't account for the magnitude of enrichment.

The lower faulted boundary of the Gordon Group is also considered a possible resource. High water discharge rates along the faults of Oceana are a negative aspect to this. The stratabound mineralisation is probably mostly remobilised by supergene processes, due to the extent of goethite, however significant intersections at other localities provides hope for exploration.

Plate set 2

2 –A: Hand sample of ore zone sphalerite 2 in mudstone band supported by massive crystalline ankerite and siderite; from ore zone of ZT-82-10A at 76.3m

2 – B: Honey brown disseminated, carbonate replacement, sphalerite overprinted by siderite galena and calcite. Galena and calcite fill intercrystalline spaces of siderite; from ore zone in ZT-80-4 at 289.3m

2 – C: Massive honey brown carbonate replacement sphalerite overprinted by red siderite. At least four generations of veined, hydrothermal compositions cut sphalerite. Numerous stylolitisation episodes which have formed along the edges of the massive sulphides. from ore zone ZT-80-7 at 289.7m

A

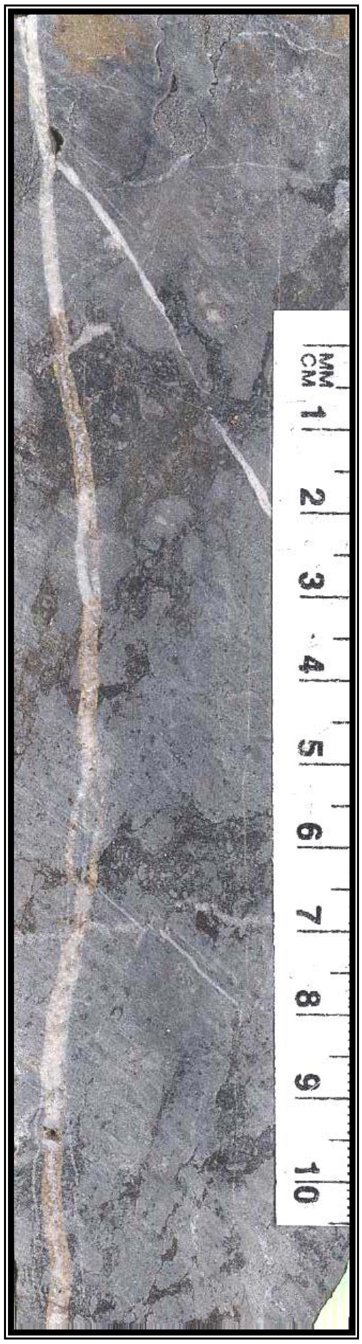
B

C

2 – D: Paragenetic sample showing pink sphalerite, lower centre, associated with early-ore siderite vein, amongst at least 3 hydrothermal carbonate generations which have been periodically stylolitised; from discordant region of ZT-82-10A at 447.2m

2 – E: Protected lagoonal micrite interbedded with argillaceous dolomicrite deformed in intraformational breccia. Note petrographic feature of siderite salvage, (honey), coincident with argillaceous components in the core parallel ankeritic vein, (white); from Pyramid core OP3.

D



E

2 – F: Massive siderite fractured by ankerite and 'vein-like' galena. Minor disseminated sphalerite is evident when viewed by a reflective microscope; from ore zone of ZT-82-10A at 445.0m.

2 – G: Massive honey brown siderite replacement with infill of galena, and subsequent infill by ankerite and calcite. Reflective microscopy shows high proportions of disseminated sphalerite surrounded by siderite, and trace minor amounts of chalcopyrite associated siderite and sphalerite grain boundaries; from ore zone ZT-82-10A at 398.6m.

2 – H & I: Massive crystalline honey brown siderite and the opposite core face as limonitic oxidised ironstone. From discordant region from ZT-82-10A at 434.2m.

F

G

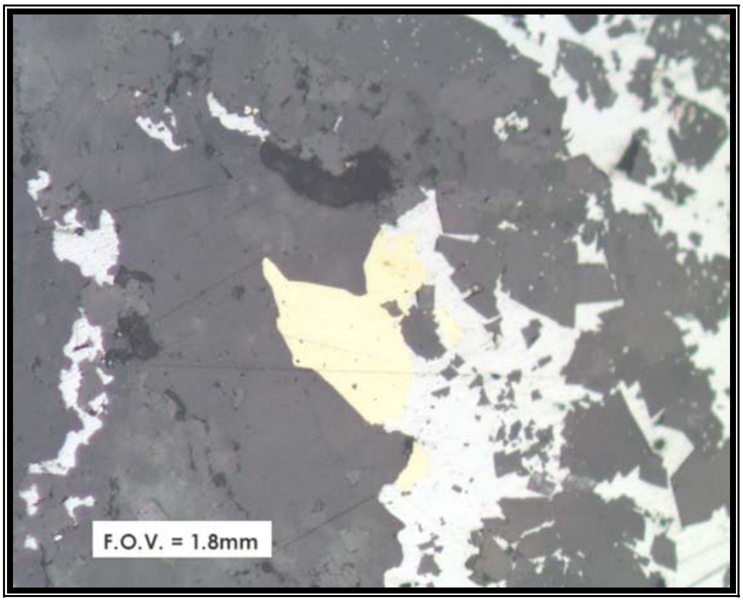
H

I

2 – J: Reflective photomicrograph of chalcopyrite, (yellow), rooted to sphalerite, (dark grey), infilled by siderite (medium grey), fractured by galena (white); from ZT-82-10A at 398m

2 – K: Chalcopyrite has grown within a mudstone laminate and included organic material, surrounded by siderite with disseminated sphalerite; from ZT-82-10A at 445m

2 – L: Dark grey sphalerite overgrown by medium grey siderite and infilled by pale grey calcite and white galena. Reddish brown bornite?! has mineralised along argillaceous bands and precedes calcite and galena; from ZT-82-10A at 445m.



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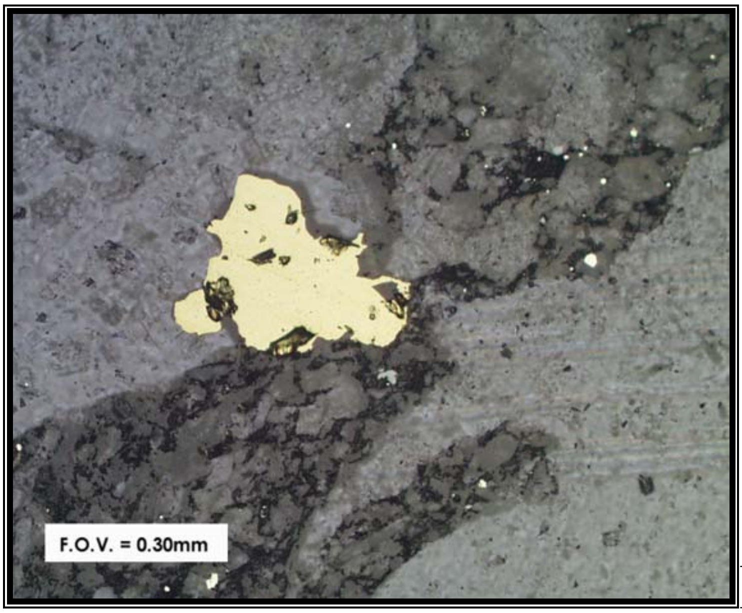

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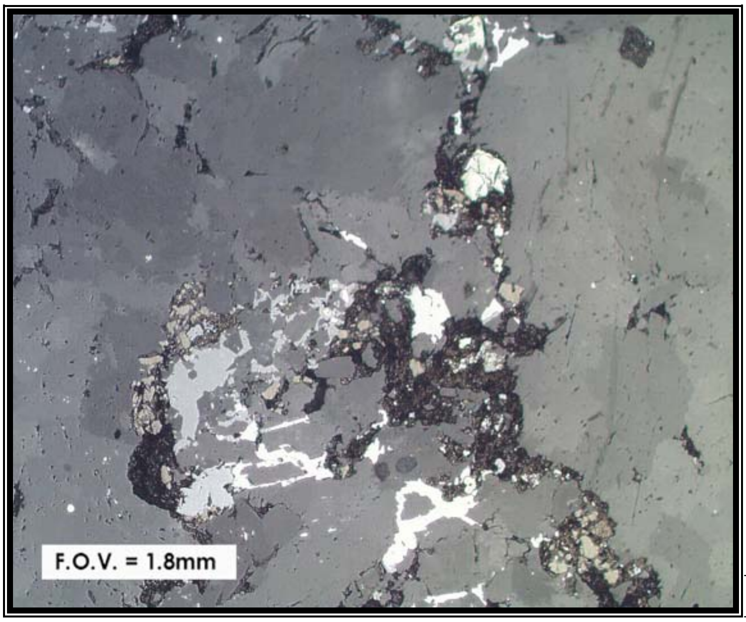
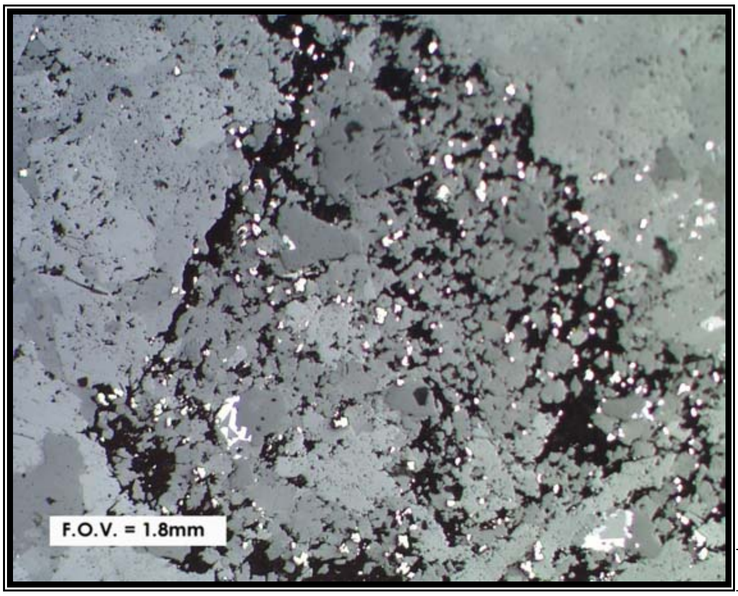


L

2 – M: Close association of pyrite, (cream), and organic material indicating a diagenetic origin, then inundated with sideritic and sphaleritic compositions, (medium and dark grey); from ZT-82-10A from 398m.

2 – N: Galena, (white), and siderite, (medium grey), with framboidal pyrite (pale yellow). Pyrite disseminated throughout siderite and is framboidal in galena indicating a similar paragenetic age to galena mineralisation; from ZT-82-10A from 398m.

2 – O: Cross section of trilobite pygidium in bio-sparite with diagenetic pyrite replacing outer margin. Pyrite composition is determined from the cubic symmetry.



