Appendix 5

McGilvray, C. T., 2003
Geology and Mineralisation of Oceana Zn-Pb-Ag deposit, Zeehan, Tasmania. Unpublished. University of Tasmania.

Geology and Mineralisation of the Oceana Zn-Pb-Ag deposit, Zeehan, Western Tasmania.

Clifton Todd McGilvray B.Sc.

INGENIIS PATVIT CAMPVS

UNIVERSITY OF TASMANIA

A research thesis submitted in partial fulfilment of the requirements of the Degree of Bachelor of Science with Honours.

CODES SRC

Centre for Ore Deposit Research

And

School of Earth Sciences,

University of Tasmania

May 26th 2003


Oceana

ABSTRACT

The Ordo-Silurian Oceana Deposit is located within the Zeehan Mineral field of western Tasmania, 4km south of Zeehan. Base metal mineralisation is hosted by Gordon Group carbonates that are bound by the underlain Moina Sandstone and the overlain Crotty Quartzite. Ore lenses are the thickest adjacent to Oceana Fault in the northwest, and decrease with distance away from the fault. Two main styles of mineralisation have been identified as massive discordant lenses occurring in two prominent shears, and stratabound lenses occurring in the most porous lithologies of intraformational breccias, and less so calcarenites. These regions are divided into the Northern and Southern Zones.

Other possible resources that could be included in the prospect estimate consist of the mineralised and faulted lower and upper boundaries of the Gordon Group, which occurs at other locations in the Zeehan Mineral Field, and the supergene enriched pug-clay overburden. Significant enrichments in both styles have been intersected at other localities which indicate similar controlling variables at Oceana.

Oceana deposit is located within the western limb of the Palaeozoic Dundas Trough, (Zeehan Syncline), and is geochronologically related to events defined by lesser and greater degrees of kinematics. The Ordovician Benambran Orogeny of southeast Victoria is sparingly evident in western Tasmania however seems to involve structural and mineralogical evolution local to central western Tasmania, i.e. Oceana, Grieves Siding, Austral, Rosebery and many others. The Devonian Tabberabberan Orogeny is characterised by three phases of pre-intrusive deformation and at least one phase, maybe two, of post-intrusive deformation. Intrusion is not specifically related to one deformation phase, and resulted in large-scale metal zonation associated with the Queen Hill cassiterite-rich vein deposit, zoning from Sn-W to Pb, Zn, Ag.

The Southern Zone is paragenetically characterised by early stratabound sphalerite and probable galena, overprinted by sphalerite and galena hosted by siderite. Carbonate replacement textures are overprinted by massive crystalline sideritic and calcareous discordant veins that show a close relationship with Oceana Fault. Two fluid compositions are evident through geochemical analysis. Early mineralisation is associated with an Fe and Mn alteration halo whereas later minerals are characterised by enrichments of acid-sulphate derived compositions, i.e. Al, Ti & Rb.

Stable isotopes indicate deposition was in tropical latitudes and cations and anions were dominantly sourced from underlain sedimentary packages or sea-water. Fluid temperatures are estimated at ~200ºC however granite-related fluids were likely to reach ~300ºC which has resulted in dissolution of minerals and the host rock.

Metal deposition was dominantly controlled by salinity and pH of the transporting fluids. Low temperatures of ore formation indicate a minor exhalative, and major epigenetic origin. In view of now absent stratiform mineralisation, the timespan associated with deposition, and the close association of this deposit to multi-generation Pb-Zn-Ag deposits in the Zeehan Mineral Field it is reasonable to classify Oceana deposit as a Mississippi Valley Type deposit overprinted by mineralisation associated with an Intrusion-Related Carbonate-Hosted (IRCH) deposit related to elements associated with the Queen Hill deposit.

ACKNOWLEDGEMENTS

First and foremost I would like to thank my 2nd supervisor Dr. Clive Burrett for his vision and guidance on all aspects of this project. This project would not have been possible if not for the knowledge and support provided by Clive.

I would secondly like to thank my supervisor Dr. Peter McGoldrick for his invaluable support and approach to understanding the complex area of Oceana. The time that was made available to me by both mentors was generous and rewarding.

This project would not have been possible without the generous logistical and financial support of Mr. Malcolm Bendall, Dr. Clive Burrett and Mr. David Tanner and the staff at Zeehan Zinc, Great Southland Minerals and Bass Resources. I would also like to thank the Zeehan Zinc fellas for making this year a pleasure and a rewarding experience, namely Mr. Paul Heath, Mr. Aaron Radonich and Mr. James Farrell.

A great big thankyou goes out to Jake, (Mike Jacobson), at the MRT core shed. Not only was Jake a pleasure to visit on a regular basis, he was prepared to go the extra foot whenever anything was asked. Without Jake at the core shed students would have been paying to view core decades ago and I commend him for his staunchness.

To all the academic staff at the Department of Geology and CODES that were involved in the whole process I thank with special mention of Dr. Ron Berry, Mr. Alan Chester, Dr. Andrew Rae, Dr. James Reid and, of course, the lovely Lin Starr, June Pongratz and Di Steffens for their support. A thanks goes out to the Honours coordinator Dr. Garry Davidson thanks for keeping me organised this year.

To all of the lab staff at the Department of Geology involved in tackling the many steps I have stubbed my toe on, namely Simon Stephens, Katie McGoldrick, Phil Robinson, Peter Cornish and Anthony ‘Dodge’ Dalton, I graciously thank you all.

To the Rm 242 crowd I would like to say thanks to all for the year that was and for the beers that will be. A special mention goes to the court of the mid-year starters, Stewart ‘Stuey’ Dawes, Darren ‘Shagga’ Andrews and John ‘Johnno’ Hooper. I don’t know about you blokes but I certainly won’t forget this year, keep on truckin fellas.

A mention goes to my friends for still answering the phone on the rare occasions I have needed to unwind, and a testament to Nick for his recovery qualities. Last but not the least I would like to thank all of my family for accommodating, (bearing), my schedule this year. Without their support this would not have possible. I respectfully name my Mother Leon McCallum, Father Clifton McGilvray, and Brother Jade McGilvray.

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Introduction 1

1.1 Preamble

Oceana was mined intermittently from 1887 to 1960 and was reported to still host 4Mt of 19.4% Pb, 4.0% Zn and 106 g/t of Ag, by Taylor and Mathison (1983), corrected to 2.5Mt at 7.5% Pb, 2.6% Zn and 51g/t of Ag (Akerman 1998). Since the 1960's intensive diamond core drilling and geochemical-geophysical surveys have since outlined a potentially feasible resource consistent with earlier findings. This project will consider available preceding information and will report detailed carbonate stratigraphic- and basin- analysis, geochemical-analyses and updated geophysical surveying. Zeehan Zinc Exploration provides all necessary support for the project.

1.2 Location of the Oceana Pb-Zn-(Ag) deposit

The Oceana prospect is located approximately 4km south of Zeehan township, within the Oceana Valley of Western Tasmania (**Figure 1**). Road access is easily achievable from the two lane, sealed Zeehan-Strahan Road, and an eroded, cut track 400m to the prospect. Oceana Valley is low-lying, marshy swampland formed between competent underlying Moina Sandstone and overlying Crotty Quartzite siliciclastics. Highly weathered residual limesone overburden is termed 'pug' by previous authors and herein, and exceeds typical thicknesses of western Tasmanian examples at Oceana. Surface exposure of carbonate lithologies are restricted to the poor exposure on the northeast face of Professor Ridge and a rapidly decomposing roadcut within a quarry/platform. Poor exposure is attributed to mine rehabilitation, drill-rig platform construction and the construction of mounds to re-direct water run-off from Mt Zeehan.

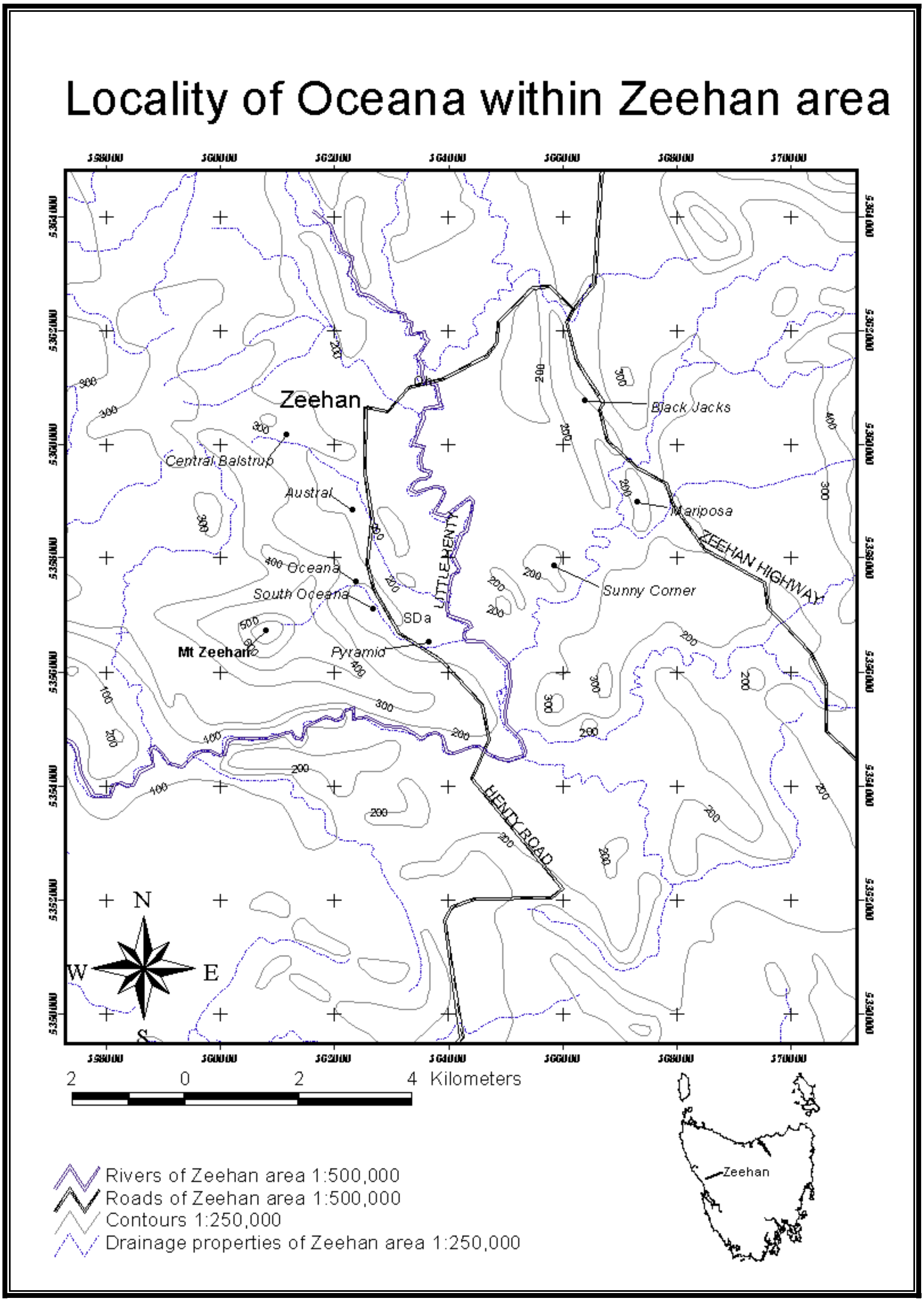


Figure 1: Locality map of Oceana within the Zeehan area (proximal localities are all hosted by the Gordon Group and traverse the Zeehan Syncline). Note – Greives Siding and Firewood Siding Fault 2km to the south of map proximity.

1.3 History of the Zeehan Mineral Field

The Zeehan Mineral Field, (ZMF), has an area of approximately 65km^2 and extends from Zeehan township to South Heemskirk (**Figure 2**). Exploration occurred in three definable 'boom' periods.

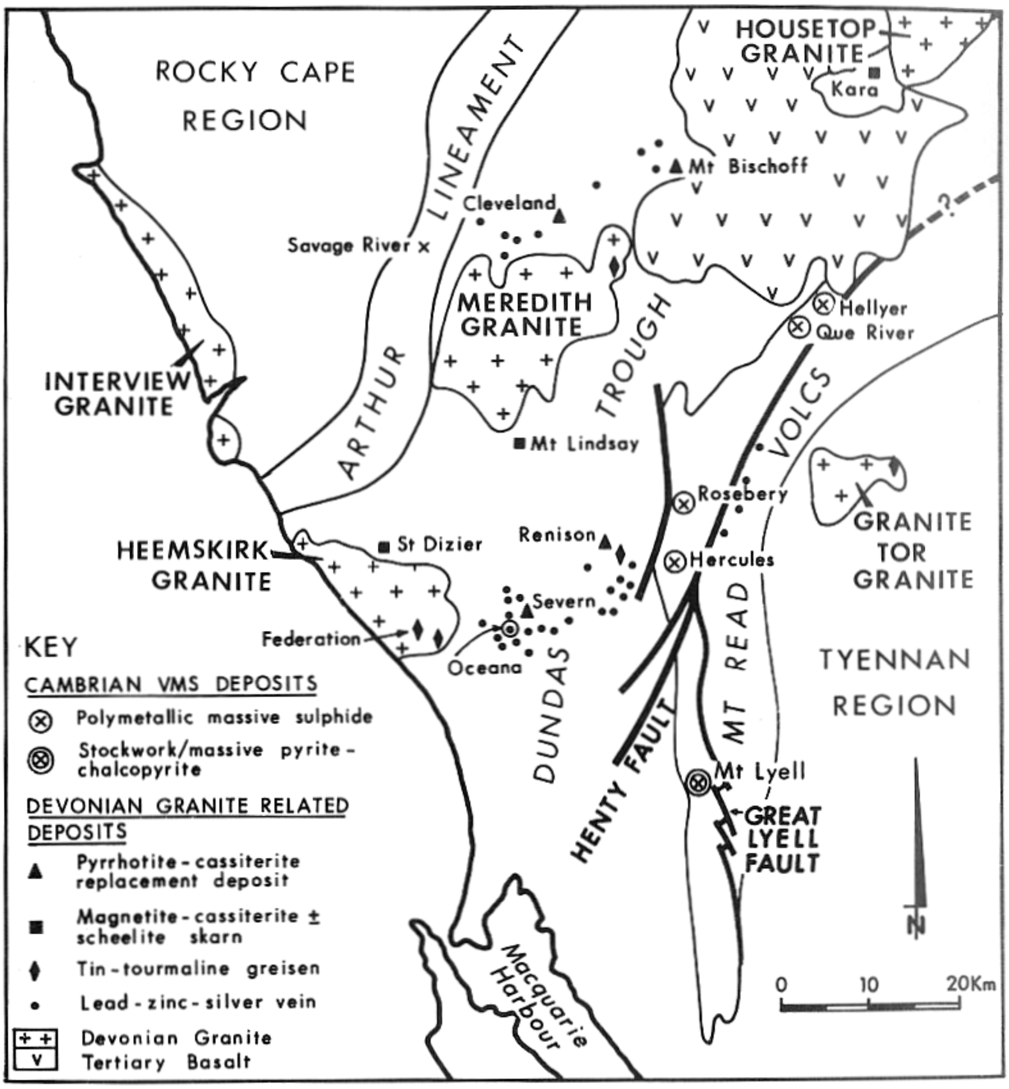


Figure 2: Location of major mines and mineral occurrences in western Tasmania (*from* Large 1989).

Following the C.P. Sprent survey expedition of 1876, Frank Long discovered trace gold and argentiferous galena in 1882 that was to become the Mt Zeehan silver-lead mine. Discovery of tin in 1890 and alluvial gold in 1891 led to 159 mining companies and syndicates established in Zeehan. The first boom crashed with the advent of

World War One in 1914, subsequently removing demand from European markets (Blissett, 1962). King and Blissett, (1968), reported silver-lead ore dominantly extracted from Proterozoic & Cambrian strata, (89.6%), and Silurian & Devonian strata, (9.8%) while Ordovician Gordon Group strata attracted minor exploration, (0.6%).

Renison Associated Tin Mines, N.L. began intensive carbonate exploration from 1936 and eventually relinquished the area to a Broken Hill North and South joint venture. The Gordon Group was again emphasised in the Zeehan and Dundas Fields, of which Oceana was the biggest single producer of Pb-Ag. Chief operations ceased in 1960 ending the second 'boom'.

The third 'boom' began in the late 1970's following intense exploration operations by Amoco Minerals Australia Pty. Ltd. with a continued focus on the Gordon Group Limestones. Data collection included geochemical and geophysical surveying which led to further exploration until 1988 by many companies, including Pasminco, Cyprus Gold, Arimco and CRA.

1.4 Oceana Mining History

Oceana Valley initially attracted explorers with the discovery of a prominent, cerrusite hosting, manganiferous gossan outcrop (Blissett 1962). Hall and Bell procured the first lease for trenching operations in 1887 and transferred holdership to Whiteman in 1891. Oceana Silver Mining Company, formed in 1892, excavated a main shaft to 44m and two drives at 10m & 24m extending 215m total. Operations produced 1,016 tonnes of ore and ceased in 1899 when the top 40 feet, (12m), of the shaft collapsed (**Table 1**). Montgomery, (1893), described the extent of operations preceding collapse. Minor tonnages were stoped and excavated by R. Fox and associates and E St Clair, D. Mather, and B. Grabe from 1909 to 1925.

Period	**Ore**	**Recovered Grade**		**Metal Produced**	
	(tonnes)	**Pb (%)**	**Ag (g/t)**	**Pb (tonne)**	**Ag (oz Tr)**
1887-1899	1016	39*	445*	396	14,537
1906-1925	569	47*	525*	271*	9,645*
1954-1960	130,236	11*	128*	14,473	537,725
Total	**131,821**	**11.5**	**132**	**15,140**	**561,907**

Note: * denotes estimated – *from* Blissett, (1962).

Table 1: Amounts of ore extracted from Oceana Mine (*from* Akerman 1998).

Renewed exploration in 1954 under a Broken Hill North and South joint venture named Zeehan Mines Pty. Ltd. continued until 1960. Geological and geophysical mapping were followed by 39 surface and 58 underground diamond drill holes (**Table 2**). 128,000 tons of Pb-Zn-Ag ore were extracted between 1954 and June 1960. Subsequent operations and resource potential were well documented before flooding of the mine (Jack 1961).

Oceana was revitalised to a modern prospect in 1978 by Amoco Minerals Pty. Ltd. under Exploration License 4/78. A greater emphasis on geophysical and costeaning methods were favoured in opposition to rigorous drilling operations. Subsequently a further 13 holes were drilled to truth results. Drilling enabled a resource delineation of 4Mt at 19.4% lead, 4.0% zinc and 106 g/t silver, extending north and south to a maximum known depth of 350m (Taylor and Mathison 1990). Cordery, (1998), has provided a comprehensive account of exploration operations from 1978.

Prospect	Company	Drilling		Comment
		Holes	metres	
Oceana	XBH/ZM	39	>3,208	surface – O1-O139
	ZeehanMines	58	?	undergound
	Amoco-Cyprus	13	3,756	ZT-79-1 to ZT-83-14
	Pasminco	1	236	OP2
Austral	Zeehan Mines	7	?	
	Amoco-Cyprus	11	2,314	ZT-79A-1 to ZT-81A-10
	Pasminco	3	647	OP4 to OP6
	Pasminco	111	1,550	Shallow aircore holes
South Oceana	Zeehan Mines	9	?	
	Pasminco	1	280	OP1
Pyramid	Zeehan Mines	5	?	
	Pasminco	1	425	OP3
From Akerman (1998)				

Table 2: Drilling Summary for EL 20/2002 – (Oceana), (*from* Akerman 1998)

Simultaneous exploration was undertaken by the Cyprus Gold Australia Corporation under EL 4/78 with subsequent geological and feasibility reports (Jones 1988). Cyprus relinquished the EL in 1988 and maintained RL 8809 (Oceana) until October 1990. Hudspeth and Company contracted the tenement and transferred their name and control to Arimco Mining Pty. Ltd. in August 1991. Arimco entered into a joint venture in May 1992 with Pasminco Australia Ltd. and allowed two tripartite ventures: CRA Exploration Pty. Ltd. during 1994-1995, to assess zonation in mineralisation phases of the Heemskirk Granite, and Porthill Resources Limited during 1995-1996, to assess open cut reserves.

By 1997 Arimco remained sole holder of RL 09/88. In September 1997 Mancala Pty. Ltd. was granted joint access and changed their name to Hercules Resources Pty. Limited. The option remained valid to the 14th of October 1999. The current exploration lease, EL 20/2002 – Oceana, is held by Zeehan Zinc Exploration.

1.5 Proposals

The proposals of this project are, to:

- Report on the lithostratigraphy and diagenetic history of carbonates for additive basin analyses.
- Report on structural elements of Oceana deposit and examine style and distribution of metals.
- Report on spatial and temporal associations of mineralogy and alteration textures.
- Report on fluid geochemistry of paragenetic ore phases.
- Report on the interpretation of available geophysical datasets.
- Construct a genetic model that can be utilised as an exploration tool within EL 20/2002.

1.6 Methodology

Sratigraphic Methods

Document host lithologies and associated mineralisation at Oceana from reviewing relevant works, field sampling and core logging.

Define Punctuated Aggradational Cycles within Ordovician transgressional stratigraphy and the shallowing-upward significance of those cycles.

Structural Methods

Collate structural orientations from previous records and relevant samples in unrestricted drill core and field mapping.

Discuss the significance and implications of related deformational events known to western Tasmania.

Geophysical Methods

Assess modern datasets and interpret regional tectono-structural elements based on residual anomalous data.