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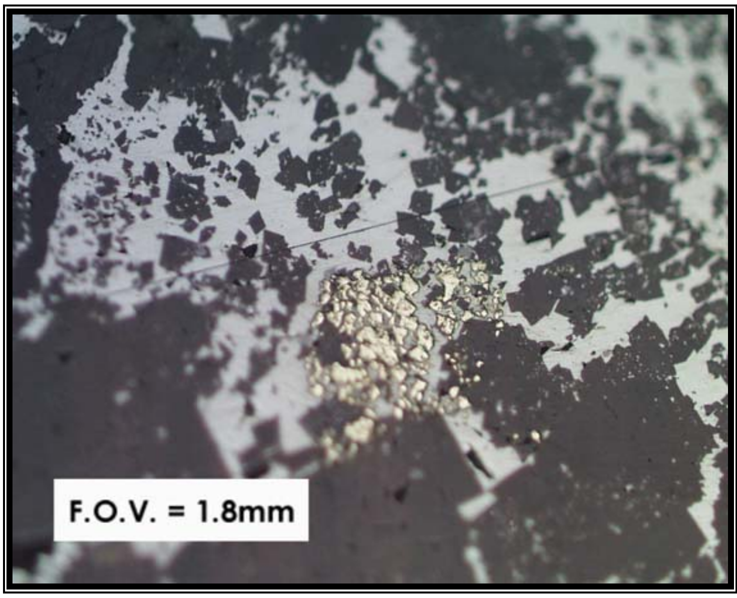

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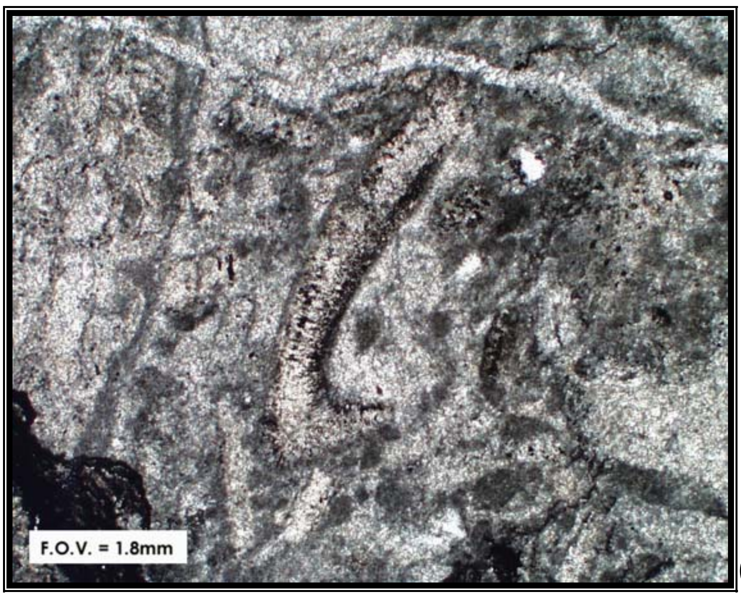
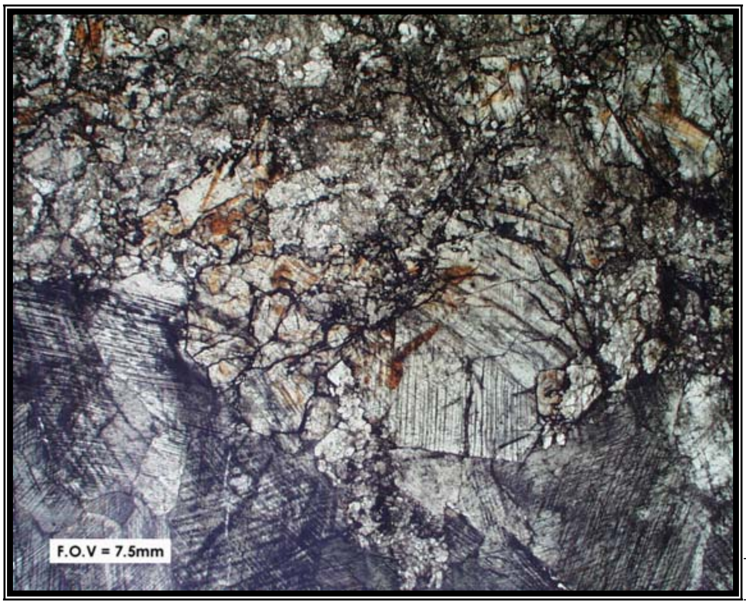


O

2 – P: Double polished thin section photomicrograph of massive crystalline calcite inundating Fe-banded sphalerite. Stringers of argillic to bituminous material and quartz connect sphalerite. Quartz cavity-fill within sphalerite indicates silica-bearing fluids occurred soon after sphalerite mineralisation or possibly sphalerite nucleated from detrital quartz cores; from ZT-82-10A at 76.3m.

2 – Q: Crossed-polar view of plate 2 – P showing isotropic sphalerite occurrences; from ZT-82-10A at 76.3m.

2 – R: Close up of sphalerite cores characterised by infill quartz which has replaced calcite, derived from the presence of relict hexagonal calcite cleavage; from ZT-82-10A at 76.3m.



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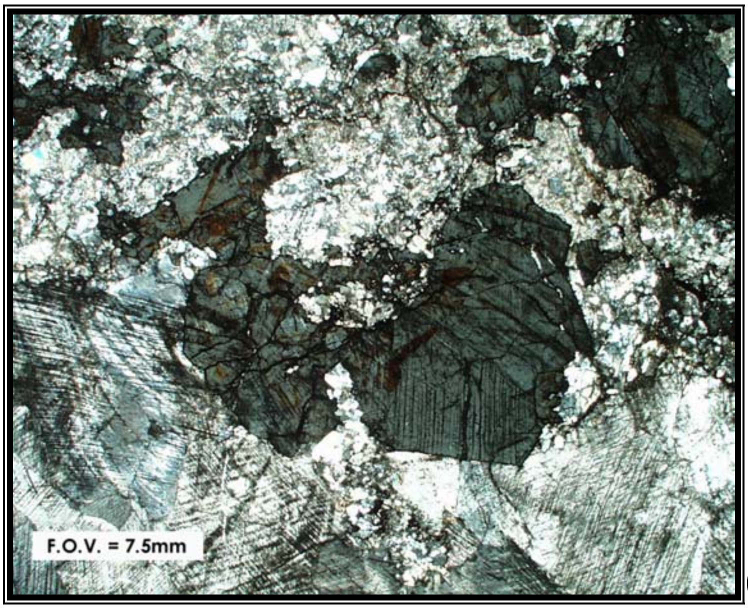

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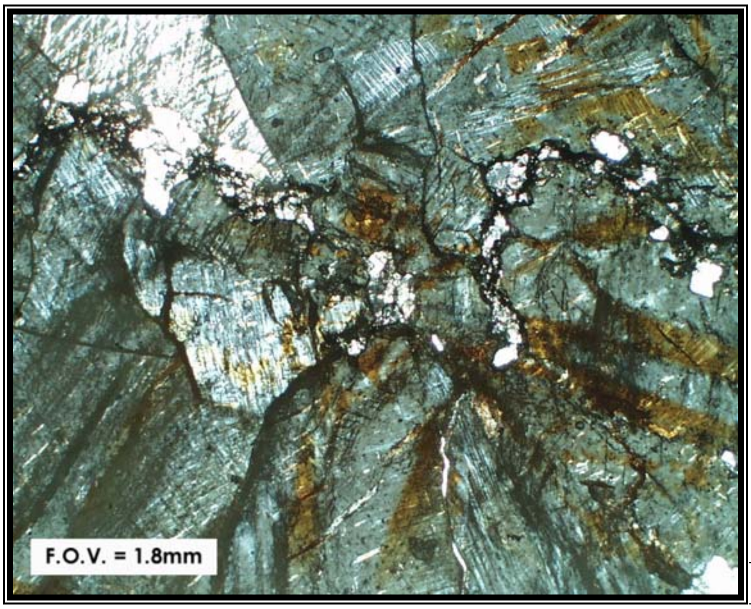
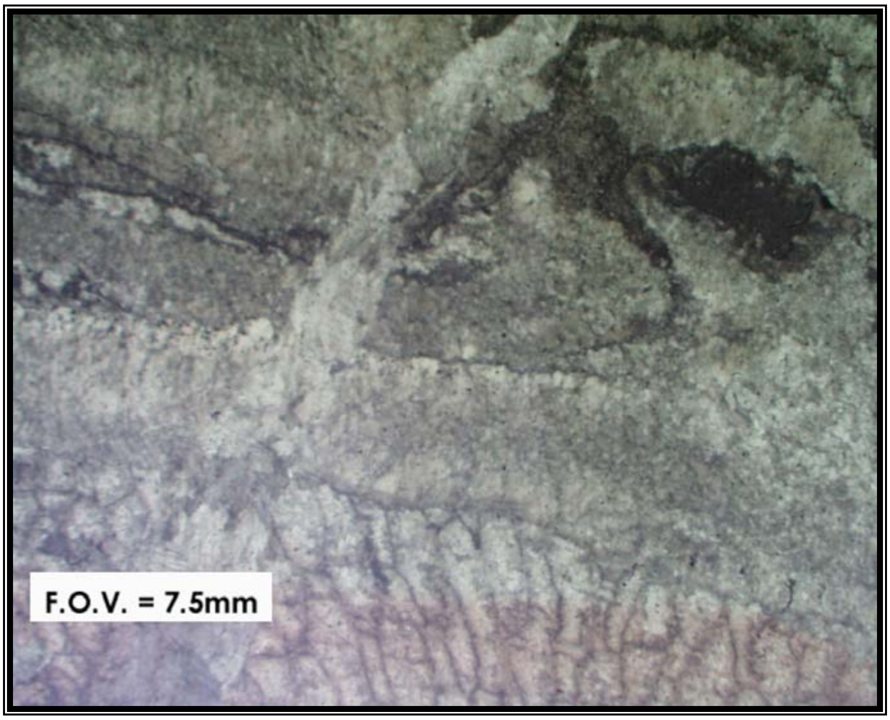


R

2 – S: Polished thin section with carbonate stain strip, (bottom), of globular layered stromataporoid discretely replaced by quartz and dolomite; from ZT-82-10A at 477.4m.

2 – T: Crossed polar view of plate 2 – S showing discreteness of quartz replacement bands. Fossil structures remain sparry while all cavities have been infilled by drusy quartz, evident from undulose extinction; from ZT-82-10A at 477.4m.



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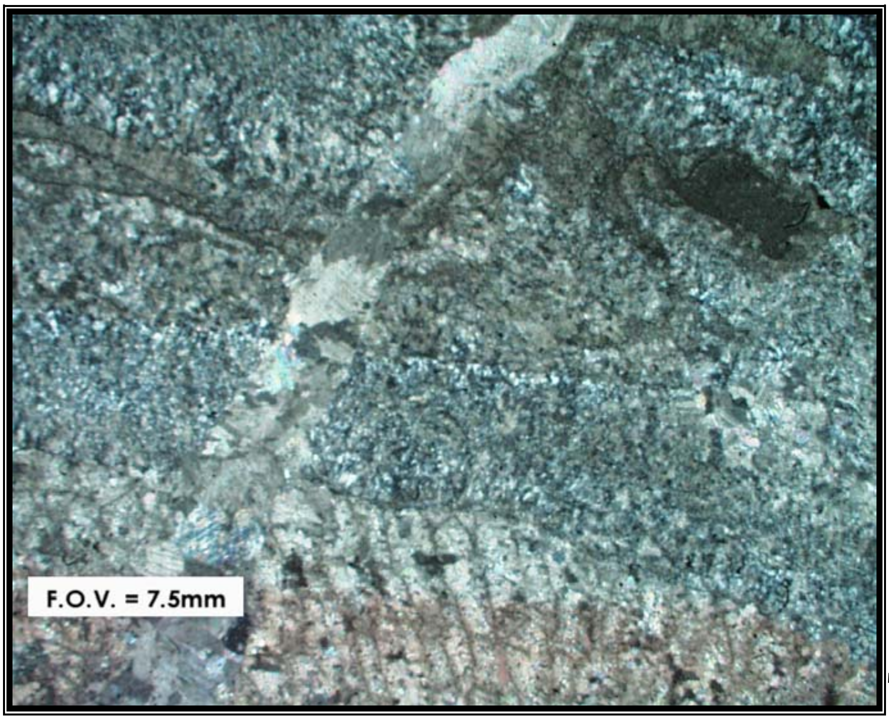

T

Stable Isotopes 5

5.1 Introduction

The focus of this study was to determine the nature of the contentious sedimentary associations and, with minor geochemical support, review all preceding data on Oceana to date. Extensive professional and academic studies have been carried out on the isotopic characteristics of the Gordon Group and this chapter will report on existing data for the sake of completeness. Datasets specific to Oceana includes Both and Williams, (1968); Williams, (1968); Ellis, (1984); Peace, (1995); and Cordery, (1998); with supplemental accounts of other Zeehan localities by Rao, (1996), Glover, (1996), and previously mentioned authors.