Alteration and Mineralogical Methods

Distinguish alteration and vein mineralogy and paragenesis within the field area.

Report on the significance and/or applicability of alteration or mineral zonation.

Fluid Geochemistry Methods

Assess various Zn indexes for available geochemical vectors to ore using unrestricted assay results from costeaning and drill core.

Carbon, Oxygen and Hydrogen isotopic appraisal of carbonate generations to define isotopic proportions and examine source criteria.

Genetic Model Construction of Oceana Pb-Zn-(Ag) deposit

Assess the relative significance of varied styles and timing of the Oceana deposits and assess replacement and vein system mineralisation. Continued exploration in the Zeehan region may benefit in utilising a genetic reconstruction of Oceana mineralisation.

Regional Geology 2

2.1 Introduction

West Tasmanian geologic information is known from the Middle Neoproterozoic to Holocene alluvium. The Wurawina Supergroup and the various movements during the Tyennan and Tabberabberan Orogenies are primarily relevant to this project. The Oceana carbonate-hosted lead-zinc-silver sulphide deposit is located in the eastern limb of the Mt Zeehan anticline, within the upper-portion of the Lower Palaeozoic Dundas Trough.

Berry *et al*., (2001), defined pre-Ordovician Tasmania as divisible into three 'time slices', (**Figure 1**), based on regional unconformities: Early Neoproterozoic (~1200-760Ma); late Neoproterozoic (~760-550Ma); and Middle to Late Cambrian (~518-495Ma). The Wurawina Supergroup consists of Late Cambrian to Middle Devonian sedimentary deposits terminated by onset of the Tabberabberan Orogeny. Sedimentary packages post-dating the Tabberabberan Orogeny, until the Triassic, are contained within the Parmeener Supergroup. Later sedimentary deposits are of little importance in central Western Tasmania (**Figure 2; Appendix B-1 & B-2**).

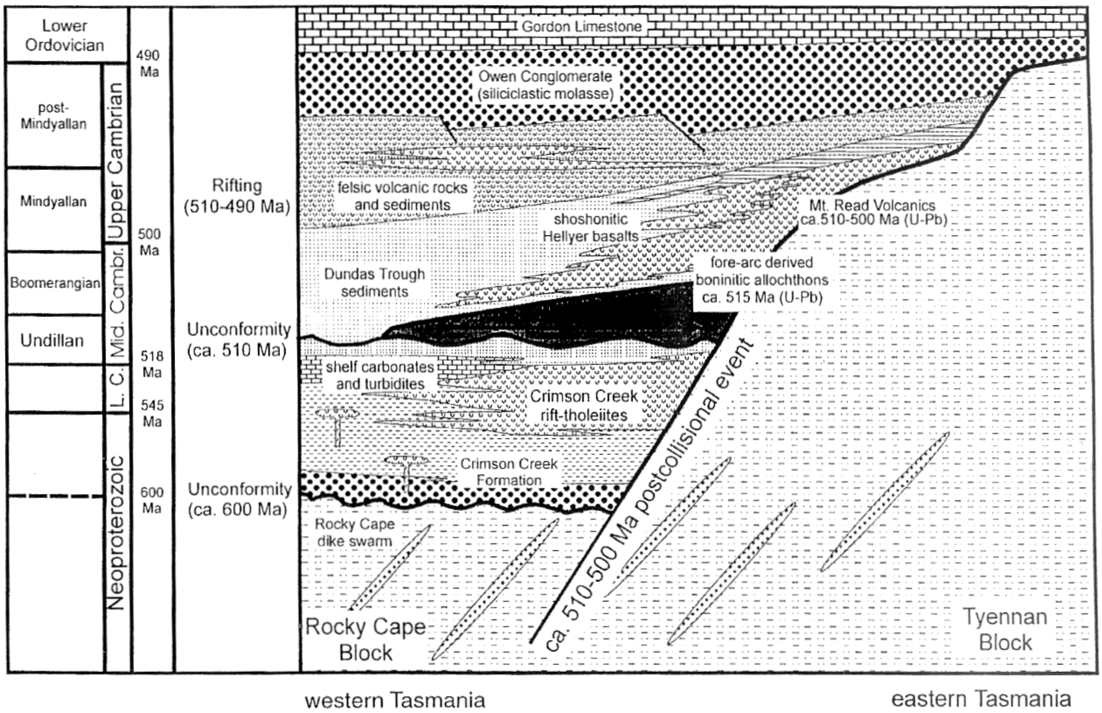


Figure 1: Generalised stratigraphic column for the Cambrian of Tasmania. Cambrian stages are those of Australia. The Cambrian timescale is *after* Tucker and McKerrow (1995), Davidek *et al.* (1998), and Encarnacion *et al.* (1999). (*after* Munker & Crawford 2000).

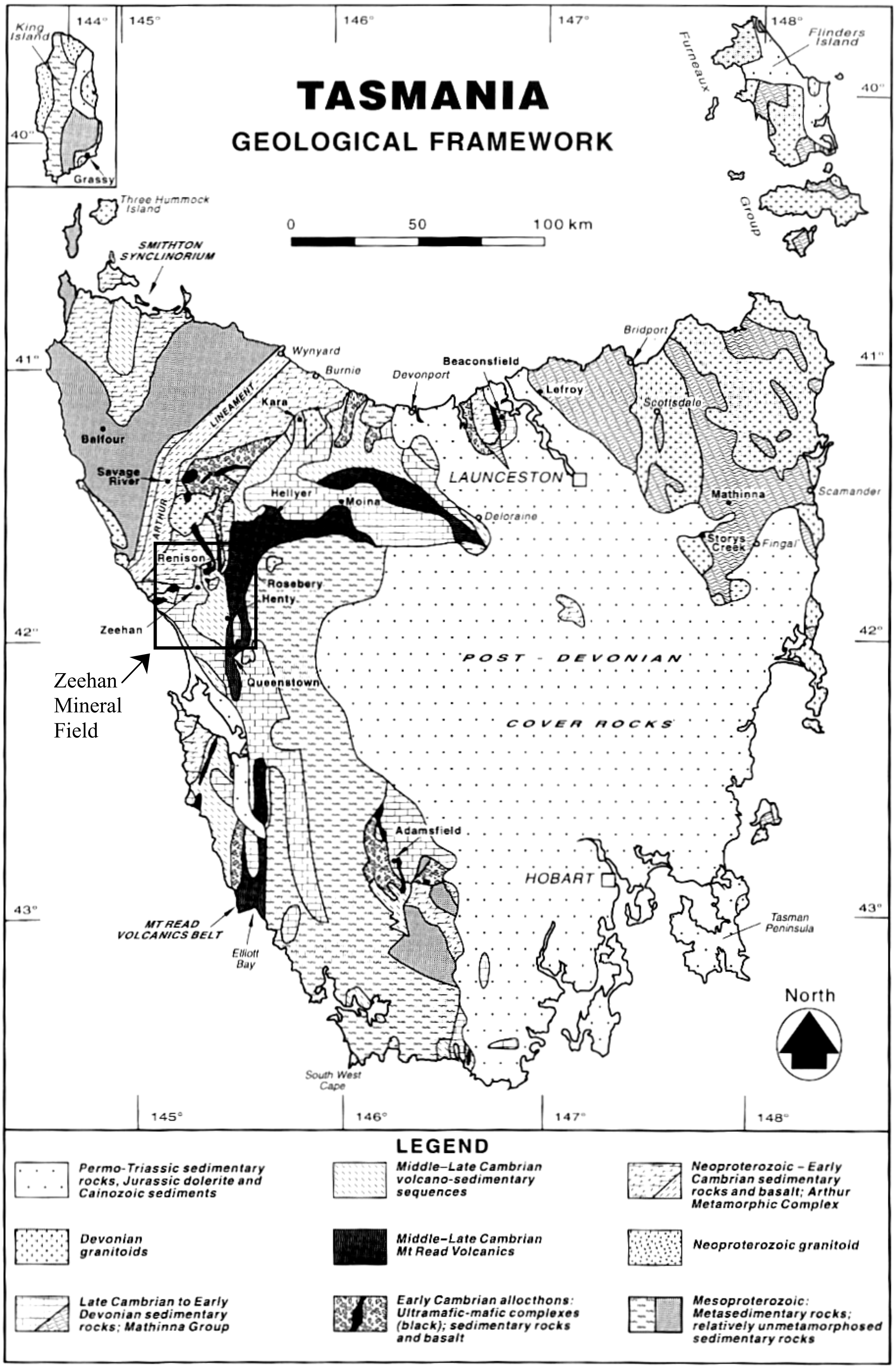


Figure 2: Summary geological map of Tasmania. Locations of major mines and mineral deposits shown by solid dots and bold upright text (Source Mineral Resources Tasmania – *from* Bottrill *et al.* 1998).

2.2 *Regional Geology*

2.2.1 Middle Neoproterozoic (~1200Ma to ~760Ma)

2.2.1.1 Oonah Formation

(*from* Turner *in* Burrett & Martin 1989)

The Oonah Formation is a correlate of the Burnie Formation in the Zeehan district, (Spry 1964). The Oonah Formation, (Spry 1958), is regionally subdivided into Upper and Lower members, of greater variation than lithologies of the Burnie Formation (Brown 1986). The Lower member is dominated by finely bedded micaceous-, arenaceous-quartzite, sandstone and siltstone interbedded with quartzwacke, mudstone and black shale. The Upper member is dominated by laminated siltstone and mudstone interbedded with pebble conglomerate, arenaceous-sandstone, dolomitic-carbonates, and mafic volcaniclastic derivatives. Brown, (1986), considered the entire formation as distal turbiditic with periodic depth variation. Crossing, (1990), re-classified the depositional environment of the Upper member to a shallow sub-aqueous depositional environment. Turner *et al.*, (1998), suggests dominant thick, sandy turbidites of the Oonah Formation and correlated Burnie Formation to reflect a general period of instability and uplift, associated with the Wickham Orogeny, consistent with interpretation by Crossing, (1990).

Basal boundaries of the Rocky Cape & Tyennan blocks and the Oonah & Burnie Formations are, as yet, unidentified and therefore chrono-stratigraphically unresolved, posed by Spry (1964). The lowermost member of the Togari Group is correlated to the Upper member of the Oonah Formation and lays at low angle unconformity upon Rocky Cape sediments, (Turner *et al.* 1998), (**Figure 3**). K-Ar slate ages, (~690Ma), defined by Adams *et al.* (1985), have been cast into doubt with recent findings of long term projective method inaccuracy, in comparison to U/Pb zircon dating (Turner *et al.* 1998). Goscombe, (1993), described Oonah Formation facies assemblages as chlorite-muscovite- quartz- calcite- plagioclase and plagioclase- tremolite- quartz- epidote.

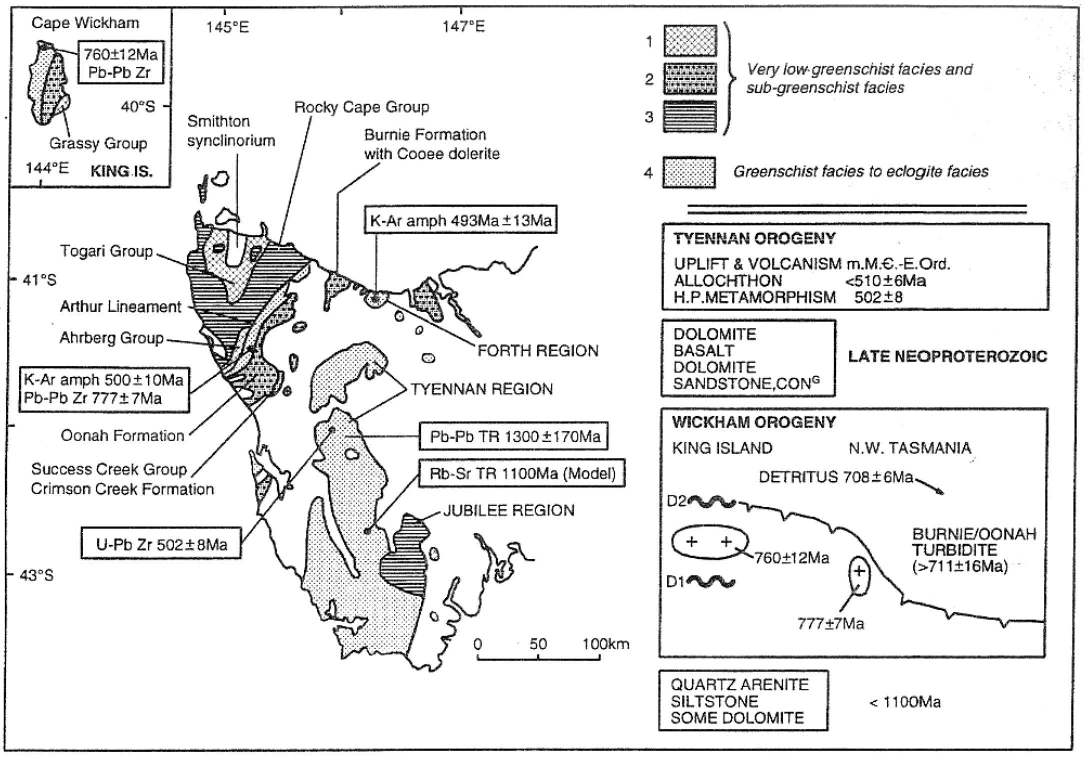


Figure 3: Precambrian inliers of Tasmania and their tectonostratigraphy. 1, continental shelf and margin deposits with rift tholeiites near the top; 2, sandy turbidite facies (siltstone on King Island is possibly equivalent); 3, quartz arenite, siltstone, minor dolomite; 4, Forth and Tyennan regions largely similar to 3. King Island unassigned; Arthur Lineament contains 2 and 3 plus metabasite and pelite (*after* Turner *et al.* 1992). Ages are from this work; McDougall & Leggo 1965; Raheim & Compston 1977; Gulson *et al.* 1990; Turner 1993b.

2.2.2 Late Neoproterozoic (~760-550Ma)

2.2.2.1 Success Creek Group

(*from* Brown *in* Burrett & Martin 1989)

The first phase of the Tyennan Orogeny is represented as an unconformable boundary separating Middle Neoproterozoic Oonah Formation sediments and Late Neoproterozoic sediments of the Success Creek Formation. Brown, (1989), identified the boundary outcropping in an elongated area, of approximately 35km^2, between Mt Lindsay and Renison Bell. The southwest margin of this area is dominated by fault contacts, as a feature of Devonian deformation, and the northeast margin is characterised by apparent unconformity with apparent onlap by Success Creek Group transgressive sediments (Brown 1986). Brown *et al.*, (1989), revised a Pieman River outcrop along the northeast margin to a sedimentary hiatus and low-grade metamorphic break.

The stratigraphic column consists of over 1000m of siliciclastic sediments deposited in a shallow water environment on a subsiding platform margin (Brown 1986). The lower formation is dominantly polymictic conglomerate with concordant lenses of coarse sandstone and siltstone, interpreted as proximal accumulations of varied basement provenance (Brown 1986). The Dalcoath Formation conformably overlies the undefined mixtite. Dalcoath Formation sediments are dominantly fine-grained, arenaceous sandstone and siltstone with subordinate granule to pebble conglomerate, deposited in a clean, shallow water environment.

The uppermost Renison Bell Formation is subdivided into conformable Renison Bell Shale and ‘red rock’ members. Both members are characterised by ubiquitous, unlithified deformation and variable amounts of mafic and felsic volcaniclastics (Brown 1982). The topmost member is representative of transition to tidal flat – flood plain conditions (Brown *et al.* 1989).

The Success Creek Group is diachronous with the Togari and Grassy Groups of northwest Tasmania, the Weld River Group of the Jubilee Region and the Barrington Chert of the Dial Range - Fossey Mountain Troughs (Calver 1998; Holm & Berry 2002).

2.2.2.2 Crimson Creek Formation

(*from* Brown *in* Burrett & Martin 1989)

The Crimson Creek Formation, (Blissett & Gulline 1961), is well exposed in the Mt. Lindsay – Parsons Hood area and consists of 3950m to 5000m thickness (Taylor 1954; Blissett 1962; Brown *et al.* 1989). The Crimson Creek Formation is considered gradational from the Success Creek Group, unconformable to the Oonah Formation and diachronous with the Kanunnah Sub-Group of the Togari Group (Calver 1998).

Sediments are turbiditic in character and consist of laminated and interbedded siltstones, mudstones and volcaniclastic lithic wacke (Brown *et al.* 1989). Coherent tholeiitic mafic volcanics and detritus increase northwards spatially and temporally. Coherent compositions range from picrites to evolved ferro-basalts (Crawford and Berry 1992). Detritus is dominantly mafic derived although Brown, (1982), and Everard *et al.*, (1992), identified felsic clasts in lower sequences, implicating syn-deposition with the evolved Mount Read Volcanic Belt (Brown *et al.* 1982).

Basal conglomerates, and interspersed thin, interbedded tuffaceous horizons and coherent lavas indicate dynamic sea level interplay. Facies types are indicative of an unstable shelf margin rift sequence with an accelerated sedimentation regime in a shallow sub-aqueous environment (Brown 1986).

2.2.3 Early to early Middle (~550Ma to ~518Ma)

2.2.3.1 Allochthonous Mafic – Ultramafic Complexes

(*from* Brown *in* Burrett & Martin 1989)

The earliest Stichtian phase of the Tyennan Orogeny involved obductive allochthonous emplacement of Mafic-Ultramafic nappe Complexes (MUC) as fore-arc thrust-sheets into and onto the Crimson Creek Formation, (510 ± 6Ma: Turner *et al.* 1998; Brown *et al.* 1989). Several bodies lie along the boundary with the overlying Dundas Group, (Brown 1986), and contention remains as to the allo-stratigraphic / stratigraphic nature of the (lower) Dundas Group, (Selley 1997; Berry & Crawford 1988), (**Figure 4**). Ultramafic detritus was identified in basal conglomerates of the Dundas Group at three localities where Brown *et al.*, (1982), concluded the Dundas Group represented an age marker for post-emplacement MUC, supporting earlier geochronologic interpretations by Carey, (1953).

Three MUC associations were recognised by Brown, (1986), in western Tasmania: a layered Pyroxenite-Dunite succession; a layered Dunite-Harzburgite succession; and a layered Pyroxenite-Peridotite-Gabbroic succession. Bodies occur as discontinuous, narrow, fault-bounded inliers that occur between Beaconsfield in the north and the Sorrell Peninsula in the west.

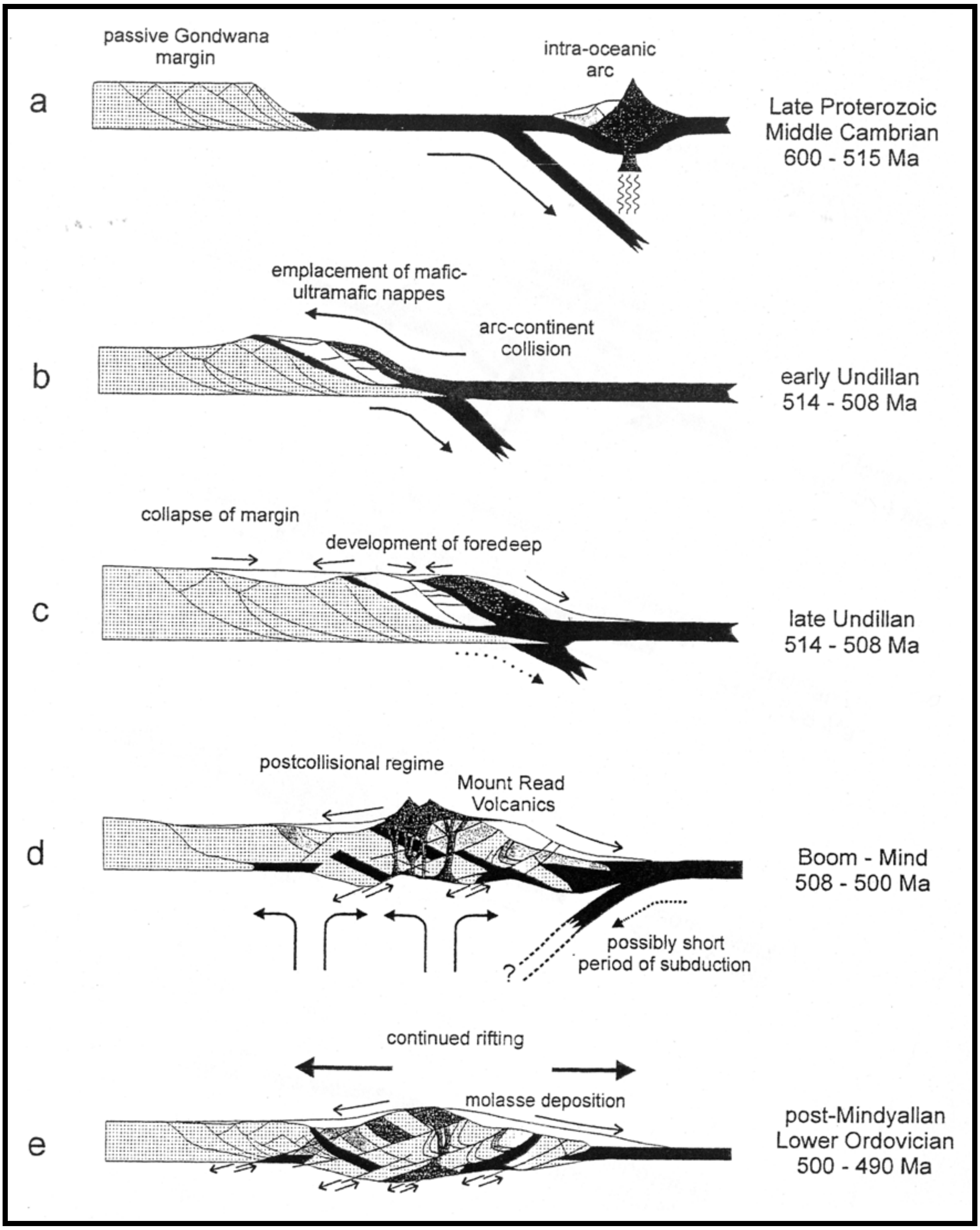


Figure 4: Schematic model for the volcanic and tectonic evolution of Tasmania in the Cambro-Ordovician, (*after* Crawford & Berry 1992). (a) Evolution of the passive proto-Gondwana margin and an intra-oceanic arc system in the late Neoproterozoic and Early Cambrian, caused by subduction of the proto-Gondwana plate beneath the Pacific plate. (b-c) Collision of the intra-oceanic arc with the proto-Gondwana margin in the Undillan stage of the Middle Cambrian, leading to obduction of the fore-arc sections onto the thinned leading edge continental crust of proto-Gondwana as boninitic mafic-ultramafic allochthons. (d) Postcollisional volcanism of the Mount Read Volcanics followed during the late Middle to early Late Cambrian. This may have been associated with a short period of possible subduction of the Pacific plate beneath the Gondwana plate, although this is not necessary. (d-e) Bouyancy-driven uplift and exhumation of the Neoproterozoic basement and erosion of the mafic-ultramafic allochthons, causing deposition of molasses sediments in the Late Cambrian, which commonly contain detrital boninitic chromites. (*after* Munker & Crawford 2000).