5.2 Carbon and Oxygen Isotopes

Oxygen and carbon isotope studies were carried out on Oceana for the purpose of defining characteristics of the fluids associated with mineralisation and their sources (**Figure 1 & 2**). Investigations have been previously carried out at Oceana to define the $\delta^{18}O$ and $\delta^{13}C$ characteristics of the host limestone and the alteration envelope surrounding the lenses. Values attained by Ellis, (1984), and Peace, (1995), were derived from a total 55 samples from calcite, dolomite and siderite pairs. Average values from Ellis, (1984), show a more depleted trend, while keeping a similar method, to values produced by Peace, (1995). This study will use both these authors datasets. Samples were from ZT-80-4, and other ZT series, recorded relative to PeeDee Belemnite standards for $\delta^{13}C$ and PDB / Standard Mean Ocean Water standards for $\delta^{18}O$.

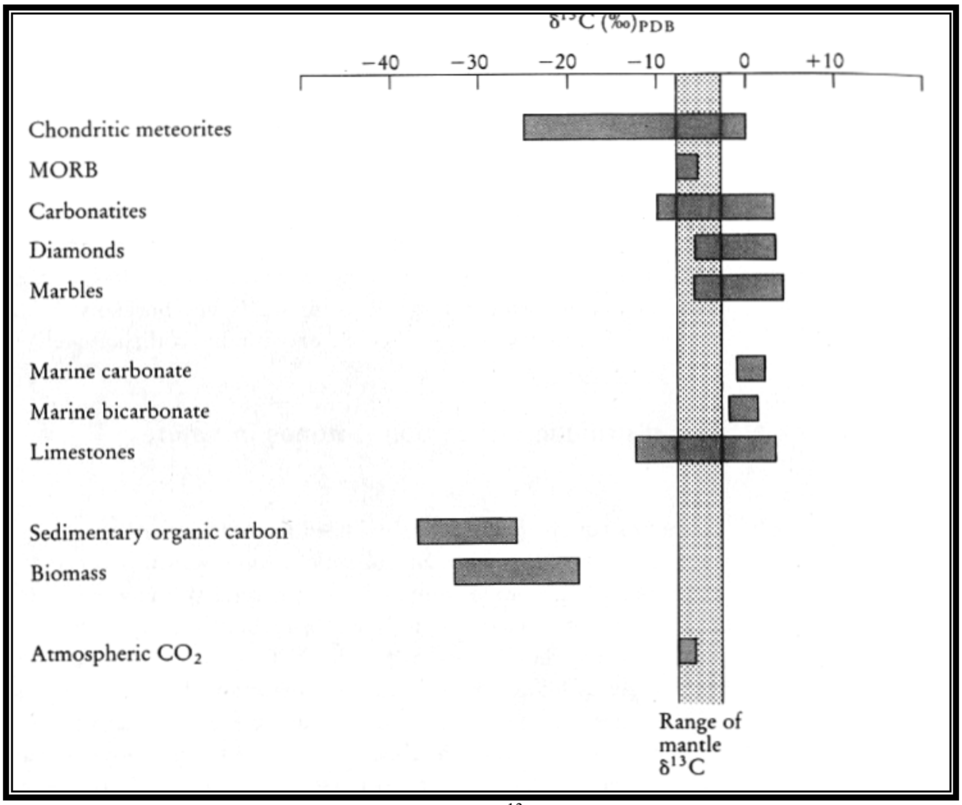

Figure 1: Natural C reservoirs. The ranges of $\delta^{13}C$ values in natural, carbon-bearing samples (*from* Rollinson 1996).

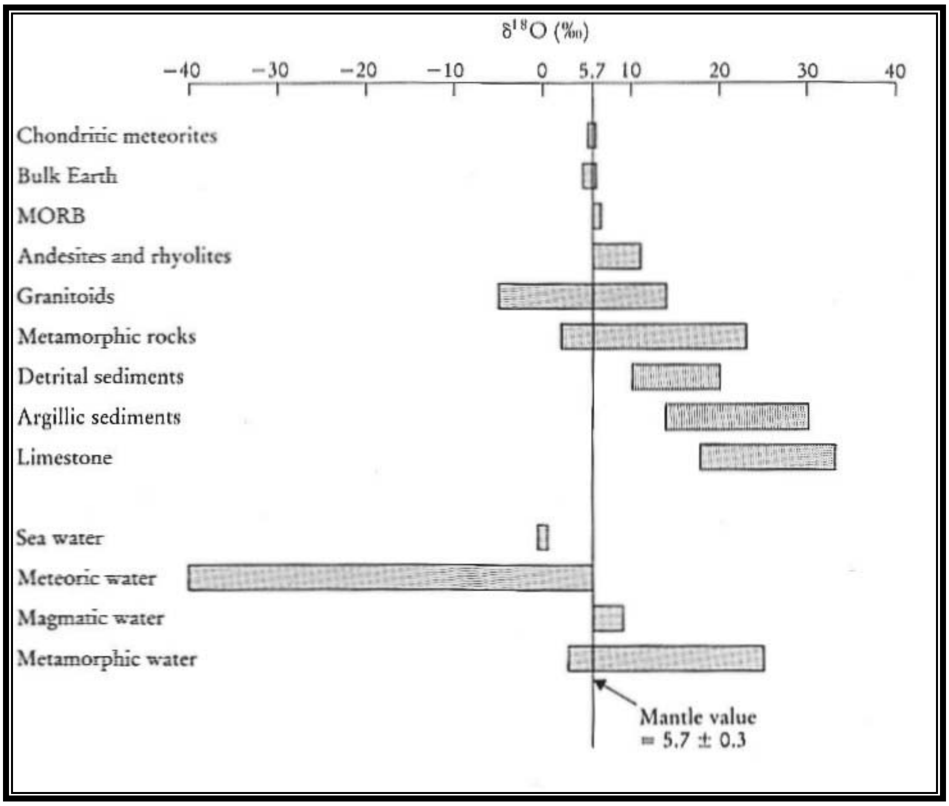

Figure 2: Natural oxygen isotope reservoirs (*from* Rollinson 1996).

Ore zone siderite showed a restricted range for $\delta^{18}O$ PDB of –14‰ to –12‰. $\delta^{18}O$ SMOW were in the range of 17‰ to 19‰ and $\delta^{13}C$ values range from –5‰ to –3‰ (**Figure 3**). Results were similar between replacement and cement phases with expected fractionation depletion in calcite phases (Peace 1995). Ore zone samples of $\delta^{13}C$ and $\delta^{18}O$ have a similar range of signatures to samples analysed by Ellis, (1984), and Both & Williams, (1968), (**Figure 4**).

Host rock data reported by Ellis, (1984), show an elevated trend decreasing towards the ore envelope with values averaging 3‰ PDB for $\delta^{13}C$ and 21‰ – 25‰ SMOW for $\delta^{18}O$ (**Figure 5**). Ellis, (1984), suggested the ore envelope values could be explained by a number of processes, including a temperature gradient, (Hall & Frieman 1969); a gradient in the isotopic composition of the pore fluid and the wall rock; or partial exchange between pore fluid and wall rock (Pinckney & Rye 1972).

Taylor, (1979), defined the phenomenon of isotopically light ore zone values to result from the preferential fractionation of lighter isotopes into mineralising phases. Sverjenky, (1981), suggested modelling ore zone and host values as a function of a variable water to rock ratio and attributed the decrease, from Upper Mississippi Valley district host rocks, to recrystallisation under conditions of progressively higher water or rock ratios near the ore body (**Figure 6**).

Peace, (1995), suggested negative carbon values to be the result of the dissolution of organic material. A mantle source was available from Queen Hill derived hydrothermal fluids however this was discounted due to the readily available carbonate source.

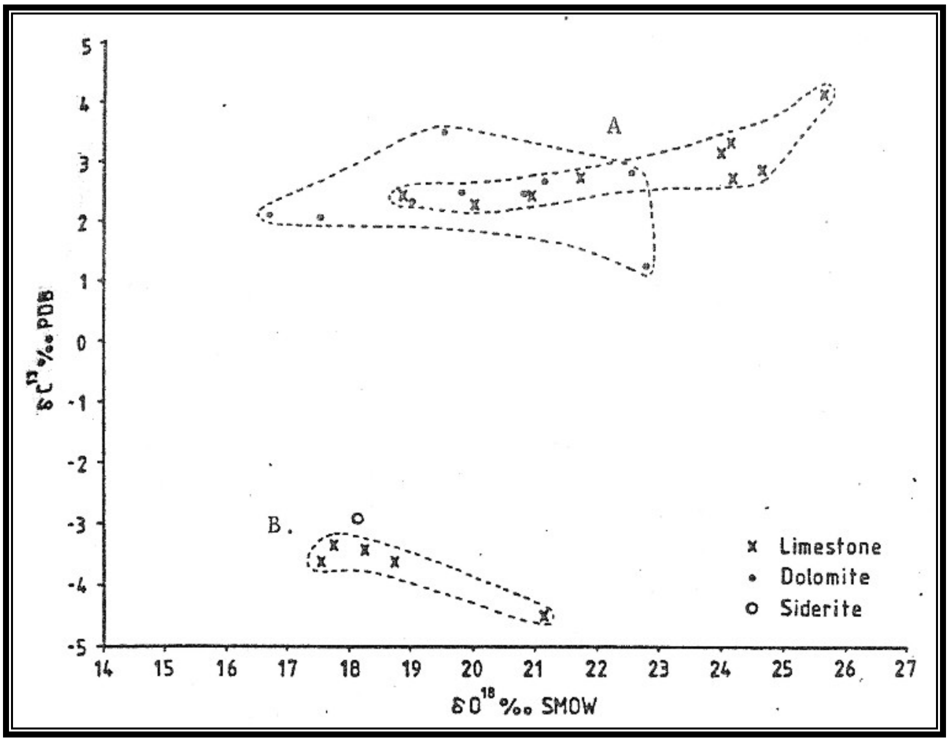

Figure 3: Carbon and oxygen isotope values from – (A) unmineralised host rock; and (B) mineralised carbonates (*from* Ellis 1984).

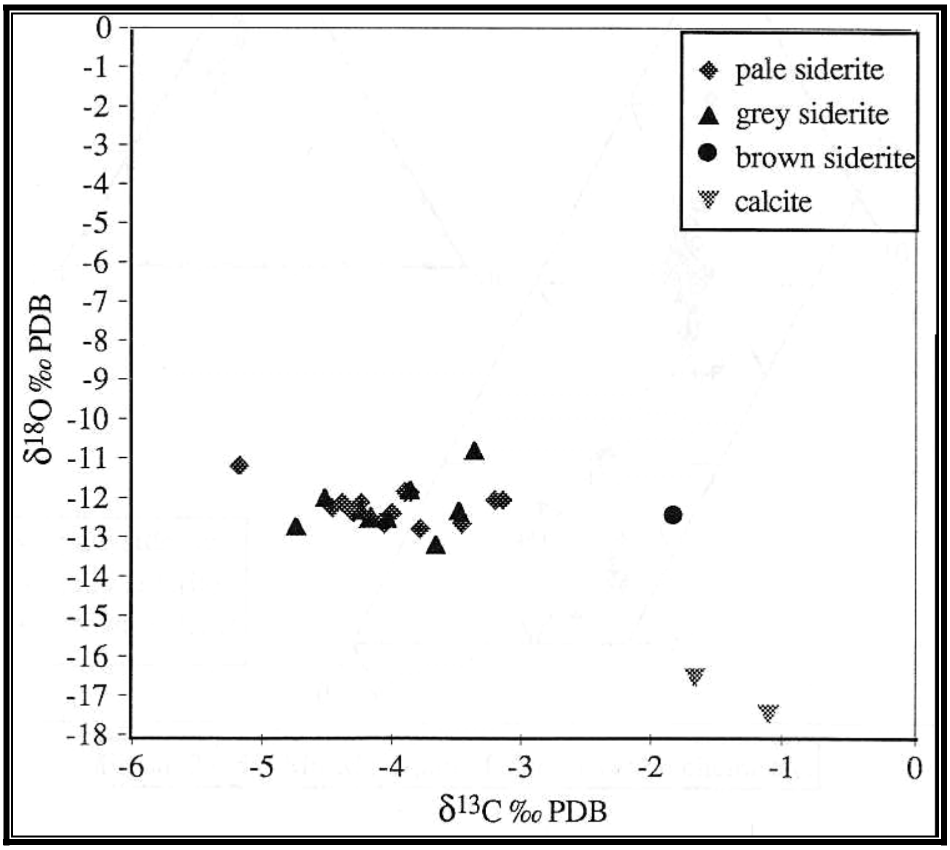

Figure 4: Carbon versus oxygen isotope values from ore zones at Oceana and Austral (*from* Peace, 1995).