MUC petrology consists of low-Ca boninites and low-Ti, magnesian quartz tholeiites with a strong depletion of Light Rare Earth Elements, (LREE), and High Field Strength Elements, (HFSE), (~0.20 wt.% TiO2 at 8 wt.% MgO). Low Ti tholeiites are transitional between arc tholeiites and high-Ca boninites (Munker & Crawford 2000).

Berry and Crawford, (1988), subsequently defined an emplacement age of middle-Middle Cambrian and proposed westward directed emplacement of boninitic allochthonous ophiolites onto attenuated Neoproterozoic crust of proto-Gondwana. Crawford *et al.*, (1991), have shown petrographic and compositional features similar to those recorded from the Bonin-Mariana and north Tongan intra-oceanic arcs. Munker and Crawford, (2000), consider emplacement to have resulted in collapse of the passive margin and development of a foreland basin–half graben, the Dundas Trough, correlated to origin of the Pacific Ocean. This scenario may well be the case although graben development is established pre-MUC emplacement.

2.2.3.2 Dundas Trough

(*from* Corbett & Turner *in* Burrett & Martin 1989)

The Dundas Trough is a north/south oriented, 20-30km wide, graben / half-graben structure considered by Berry and Crawford, (1992), to represent an extensional relaxation rift of a foreland basin. Dundas Trough sediments are flanked to the northwest and southeast by Rocky Cape and Tyennan Block sediments, respectively. The trough extends from the Dundas region to the Fossey Mountain and Dial Range regions and outcrop over 300km. A continuous belt of intermediate volcanics occupies the eastern margin, MRV, and interfingers middle-Middle Cambrian Dundas Group sediments in the central and western portions. Selley, (1997), concluded the sediments were deposited in a series of meridionally trending sub-basins, (west-central-east). The Jukesian Movement associated a following period of uplift and subsequent basin fill of dominantly Tyennan basement provenance. Basement was rapidly eroded and redeposited as the Denison Group.

2.2.3.3 Dundas Group

(*from* Corbett & Turner *in* Burrett & Martin 1989)

The Dundas Group is a fossiliferous flysch sequence of interbedded mudstone, greywacke, conglomerate, mafic volcanics and minor felsic volcanics comprising over 3000m (Elliston 1954). The basal Read Lead Conglomerate, RLC, represents sub-aqueous fanglomerate deposition of crude-stratified, clast-supported conglomerate and mud-dominated inter-channel deposits. Low titanium mafic and felsic detritus indicate provenance from both MRV and MUC facies. The uppermost formation of the Dundas Group is diachronous to the Tyndall Group and unconformably overlies the Central Volcanic Complex in the north (Komyshan 1986). General sedimentation regimes are largely confined to turbiditic, sub-wave base facies (Selley 1997).

The sedimentary association with the MUC is proposed by Selley, (1997), as proximal, disconformable deposition, however Berry & Crawford, (1988), propose allo-stratigraphic emplacement and syn-orogenic sedimentation as components of an obducted fore-arc section upon the Crimson Creek Formation. A fault-bounded discontinuity within a medial member of the Dundas Group is stressed as evidence by Berry and Crawford, (1988). Recent identification of the allo-stratigraphic Timbs Group in northwest Tasmania by Holm and Berry, (2002), favours their argument.

2.2.4 Middle to Late Cambrian (~518-495Ma)

2.2.4.1 Mount Read Volcanics – CVC

(*from* Corbett & Solomon 1989)

Corbett, (1992), sub-divided the volcanic sequence between Queenstown and Hellyer into six litho-stratigraphic facies associations. (1) The Sticht Range Formation is a basal siliciclastic conglomerate and sandstone unconformably overlaying ?Mesoproterozoic basement Tyennan metasediments. The basal unconformity and facies represent the Stichtian Movement of the Tyennan Orogeny. (2) The Eastern quartz-phyric sequence consists of extrusive and intrusive quartz-feldspar-phyric volcanics and volcaniclastic derivatives.

(3) The Central Volcanic Complex is a belt of quartz-poor, feldspar-phyric volcanics with characteristic sub-aqueous textures as peperitic contacts, flow-banding and hyalo-clasts. Pervasive potassic alteration is considered a product of proximal shallow intrusion. (4) The Western volcano-sedimentary sequences are extensive, interbedded sequences of volcaniclastic conglomerate, sandstone and siltstone that interfinger the CVC.

(5) Andesitic-basaltic sequences occur as large lenses stratigraphical near the top of the CVC and the base of the Tyndall Group. (6) The Tyndall Group is an upper sequence of volcaniclastic sandstones, breccias and conglomerates with minor felsic flows. Medial locally-distributed, welded ignimbrites indicate basin shallowing before the onset of 'Molasse-type' deposition of the Denison Group.

2.2.4.2 Tyndall Group

(*from* Corbett & Solomon, 1989)

The Tyndall Group is considered the 'third' volcanic sequence overlaying the 'first' CVC and the 'second' western sequence (Corbett & Solomon 1989). The sequence consists of quartz-feldspar-phyric lavas and pyroclastics with locally abundant volcaniclastic conglomerates. Corbett and Solomon, (1989), cite Cambrian fossils to occur in the basal part of the group at Queenstown, and Middle or Late Cambrian fossils in the correlated Sticht Range beds, which rests unconformably on Precambrian basement. Corbett, (1981), defined the Tyndall Group as unconformably overlaying Precambrian metasediments of the Tyennan Block which continued to Late Cambrian age.

Corbett and Solomon, (1989), conclude that the Tyndall Group must be laterally equivalent to at least part of the Dundas Group. Berry and Crawford, (1988), contribute that based on no unforeseen breaks within the Tyndall Group, the allochthonous sheets must entirely predate this unit. If the CVC is also post-orogenic it must have erupted in a very short time (<5Ma) during late Middle Cambrian. Despite this, the CVC lavas are compositionally more consistent with a post-collisional origin than an origin in the allochthon.

2.2.5 *Upper Cambrian to Lower Devonian*

2.2.5.1 The Wurawina Supergroup

(*from* Banks & Baillie *in* Burrett & Martin 1989)

The Junee Series of Lewis, (1940), was re-evaluated by Corbett and Banks, (1974), to consist of the Denison and Gordon sub-groups, and the Eldon Group. Burrett *et al.*, (1984), elevated sub-groups to group status. Banks and Williams, (1986), proposed the tripartite Wurawina Supergroup. The Supergroup is named after Lake Wurawina in the 'type-area' of the Denison Range in south-central Tasmania. **(Figure 5)**.

<table>
<tr><td rowspan="5">TIGER RANGE GROUP</td><td colspan="4">MCLEOD CREEK FORMATION</td></tr>
<tr><td colspan="4">CURRAWONG QUARTZITE</td></tr>
<tr><td colspan="4">RICHEA SILTSTONE</td></tr>
<tr><td colspan="4">GELL QUARTZITE</td></tr>
<tr><td colspan="4">WESTFIELD [=ARNDELL] SANDSTONE</td></tr>
<tr><td rowspan="5">GORDON GROUP</td><td rowspan="3">BENJAMIN LIMESTONE</td><td colspan="3">UPPER LIMESTONE MEMBER</td></tr>
<tr><td colspan="3">LORDS SILTSTONE MEMBER</td></tr>
<tr><td colspan="3">LOWER LIMESTONE MEMBER</td></tr>
<tr><td colspan="4">CASHIONS CREEK LIMESTONE</td></tr>
<tr><td colspan="4">KARMBERG LIMESTONE</td></tr>
<tr><td rowspan="6">DENISON GROUP</td><td rowspan="3">SQUIRREL CREEK FORMATION</td><td>UPPER SANDSTONE MEMBER</td><td rowspan="3">FLORENTINE VALLEY FORMATION</td><td>MOUNT FIELD SILTSTONE MEMBER</td></tr>
<tr><td>SILTSTONE-LIMESTONE MEMBER</td><td>PONTOON HILL SILTSTONE MEMBER</td></tr>
<tr><td>LOWER SANDSTONE MEMBER</td><td>CHURCHILL SANDSTONE MEMBER</td></tr>
<tr><td colspan="2">REEDS CONGLOMERATE</td><td colspan="2">TIM SHEA SANDSTONE</td></tr>
<tr><td colspan="2">GREAT DOME SANDSTONE</td><td colspan="2"></td></tr>
<tr><td colspan="2">SINGING CREEK FORMATION</td><td colspan="2"></td></tr>
</table>

Figure 5: Stratigraphy of the Denison, Gordon, and Tiger Range Groups in their type areas (Denison Gp left), and southeast of the Florentine Valley (Denison Gp right). Based on Corbett & Banks (1974, 1975), Corbett (1975), Baillie (1979) and Stait & Laurie (1980), (*from* Laurie 1991).

The Denison Group rests unconformably upon Late Cambrian sediments and grades from fanglomerate siliciclastics to high-subtidal and intertidal arenaceous sandstone and siltstone. Thickness and character provide little evidence for classification to wholly Late Cambrian or Early Ordovician however intra-formational hiatus suggests an extended period of deposition, (Banks and Burrett 1980), preceding the Gordon Group carbonates. Gradational Tiger Range siliciclastic beds are truncated with angular unconformity and are overlain by Late Carboniferous to Triassic Parmeener Supergroup sediments (Banks & Williams 1986).

2.2.5.1.1 Denison Group (*Upper Cambrian to Lower Ordovician*)

(*from* Banks & Baillie 1989)

The Denison Group (Corbett 1975; Burrett *et al.* 1984) is the lowermost member of the Wurawina Supergroup in the 'type area' of south-central Tasmania (Banks 1989). The Group is geochronologic to the Owen Conglomerate (Wade & Solomon 1958); Pioneer Sandstone (Banks 1989), and the Mt Zeehan Conglomerate, (Blissett 1962); Moina Sandstone, in central-western Tasmania. The lower boundary truncates Mindyallan to Idamean Cambrian sediments and represents the Jukesian Unconformity, (Carey and Banks 1954), and the Jukesion phase of the Tyennan Orogeny (Turner 1989). The Owen Conglomerate is sub-divided into Lower and Middle conglomerate and Upper sandstone, siltstone and minor carbonate units, (Pioneer Sandstone), (Banks 1989). Solomon, (1962), identified merostome trails in the upper Middle Owen, near the western end of Mt Owen, characterising marine deposition. The Pioneer Sandstone contains worm castings and burrows, coarsely costate-brachiopods and euomphalid-gastropods of Ordovician age (Banks 1989).

Blissett, (1962), defined the Mt Zeehan conglomerate in the Zeehan area as a generally acceptable equivalent to the Owen conglomerate similarly unconformable upon Cambrian rocks. The Mt Zeehan conglomerate and Moina Sandstone reach maximum thicknesses of 450m and 360m respectively. Pitt, (1962), defined the Mt Zeehan Conglomerate as conformable upon Dundas Group sediments, southwest of Zeehan, with ripple marks and palaeocurrent directions originating from the north. Minor contention remains to a west Tasmanian diachronous Early Palaeozoic conglomerate package. The Denison Group and Mt Zeehan Conglomerate is used herein in accordance with Banks and Williams, (1986).

Banks, (1989), defined five 'types' of successions within the Denison Group. Marginal to Tyennan and Rocky Cape regions, slope or basinal deposits pass into shallow marine deposits and into alluvial-fan associations. Littoral sands occur above fan deposits and continue into shallow marine limestone and mudstone. Type 1 is indicative of late Cambrian regression then Early to Middle Ordovician transgression as uplift and erosion, downwarping and sea level transgression. Type 2 incorporates siltstone beneath alluvial fan deposits. Type 3 begins with unconformable conglomerate or breccia in alluvial fans or screes passing into littoral sands (Tremadoc - Arenig). Type 4 begins with littoral sandstone unconformably overlaying pre-Ordovician rocks. Type 5 is characterised by rocks synchronous with slope deposits overlain by or faulted against younger rocks than the Denison Group, with absent shallow marine and terrestrial sediments (Banks, 1989).

Blissett, (1962), described the Moina Sandstone as successive pale grey, thin-bedded, quartzose, pebbly-grit with a single, poorly preserved, unidentified, trilobite pygidium from the eastern limb of the Mt Zeehan anticline near Oceana Mine. Pink and purple conglomerate with quartzite pebbles in a matrix of siliceous pebbly-grit are overlain by pale grey pebbly-grit into sub-greywacke grit with small chert fragments. Mature sandstone and siltstone with interbedded pebbly grit, noted ¼ mile (400m), west of Oceana Mine, contain ripple marks, cross-beds and intensely bioturbated units indicative of a neritic sub-aqueous environment (Blissett, 1962).

2.2.5.1.2 Gordon Group (*Early Ordovician to Early Silurian*)

(*from* Banks & Burrett 1989; Burrett 1995)

The Gordon Limestone was originally described by Strzelecki, (1845), as a continuous, homogenous package, and was classified as the Gordon Limestone by Gould, (1866). Corbett and Banks, (1974), reviewed the stratigraphy at the Florentine Valley section and titled the 'Gordon Sub-group'. Burrett *et al.*, (1984), elevated the subgroup to group status and Banks and Williams, (1986), proposed the Wurawina Supergroup. Banks and Burrett, (1989), have since identified the Gordon Group to be the most complete shallow-water Ordovician sequence in Australia, (Laurie 1991), widely distributed in Tasmania west of 147°E (**Figure 6**). Transgression from southeast to northwest produced an older, southeastern basal limestone formation, the Florentine Valley Formation, considered equivalent to the Squirrell Creek Formation.

The Gordon Group reaches 1200m to 1800m thickness in the 'type area' of the southern Florentine Valley, (Corbett & Banks 1975), and conformably-disconformably overlies and inter-fingers the Moina Sandstone in the Zeehan area (Banks and Burrett 1989). The base of the Gordon Group is considered by Burrett *et al.*, (1984), as clearly diachronous from the Middle Arenig in the east (Florentine Valley); to Chazyan; and Blackriveran in the northwest, (Queenstown; and Vale of Belvoir).

The Gordon Group is characterised as open and closed environment, high-subtidal to peritidal micrites and dolomicrites with subordinate argillaceous dolomicrites. Fossiliferous beds host nautiloids, conodonts, brachiopods, trilobites, stromatoporoids, corals, gastropods, pelecypods, rostroconchs and bryozoans. Fossils range in age from Middle Arenig to Edenian or Maysvillian (Banks & Burrett 1980). Cyclical and irregular periodic sedimentation, attributed to rapid sea-level transgression, has produced Punctuated Aggradational Cycles, PACs, indicative of lithofacies compensation within particular depositional environments to eustatic change. Micritic units range to sparitic, and mud-rich, representing minor variation in a closed shallow-marine, intertidal environment with a macroscopic-coast (Banks & Burrett 1989). Conodont yields from higher parts of the Gordon Group are usually very low and are possibly attributable to harsh peritidal environmental conditions and a very high rate of sedimentation (Burrett *in* Webby 1981).

Corbett and Banks, (1975), proposed a tripartite division of the Gordon Group to consist of the constituent Karmberg, Cashions Creek and Benjamin Limestones. Within the Benjamin Limestone Formation Lower and Upper members are divided by the Lords Siltstone member. The Lords Siltstone Member is a laterally extensive unit that conformably disrupts carbonate sedimentation, <1m to 15m thick, and provides a litho-stratigraphic marker unit for the upper Gordon Group. The division of Corbett &

Banks, (1975), was applied to the Zeehan region by Burrett, (1995), who defined the lower Ugbrook Fm (Karmberg correlate), Myrtle Fm (Cashions Ck correlate), and Black Jacks Fm (Benjamin correlate).

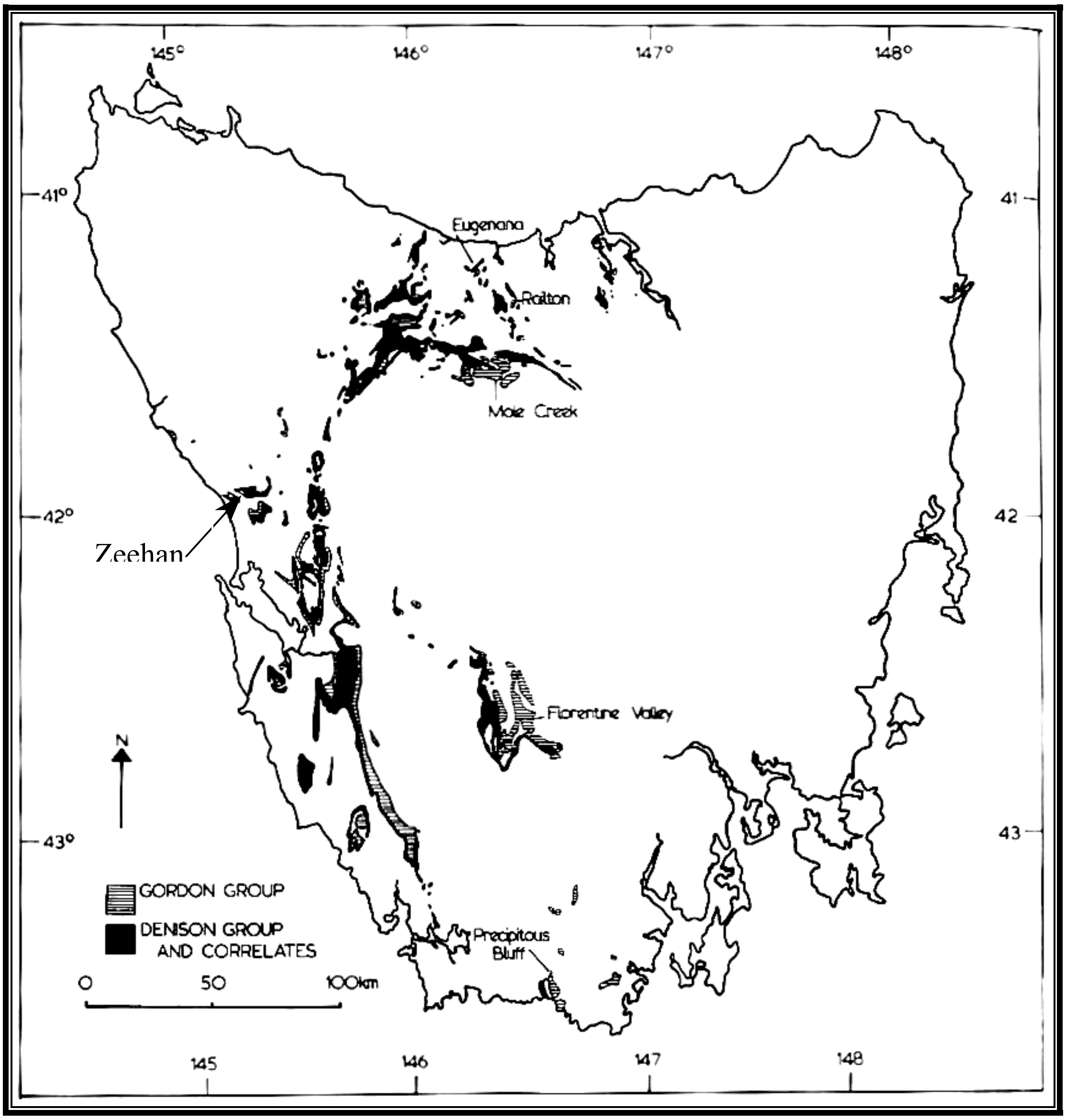


Figure 6: Location of known outcrops of Denison Group and Gordon Group rocks, or correlates thereof, in Tasmania. Areas of particular importance are indicated by name. (*from* Laurie 1991).

2.2.5.1.3 Eldon Group (*Early Silurian to Early Devonian*)

(*from* Banks & Baillie 1989)

Siliciclastics of the Eldon Group, (Gould 1866; Gill & Banks 1950), in western Tasmania are correlated to the Tiger Range Beds in the south-central Tasmanian 'type area' of the Wurawina Supergroup, (Banks 1989), (**Figure 7**). Shallow marine siliciclastic sequences at least 2.3km in thickness conformably and disconformably overlay the Gordon Group (Blissett 1962). Sediments consist of pebble-grit to mudstone with intermittent, fossiliferous units. Fossils include echinoderm fragments, *Rostricellula*, and bioturbation.

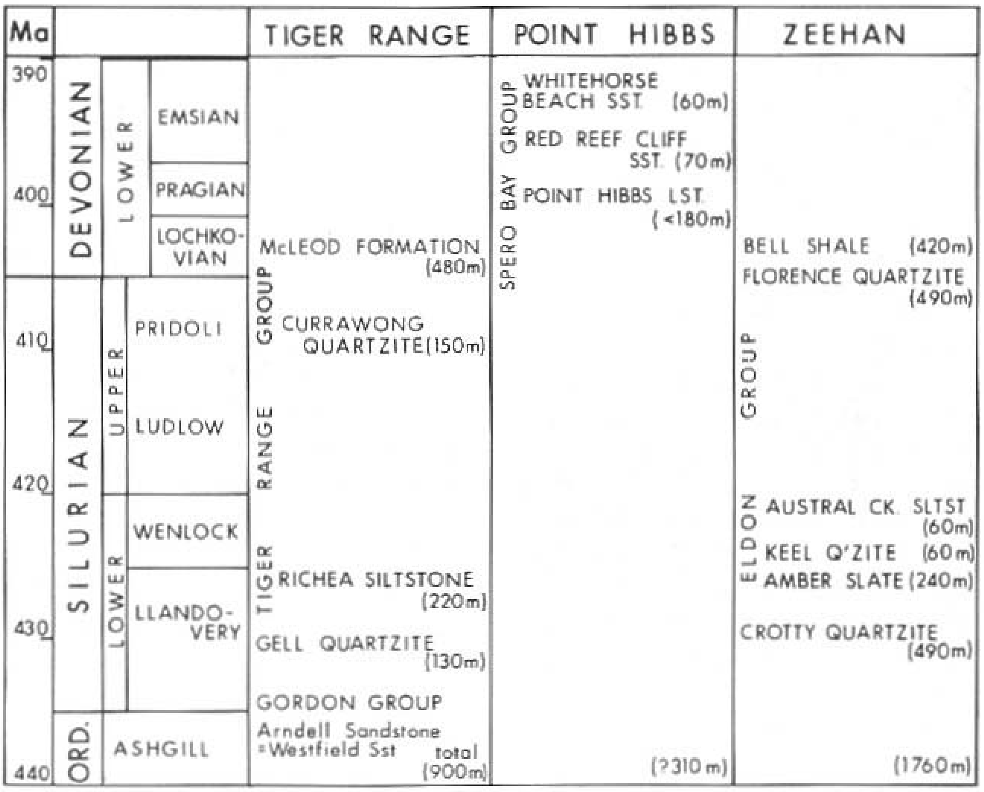


Figure 7: Stratigraphic table for Silurian and Lower Devonian formations in the West Tasmania Terrane, time scale after Snelling (1985), (*after* Banks & Baillie 1989).

2.2.6 Late Carboniferous to Triassic

2.2.6.1 Parmeener Supergroup

(*from* Clarke & Forsythe *in* Burrett & Martin 1989)

Forsyth *et al.*, (1974), defined Lower and Upper lithological major sub-divisions of the Parmeener Supergroup. The Lower Group, (Upper Carboniferous to Permian), consists of glacigene sediments and local lacustrine sediments with a single minor coal measure. The Upper Group, (Upper Permian to Triassic), consists of terrigenous dominated sediments with substantial coal measure development. Clarke and Farmer, (1976), formally provided four palynological sub-divisions. The Hellyerian Stage, (*Potonieisporites* Microflora), includes deposits of tillite, glacio-mixtite and glacio-lacustrine rhythmic claystone with subordinate till-derived pebbly mudstone, turbidite sandstone and outwash conglomerate.

The Tamarian Stage consists of mudstone, siltstone and sandstone with subordinate limestone and conglomerate. The lower Tamarian is characterised by glacigene rocks, *Tasmanites* oil shale and abundant glendonites. The base coincides with the Quamby Mudstone, (Treswell 1978), and signifies the Carboniferous/Permian boundary. The Bernacchian Stage retrogrades from terrigenous sediments with substantial coal measures to impure micrite and calcareous siltstone. Thickly-bedded, pale grey limestone comprises the remaining section.

The Lymington Stage is dominated by shore platform mudstone, siltstone and sandstone with minor limestone and conglomerate. Sandstones are glauconitic and arkosic, becoming less fossiliferous up-section.

2.3 *Regional Structure*

2.3.1 **Wickham Orogeny** (*Nepr*D_1 & *Nepr*D_2)

(*from* Cox 1989)

Two phases of deformation have been substantiated as the Wickham Orogeny. The first phase is represented by prograde dynamo-thermal metamorphism, represented by andalusite mineralisation in alumina rich beds in southern King Island. A later phase of granite emplacement, (~760Ma ± 12Ma), is interpreted by Taylor *et al.*, (1998), to represent an associated latter phase of *Nepr*D_1. Transected pre-emplacement folding is evident but not substantiated to date. Post-emplacement sediments of the Grassy Group unconformably overlay a siltstone member, correlated to the Togari Group (Brown 1989), which may represent a final uplift phase to the Orogeny (**Figure 8**).

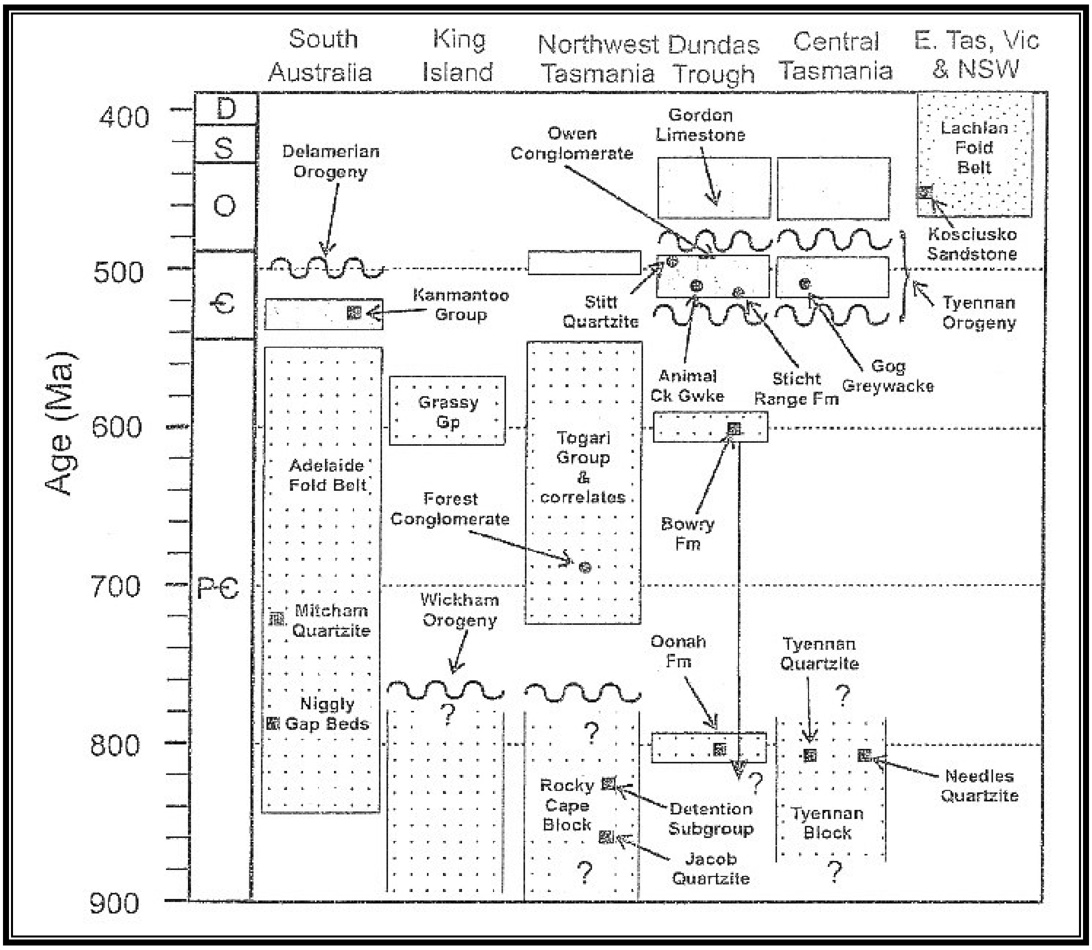


Figure 8: Space-time diagram showing significant episodes of orogenesis and sedimentary deposition in southeastern Australia. The stratigraphic position of zircon samples is shown (*from* Berry *et al.* 2001).

2.3.2 Tyennan Orogeny (*Ca*D_1 &*Ca*D_2)

(*from* Turner *et al.* 1998)

The Tyennan Orogeny is a conceptual replacement of the Penguin and Frenchman Orogenies (Turner *et al.* 1998). The Penguin Orogeny was interpreted from the exposed juxtaposition of the Oonah Formation to Success Creek & Crimson Creek sediments in western Tasmania. The Tyennan Orogeny is subdivided into two phases each encompassing several episodes (**Figure 9**). The first phase, the Stichtian Movement, is relatively obscure in Western Tasmania with emphasis placed on dating of relative samples, i.e. the Sticht Conglomerate (Turner *et al.* 1998).

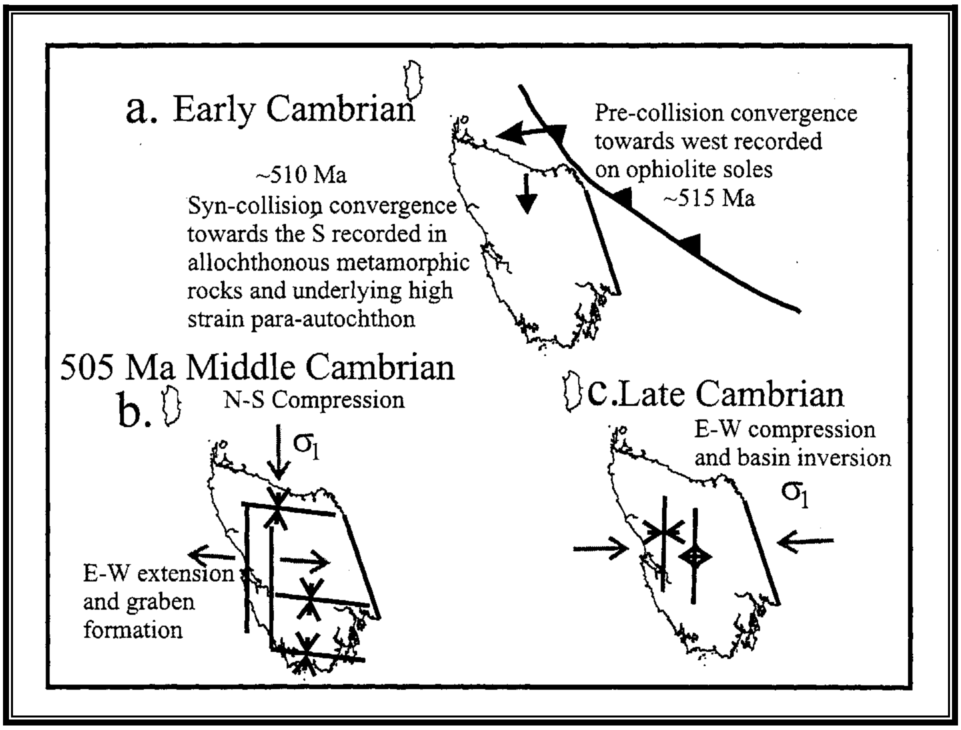


Figure 9: Speculative model for the evolution of the Tyennan Orogeny in Tasmania (*from* Berry & Gray 2001).

Middle-Middle Cambrian arc-continent collision, (~510Ma), resulted in obductive, allochthonous emplacement of boninitic ophiolites to allostratigraphic positions. Post-collision extension associated with Benioff Zone transition resulted in the exhumation of underthrust Neoproterozoic crust, (Scotchfire Metamorphic Complex), post-collisional arc-magmatism, (Mount Read Volcanics), and extensive fore-arc graben development, (the Dundas Trough), (Munker & Crawford 2000). Plagiogranites associated with the allochthonous sheets are representative of boninitic magmatism and yielded U-Pb zircon ages of ~514Ma ± 5Ma (Black *et al.* 1997).

Arc volcanism and eugeosynclinal deposition are terminated by the Jukesian Unconformity. The overlain Denison Group siliciclastics are dominantly basement-derived and represent sedimentation during the Jukesian Movement (Turner *et al.* 1998). Middle Cambrian graben development is probably synchronous to north-south shortening and east-west extension (~505Ma). Late Cambrian east-west compression produced basin inversion and rapid deposition of basement-derived material. Reverse movement along the Jukesian Unconformity at Mt Lyell (Great Lyell Fault-Haulage Unconformity), during deposition of the Owen Conglomerate, consisted of dip-slip displacement of over 1km (Arnold & Fitzgerald 1986).

Quiescent sedimentation during the Ordovician is disrupted by episodes associated with an active sedimentary shelf margin. Considerable regional geochemical analyses by Gulson *et al.*, (1984), with emphasis on radiogenic Pb signatures, indicated proportions between known Cambrian and Devonian signatures, suggesting a mixture of variable aged Pb sources were sampled. The mineralisation style develops into MVT deposits at similar stratigraphic locations elsewhere in west Tasmania, i.e. Bubs Hill, (Taylor 1983). Similar questionable metalliferous occurrences are recorded by Large, (1989), who defined a radiogenic element 'reset-event' that had effected Cambrian metals.

Marine transgression gave way to siliciclastic loading and probable lowstand sedimentation during Eldon Group deposition. Pitt, (1962), defined the Oceana Fault extending well into the Crotty Quartzite which is unapparent in Devonian strata, indicative of syn-sedimentary kinematics.

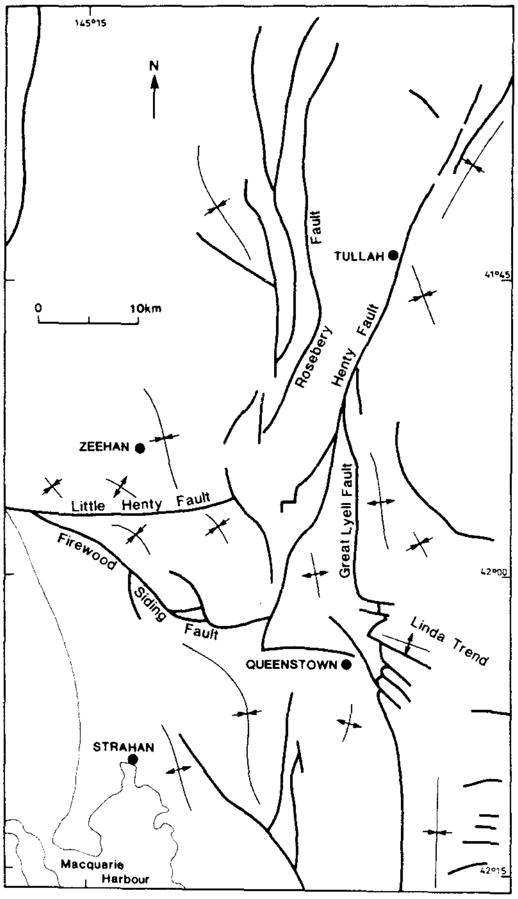


Figure 10: Map of part of the west coast of Tasmania giving Devonian structural elements referred to within. Structures are from fig.1 of Corbett and Lees, 1987, (*after* Berry (1989).

2.3.3 **Tabberabberan Orogeny** (*De*D_1, *De*D_2, *De*D_3 & *De*D_4)

(*from* Banks 1959; Williams *et al. in* Burrett & Martin 1989)

Eldon Group deposition was terminated during the middle-Middle Devonian by movements associated with the Tabberabberan Orogeny (Corbett & Turner 1989). Three regional phases are evident: North-northwest macro-scopic folds and thrusting of the West Coast Range / Valentines Peak trend; Northwest macroscopic folds of the Zeehan/Gormanston trend; and an east-west event developed locally in western Tasmania, (Williams 1989), (**Figure 10**).

I- and S-type granites sequentially intruded during and after *De*D3 along north-oriented anticlinal cores with east-west axes at depth (Leaman & Richardson 1989), (**Figure 11**). Locally developed deformation is associated with intrusion, i.e. Renison (Kitto 1994). Shallow intrusion into carbonate-dominated host rock resulted in endogranitic greisen vein tin, Tin-tungsten distal skarn and carbonate-replacement, Tin-tungsten vein deposits and marginal silver-lead-zinc vein deposits (Williams *et al.* (1989). Deposits occur in the contact aureole of non-magnetic granitoid intrusives approximately 500m-1500m from granite-sediment contact (large 1989). Fluid inclusion analysis by Manly, (1982), of diopside-garnet-amphibole skarn minerals from the Pine Hill granite host rocks indicate temperatures of 500°C to 600°C. Granite ages range from 367Ma to 340Ma ± 10Ma and are considered to intrude from east to west across Tasmania. Intrusions in western Tasmania, into dominant carbonate host lithologies, provide a mineralogical, metasomatic contrast to the dominant siliciclastic host lithologies of Eastern Tasmania (Williams 1989). Any developed relief was selectively decomposed or preserved by glacigene sediments.

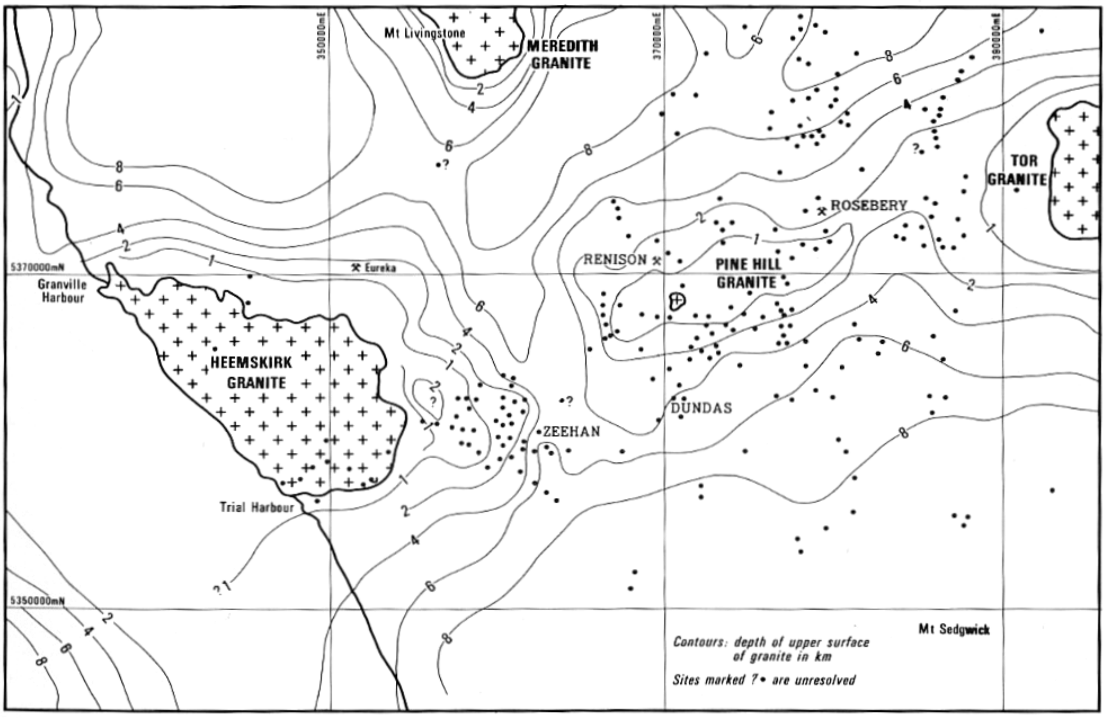


Figure 11: Provisional interpretation of the subsurface form of the Heemskirk and Pine Hill Granites, with sites of mineralisation indicated (*after* Leaman & Richardson 1989).

2.3.4 Post-Devonian activity

(*from* Burrett & Martin 1989)

Glacigenic, terrigenous and shelf-margin siliciclastics of the Parmeener Supergroup are disrupted by voluminous intrusion of Jurassic Dolerite. Massive sills and dykes occur throughout eastern Tasmania with little occurrence in western Tasmania. Intrusion of silica-saturated magmas during tensional stress probably corresponds to break up of Gondwana. Continental break-up resulted in formation of extensional sedimentary basins of Late Mesozoic and Cenozoic age (Baillie 1989); (**Figure 12**).

Figure 12: Jurassic reconstruction of Australia, Antarctica and Tasmania showing fold belt boundaries. Locations indicate zircon samples from mainland Australia (*from* Berry *et al.* 2001).

Local Geology and Basin Analysis 3

3.1 Introduction

The local geology of the Oceana Mine is confined to the Wurawina Supergroup. The economic potential of Oceana is within the Gordon Group and consists of stratabound and discordant, vein-hosted metals. Both styles of mineralisation are considered individually uneconomic however the combination of both is feasible. Gordon Group sedimentation has been regionally classified into nine lithostratigraphic units, each representing a defined environment of deposition. This chapter will document each litho-facies at Oceana and will provide a description of the characteristic depositional environment.