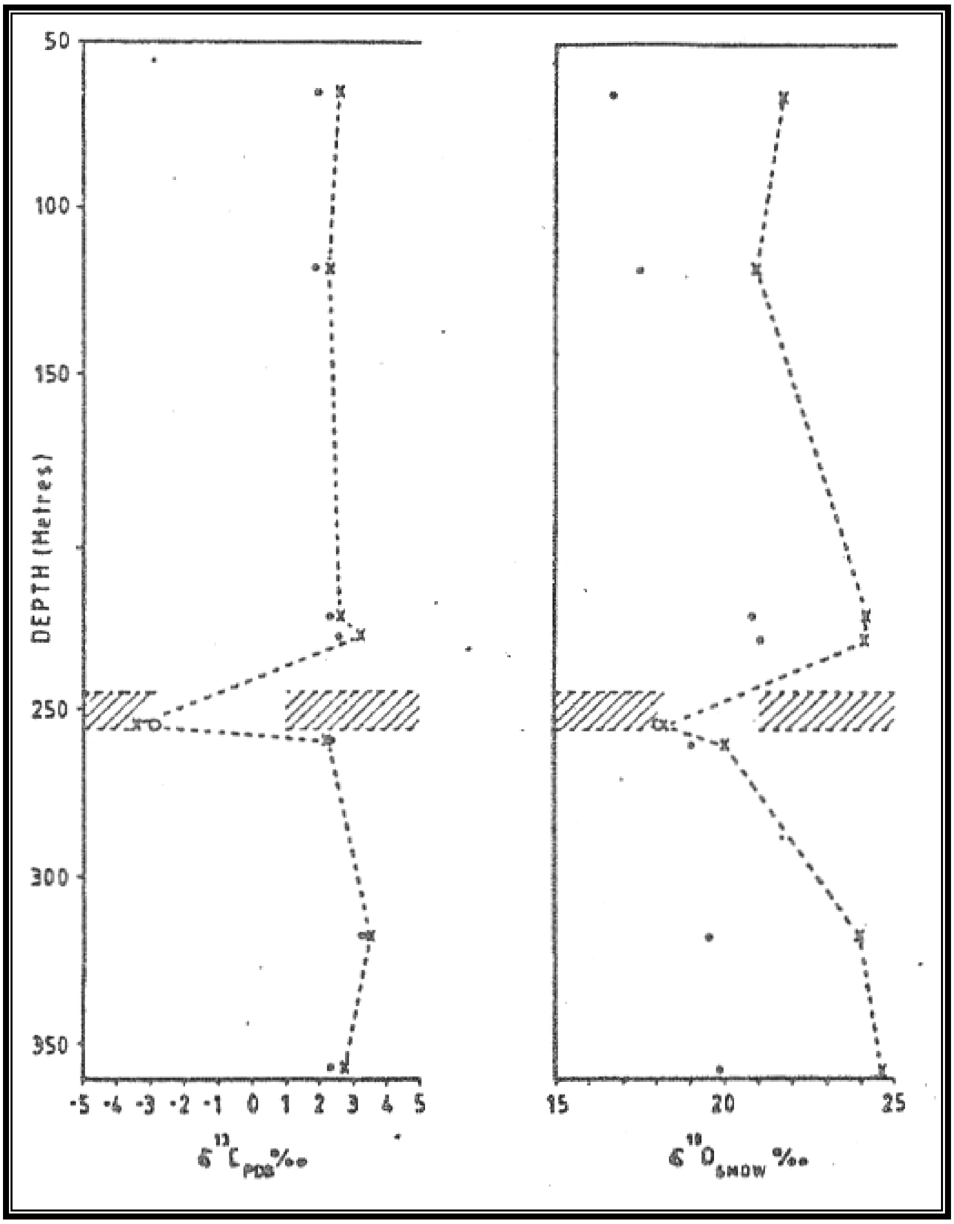

Figure 5: Carbon and oxygen isotope values as a function of increasing distance away from the mineralisation. Shaded area represents mineralised zone. Samples taken from DDH ZT-80-4 (*from* Ellis 1984).

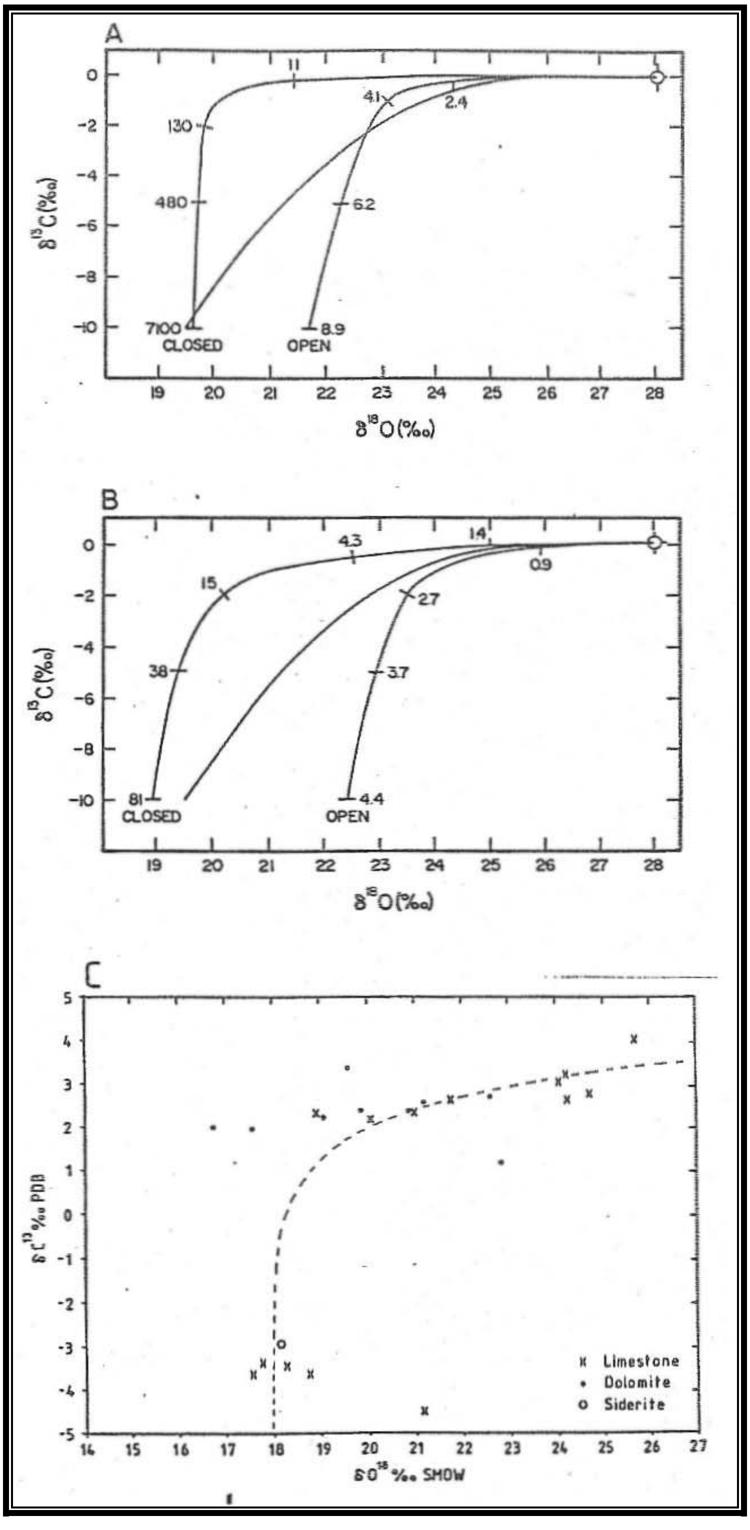

Figure 6: Graph A and B are two models proposed by Sverjensky, (1981), for the exchange of carbon and oxygen isotopic transitions (relative to SMOW) of calcite as a function of water to rock ratio (shown as moles of calcite) in both open and closed systems. The centre plot in each graph represents isotope data for Upper Mississippi Valley ore deposits. Graph C shows the values obtained for the Oceana carbonates. The dotted line represents a possible relationship, which may also be explained by progressively increasing water to rock ratio near the ore body altering the carbonates (*from* Ellis 1984).

5.3 Sulphur Isotopes

Several sulphur isotope studies have been carried out on Oceana ore minerals (Both & Williams 1968; Both *et al.* 1969; Williams & Both 1971, Ellis 1984; and Peace 1995). The isotopic composition of sulphur in sulphide phases can provide information on the source of the sulphur and temperatures of mineralisation (**Figure 7**). Galena and sphalerite were analysed in all investigations by various methods with results relative to the Canòn Diablo Troilite standard, (CDT). Samples were collected over a wide spread of the Oceana area, and other relevant localities.

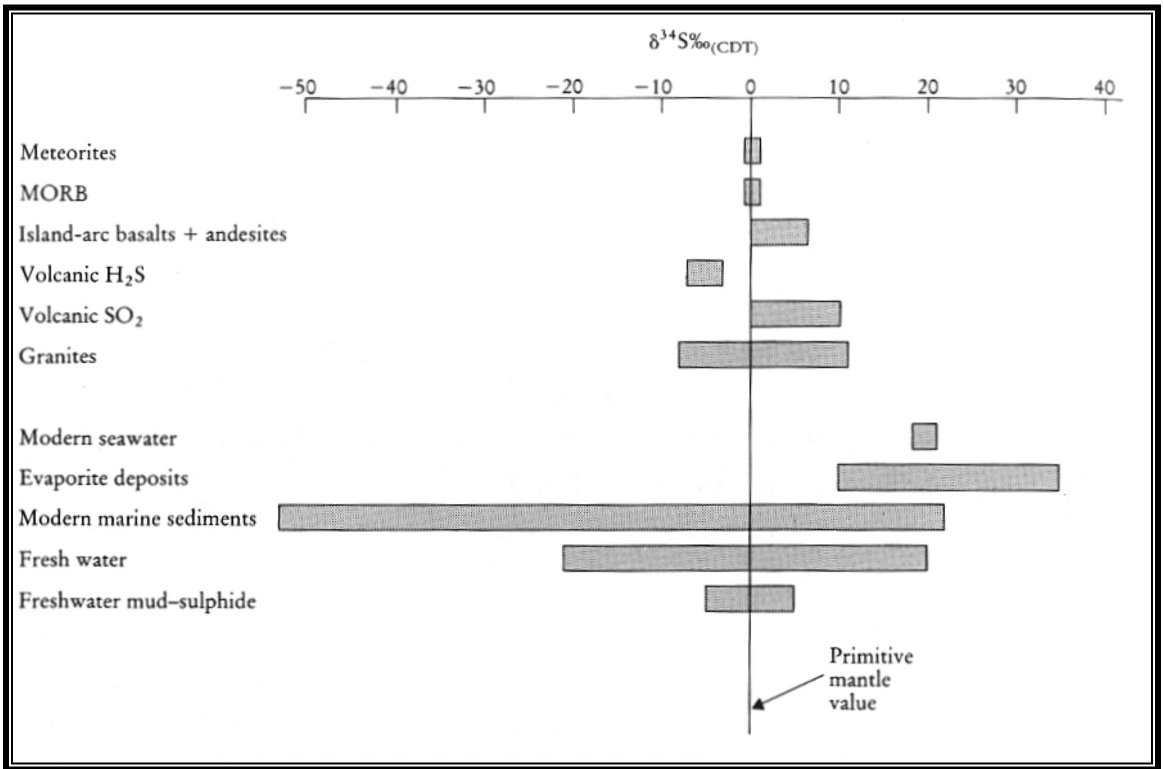

Figure 7: Natural sulphur isotope reservoirs (*from* Rollinson 1993).

Sulphur values compiled by Ellis, (1984), at Oceana show a spread from 3‰ to 15‰. Values taken from ZT-80-4, representing the eastern lens, are characterised by heavy values, whereas the western lens was relatively light. Geothermic properties of sphalerite-galena pairs yielded temperatures of 275ºC. The projected temperature was considered as an overestimate due to variably generated sulphide phases not likely to be in isotopic equilibrium, (Ellis 1984), (**Figure 8**).

Few values were produced at Oceana by Peace, (1995), however, these were consistent with those recorded by Ellis, (1984). Values range from 8‰ to 13‰ and combine to an average ore value of 9‰ to 10.5‰ (**Figure 9**). This range shows similarities to a number of deposit models including Irish-type, MVT, Intrusion-Related Carbonate-Hosted (IRCH) types and SEDEX types.

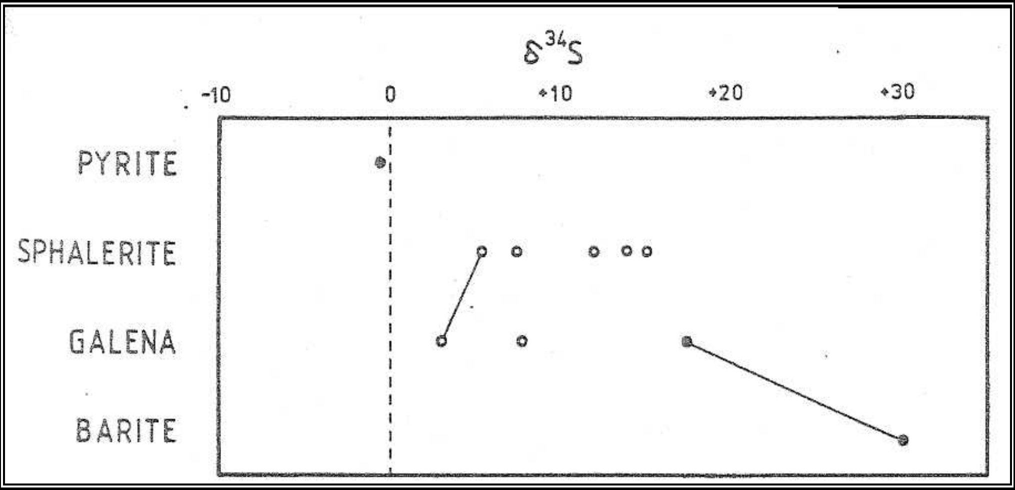

Figure 8: Sulphur isotope ratios: Hollow dots represent Oceana samples; Solid dots represent Myrtle samples (*from* Ellis 1984).

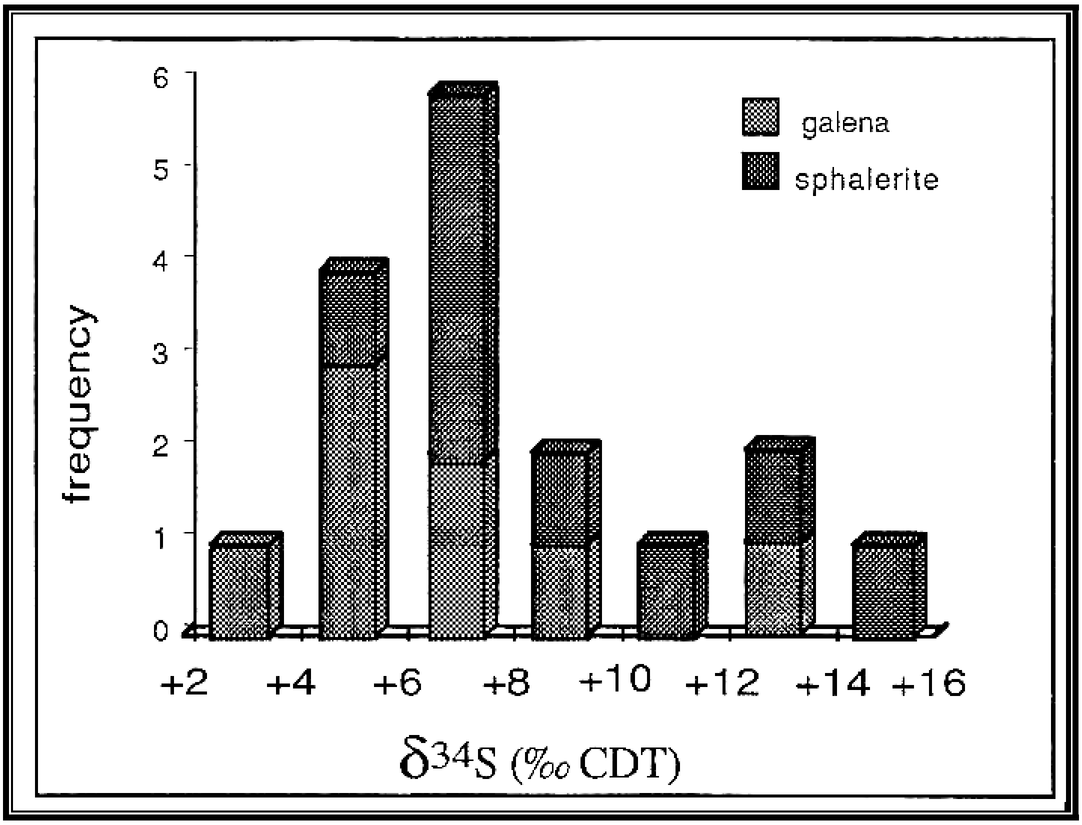

Figure 9: Histogram of sulphur isotope ratios, including data from Ellis, 1984 and Peace, 1995, (*from* Peace 1995).

Nearby deposits such as Austral and Grieves Siding have similar host rock sulphur and ore mineral sulphur ranges to Oceana. Glover, (1996), defined ore stage sulphide values in the range of 20.9‰ to 21.4‰ and diagenetic pyrite signatures ranging from –29.4‰ (**Figure 10**). The isotopically light values were considered to indicate the presence of biogenically reduced sulphur. A quiet, shallow-subtidal, lagoonal environment such as the Ugbrook Fm would have provided an ideal setting for bacteria to thrive in.

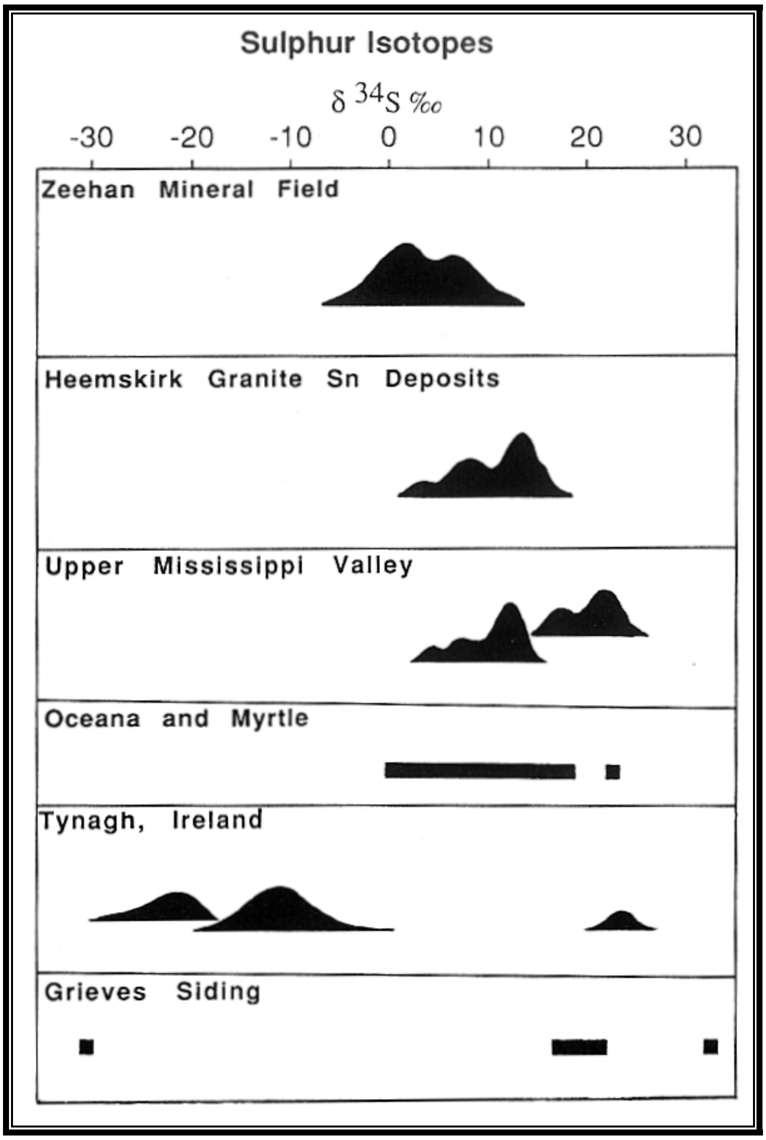

Figure 10: $\delta^{34}S$ values from Grieves Siding and other western Tasmaniaqn examples relative to signatures characterising Upper MVT and the Irish-type Tynagh deposit (*from* Glover 1996).

5.4 Lead Isotopes

Gulson, (1984), provided analysis of galena samples from the north and south sections of the Mine Fault, (Northern Zone), from the eastern lens. Samples were analysed for their ^{207}Pb, ^{206}Pb and ^{204}Pb proportions and compared to the radiogenic growth curve of Cummings and Richards, (1975). Values are consistently less radiogenic than the growth curve, as are other West Tasmanian examples such as Elliott Bay and Rosebery, and are younger than signatures associated with Devonian mineralisation, relative to Earth history (**Figure 11**). Gulson *et al.*, (1987), suggested a Precambrian source for Cambrian and preceding deposits based on the linear relationship of the populations within the experimental error. Lead in these deposits was likely remobilised or leached by basinal or connate brines and mineralised during the Ordovician – Silurian times.

Values are consistently less radiogenic than known Devonian related examples, similar to populations observed in Rosebery ore galena and slightly more evolved than mineralisation of the Elliot Bay disseminated Pb-Zn deposit. Data from Rosebery and Oceana is more homogenous and contrasts to the wide range in typical Devonian vein-related populations (Gulson *et al.* 1987). Mixing lead from a variety of sources produces a wide range in isotopic compositions. In contrast, major accumulations of lead have homogenous compositions (Gulson *et al.* 1987). By projecting a linear trend through the spread of West Tasmanian deposits, along the x-axis, back to the original growth curve, results indicate a source age of 1000Ma for Cambrian galena.

The combination of data acquired by Gulson *et al.*, (1984), Taylor and Mathison, (1990), and Large, (1986), suggests the Southern Zone stratabound and stratiform mineralisation have affinities with exhalative stratiform sediment hosted deposits. Lead signatures are typically less radiogenic than Devonian vein-related values and were probably overprinted by that phase.