3.2 Methodology

Sedimentologic data is available in diamond drill- and air-core, field sampling and costeaning. Diamond drill core logs of good condition core were intermittently produced from 1954 to 1995, however detailed analysis of the stratigraphy excluded the carbonate classification scheme of Folk, (1962), and hence, provided little evidence of eustasy or unit continuity. Previous authors, (Ellis 1984, Peace 1996), chose to employ the carbonate classification of Dunham, (1964), however this scheme was constructed on well-developed carbonate sediments of the Bahama Bank, a vast regional platform, and is too advanced for classification on a ramp to mini-platform. The allochemical component of Folk’s, (1962), classification, in conjunction with considerations of sediment structures and allochem descriptions common to the Gordon Group by Burrett, (1978), provides a valuable application in understanding the carbonates in Zeehan.

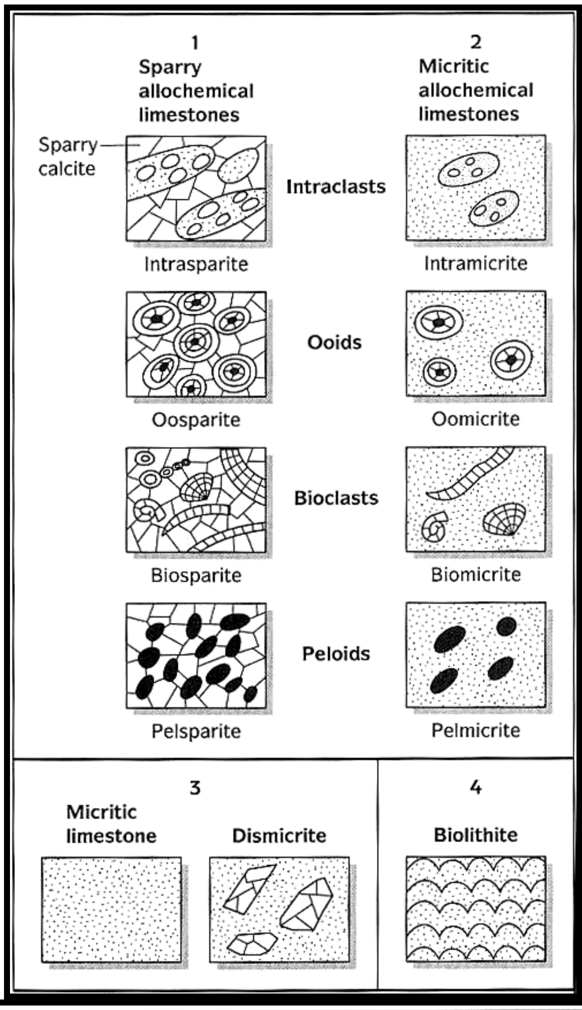
Selected diamond drill cores were re-logged and sampled employing polished thin-sections for meso- and micro-scopic analysis. Carbonate mineral staining was used to determine the compositions of carbonate minerals using the procedure of Hitzman, (1999), adapted from Dickson, (1965). This technique, using a combination of Alizarin Red S and potassium ferricyanide, allows for the rapid identification of calcite, ferroan calcite, ferroan dolomite (ankerite), and rhodochrosite (**Table A**).

Carbonate mineral	Alizarin red S	Staining reagent potassium ferricyanide	Combined reagents
Calcite ($CaCO_3$)	Pink to red	Unstained	Pink to red
Aragonite ($CaCO_3$)	Pink to red	Unstained	Pink to red
Ferroan calcite $(Ca,Fe)CO_3$	Pink to pale pink	Pale to deep blue	Purple to royal blue
Dolomite ($CaMg(CO_3)_2$)	Unstained	Unstained	Unstained
Ferroan dolomite ($Ca(Mg,Fe)CO_3)_2$)	Unstained	Pale to deep turquoise	Pale to deep turquoise
Siderite ($FeCO_3$)	Unstained	Unstained	Unstained
Rhodochrosite ($MnCO_3$)	Unstained	Very pale brown	Very pale brown
Magnesite ($MgCO_3$)	Unstained	Unstained	Unstained
Witherite ($BaCO_3$)	Red	Unstained	Red
Cerussite ($PbCO_3$)	Mauve	Unstained	Mauve

Table A: Colour of common carbonate minerals after staining (*from* Hitzman 1999).

The carbonate rock classification of Folk, (1962), was used to define nine lithofacies, each defining a depositional environment (**Figure 1&2**). Lithofacies descriptions and classification of biota, based on the scheme produced by Burrett, (1978), provide unique markers to the particular depositional environment and the subsequent response to sea level change (**Figure 3, 4 & 5; Table B**).

The Gordon Group is widespread in the Zeehan district although outcrop is very limited and decomposed. Exploration activity at Greaves Siding, Pyramid, Oceana and Austral Creek provide sufficient data for a local character of the Gordon Group. Research by Burrett & Goede, (1987), and Burrett *et al.*, (1989), and generally by Burrett, (1995), on the western limb of the Zeehan structural basin have defined seven intraformational members within the Ugbrook, Myrtle and Black Jacks Formations. The units are difficult to determine due to veining, faulting, folding, cleaving, stylolitisation, stylolamination and tecto-stylolitisation with pervasive- and selective-dolomitisation, -silicification and –dissolution. The combination of destructive textures affect the true thickness of stratigraphy, (dip-corrected), and therefore uncorrected downhole thicknesses, (apparent thicknesses), are employed within.



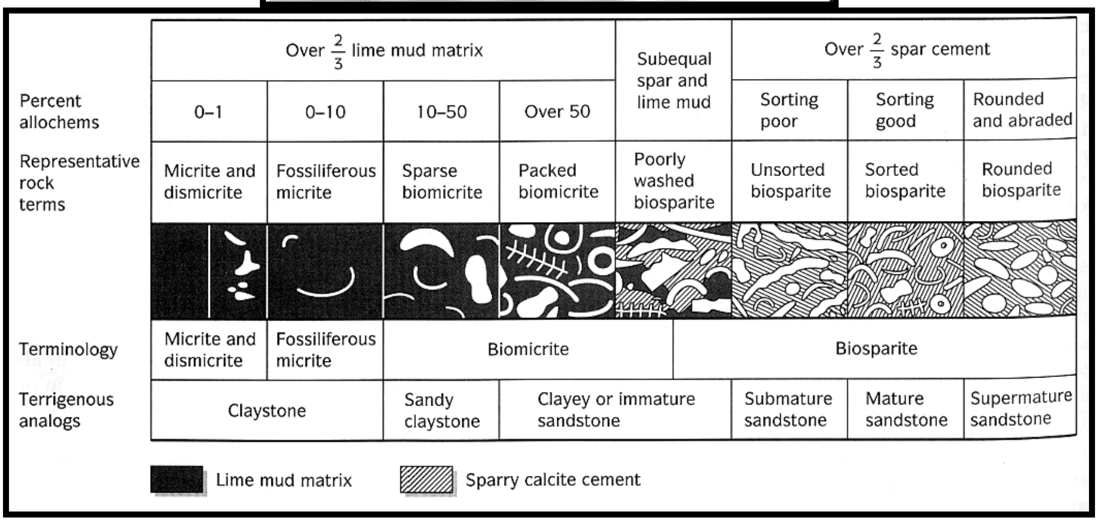


Figure 1: (A) R.L. Folk's, (1959; 1962), classification of limestones, which uses prefixes to indicate the framework grains present (*bio-* for fossils, *pel-* for peloids, *oo-* for ooids, and *intra-* for intraclasts), and stems to indicate whether the interstitial calcite is micritic or sparry. If the rock is originally bound together (i.e. reef rock), it is a *biolithite*. **(B)** Textural maturity classification of limestones proposed by Folk, (1962). Textural maturity classes are based on the percentage of allochems present, their degree of sorting, and the extent of rounding (a function of abrasive history). (*After* Folk 1962 *in* Prothero & Schwab 1996).

Depositional Environment	Lithofacies at Oceana
Supratidal to Peritidal	1. **Red Beds** – Reddened, oxidised dolomicrite with extensive dolomitisation. Bed tops scoured, ripped-up and faulted.
Upper Intertidal Medium Intertidal to Shallow Protected Lagoonal Subtidal	2. **Micrite & dismicrite** – Pale grey homogenous, fenestrae vuggy, laminar, bioturbated micrite 2a. **Pale Micrite** – Pale grey micrite with silt beds and packed, dominant broken fossil debris 2b. **Pale Micrite** – Pale grey homogenous micrite with isolated, disseminated sand grains
Low Intertidal to Shallow Open and Protected Subtidal	3. **Biosparite & Pel-bio-sparite** – Pale grey to blue poorly washed biosparites with ooids, oncolites and intraclasts
	4. **Calcarenite & Biosparenite** – Massive and bedded crinoidal dominant, subtidal and intertidal fossil debris
	5. **Oncobiomicrite** – Medium-grey to black micrite and argillaceous micrite supporting concentric oncolites
Shallow Protected Subtidal to Medium and Low Subtidal	6. **Biomicrite** – medium-grey to black unfossiliferous to packed micrite with diverse fossils, biolithites
Intertidal to Subtidal	7. **Argillaceous micrite & Mudstone** – Black to brown-red bedded and laminated, fossiliferous to packed with depth, bituminous films
	8. **Nodular Limestone** – Pale to dark grey micrite with argillaceous micrite matrix, random fossils, rounded clasts
	9. **Dolomite** – syn-genetic, epi-genetic, partial and complete replacement, extensive.

Table 2: Summary of depositional environments and lithofacies at Oceana.

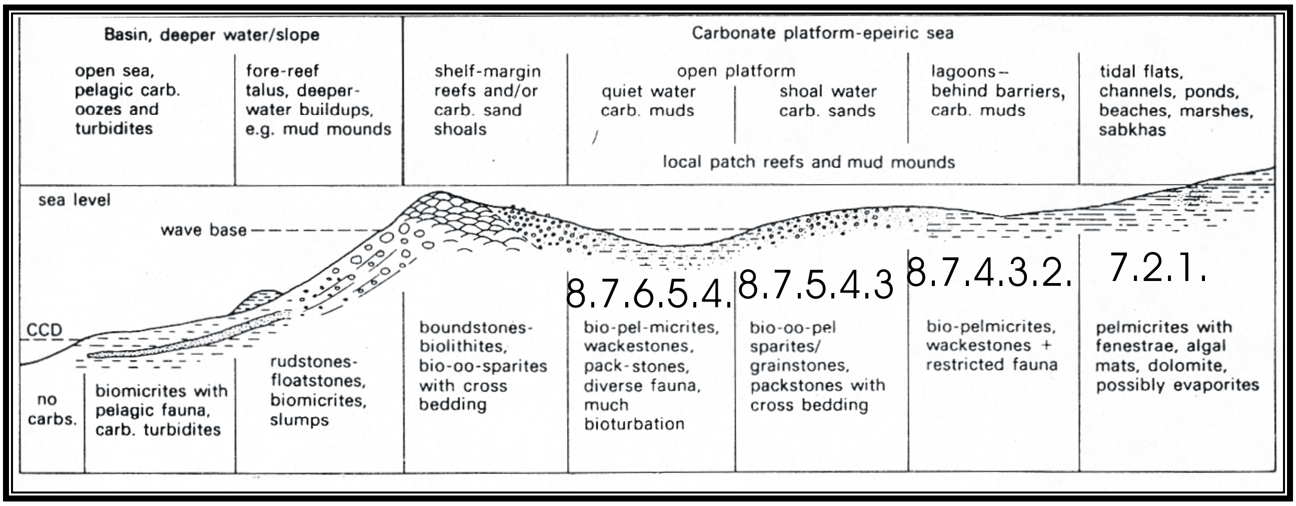


Figure 2: Principle marine depositional environments of carbonate sediments and their dominant facies characteristics (*from* Tucker 1981), applied to Oceana (*Modified from* Tucker 1981).

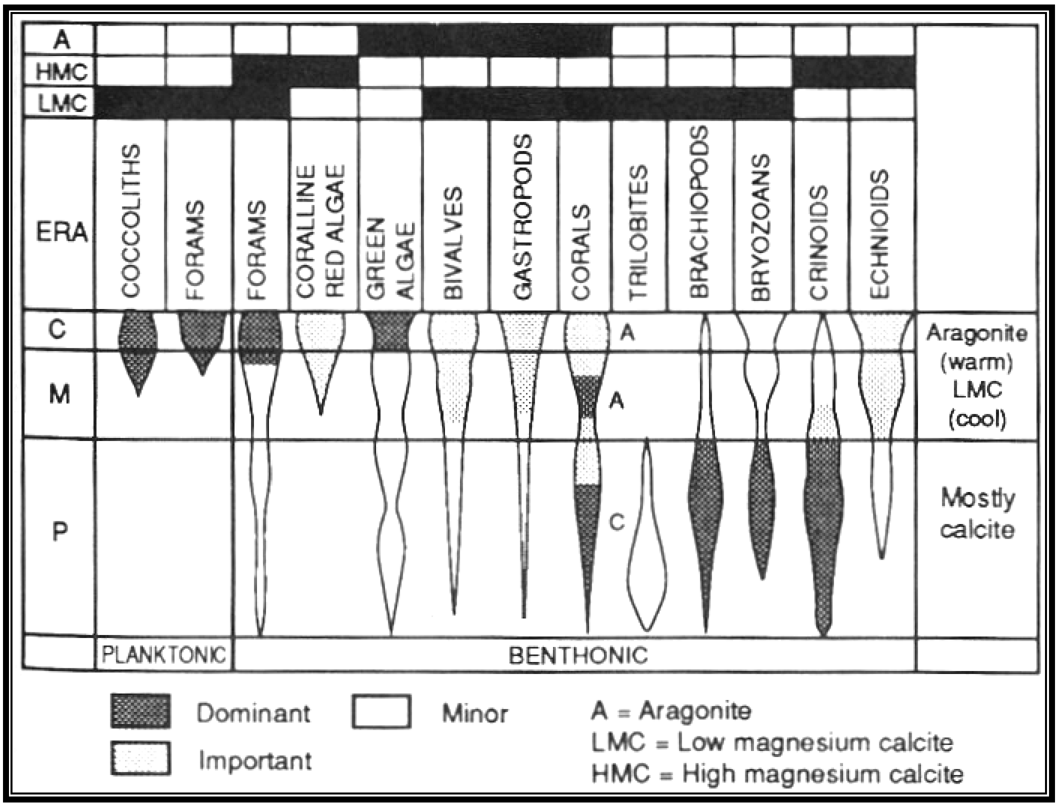


Figure 3: Distribution of main groups of animals and plants through Palaeozoic (P), Mesozoic (M), and Cenozoic ©. The fact that the different groups of animals and plants have skeletons formed of different mineralogies means that there are substantial differences between the Palaeozoic and Mesozoic/Cenozoic sediments and cool versus warm water sediments (*from* Jones & Desrochers 1992).

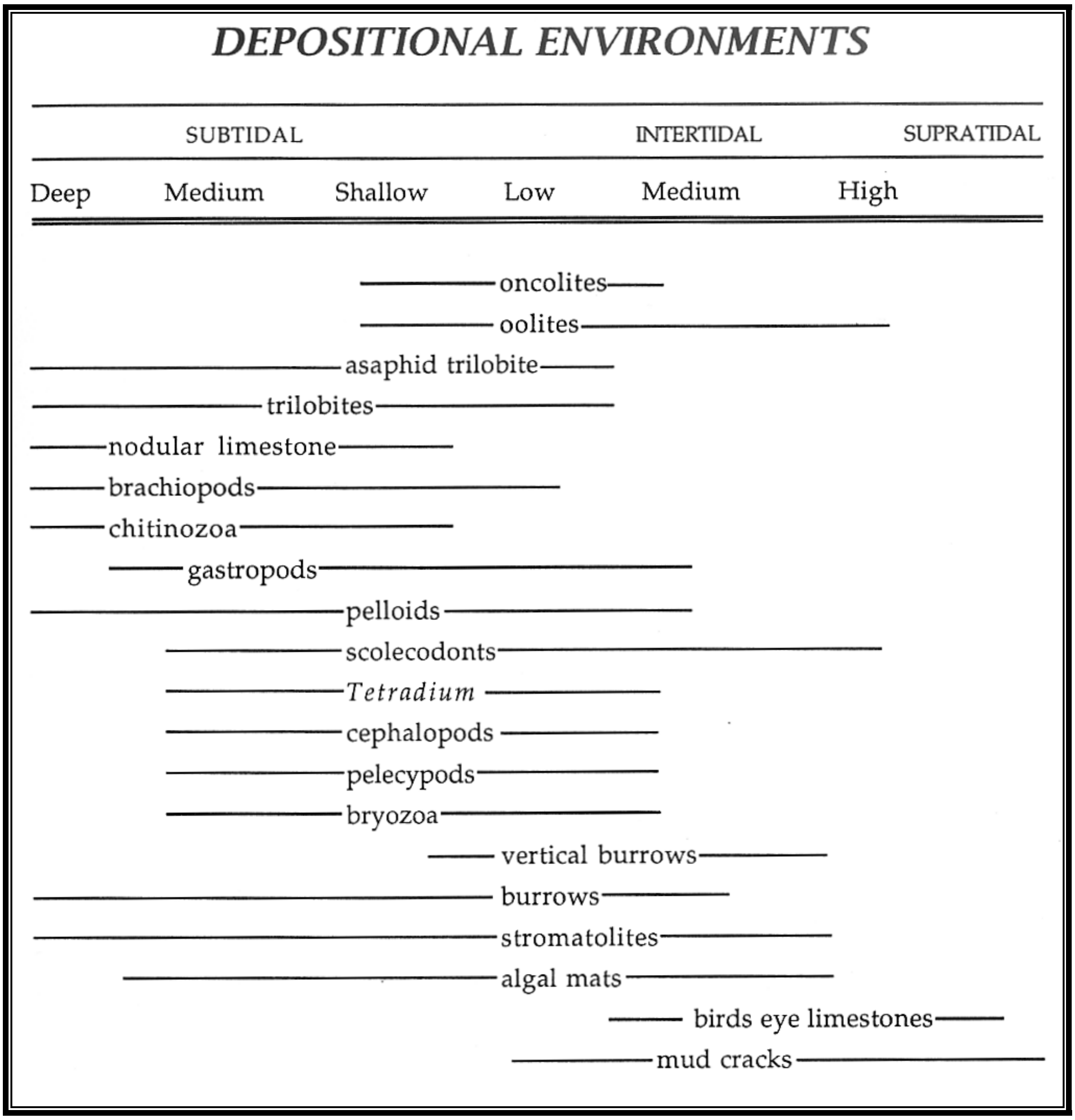


Figure 4: Depositional environments with major allochemical and sedimentary structural components applied to the Gordon Group in Zeehan (*Modified from* Burrett 1978; and Glover 1996).

Subtidal	**Low Intertidal**	**High Intertidal**	**Supratidal**
Stromatolites rare	Stromatolites present - common	Stromatolites common	-
Algal mats rarely	Algal mats rarely	Algal mats common	Algal mats common
-	-	Birdseye limestone (dismicrites)	Dismicrites present
Oncolites present	Oncolites abundant	-	-
-	-	Mud cracks	Mud cracks common
Dolomite rare – present	Dolomite present	Dolomite common	Dolomite very common
Scolecodonts rare and large	Scolecodonts abundant	Scolecodonts abundant	-
-	Horizontal worm burrows common	Vertical worm burrows	-
High diversity	Low diversity fauna	Very low diversity	Very little of any fauna
Gastropods present – high spired	Gastropods abundant – low spired	Gastropods present to abundant	-
Sponge spicules common	Sponge spicules rare	-	-
Holothurian sclerites common	-	-	-
Trilobites common	Trilobites rare	-	-
Articulate brachipods common	Articulate brachiopods rare	-	-
Chitinozoa abundant	Chitinozoa present – rare	-	-
Corals abundant	Corals other than Tetradium	-	-
Cephalopods often abundant	Cphalopods present	-	-
Pelecypods common	Pelecypods often common	Pelecypods rare	-
Bryozoa common	Bryozoa present	-	-
Intraformational breccia present	Intraformational breccia common	Flat pebble conglomerate	Aeolian input

Figure 5: Summary of the major lithic and faunal criteria used to discriminate depositional environments of the Gordon Group in Zeehan, including Oceana (*Modified from* Burrett 1978).

3.3 Lithostratigraphic Unit Descriptions

3.3.1 *Upper Denison Group (Moina Sandstone Formation)*

The Moina Sandstone and Mount Zeehan Conglomerate, (Waller 1904), occupies a similar stratigraphic position beneath the Gordon Group as the Lower, Middle and Upper (Pioneer Beds), Owen Conglomerate of Wade & Solomon, (1958), (Blissett 1962). Moina Sandstone beds conformably overlay Mt Zeehan Conglomerate to the west of Oceana and are fault-bounded and conformable with the overlain Gordon Group to the east (Blissett 1962), the fault being moderately prospective for base metal mineralisation.

Blissett, (1962), defined the Moina Sandstone on the eastern limb of the Mt. Zeehan anticline, (within Oceana Valley), as ~350 metres of pale grey, thin-bedded, quartzose pebbly grit and grit. The sequence was described to include bands of pink stained, coarse quartzite and upper distinctive bands to ~3m thick of quartzose grit and sandstone crowded with ?*Scolithus*. The northern head of Oceana Valley exposes pale grey pebbly-grit and sub-angular to sub-rounded conglomerate juxtaposed to limestones by the dextral-offset Oceana Fault. The western head of Oceana Valley exposes pale grey pebbly-grit passing into sub-greywacke grit with small chert fragments and interbedded sandstone and pebbly-grit. Blissett, (1962), observed the thickness of the Moina Formation as approximately 400m – 500m near Mt Zeehan, and the total Denison Group thickness in the Zeehan area to be ~1500m.

Denison Group detritus forms a wedge over the boundary with the Gordon Group at north Oceana Valley. The Oceana drilling project, (OP1 – South Oceana), intersected the upper boundary with the Gordon Group and implies it is thrust under the Moina Sandstone 20m true thickness (Cordery 1998). The nature of the boundary is poorly understood in the Zeehan area due to encryption by tectonism and hydrothermal processes. Blissett, (1962), observed outcrop at several locations along the Smelters Road and south of Oceana Mine exposing 1m of siliceous pebbly grit overlain by rotten arenaceous limestone and calcareous sandstone. Burrett, (1995), compensated for this description by stating the delineation of the boundary is arbitrary, because it is a 1m - 30m thick transitional, interdigitating siltstone to mudstone feature representing the 200m thick Florentine Valley Formation in southeast Tasmania. Burrett, (1995), also suggested since the Denison Group and Gordon Group separation is based on lithological dominance the siltstone to mudstone transition is historically and empirically regarded as the topmost part of the Moina Formation.

The Denison Gp – Gordon Gp boundary at Oceana was subject to prolonged multi-generation hydrothermal fluids. X-ray diffraction analysis of the boundary at Grieves Siding, by Glover, (1996), revealed high abundances of dickite ($Al_2Si_2O_5(OH)_4$) in conjunction with illite, sphalerite, haematite, goethite and crandallite, supporting the proposition that the boundary acted as a conduit for hydrothermal fluids. Similar kaolinised compositions at Oceana are coincident with local, vertical-oriented faults and not associated with regional structures.

Moina Sandstone beds are dominantly pink, weathering to pale grey and white, thin bedded and massive, well sorted, arenaceous sandstone with subordinate pale grey to white siliceous angular pebbly grit and sub-angular to sub-rounded conglomerate with clasts to 4cm of dominant quartzite composition (Blissett 1962). Minor imbrication is recognised in conglomeratic units, while prevailing sedimentary structures, such as cross bedding and ripple marks, occur in sandstones. Vertical worm burrows, perpendicular to bedding, were probably developed by *Arenicolites* sp., which define the depositional environment as littoral to sub-littoral (Banks 1989).

3.3.2 *Gordon Group Limestone*

3.3.2.1 Ugbrook Formation (*from* Burrett & Goede 1987, Burrett *et al.* 1989)

There is question to the extent, or presence at all, of the Ugbrook Formation at Oceana due to the faulted and decomposed lower boundary with the Moina Formation, the high incidence of local faults and the destructive nature of mineralisation. The sinusoidal character of grainsize, spanning all carbonate facies, describes calcarenites as a coarse medial member, characterising energetic, shallow subtidal conditions. The abundance of this lithofacies near the lower boundary at

Oceana, in conjunction with dominant subtidal lithofacies, implicates classification as the Ugbrook Formation.

The Ugbrook Formation was classified by Burrett *et al.*, (1989), in the Mole Creek section as alternating centimetre-to decimetre-scale beds and laminae forming sequences to a few metres thick with a possibility of extent up to 40m thick. Glover, (1996), described the Ugbrook Formation at Greives Siding up to 230m thick, which is thick compared to observations at Oceana. A few metres of massive siderite and goethite are succeeded by 50m – 80m of biocalcarenites and bio-micrites. Beds are frequently bioturbated, nodular and soft sediment deformed with occasional shoaling of calcarenites, oncobiomicrites and biosparites.

Present lithofacies observed at Oceana include from lithofacies 4 to lithofacies 8 with rare beds of lithofacies 3. Lithofacies 7 (Argillaceous dolomicrite) occasionally develops to mudstone and shale associated with slickensides and bituminous, carbonaceous material. Allochemical components are dominated by pelloids and/or crinoidal debris with very diverse minor fossils, i.e. calcareous algae, microbial mats, oncolites, brachiopods, gastropods, fenestrate and branched bryozoans, trilobites, asaphid trilobites (Burrett 1995), Tetradium, bivalves and oolites.

Minor shallow subtidal beds at the base of the Gordon Group continue to basal calcarenite and bio-micrite beds. The first appearance of calcarenites, proximal to Oceana Fault, are destroyed by intraformational brecciation and post-diagenetic tectonic brecciation. The first appearance in core to the south, where total thicknesses thin and hence, calcarenites increase in intensity, defines fine basal beds of highly fossiliferous shoal biocalcarenite or calcisiltite interbedded with rhythmic-bedded, medium- to dark-grey dolomicrite and argillaceous dolomicrite. Beds exhibit a basal shoaling habit, also coincident with the upper gradational boundary, and advance to massive in the bulk of the sequences. Calcarenite beds are commonly associated with intraformational breccias and fault breccias, suggesting lower competence and higher permeability than finer units. The high proportion of sparry calcite in these beds may be an influential factor in the poor development of dolomitisation and stylolitisation.

Extensive faulting at Oceana has rendered litho-stratigraphic correlations difficult to non-existent across drill core. Available examples of this formation can be seen in cores at azimuth 060 and occur to thicknesses of 100m. Average thicknesses of this formation at Oceana are 50m to 80m, which maintains thickness to the south through dramatically thinning limestone extent. Dolomicrite and argillaceous dolomicrite lithofacies, (6 & 7), dominate up stratigraphy.

Alternating thin micrite and shale with local siltstones and sandstones are bedded at a centimetre to decimetre scale. Micrite beds and laminae range from unfossiliferous to packed with biosparite and biocalcarenite developments. Peloids, comminuted shells and crinoidal debris with present asaphid trilobites and rare fossils of various phylae dominate bioclasts. Beds are often nodular and bioturbated resulting in a soft-sediment deformed texture at a mesoscopic scale.

3.3.2.2 Myrtle Formation (Burrett 1995)

The Myrtle Formation was formally named by Burrett, (1995), in Zeehan defining 40m to 170m of micrites, biomicrites, dolomitised micrites and minor calcarenites and shales. Sediments were deposited in upwardly shallowing tidal flat cycles, known as Punctuated Aggradational Cycles (PACs), representing lithofacies 1, 2 and 3 with minor incursions of lithofacies 4, 5, 6 and 7.

PACs were first used as a correlation tool by Calver, (1977), in the Florentine Valley Formation, defining 18 lithofacies in the lower member of the Benjamin Limestone, however he did not publish and PACs are now used worldwide as a correlation and palaeoenvironmental tool (Burrett 1995). Burrett, (1995), suggested the PACs at the Florentine Valley and Zeehan were essentially isochronous due to basin wide or sub-basin wide response to changing sea level. The Myrtle Formation contains 15 PACs although faulting obscured these cycles at Greives Siding. At Oceana these cycles range from 30m to 30cms and progress from shallow subtidal argillaceous dolomicrite and mudstone to bioturbated dolomicrites to pale-grey dolomicrites to intertidal pale-grey stromatolitic, laminated dolomicrites. PACs are dominantly topped by pale-grey dolomicrite with 5% to 10% birdseye and fenestrae vugs and rarely aggrade to red bed lithofacies.

The occurrence of lithofacies 7, (argillaceous dolomicrite), at Oceana may be representative of two depositional environments, being protected shallow subtidal or low to high intertidal tidal channel muds. For this reason, emphasis must be placed on the next indicative lithofacies. PAC bases at Oceana are commonly faulted, providing spaced areas of structural weakness, which has obscured actual cycle bases, requiring similar emphasis on the next available lithofacies. The erosive nature of tidal flat channels, discerned by rip-up clasts, ripple marks and load casts cut into underlain PACs providing further hinderence to classification.

Calver suggests PACs were probably developed by the repeated buildup to sea level and progradation to aggradation of the tidal flat complex. Pratt *et al*., (1992), defined the cyclicity of aggradational cycles as representative of a probable combination of rhythmic eustatic change and/or rapid periodic subsidence. Fifteen cycles were recognised by Burrett, (1995), in the Zeehan area and by Glover, (1996), in the Greives Siding area. At Oceana up to seven PACs are definable in the stratigraphy, and decrease to the south with the thinning Gordon Group. The remainder of the cycles, observed at Myrtle Formation outcrop, were destroyed by faulting, stylolitisation and folding.

3.3.2.3 Black Jacks Formation (Burrett 1995)

The lower Black Jacks Formation conformably overlays the Myrtle Formation and consists of alternating dolomicrites and micrites, argillaceous dolomicrites and mudstone, with minor bio-calcarenites, calcisilts, biomicrites and rare biosparites. The Black Jacks Formation is defined into Lower and Upper sequences divided by the Lords Siltstone Member.

3.3.2.3.1 *Lower Black Jacks Formation*

The lower Black Jacks Formation consists of two PACs classified by Burrett, (1995), BJ1 and BJ2. Lithofacies consist of pale-grey biomicrites, argillaceous dolomicrite and shales with minor calcarenite shoals and calcisilt, biosparites, mudstones and lumpy micrite, which is similar in character to nodular limestones. Red beds, (lithofacies 1), seem to be poorly developed at Oceana although this may be mis-diagnosis due to faulted PAC boundaries, intensive, multi-generational dolomitisation and kaolinisation of fault planes and adjacent sediments. Bedding commonly has the appearance of soft sediment deformation, which is due to the frequent physical processes associated with migrational tidal channels associated with macroscopic, tidal activity (<30cms to 2m extent).

3.3.2.3.2 ***Lords Siltstone*** (Corbett & Banks 1974)

The uppermost PAC of the lower Black Jacks Formation, (BJ2), is conformably overlain by a thin, laterally extensive siltstone, shale and rarely sandstone bed, or beds, classified as the Lords Siltstone Member, (sandstone at Firewood Siding - Burrett 1995). The variability in stratigraphic thicknesses are in contrast to the state-wide occurrence from Zeehan (west) to Mole Creek (northwest) to the Florentine Valley (southeast) to Precipitous Bluff (southwest). Weldon, (1974), described calcareous nodules and beds of dark-grey to black micrite associated with bituminous films occurring within the member. Burrett, (1995), observed a distinctive faunal characteristic of the member consisting of abundant *Pliomerina* trilobites, strophomenid brachiopods (*Sowerbyites*) and the Tasmanian endemic ostracod *Dominina.*. The Lords Member can be defined by preceding gradual deepening of both lithofacies and biofacies suggesting a gradational appearance.

Fault displacement at Oceana provides the appearance of a laterally discontinuous nature to the Lords Member. A single example was intersected in DDHOP2 at 98m overlaying dark-grey, fine-bedded bio-dolomicrite with minor stromatoporoids and corals. Two beds of well-sorted, orange, clay-rich siltstone, (50cm & 30cm), are divided by a similar dolomicrite bed as those underlain. The upper unit is overlain by interbedded fossiliferous, argillaceous bio-dolomicrite and packed brachio-bio-dolomicrite. Bed bases are characterised by granule size clasts of micritic sub-angular debris (Ellis 1984). The Lords Siltstone Member is deemed absent or destroyed in other logged drill cores from Oceana due to poor stratigraphic correlation between the drillholes.

Banks and Burrett, (1989), consider the depositional environment of the Lords Member as deposited below wave-base, based on the fossil content, which would require significant transport past the tidal flat and inner shelf regions. The upper boundary at Oceana is sharp and conformable, similar to observations by Ellis, (1984). A variety of fossils have been recorded within this member at other select locations, and include gastropods, bivalves, echinoderms, bryozoa, orthids, rhynchonellids and asaphid trilobites throughout (Ellis 1984, Burrett *et al.* 1989, Glover 1996).

3.3.2.3.3 *Upper Black Jacks Formation*

The upper Black Jacks Formation consists of alternating pale-grey dolomicrite, biosparite and argillaceous dolomicrite with dominant punctuations of massive calcarenite and minor lenticular calcarenite associated with bases of tidal channels. Allochems are generally larger than underlain members associating 3cm oncolites, pellets and a combination of pisoliths and oolites. Minor occurrences of biolithite occur in a smaller proportion to beds containing coralline and stromatoporoidal debris. The sequence can be broadly defined into a lower, subtidal biomicrite member and an upper peritidal member. The lower member has been defined by Pitt, (1962), to include a diverse trilobite-brachiopod-bryozoan fauna known as the Smelters Fauna. The upper peritidal member has been correlated to many other locations but is not ubiquitous to the upper Black Jacks Formation, (Burrett 1995).

The upper boundary of this member is generally faulted to the Crotty Quartzite and is characterised by silicification, intense dolomitisation, karsting and tectono-brecciation. Complete dolomitisation in the Gordon Group would be associated with up to 12% mass volume loss while replacing calcite, increasing permeability and vuggy porosity during the process. Pervasive dolomitisation is considered unusual by Burrett, (1995), due to the intermittent nature of processes. The upper boundary is defined by Blissett, (1962), as disconformable to the Crotty Quartzite.

3.3.3 *Lower Eldon Group (Crotty Quartzite)*

Siliciclastics of the Crotty Quartzite form the basal Eldon Group member, bounded to the upper Black Jacks Formation. The eastern limit of the Oceana Valley, (Professor Ridge), poorly exposes Crotty Quartzite beds although exposure is freshly available due to re-cutting of access tracks by Pasminco Exploration during 1995-1998 for drilling rigs. The lower boundary is not exposed in the Oceana area although drilling revealed a faulted, hydrothermally replaced boundary zone. Earlier observations of Pitt, (1962), described rolled fragments of *Tetradium* from the Gordon Limestone in the lower part of the Crotty Quartzite, indicating there may be a disconformity at the base. Banks, (1989), proposed the Zeehan section as the type area for the Crotty Quartzite even though greatest thicknesses are achieved in the Strahan-Queenstown-Little Eldon areas, 490m and 2300m respectively. Eldon Group sediments commonly occupy the axial regions of synclinoria in central-Western Tasmanian terrane (Baillie 1989).

Descriptions compiled by Baillie, (1989), from Gill and Banks, (1950), and Blissett, (1962), are considered supplemental to observations by Pitt, (1962), who defined four members within the Crotty Quartzite in the Zeehan area:

Member A consists of fine pebble grit and conglomerates, quartzose sandstones, calcareous sandstones and cross-bedded coarse-grained siltstones.

Member B is conformably overlain and consists of quartzose pebble grit and conglomerates, pebbly arenites, cross-bedded sandstones and thin bedded siltstones. Sub-parallel worm casts and minor sedimentary slumping occur with *Tetradium* debris, brachiopods (*Camarotoechia synchoneua.* – Gill 1950), pelecypods and trilobite pygidia.

Member C is conformably overlain and consists of coarse-grained, clay-rich, homogenous siltstones

Member D is conformably overlain and consists of pink, cross-bedded arenaceous sandstones with interbedded cobble conglomerates, siltstones and mudstones. Indicated fossils include tubicolar casts, pelecypods, cephalopods, planispirally-coiled gastropods and arthropod tracks (?).

Blissett, (1962), defined large crinoid ossicles and branched polyzoa (bryozoa) in a number of places around Zeehan. Baillie, (1989), adds *Rostricellula* and worm castings to existing descriptions. Outcrop is usually deeply weathered and intensely cleaved, sheared and folded showing up to 40º variability in axial plane plunge at a mesoscopic scale. Gill, (1950), placed emphasis on the occurrence of the brachiopod species *Camarotoechia synchoneua.* which suggests an Upper Silurian age of deposition. The Crotty Quartzite is gradationally overlain by the Amber Slate which is characterised as a transition to dominant mudstones, subordinate siltstones and fine-grained sandstones.

3.4 Lithofacies Descriptions

The Gordon Group consists of a sequence of carbonates with minor siliciclastics ranging in age from Early to Late Ordovician, (Banks 1989). The group is distributed widely in Tasmania west of 147°E and is considered the thickest, (~2km), and most stratigraphically continuous Ordovician sequence, (Arenig to Ashgill), in the southern hemisphere (Banks & Burrett 1979; Banks & Baillie 1989; Rao 1990, Laurie 1991).

Burrett *et al.*, (1987), and Burrett, (1995) sub-divided sub-groups into litho-stratigraphic units to interpret and correlate the depositional environment throughout Tasmania. These units were recognised at the Florentine Valley by Calver, (1977), at Mole Creek by Burrett *et al.*, (1987), in the Zeehan area by Burrett, (1995), at Greives Siding by Glover, (1996), and are similarly recognised at Oceana. The broader litho-stratigraphic units are divisible into several litho-facies associations described in detail herein (**Plate set 1**).

Carbonate petrographic terminology is based on the scheme proposed by Folk, (1962). The extensive presence of syn- and epi-genetic dolomite has partially and wholly recrystallised micrite compositions to dolo-micrite. Dolomitisation has selectively replaced ortho-chemical components, which cannot be defined in hand specimen. The fine scale of bedding also limits the amount of sampling that can be feasibly done. Dolomitisation is absent to poorly developed in sparite beds, (allochems >50%), and generally does not replace sparitic material or argillaceous sediment. Therefore, classification as dolo-micrite seems reasonable.

Punctuated Aggradational Cycles are shallowing-upwards cycles representing the periodic characteristic of sea-level rise. Each minor transgression of sea level will be succeeded by a subtidal to peritidal sequence consisting of <1m to >30m, depending on the carbonate production factory, subsidence and dynamic eustacy. The Myrtle Formation is widely regarded to contain up to 15 PACs and are dominated by bio-dolomicrites and pel-dolomicrites characterising a lagoonal environment. PACs are well-developed in examples outside of Oceana and suggest transgression occurred over a prolonged period, allowing each cycle to fully-develop.

3.4.1 *Lithofacies 1: Red Beds*

In hand specimen this lithofacies ranges in colour from medium grey to red/brown. The rock is dominantly orthochemical in composition with the exception of 1-5cm sparse, broken, sparry fossil beds at intervals. Subordinate mud interlaminates consisting of black, carbonaceous and red, nodular-haematitic material rarely exceed 1mm in thickness. Beds range from 50cms to less than 1cm from conformable boundaries. Mud cracks, rippled laminates, rip-up mud clasts, fine cross-bedding and sporadic reverse grading to calcisilt are characteristic features associated with this lithofacies.

Extensive dolomitisation is usually associated with this lithofacies as syngenetic, diagenetic and post-diagenetic partial and complete replacement types. Hand specimen dolomite also has a brown-red colour, which acts to support the red hue. Thin section reveals small to large rhombohedrons, (<1mm to 3mm), with compositionally zoned margins. Red beds are associated with PAC tops and indicate progradation above sea level. At Oceana, red beds are rarely recognised, which may be due to poor development associated with rapid sea-level rise, tectonic associated offset during deposition, or destruction of the facies by post-diagenetic tectonism. The third suggestion seems the most plausible due to the faulted nature of PAC tops/bases, probably due to associated weakness along cycle boundaries.

Interpretation

The close association with birdseye or fenestrae vuggy lithofacies is indicative of dominant sub-aerial conditions with little induration of water. Marginal low supratidal conditions are typically subject to storm surges evident by the presence of dessicated mud, reverse graded calcisiltstone beds and thin, sparry beds. Rare scour surfaces are usually destroyed by faults concentrated on PAC tops/bases although general absence indicates little inter-cycle re-working and relatively rapid transgression of sea level, in contrast to implications of well-developed cycles.

Diagenetic dolomite has destroyed most original textures. Oxidised compositionally zoned dolomite rhombs are representative of mixed saline and meteroric waters during late stage diagenesis (Tucker 1981). Characteristic environmental processes beyond red bed lithofacies consist of transient aeolian deposition, or erosion, and the lack of these influences suggests rapid sea-level increase, and/or subsidence. Red bed lithofacies represents the highest lithofacies of a PAC for this reason.

3.4.2 Lithofacies 2: Pale micrite and dismicrite

Lithofacies two is typically massive and extensive pale-grey dolomicrite and pale-grey dismicrite interbedded with dark-brown argillaceous dolomicrite. Pale-grey dolomicrite is generally bioturbated with rare beds of sparry intra- and bio-clasts, i.e. gastropods, domed and laminated stromatolites, rare oncolites, and pellets. A sub-type lithofacies 2A, in similar stratigraphic positions, contains broken brachiopod shells and coral debris. Lithofacies sub-type 2B contains isolated detrital quartz grains and rare gastropods. Meso-scopic ooidal wash-beds, mud-diapirs and water-escape structures, intraclasts and haematitic ooliths are present in this lithofacies. Stylolitisation is well developed and bed thicknesses rarely exceed five metres, (~10m max.). At a microscopic scale, pale-grey micrites are orthochemical-rich, homogenous micrites with rhythmic argillaceous interlaminates and variable syngenetic to epigenetic zoned-dolomite. Euhedral and subhedral dolomite selectively replace all orthochemical components and avoid argillaceous and sparry components.

A common constituent to each type of this lithofacies is the presence of irregular birdseye and fenestrae vugs. Vugs are dominantly sparry calcite filled and comprise ~2% to ~5% of total volumes. Tucker, (1981), considers vugs as representative of sub-aerial exposure formed as sediment dessicates and gases escape through pore space. The lensoidal or irregular cavities are filled with sparry cement during diagenetic processes. Rare zones of stromatactis cavities are associated with mud-rich interbeds.

Interpretation

Massive and laminar pale grey micrites with rare gastropods, stromatolites and birdseye vugs represent prevalent high-intertidal to low-intertidal sedimentation. Broken shells and coral debris indicates intermittent periods of energetic conditions associated with storm cycles amongst prevalent quiet peri-tidal conditions. Argillaceous dolomicrite within this lithofacies is considered typical of tidal flat muds deposited in a medium to high intertidal zone. The presence of laminated, rippled and cross-bedded argillaceous dolomicrite and mudstone beds supports this interpretation.

Mud cracks and water-escape structures such as mud-diapirs are also indicative of an intertidal interpretation. The absence of aeolian siliciclastic deposition remains in contrast to the occurrence of isolated sand grains that may represent minor opportunistic aeolian influence. Dismicrite beds are indicative of high intertidal to supratidal conditions with dissolution and little inundation of waters. Dismicrite is generally a marker horizon for the top of PAC's due to obvious dissolution of allochemical constituents. Dismicrites are poorly represented at Oceana as are lithofacies 1.