The homogeneity of signatures suggests a single mineralising event during the Ordovician from a well mixed Cambrian or older metal source. Lead isotope data from Grieves Siding by Glover, (1996), on both the Upper and Lower Mineralised Zones, are consistent with values observed in the Southern Zone of Oceana.

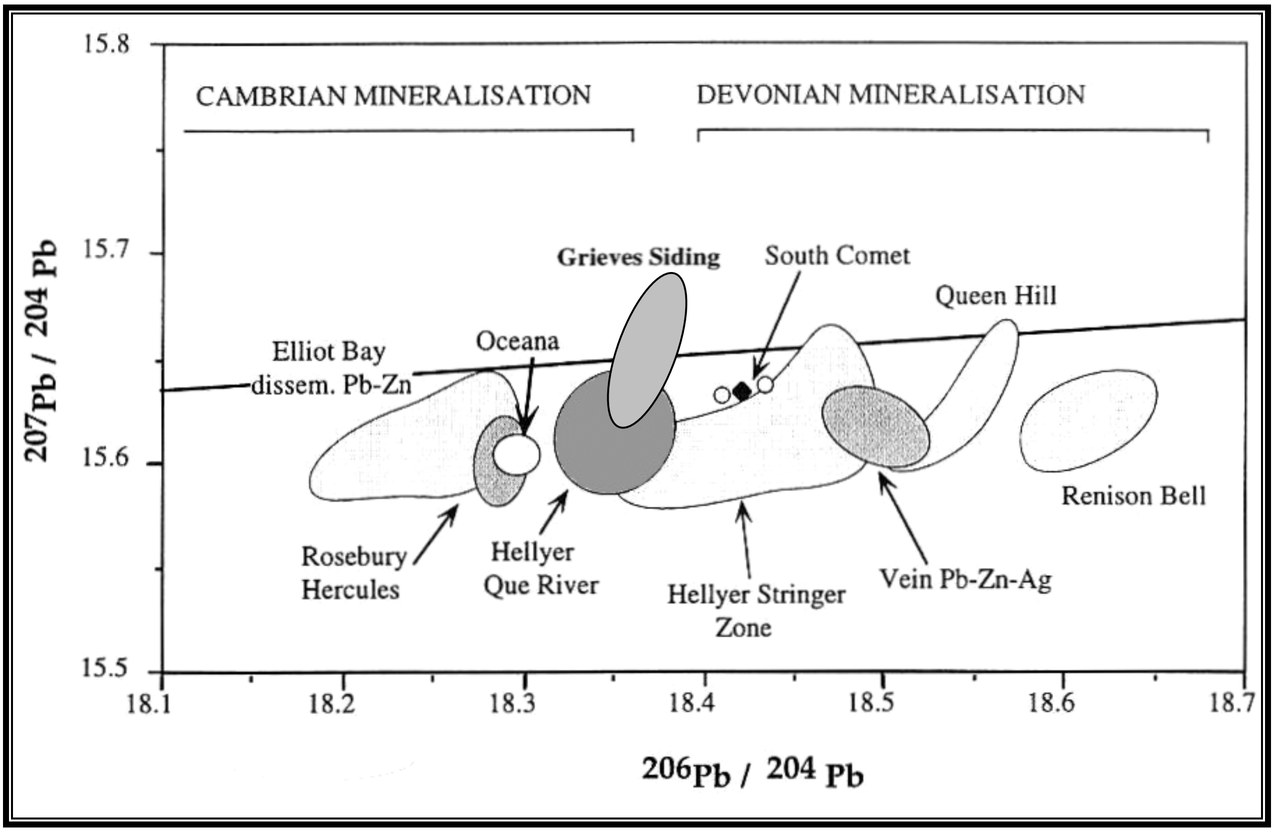

Figure 11: Lead isotope compositions of samples obtained from west Tasmanian deposits. Growth curve of Cummings & Richards, (1975), used as a reference (*Modified from* Gulson *et al.* 1987; and Glover 1996).

5.5 Discussion

Carbon and oxygen isotope analyses at Oceana proved to be valuable in defining the alteration halo associated with the ore lenses. Significant depletions of carbon isotope signatures occur sharply on the ore zone whereas oxygen isotope signatures are gradationally depleted from beneath the deposit. The highest $\delta^{18}O$ values are considered by Taylor, (1979), to reflect the highest temperatures and salinities. By using the fluid temperature derived from sphalerite – galena pairs, 270ºC, an $\delta^{18}O$ PDB of –23‰ is obtained for the mineralising fluids (Ellis 1984). However, sphalerite and galena textures indicate they were not in isotopic equilibrium and the temperature is probably an exaggerated value.

Values from Oceana compared to typical values from the Florentine Valley can be used for defining any regional isotopic trends (Ellis 1984; Rao 1990). Results show a consistent decrease of 3‰ in $\delta^{18}O$ values, which suggests higher temperatures and a greater isotopic equilibrium were achieved in host rocks in the Florentine Valley. Typical Zeehan region $\delta^{13}C$ values were heavier than samples from the Florentine Valley which is considered to represent a relatively more sea water dominated, probably subtidal, environment in comparison to the dominantly peritidal environment in Florentine Valley carbonates. Ellis combined the available sedimentological and palaeontological evidence to suggest a warm, shallow subtidal environment, characterised by temperatures of 20ºC to 26ºC, similar to modern day tropical climate waters.

By combining sulphur isotope data from Oceana with data other localities, such as Myrtle, Austral and Grieves Siding, a regional aspect can be recognised (Ellis 1984; Peace 1995; Glover 1996). Myrtle is characterised by the occurrence of barite and relatively heavy isotopic values whereas barite is poorly concentrated at Oceana and values are generally lighter. This may be indicative of two possible styles of mineralisation between each location or district features of a single event. Similar patterns in the southeast Missouri District MVT deposits were explained by relating sulphur to reduction by organic compounds of seawater or ancient evaporates (Ellis 1984).

Irish-type deposits show a more depleted trend in sulphur isotope signatures and this was taken to indicate mixing of the mineralised fluids with a large freshwater component (Boast *et al.* 1981). Although projected temperatures were considered too high for this style of mineralisation chalcopyrite associated with Oceana Fault, (Ellis 1984), and the stratabound lenses indicates higher than expected temperatures were present.

Lead isotope analysis of the various paragenetic sulphide phases at Oceana by Gulson *et al.*, (1984), and review by Taylor & Mathison, (1990), indicates that signatures are homogenous and of a different variety than populations characterising Devonian vein-galena. Devonian vein galena is isotopically defined by a wide spectrum of values and implies mixing of Devonian and Cambrian relative sources. An interesting feature of the data is the similarities in age and homogeneity between Oceana and Rosebery, which suggests a common genesis for the deposits. If the lead source was not associated with Devonian or remobilised Cambrian sources it is probable metals were derived from underlain sedimentary and volcanic piles, with remobilisation or leaching by basinal or connate brines (Ellis 1984). The genetic model age implicated by the data is remobilised Cambrian or an entirely Ordovician population.

Evidence for an 'event' during this period includes active orogenesis in eastern Victoria, (Benambran Orogeny), which is temporally equivalent in deposits local to western Tasmania, a lead isotope 'reset' event noted in values from Elliott Bay Pb-Zn deposit, deposition of the Lords Siltstone Member, syn-diagenetic movement along faults and deposition of the Eldon Group indicating resurgent uplift. It is entirely probable that lead isotope values represent Ordovician mineralisation with a superimposed Devonian vein system.

Geophysics 6

6.1 Introduction

The properties of sphalerite, as the main ore of zinc, and its metal associations are unsuitable to most available geophysical methods in the exploration field. The relatively low density to ubiquitous sulphide associations, low conductivity, moderate permittivity and low magnetic susceptibility characterise zinc deposits as difficult targets. The metal association with galena provides an alternative target, with emphasis on the relatively higher density properties. Similar conductivities are observed in pyrite and galena but the deposit size typically enhances the geophysical properties.

Mineral and metal associations at Oceana consist of galena dominant, carbonate-hosted, discordant and stratabound lenses over prospective strike extent of 1.5km. Langron, (1966), concluded geophysical methods were unreliable in the Zeehan area. Taylor, (1983), reported poor results from Pulse Electromag, Dighem, downhole PEM and gravity. Methods providing reasonably good responses included downhole gamma logging for stratigraphic correlation, ground and core magnetics for near surface ironstone and siderite, and downhole Sirotem for inhole and outhole conductors. The prominent feature of Mt Zeehan acts to swamp anomalies although, if sufficiently corrected, can be filtered from datasets (Leaman 1992). This chapter is to serve as a supplimentary with the intent to include newly released data and relevant existing data for professional completeness (**Appendix E**).

6.2 Gravity

The gravity survey conducted by Amoco M.A.C. during the 1981 tenement has been reviewed and re-processed since being re-classified in the public domain (Leaman

1992; Saxon 1995). Reasons for initiating this survey were the high proportion of galena in ore occurrences and regional fault-associated stratabound mineralisation (Jones 1981). Problems associated with the survey included the large influence of Mt Zeehan on residual anomalies and the extensive faulting of the area.

Local and regional scales were included for interpretation by Leaman, (1992). Local scale methods define anomalies associated with dominant lithologies and some of the regional faults, i.e. Oceana and South Oceana Faults, however showed no reliable response associated with mineralisation. The regional model indicates granitic intrusion at ~3km beneath Oceana deposit and suggests underlain Oonah Formation beneath Mt Zeehan Conglomerate. The probable presence of the Dundas Group, beneath Mt Zeehan Conglomerate, has been occluded from this model and may indicate granitic intrusion at relatively greater depths. The model provides a satisfactory representation of the region surrounding Oceana.

6.3 Magnetics

Numerous gravity surveys have been carried out on the local grid at Oceana (refer **Appendix A** for Exploration History). The most recent surveys were undertaken and reviewed by Jones, (1981), Leaman, (1992), Saxon, (1995). Local surveys are notably subject to surface and cultural effects which have been factored into data acquisition and processing. Moderate susceptibilities of galena provide a target for unmined extensions in the southern zone.

Data was presented by Leaman, (1992), after extraction of residuals using the Mantle91 separation process and subsequently 2D modelled using Potent. Leaman considered the physical property tests on a number of drill holes to indicate mineralised and sideritised zones have a magnetic susceptibility of approximately 25 times magnitude than the background. Although the siderite gangue has a low tenor, values contrasted significantly with the bland background response (Quayle 1995).

6.4 Various EM methods

A large project has recently been undertaken by Mineral Resources Tasmania to investigate the EM and magnetic properties of western Tasmania, Regional Minerals Program Western Tasmania. Data was made public and was conveyed by Dr. James Reid (pers. comm.), and is included for the implications posed by the data.

Elevation data has recognised Mount Zeehan to the west of the view, however Professor Ridge to the east was only vaguely identified. 880Hz and 980Hz apparent resistivity were acquired to test relatively shallow depths (~100m). Data showed minor conductive properties coincident with the faulted lower boundary of the Gordon Group and a highly resistive upper boundary, defining the extent of the Gordon Group. Values indicate the limestones are pinched out by South Oceana however a structural illusion conceals them beneath a wedge of Moina Sandstone.

TMI results projected with the 1st vertical derivative are ineffective at Oceana, however the anomaly at 5358 500 is coincident with the Austral prospect at the mineralised upper boundary of the Gordon Gp with the Crotty Quartzite. Ternary conductivities are similar to apparent resistivity results broadly illustrating the lower faulted and mineralised boundary of the Gordon Gp. Ternary radiometric surveying has shown general enrichments of prospective radiogenic elements. The most obvious enrichments are expectantly of potassium which is likely associated with erosion of felsic intrusives and leaching associated with hydrothermal waters.