3.4.3 Lithofacies 3: Bio-sparite and Pel-bio-sparite

This lithofacies consists of poorly washed, bioclastic-dominant, sparry-clast and -matrix bio-sparite. Beds are typically less than 5m in thickness, poorly sorted, un-graded and show aligned and random orientations of fossils to bedding. Bioclastic components dominate the lithofacies with less than 20% intraclasts. Intraclasts consist of argillaceous rip-up dolomicrite. Lithofacies variants include poorly-washed oo-bio-sparites, onco-bio-sparites and pel-oo-bio-sparites. Macro-invertebrate fossils include corals (Tetradium), stromatoporoids, articulate brachiopods, gastropods, bryozoans and rare crinoids, trilobites and nautiloids.

Argillaceous dolomicrite interbeds remain strongly dolomitised and have sharp boundaries with sparites, which are generally un-dolomitised and non-ferroan. Beds range in thickness from 5cm to fine laminates and are rarely absent. Stylolites are poorly developed, flat and show little displacement. Corals and stromatoporoids are *in situ* and fragmentary ranging from well preserved to partially or wholly replaced by sparry calcite, chalcedonic quartz and dolomite. Ooidal shoal-beds occur randomly within this lithofacies associated with an increase in grain size to calcarenite. This sub-type is termed biosparenite in accordance with Folk, (1962).

Interpretation

This lithofacies is characteristic of an open, low inter-tidal to shallow sub-tidal depositional environment associated with a micro-tidal coastline. Randomly oriented bioclasts, intraclasts, poor-sorting and exotic ooidal shoals are all suggestive of an open, energetic shallow sub-aqueous environment. Alternatively, bedding-parallel bioclasts and rhythmic argillaceous dolomicrite deposition are indicative of sedimentation in a closed, quiet, shallow sub-aqueous environment with storm disruption. Rare peloids and oncolites are indicative of a medium to low intertidal depositional environment. Non-ferroan sparry calcite matrices are consistent with a syn-sedimentary submarine or intertidal origin, opposed to ferroan spar suggesting the meteoric, phreatic zone (Tucker 1981). Therefore, deposition of this lithofacies at Oceana is interpreted as a dominant open-water medium intertidal to shallow subtidal environment with rhythmic transitions to a storm-disrupted, closed-water medium-intertidal to shallow-subtidal depositional environment. Chalcedonic quartz, (length fast), may have occurred penecontemporaneously or during early diagenesis, due to selective replacement of fossils, and of layers within fossils, i.e. isolated layers within globular corals.

3.4.4 Lithofacies 4: Calc-arenite and bio-calc-arenite

Examples of this lithofacies are typically pale-grey to medium-blue, fine-grained, coarse-bedded calcarenite. Beds range from 5cm to 20m, are unfossiliferous to packed, range from fine sandstone to fine siltstone. Beds are generally ooidal and/or intensely bioturbated. Ooids rarely advance to pisolith size and consist of concentric sparry calcite with micrite, quartz or rarely pyritic/limonitic cores.

Bio-calcarenite beds generally show basal normal grading and contain bryozoans, crinoids, pellets and rare gastropods. Bryozoa and fenestellid colonies are abundant at particular intervals and completely absent within 5cms of those intervals. Lack of sedimentary structures is attributed to bioturbation. Argillaceous dolomicrite is absent to coarse laminated.

Interpretation

This lithofacies represents an open, shallow-subtidal depositional environment. Massive, bioturbated calcarenite and massive, ooidal bio-calcarenite are indicative of protected regions within an open, shallow-marine environment that undergo little re-working of sediment. Thinner beds and lenses of ooidal shoals are considered as indicative of an open, shallow-marine environment representating a breached-bar, where strong tidal currents have been allowed to pass beyond the protective, migrational carbonate barrier.

3.4.5 Lithofacies 5: Onco-bio-micrite

This lithofacies is characterised by medium grey to dark grey, coarse to fine fossiliferous onco-bio-dolomicrite. The matrix is dominantly dark-grey dolomicrite with rare excursions to calcisilt. Examples of this lithofacies are generally heavily stylolitised suggesting a dominant orthochemical composition. Oncolites comprise ~5% to ~20% of the allochemical component. Bioclasts compose <5% of petrography and include gastropods, trilobites, brachiopods stromatolites and rare coral debris. Oncolites range from 1mm to 2cms in diameter and occur as elliptical, concentric, layered arrangements around micritic, bioclastic and siliciclastic nucleii. Intraclasts are dominated by micritic compositions and compose ~5% to ~10% of the total volume. Dominant micritic intraclasts and subordinate argillaceous dolomicrite and calcarenite intraclasts parallel oncolite nucleii compositions.

Argillaceous dolomicrite beds are commonly associated with this lithofacies. Rare examples show incorporated oncolitic material. It is possible that oncolites are exotic to both lithologies although probable that oncolites were transported from micritic beds during deposition of argillaceous dolomicrite.

Interpretation

The presence of gastropods, trilobites, brachiopods and coral debris are indicative of transport from a proximal low-intertidal to shallow-subtidal environment. Rice, (1985), proposed the large size of oncolites in western Tasmania to reflect formation at a depth close to the wave-base, i.e. medium-subtidal. Laminated and bedded argillaceous dolomicrite represents tidal-flat to closed medium-subtidal deposition. Therefore oncolites formed in an open, low-intertidal to shallow sub-tidal depositional environment with intermittent periods of closed conditions.

3.4.6 Lithofacies 6: Bio-micrite

This lithofacies is characterised by equal proportions of allochemical and orthochemical components. The lithofacies is a dark-grey, fine-grained, packed bio-dolomicrite with maximum bed thicknesses of ~5m. Fossils are pervasively replaced to sparry calcite and consist of dominant population sub-lithofacies. The prevalent sub-type 6A consists of algal mats and oncolites, brachiopods, bryozoa and lesser gastropods, stromatoporoids and trilobites. The lesser occurring sub-type 6B is dominated by corals and stromatoporoids with minor brachiopods, gastropods, trilobites, bryozoans and fenestellid. Corals species are dominated by tabulate corals of the sub-family *Tetradiinae*, although rare, isolated beds of rugose corals occur.

Beds are frequently composed of ooids, pelloids and rare oncoids although these components are subordinate to bioclastic debris. Bioclasts are poorly-sorted, variably oriented, and are selectively replaced by sparry calcite. Dolomite replaces any remaining orthochemical material amongst sparry and argillaceous components.

Interpretation

Co-existing coral sub-facies and bryo-brachio sub-facies are indicative of an open, shallow-subtidal depositional environment. It is probable that the coralline sub-facies is indicative of more distal sedimentary processes due to the lesser proportion of brachiopods and bryozoans, and the absence of oncolites and stromatolites. Burrett, (1978), indicated the habitat range for Tetradium as medium subtidal to medium intertidal. Tucker, (1982), defined packed bio-micrites as occurring below the wave-base and therefore medium, open subtidal. The presence of comminuted shell debris indicates periodical reworking by storm swells and supports the interpretation of a shallow, protected subtidal depositional environment. Prior investigation by Calver, (1977), Ellis, (1984), and Rice, (1985), support a shallow subtidal depositional environment.

3.4.7 Lithofacies 7: Argillaceous micrite and mudstone

This lithofacies occurs throughout carbonate stratigraphy of the Gordon Group at Oceana irrespective of the depositional environment. Argillaceous dolomicrite ranges from fine- to coarse-laminated, to fine-bedded, and may change character within deposition of a single lithofacies. The most common lithofacies-type occurs as interbeds dividing intra-facies deposition. Beds rarely terminate abruptly and generally decrease or increase periodically with carbonate deposition. Beds are composed of >40% mud and remaining orthochemical constituents range from micrite to dolomite. Black to red subhedral and euhedral dolomite crystals are syn-diagenetic. Bioclasts include isolated and clustered gastropods, brachiopods, oncolites and trilobites that are generally broken and abraded. Bioturbation is a common feature of this lithofacies obvious by inclusion of micrite and calcarenite into boreholes.

A different type of argillaceous dolomicrite generally occurs towards the bottom of PAC's. This sub-lithofacies is black to dark-grey and generally massive. Bioclasts are rare and irregular and intraclasts are ubiquitous with basal and upper boundaries. Micrite intraclasts are absent within this lithofacies. Bedding ranges from fine laminates, (1mm), to coarse beds, (~3m), and are commonly slumped. Pure 'end-member' mudstone and micrite are rare compared to the typical homogenous lithofacies-type.

Interpretation

Sediment grainsize and lesser bioclastic components indicate deposition in a quiet, shallow to medium subtidal environment. The constant repetition of this lithofacies with pale-grey micrites, producing extensive argillaceous dolomicrite – pale-grey dolomicrite sequences, is diagnostic of a high-intertidal lagoonal depositional environment (Burrett 1995).

The common occurrence of the ubiquitous sub-lithofacies can be attributed to tidal channel-mud deposits that may have represented periodic siliciclastic sediment input, which interrupted allochemical and orthochemical deposition.

3.4.8 Lithofacies 8: Nodular Limestone

Nodular Limestone at Oceana is intimately associated with argillaceous dolomicrite and mudstone. Argillaceous dolomicrite and carbonaceous mudstone compose independent beds and the matrix of clast-supported, nodular limestone beds. Nodular intraclasts consist of sub-rounded to rounded, pale-grey micrite and calcisilt that causes undulose bedding surfaces. Nodular intraclasts range in size from 5mm to 3cms and are composed of homogenous orthochemical micrite or <40% allochems. Non-homogenous nodular intraclasts consist of intraclastic micrite and argillaceous dolomicrite, brachiopod, crinoid and trilobite fragments and segments of sparry replacement, (<5mm). Stylo-lamination and tecto-stylolitisation occur in this lithofacies as poorly developed, flat examples. Basal boundaries are characterised by intraformational truncation surfaces although are often stylolitised or faulted.

The argillaceous dolomicrite interbeds and matrix are composed of carbonaceous mudstone/shale and euhedral to subhedral dolomite. Zoned dolomite has selectively replaced the orthochemical composition and produced ferroan aureoles to sparry patches. The argillaceous dolomicrite associated with this lithofacies is typically fossiliferous, in contrast with every other lithofacies, and contains fragments and complete bryozoans, corals, stromatoporoids, brachiopods, crinoids and gastropods. Boreholes are difficult to distinguish however can be identified by the presence of carbonaceous (bituminous) films on inner margins associated with diagenetic-catagenetic processes (Glover 1995). Stylolites are commonly associated with argillaceous dolomicrite and show little displacement proportional to average bed thicknesses.

Interpretation

Many interpretations have been proposed for the development of nodular limestones. Interpretations range from slumping, (Weber 1965; Seyfried 1980), to concretional growth associated with diagenetic differentiation of varied lithologies (Hildebrand 1929; Schindewolf 1925), to sedimentary boudinage and differential compaction (Born 1921; McCrossan 1958; Nichols 1966), (**Figure 6**). The most modern and credible interpretation, proposed by Cook and Mullins (1983), is based upon intensive observations of the modern and ancient varieties of submarine mass transport on slopes (**Figure 7**). Translational slides are typically associated with deformed bedding particularly at the base and margins where intraformational breccio-conglomerate can develop. Slides can form 10's to 1000's of metres in thickness and extent, and are characterised by a hummocky surface (Cook and Mullins 1983). Thicknesses of stratigraphy at Oceana, (~400m), are relatively insufficient for large volumes of the lithified host to be included, and therefore tectonic processes probably initiated and/or expanded the extent of the intraformational breccio-conglomerates.

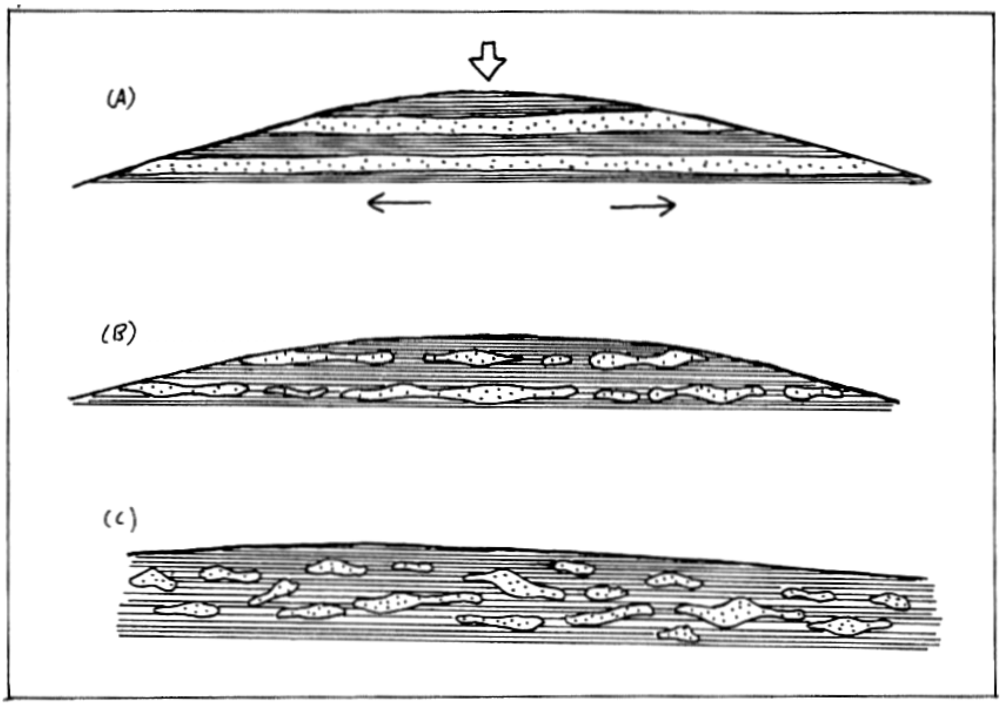


Figure 6: Stages in the development of sedimentary boudinage (*from* McCrossan).

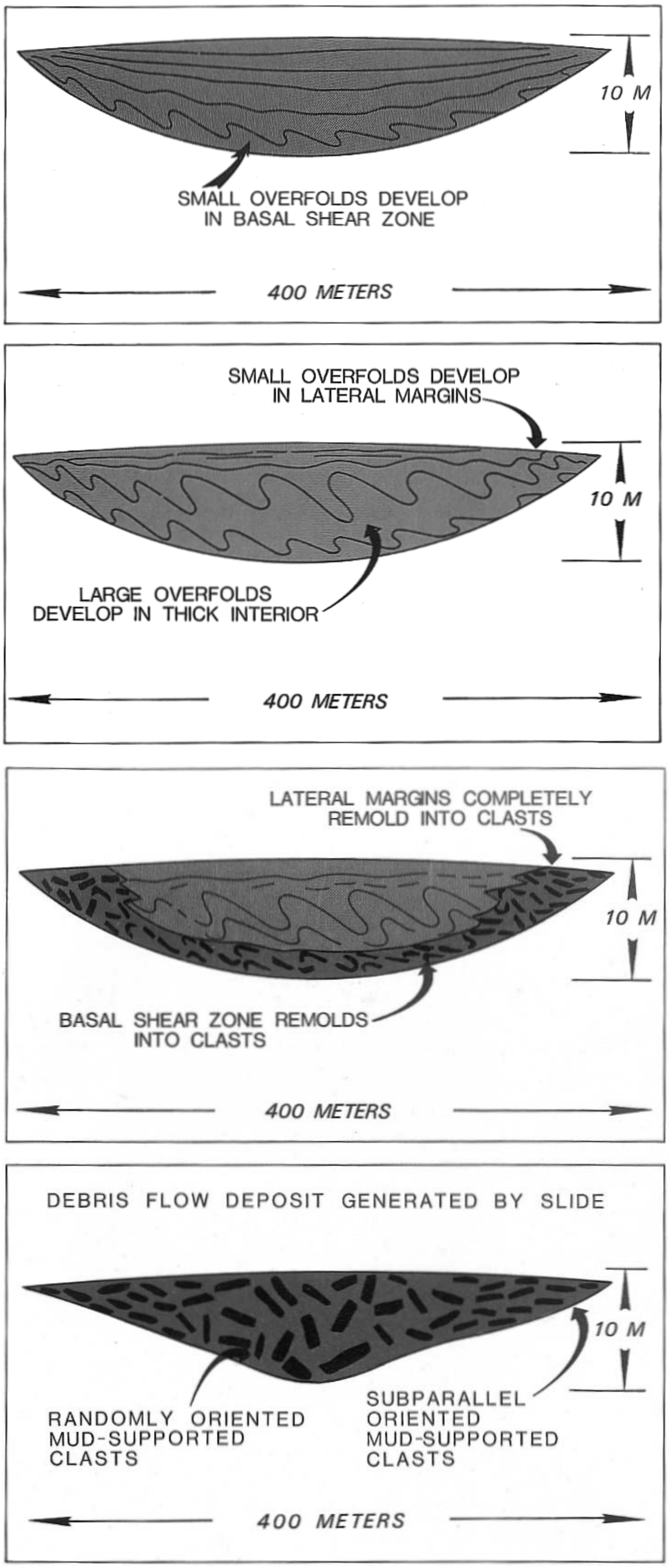


Figure 7: Model of progressive deformation of semi-consolidated slide moving downslope; Stages 1 to 4. By Stage 4 the slide has completely remolded into clasts and mud, and moves as a debris flow (*drawn by* H. E. Cook; *from* Cook & Mullins 1983).

3.4.9 Lithofacies 9: Dolomite

Numerous generations of dolomite are evident in both meso- and micro-scopic scales in abundance at Oceana. In hand specimen, selective dolomitisation affects orthochemical compositions of argillaceous and micritic beds throughout lithofacies sub-divisions. Selective dolomitisation is exaggerated in supratidal and intertidal lithofacies and subordinate in subtidal lithofacies. Some faults are associated with massive, euhedral, pervasive dolomitisation which selectively replaces argillaceous components with increasing distance from the faults.

In thin-section dolomite is prevalent as isolated, zoned euhedra and subhedral replacement masses destroying orthochemical constituents. In all cases sparry calcite is buffered or contains ankerite (ferroan calcite) replacement aureoles resulting from various stages of dolomitisation. Buffering has resulted in preservation of all replaced sparry calcite features such as the majority of allochemical constituents.

Interpretation

Syn-genetic dolomitisation is dominantly associated with intertidal facies and decreases into sub-tidal facies. One modern day example is known where syngenetic dolomite precipitation occurs in a subtidal environment, (Behrans & Land 1972 – Baffin Bay in Texas, Gulf of Mexico), although this is a shallow, hypersaline lagoon with restricted reflux. The diversity of fossils at Oceana, and the absence of length-slow quartzine eliminates the possibility of hypersaline conditions. Therefore, dolomite associated with subtidal lithofacies is likely epigenetic.

Many late stage dolomite crystals, replacements and cements, are often iron-rich (ferroan), revealed by staining, that show chemical or inclusion defined zonation (Tucker 1981). Other possible means of epi-genetic dolomitisation can result from direct precipitation through an increase in the Mg/Ca ratio of the porewater, with no salinity increase. The two possible ways this can take place are recorded by Tucker, (1981): 1) Through leaching of Mg from high Mg calcite grains in the limestone, where the local source of Mg from high Mg calcite is reflected by the occurrence of scattered dolomite rhombs. 2) Through leaching of Mg absorbed on to clays in argillaceous horizons, where local dolomitisation of thin micrites bounded by thick argillaceous sequences could reflect Mg from adjacent clays.

The later diagenetic type of dolomite, if there is complete replacement, is typically related to an increase in porosity and ~13% loss in volume from the original limestone. This is an important factor in the consideration of source, transport and trap parameters for a hydrocarbon reservoir potential (Tucker 1981).

3.4.10 Intraformational Breccia / breccio-conglomerate

The stratabound lenses of carbonate-replacement generally coincide with massive beds of clast-supported intraformational breccias. Bed bases and tops are commonly mineralised and faulted which indicates boundaries acted as porous channel ways for fluids from Oceana Fault. Intraformational breccias occur over 50m in thickness and are composed of chaotically distributed clasts of several lithofacies. Clasts are dominated by crino-biocalcarenites, crino-biomicrites, bio-sparites onco-biomicrites with subordinate laminated and bedded pale micrites. Argillaceous components have withstood deformation and remain in soft-sediment deformed interbeds or as a matrix. Units are generally conformably transitional, when not mineralised or faulted, with bounding lithologies indicating a post-deposition association. Clast populations are homogenous carbonate lithofacies and do not include extraformational types.

Intraformational breccias can be result of several sedimentary and tectonic processes. Cook and Mullins, (198), describe the occurrences of nodular limestone and intraformational breccias at the Bahama Bank to be rare in comparison with Palaeozoic carbonate examples, which is likely to be the result of poorly-developed hardgrounds. Ancient examples are associated with shelf interior and marginal environments and occur up to 20m thick as individual sheets at ‘low depositional’ margins with low relief between the margin and slope. The plastic deformed debris flow sheets can be initiated across slope angles of 1º or less and can transport very coarse material in excess of 10 km. Examples are typified by an overlain bed of carbonate sands a few metres in thickness (Cook and Mullins 1983).

‘High depositional’ margins involve escarpments with 100m to 300m displacement characterised by channel intraformational breccias occurring up to 200m deep and 400m wide, i.e. in Devonian examples in the Yukon Territory, Canada. Bed bases are typically disconformable and scoured although it is not known whether the basal shear planes are transitional or rotational (Cook & Mullins 1983).