6.4 Discussion

Geophysical techniques seem to have been tried and tested at Oceana due to the considerable amount of surveying done, with no particularly effective results. The most successful method used at Oceana was ground and regional magnetics due to the magnetic properties of the siderite gangue, which is intimately associated with ore mineralisation. Magnetic susceptibility readings can be taken at the core scale if logging does not suffice.

Summary, Conclusions And Genetic Model 7

7.1 Introduction

The Oceana deposit has been a subject of debate since re-analysis by Taylor, (1983). Many studies have been carried out on the sedimentology and provide a number of alternate views providing more questions than answers. The aim of this study was to define the sedimentology of the Gordon Group at Oceana. By understanding the processes represented in the sedimentology, which all orogens are based on, it is hoped this would provide a further understanding to the mineralisation. This study is to provide information on the geological setting and the characteristics of mineralising fluids, metal transport, concentration and deposition, within a carbonate host.

7.2 Geological Setting

Oceana is located at the eastern foot of Mt Zeehan and the western limb of the Zeehan Syncline – Mt Zeehan Anticline. Host rocks are contained within the Wurawina Supergroup and represent a transition from Late Cambrian basin fill siliciclastics through to trangressive carbonates, and Siluro-Devonian terrestrial-proximal sediments. At Oceana the upper boundary of the Moina Sandstone to the overlain Gordon Group has not been intersected at depth, although it is represented in outcrop by arenaceous shale and calcareous sandstone. Drilling at the Pyramid prospect has shown that the boundary is faulted and mineralised with massive decomposed siderite and sulphides, limonite and goethite.

Previous studies on the Gordon Group in Zeehan have defined three formations with five intraformational members. Nine lithofacies with two sub-lithofacies were recognised and can be distinguished in the formations at Oceana. The lowermost Middle Ordovician Ugbrook Formation characterises rapidly shallowing open subtidal to dominant protected, lagoonal, shallow subtidal conditions. The prevalence of coarser sediments overlaying open subtidal facies, and development to protected conditions, indicates the influence of a rapidly migrating carbonate bar. This member was only observed in drill core nearest to the Oceana Fault where the carbonates are thickest.

The Middle to Upper Ordovician Myrtle Formation is known to consist of 15 shallowing-upward cycles from protected subtidal to peritidal environmental conditions. At Oceana the high incidence of faulting and dissolution meant that only 10 of these cycles can be recognised. PACs are generally 1m thick near formation boundaries and increase to 10m thick in centre of the formation.

The Upper Ordovician Black Jacks Formation is dominantly open subtidal to protected subtidal consisting of Lower and Upper sub-divisions. Deposition of the Lower Black Jacks Formation was disrupted by the Lords event during the Late Caradoc resulting in two clay rich beds being deposited at Oceana. The Lords Siltstone Member is known up to 15m thick in other locations of west Tasmania and forms an extensive sheet that can be used as a marker bed for stratigraphic correlation. The upper Black Jacks Formation is dominantly peritidal at Oceana and is characterised by mud island deposits within a protected lagoonal environment.

The upper boundary of the Gordon Group at Oceana was intersected by drilling operations and is characterised by faulting, dolomitisation, silicification and kaolinisation. Other prospects at similar stratigraphic levels contain stratabound massive sulphide deposits in combination with several metres of highly prospective clay beneath the boundary. The Crotty Quartzite is the lowermost member of the Eldon Group and represents a transition of the depositional environment to a littoral environment. The thick pile of pebble conglomerate to mudstone is dated during the Late Ordovician, (Ashgill), and is correlated temporally with stages of the Benambran Orogeny of southeastern Victoria.

Nodular limestone lithofacies at Oceana are generally finely developed which can be attributed to the relatively thin ramp to mini-platform shelf environment. In larger Palaeozoic platforms nodular limestones can occur over 1000m's thick and have boundaries associated with intraformational limestone breccias. The intraformational limestone breccia beds at Oceana are considered too thick to have formed under typical sedimentary conditions, and occur in two zones associated with a change in grainsize.

The breccias include clasts of various lithofacies and are considered to have formed post-sedimentation. The temporal association with the Benambran Orogeny, which probably caused movements along the Oceana Fault, is considered as a mechanism for propagation of these pre-stylolitised, sedimentary slides. Stylolites act as teeth grips on carbonate platforms preventing collapse that is commonly associated with platform construction and subsidence.

7.3 Mineralisation

Oceana deposit can be locally divided into a discordant Northern Zone and a stratabound Southern Zone. The Northern Zone is structurally bound by the Oceana Fault to the northwest and the South Oceana Fault to the southeast. Displacements along the Oceana Fault exceed 700m and are uncertain along South Oceana Fault. The Northern Zone is mined out for the majority of its length, although reports clearly state the ore lenses were open at depth. Ore petrography and paragenetic analysis has shown mineralisation occurred in discordant, irregular zones and veins supported by sideritic compositions. Veins and lenses thin to the southeast and become stratabound in character.

The Southern Zone occurs from South Oceana Fault to South Oceana, and Pyramid, and consists of stratabound western and eastern lenses. Each lens generally thins with depth and has been mined to 200m, also open at depth. Early diagenetic dolomite and pyrite is replaced by sphalerite associated with dolomitisation, silicification and sideritisation. Massive hydrothermal siderite overprints these generations and is associated with initial sphalerite and later sphalerite - galena with late stage calcite. Ore occurrences are generally fractured in parallel lenticular cavities filled with calcite, representing post-ore system kinematics. Faults and quartz-rich calc-arenites are typically kaolinised in the Southern Zone.

Ore mineralogy is similar to examples of MVT and Irish-type Pb-Zn deposits with the notable exception of siderite. Paragenetic textures indicate that although massive siderite is probably associated with Devonian granitoid-related fluids, the earliest sphalerite is associated with syngenetic replacement siderite.

7.4 Geochemical analysis

Southern Zone ore at Oceana is characterised by an alteration halo of Mn and Fe. Trace elements are generally not enriched with respect to the ore zone however some elements, i.e. Cd, show a relationship with sulphide mineralisation. Chalcophile elements are broadly dispersed which indicates a variety of controlling processes.

Oxygen and Carbon isotope analysis of the host sediments at Oceana are characteristic of typical marine carbonate values. Mineralisation is characterised by sedimentary values reflecting a reduced sedimentary basin brine as the source. Depleted values in the ore zone are representative of preferential dissolution and wall-rock reactions. Carbon depletions occur sharply towards the ore zone whereas oxygen depletions are gradational.

Sulphur isotope values from the ore zone at Oceana have a restricted range, which is dissimilar to isotopic ranges in MVT and Irish-type deposits. The observed range is characteristic of hydrothermal fluids with little influence from highly reduced bacterial sources. Seawater sulphate values are effectively unchanged from the Ordovician and are probably the dominant source of sulphur within fluids. A 10‰ to 15‰ fractionation shift in sea water at 150ºC is a positive explanation for reduced sulphur near the ore. If there were bi-modal populations of sulphur at Oceana the Earlier values would have been inundated with Devonian granite-related sulphur.

Ore zone lead isotopes are less radiogenic than established Devonian populations. Oceana galena values plot nearer to Cambrian deposits, such as the Elliott Bay disseminated Pb-Zn sulphide deposit, than to Devonian granite-related deposits. The homogenous populations at Oceana indicate a probable single source.

Deposition of the Lords Siltstone Member roughly corresponds to radiometric age peaks, 475 – 455Ma, which are described as chronological resetting events. The time of deposition of the Lords Siltstone Member was partially synchronous with tilting of the depositional surface and resurgent uplift, which is also evident by the presence of intraformational breccio-conglomerates. Resurgent uplift occurred relatively soon after the Lords Member and resulted in deposition of the Crotty Quartzite. These 'events' are features of the geological record and indicate mineralising events consistently occurred from Middle Cambrian to Late Devonian.

Feature	MVT deposits	Irish-type deposits	Oceana
Metal Grades	Zn: 2 – 6 wt.%; maximum 16% Pb: 1 – 3 wt.% Ag: <40 g/t Cu: low Possible Cd, Ge.	Zn: 2 – 13 wt.% Pb: 0.2 – 6 wt.% Ag: <40 g/t Cu: low	Zn: 2.6 wt.% Pb: 7.5 wt.% Ag: 51 g/t Cu: low Others: Cd, Ga.
Mineralogy	Ore: low Fe sph, gal ± cpy, bn Gangue: Py, marc, dol, cal, qtz ± fl, ba	Ore: Low/high Fe sph, gal, minor ten, cpy ± bn Gangue: py, marc, dol, cal, qtz ± ba, sid	Ore: low Fe sph, gal ± cpy, bornite, Sb sulphosalts, supergene associates. Gangue: sid, cal, dol minor py, marc ± quartz
Characteristic Textures	'Snow on roof', open-space fill, colloform sulphides, sphalerite dissolution, carbonate replacement	Massive sulphides, colloform sulphides, carbonate replacement, sphalerite dissolution	Massive sulphides, colloform sulphides, carbonate replacement, sphalerite dissolution.
Deposit Morphology	Irregular or tabular breccias, veins, massive stratabound carbonate replacement	Massive stratabound and stratiform, irregular veined feeder zones with disseminated and veined sulphides	Irregular to stratabound lenses with minor stratiform massive sulphides, fault-related feeder zones.
Alteration	Pre-mineralisation dolomitisation halos and some districts show silicification	Diagenetic and hydrothermal dolomitisation common and weak silicification and silica-iron oxide alteration	Diagenetic and hydrothermal dolomitisation, weak silification, dedolomitisation
Metal Source	Sediments and/or basement	Unknown – probably sediments and/or basement	Sediments and/or basement
Sulphur Source	Variable, thermochemical sulphate reduction of evaporates or seawater sulphate, mixture of light and heavy sources	Probably isotopically heavy, reduced source with metals and light biogenically reduced source	Probably diagenetic reduced source, magmatic source and modified seawater source
Formation Temperatures	90°C – 150°C	100°C – 280°C	180°C – 250°C
Fluid Salinities	15 – 25 eq. wt.% NaCl	10 – 24 eq. wt.% NaCl	16 – 19 eq. wt.% NaCl
Fluid Flow Mechanisms	Thermal convection, topography driven, tectonic, overpressuring, episodic	Deep Convection or topography	Convection, topography, diagenetic compaction
Age of Mineralisation	Early to late diagenetic; probably associated with tectonism younger than sedimentation of host, epigenetic	Syndiagenetic to epigenetic related to periods of uplift and extension	Late diagenetic (epigenetic) related to Benambran Orogeny and post-diagenetic granite-related to Tabberabberan Orogeny

Table 1: Group summary of the characteristics of MVT and Irish-type deposits, and characteristics of Oceana. Data for MVT & Irish-type deposits is from Muhling, (1998), Hitzman, (1995), Leach & Sangster, (1994), and Russell, (1987).

7.5 Genetic Model

Compilation of available evidence suggests a near-complete stratigraphic column of the Gordon Group exists at Oceana, with limited displacement of faults concentrated on dominant lithological, intraformational and PAC boundaries. The timing of the mineralisation is suggested to be Late Ordovician to Early Silurian, with a consistent style as MVT deposits. Very active tectonism during the Devonian remobilised the majority of this mineralisation. Other Zeehan Mineral Field deposits are associated with Devonian age intrusive cupolas, i.e., Queen Hill Sn deposit.

Patterns of gangue and metal zonation indicate Oceana lays within the alteration halo of the Queen Hill Sn deposit. Zonation is centred on the Heemskirk Granite however recent exploration by Zeehan Zinc has intersected a cupola beneath the Queen Hill deposit, which indicates metal zonation is located too low in the stratigraphic column to be related to the Heemskirk Granite. Metals were derived from possibly an Ordovician source or a mixture of Cambrian and Devonian sources.

Fluids were probably sourced from connate basinal brines which were circulated under pressures from compaction, dewatering and tectonic loading. Fluid temperatures of less than 200ºC are similar to expected values for circulating basinal brines. Low to moderate salinities are inconsistent with connate brine compositions and indicate the absence of evaporates, or the presence of a mixing fresh water body during mineralisation.

The small extent of the carbonate ramp and the underlain, structurally-segregated lithologies indicate that a deep convection source would have been probable. Typical Irish-type deposits involve a large, deep convection system or a series of small, local convection plumes. MVT deposits involve thermal convection and regional topographic and tectonic driven flow of dominantly chloride-rich basinal brines. Modern analogues are oil field brines in sedimentary basins. A similar model to MVT deposits is implied at Oceana, associated with leaching of underlain Cambrian lithologies and discharge of fluids along structures such as the Moina Sandstone –

Gordon Group boundary and northeast strike faults, i.e. Oceana Fault. A larger convection cell was postulated by Glover, (1996), as involving greater sourcing of metals due to more effective leaching of fertile sources such as the Crimson Creek Formation and the Success Creek Group.

A seawater source can be considered as a transport mechanism due to expected isotopic fractionation values of sulphur. Limited development of sulphate reducing organics, and reduced values, support a modified seawater source. Oxygen isotope values are relatively heavy in host rocks and lighten towards mineralisation. This is possibly evidence for considerable isotopic fractionation out of the host, or relatively none at all. Large channelways were provided by associated faults and boundaries which indicates little interaction occurred between fluids and the wall-rock, and hence, original mineralising fluids were isotopically light.

Metal solubility of Pb and Zn is dependent on the redox state of the fluids during transportation. If the fluids were reduced, pH and temperature would have been the dominant controls on metal solubilities. If the fluids were oxidised, oxygen fugacity would have been the dominant control on metal solubilities (**Figure 1**). Sulphur can be precipitated from oxidised brines by a two dominant processes, Biogenic sulphate reduction and thermo-chemical sulphate reduction. The poor occurrence of reduced sulphur and the mildly reduced character of the Gordon Group at Oceana may indicate fluids were slightly reduced however would not have provided an efficient trap. This implicates thermochemical reducing processes as the dominant trap mechanism for sulphides. Processes responsible for this include mixing of meteoric or ground-waters with hydrothermal fluids, or mixing and interaction with the carbonates.

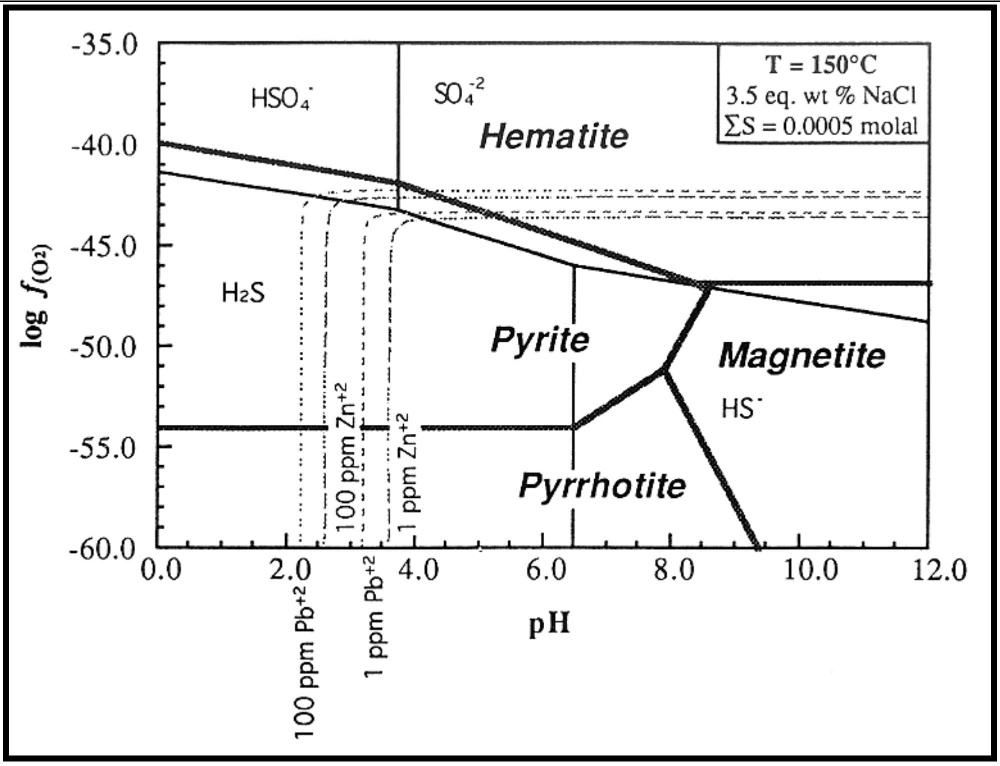

Figure 1: Log $f_{(O2)}$ – pH diagram showing the solubility contours for Pb and Zn, the stability fields of minerals in the Fe-O-S system and the predominance fields of S-bearing species at 150ºC in 3.5 eq. wt.% NaCl solutions (Dr. David Cooke pers. comm. 2002).

Effective considerations of source, transport and trap mechanisms at Oceana describe basin-derived fluids repeatedly accessing regional structures and mineralising carbonate stratigraphy. Regional intrusion-related metals have overprinted the Ordovician system at Oceana but this is not the case for every Gordon Group carbonate-hosted deposit in the Zeehan Mineral Field, i.e. Grieves Siding. Shallowing basement fluids under loading pressures would have escaped along significant structures such as the Oceana Fault and the lower boundary of the Gordon Group. The Moina Sandstone probably acted as an aquifer to fluids and may be associated with minor occurrences of mineralisation.

Pb and Zn ores were heavily overprinted by granite-related fluids during the Devonian. Structural conditioning prior to intrusion includes the disassociation of carbonate lithologies between siliciclastic formations, and the regional establishment of faults at these zones and throughout Oceana. It is likely that the upper boundary probably remained unmineralised until Devonian episodes at Oceana however this was not the case for all carbonate hosted deposits in the Zeehan Mineral Field, i.e. Austral, Black Jacks and Mariposa.

Deposit models that are similar to Oceana include MVT deposits and lesser applicable Irish-type deposit models. Consistencies between the deposits include timing, textures, mineralogy and metal-source, -transport and -trap. Although Oceana deposit has characteristics of both these deposit types it can be classified, along with Bubs Hill, as an MVT deposit (**Figure 2**). Similar genetic characteristics include ore mineralogy, deposit morphologies, metal source and salinities of fluids.

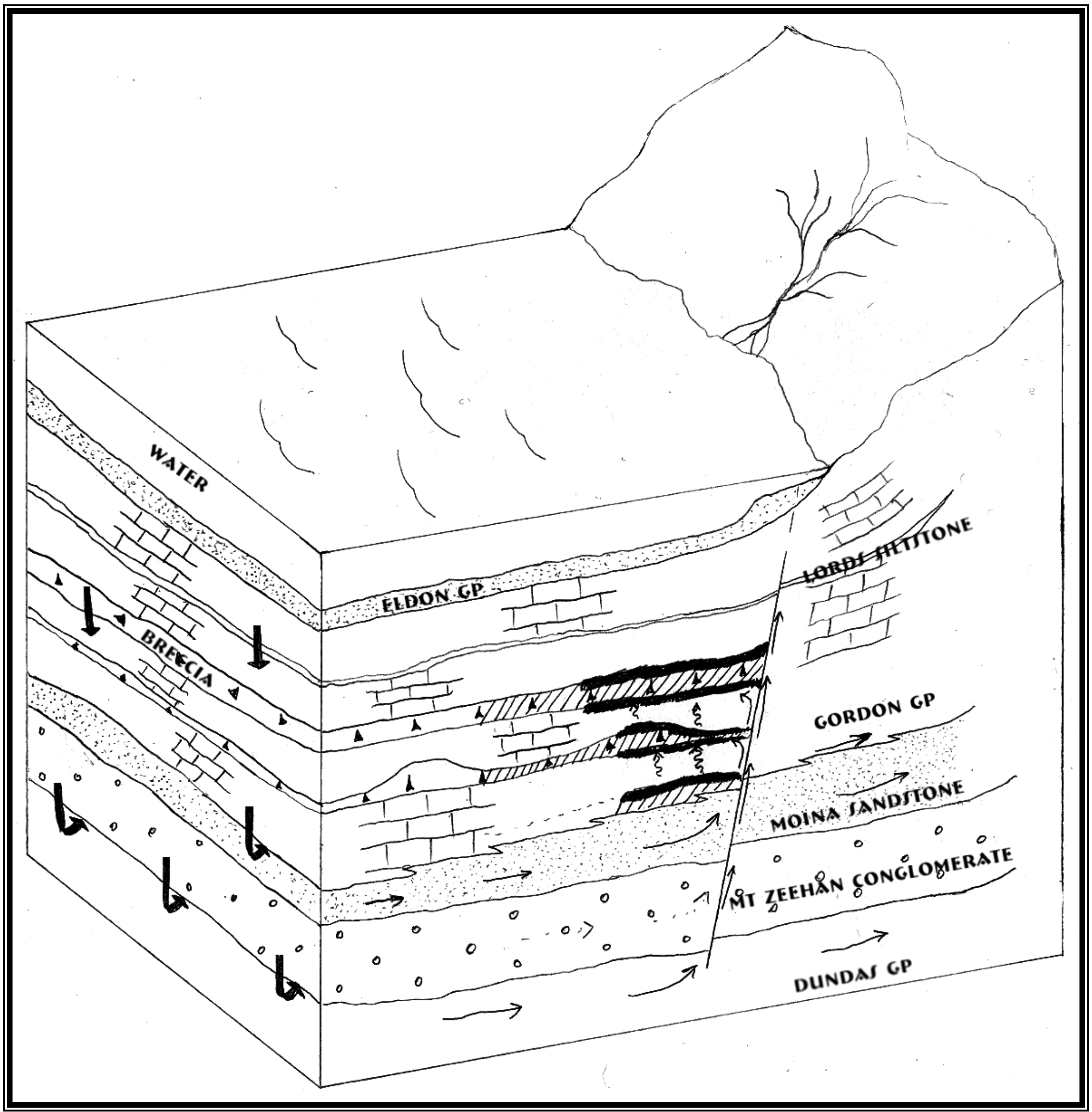

Figure 2: Genetic model reconstruction during the Ordo-Silurian for mineralisation of the stratabound lenses at Oceana. Mineralisation was subsequently remobilised during the Devonian which deposited ore along fault zones and Gordon Group boundaries. Bold arrows indicate fluid recharge; standard arrows indicate fluid discharge.

7.6 *Future recommendations to ZZ Exploration*

Numerous programs have been focussed on the Oceana prospect for over a century and have outlined and developed the more accessible parts of the mine, however have not exhausted the deposit (2.5Mt of 2.6% Zn, 7.5% Pb and 51g/t Ag). Indicated reserves are reported open at depth with a significant deposit remaining.

The supergene cerrusitic pug blanket can be considered as a resource. Open cut operations may be feasible in combination with underground operations however are probably uneconomic free-standing. Aircore analysis did not sufficiently test Oceana although indicated peripheral reserves which continued to Austral. The lower boundary remains the most elusive target to date. Drilling by Pasminco revealed the Gordon Group does not thin stratigraphically and is actually overthrust by the Moina Sandstone. The lower boundary was faulted and decomposed to goethite although may be better preserved towards Oceana Fault, which would have provided an excellent conduit for fluids.

It is unsure exactly where the thick eastern lens fades out at Oceana. Further drilling may be required to locate the extent of this mineralisation (**Appendix F**). Pods of mineralisation probably continue through to South Oceana and beyond to Pyramid however this has not been substantiated. Geophysical surveys such as magnetics have played a role in this and indicate the resource is probably greater than already predicted. More recent geophysical methods, heliborne EM, predicted the northeast-dipping lower boundary to plunge at a relatively steeper than expected angle (overturned).

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