Shoaling-up limestone sequence carbonate cycles are characterised by basal intraformational conglomerates passing into deep-subtidal bio-pel-micrites (Tucker 1981). Clast types are varied and may include extraformational debris. Thickness are dependent on the size of the cycle, which can range from >30m to <1m, typically occurring up to 1m in thickness (Tucker 1981).

3.5 Stratigraphy and palaeoenvironments (Burrett 1995)

Sediments of the Moina Formation are described by Banks, (1989), who emphasised imbrication, cross-bedding and ripple marks, suggestive of southerly palaeocurrent directions, in conjunction with abundant *Arenicolites* sp. as evidence for a littoral to sub-littoral marine environment. Southerly palaeocurrent directions are consistent with rapid thickening of the formation to the southeast, (100m/km), which represents fault- or down-warping contemporaneous with deposition (Banks 1989). The Moina Formation was deposited as the upper member of the Denison Group overlaying basin slope and fan deposits during the Early to Middle Ordovician (Tremadocian – Llandeilo). The stratigraphic order of sediments led Banks, (1989), to conclude probable late Cambrian to early Ordovician regression and/or progradation to a shallow marine shelf environment (**Figure 8**).

Conformable and disconformable overlain Gordon Group carbonates indicate biogenic activity increased beyond the supply of sediment, which may be due to a decrease in siliciclastic input or enhancement of limestone production associated with rapid sea level transgression (Banks 1989).

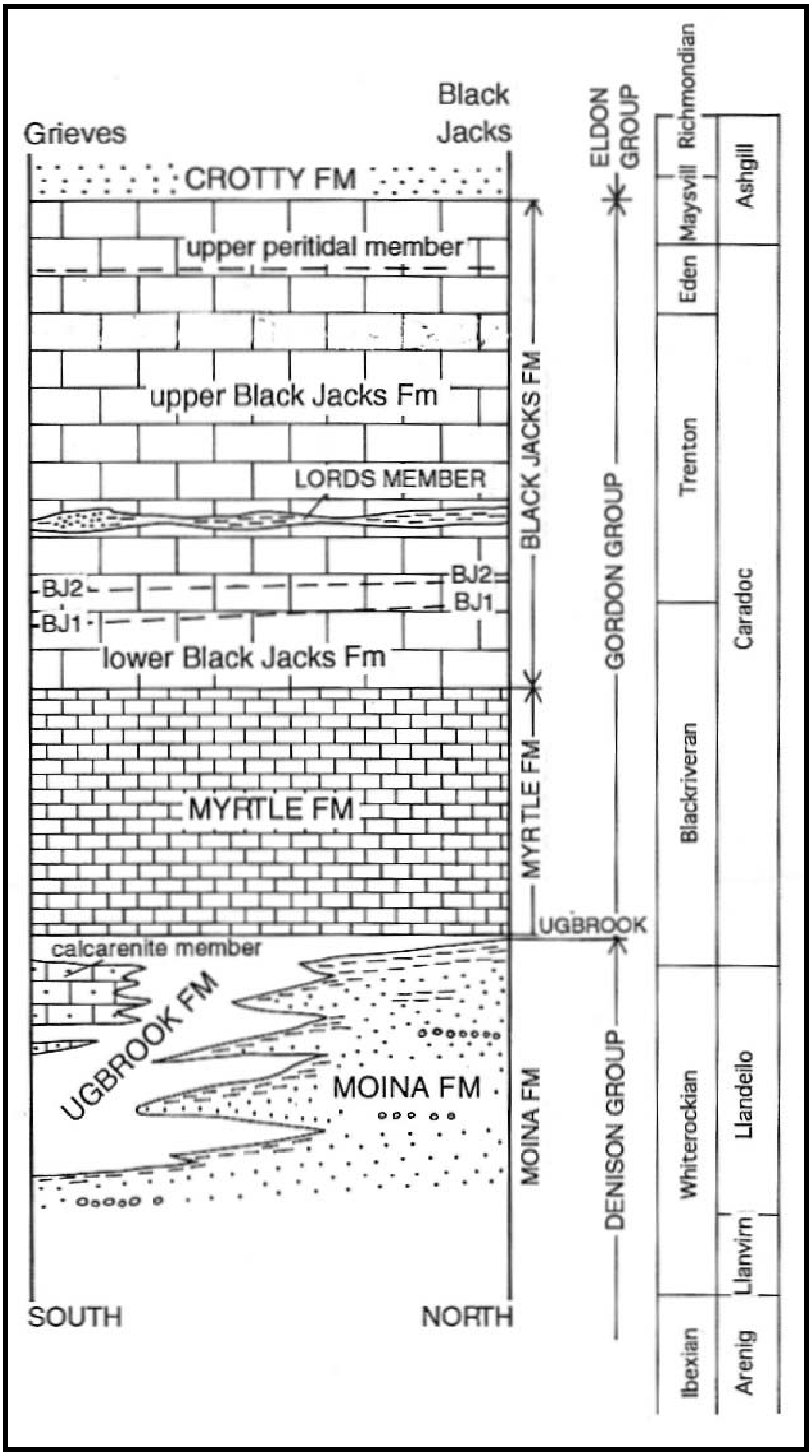


Figure 8: Summary of Ordovician lithostratigraphy in the Zeehan region. Chronostratigraphic units are based on the standard North American scheme and standard British scheme. Correlations are most easily made to the North American scheme but the British scheme is used in the text because of its greater familiarity (*from* Burrett 1995).

Late-Early Cambrian to Middle Cambrian evidence of transgression occurs from the Tremadoc, (Florentine Valley), to the Late Caradoc, (Zeehan), with the possibility of continuation to the Early Ashgill (**Figure 9**). Dating of the transgressive event is based on conodont dates on the lowest Gordon Group carbonates supplemented with Denison Group macrofossils (Burrett 1995), defining a shallow subtidal depositional environment aggrading to peritidal conditions. Burrett, (1995), defined marine transgression from the south, west and east towards the Precambrian – Cambrian islands of the Tyennan and Rocky Cape regions associating mini-platform development throughout the Lower Palaeozoic Dundas Trough (**Figure 10**).

Carbonate accumulations are characterised by very diverse ranges in fossils. Fossil diversity in conjunction with proposed Ordovician seawater temperatures of 23ºC to 25ºC, are indicative of a tropical environment of deposition (Rao 1990).

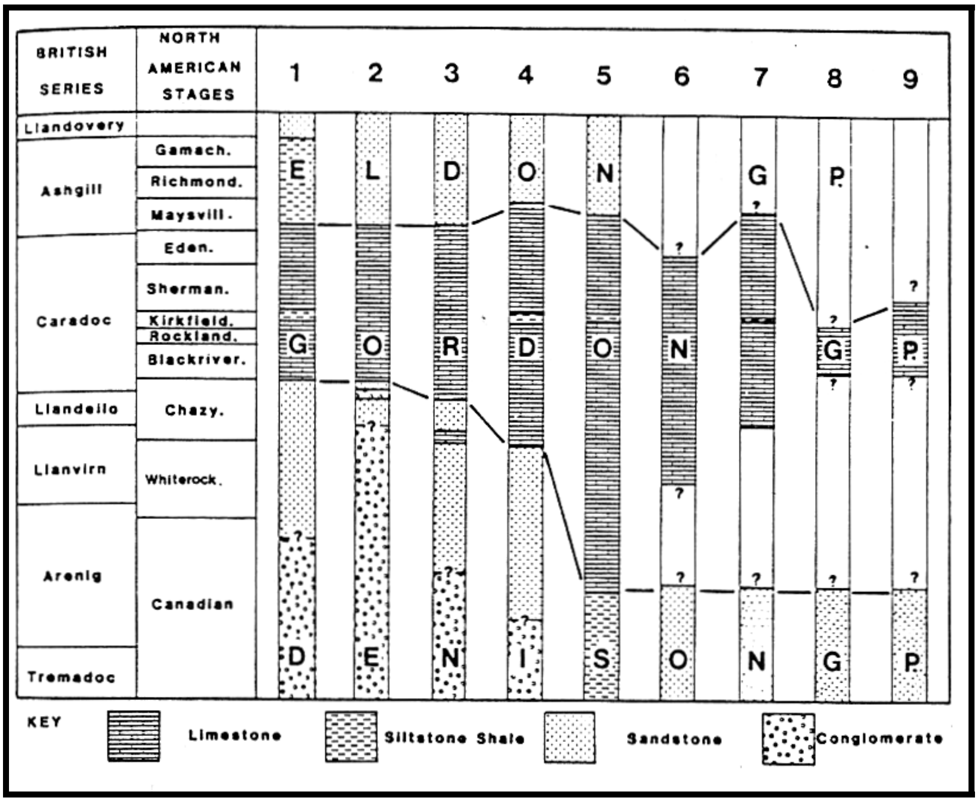


Figure 9: Simplified stratigraphic columns showing the diachronous base of the Gordon Grp and of the Moina Fm. 1=Queenstown, 2=Vale of Belvoir, 3=Lower Gordon River, 4=Mole Creek, 5=Florentine Valley, 6=Ida Bay, 7=Precipitous Bluff, 8=Point Cecil, 9=Surprise Bay (*from* Burrett *et al.* 1984).

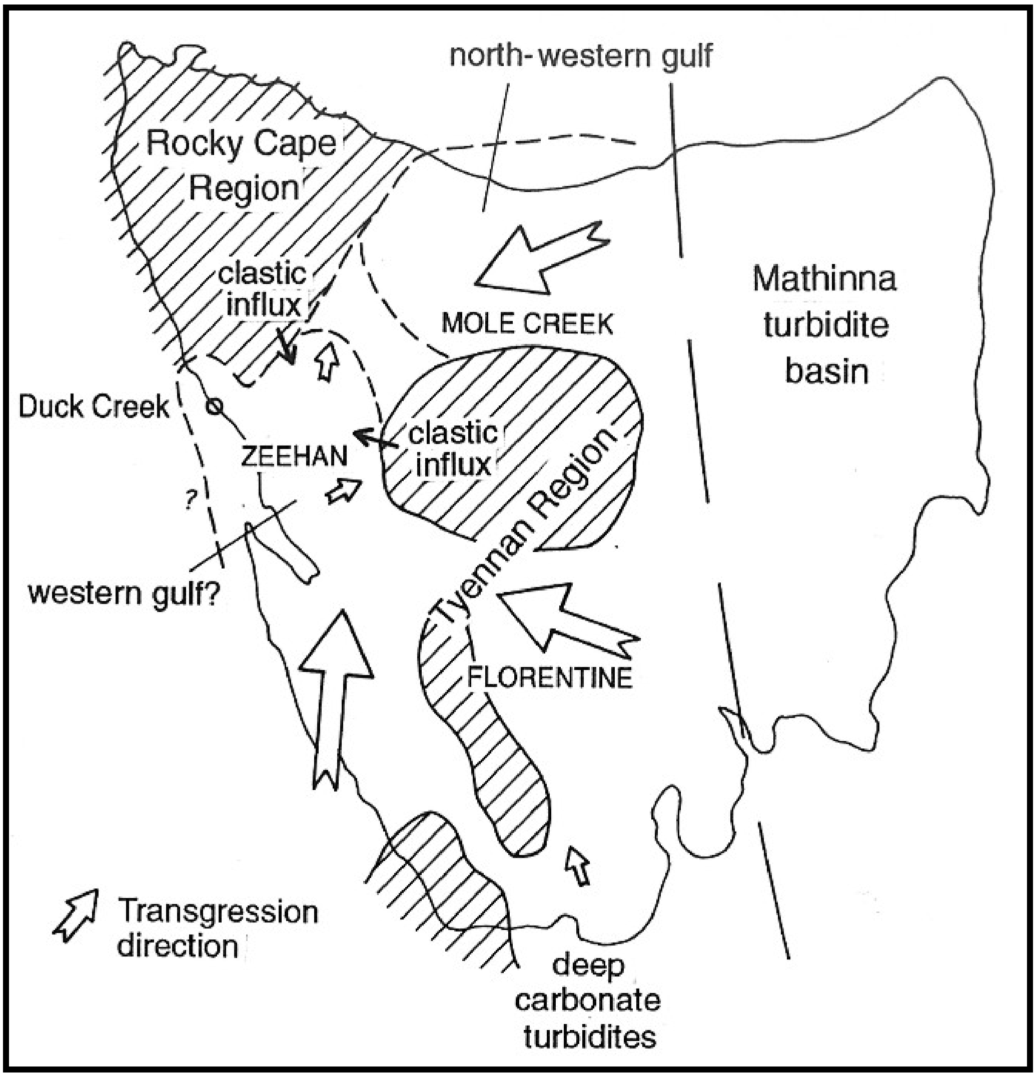


Figure 10: Generalised palaeogeography of the Tasmanian mini-platform in the Caradoc showing inferred directions of transgression. Dotted link between the Tyennan and Rocky Cape regions may be an isthmus transgressed during Late Caradoc times, (*from* Burrett 1995).

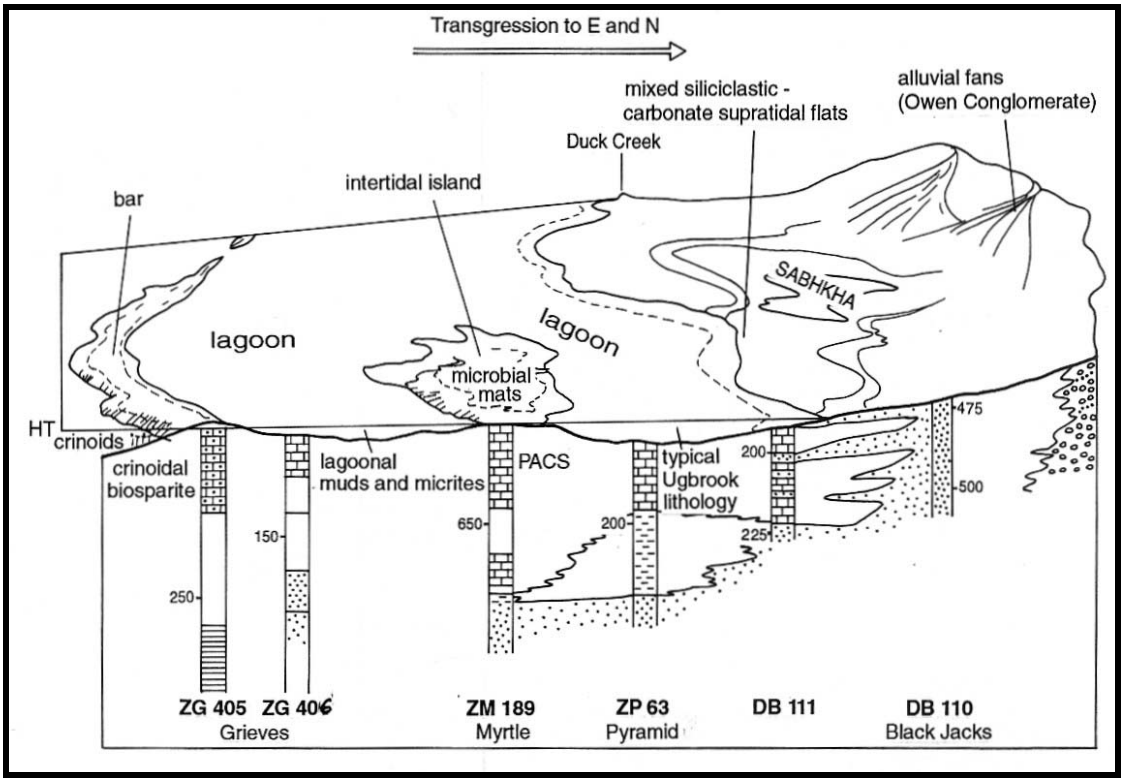


Figure 11: Environmental reconstruction of the Zeehan area for early Ugbrook Fm times (about Early Caradoc) from the south of the area at Greives Siding through Oceana, to Black Jacks in the north. Shoreline is to the north (right) and east (behind viewer). Not to scale. HT = normal high tide level. Numbers refer to down hole depth in metres, not stratigraphic thickness (*from* Burrett 1995).

Sedimentation at Oceana is consistent with regional observations, consisting of: 1, middle shelf to platform, high-energy, shallow-subtidal facies; 2, inner shelf, shallow-subtidal to low-intertidal migrational bars and shoals; 3, inner shelf, energetic and protected lagoonal facies; 4, macrotidal, intertidal to peritidal and supratidal flat facies with fluvial estuarine, terrigenous and subtidal facies (**Figure 11**). Dominant gulf-type deposition is observed in modern analogues such as the Persian Gulf, the Great Bahama Bank, Shark Bay – Western Australia and probably within the Torres Strait of northeast Australia (Perser 1973; Hardie 1977; Logan *et al.* 1970).

3.6 Litho-stratigraphic unit deposition (Burrett 1995)

The basal Ugbrook Formation consists of lithofacies 4, 5, 6 and 7 with minor occurrences of lithofacies 8, composed of pelloidal, bioturbated biomicrites, argillaceous biodolomicrites, biocalcarenites and mudstones with minor biolithites. Dominant lower massive biocalcarenites are preceded and succeeded by oolitic calcarenite shoals. Massive calcarenites are defined throughout Zeehan, by Burrett, (1995), to occur as northerly to northeasterly migrating offshore carbonate bars with minor local PAC carbonates formed on intertidal, tidal flat islands within a lagoon. Lower and upper gradational shoal calcarenites, associated with tidal channel breachs, indicate a progressional character to the migrational process. North of the carbonate bar is defined as protected lagoonal, shallow, subtidal lithofacies composing the majority of the upper Ugbrook Formation (**Figure 12**).

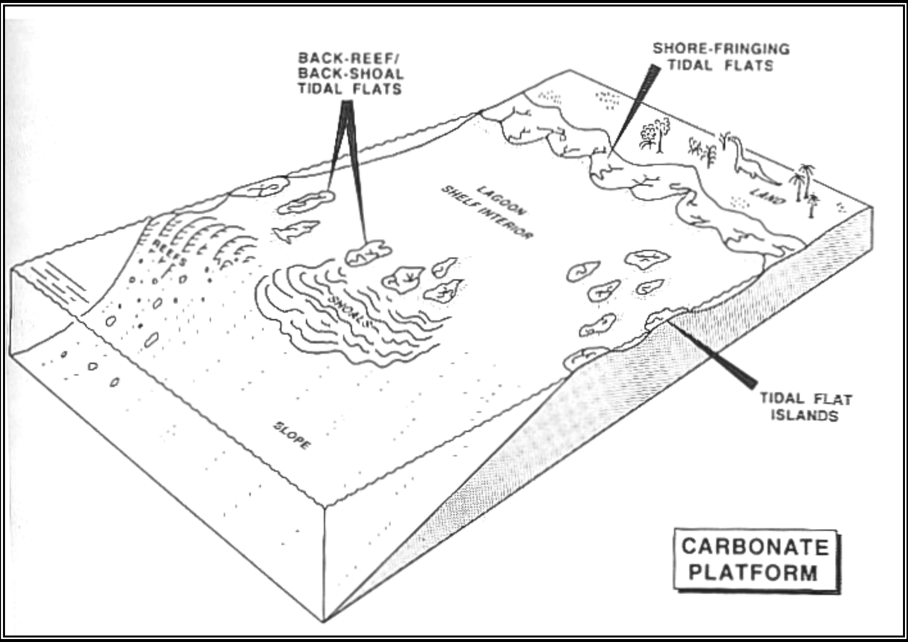


Figure 12: Block diagram of a carbonate platform, with basinward to left and landward to right, showing possible locations of tidal flats; in the lee of reefs and carbonate sand shoals, as islands, and as shoreline deposits (*from* Pratt *et al.* 1992).

The north to south encroachment, in the west, and east to west encroachment, in the north, form two transgressional shorelines enclosing the western and northwestern gulfs (Burrett 1978, Burrett 1995). Burrett, (1995), proposed that as transgression continued, the carbonate bar migrated from Greives Siding towards Myrtle during deposition of the upper Ugbrook, the shoreline probably moving east to the Tyennan region by that time. Allochems in biosparite and biocalcarenite beds associated with lagoonal facies are characteristically rounded or fragmented which suggests accumulation in marine waters less than 5m – 10m depth (Tucker 1981). Red bed lithofacies, (1), are poorly developed in conjunction with scattered tidal-flat facies which may represent a number of factors, i.e., rapid ingress associated with transgression, rapid subsidence of intertidal island lenses or destruction of PAC tops related to mechanical or biogenic activity. Aggradation of the Ugbrook Formation sediments to Myrtle Formation intertidal sediments, covering the whole Zeehan area, during the Upper Blackriveran suggests stabilisation of migratory bars and an increase of waxing and waning PACs (Burrett 1995), (**Figure 13**).

The Myrtle Formation intertidal to peritidal sediments are stratigraphically the thickest at Oceana. A typical characteristic of these sediments are rhythmic, monotonous pale-grey dolomicrites interbedded with argillaceous dolomicrites aggrading into peritidal-flat laminae. The local variation of these cycles at Oceana suggests deposition consisted of dominant allocyclic processes with minor autocyclicity, associating rapid, long-term sea level rise with continued renewing of accumulation space, forming laterally discontinuous peritidal units (Pratt *et al.* 1992).

Periodic fluctuations of eustacy, in combination with subsidence, provide a ‘window of opportunity’ for a shallowing upward succession, (PAC), to form (Pratt *et al.* 1992), (**Figure 14**). Therefore, based on correlations of the Zeehan area by Burrett, (1995), expected intertidal to peritidal sequences would extend from Grieves to Black Jacks, which is the case at Oceana (Burrett 1995; Glover 1996). Calver, (1977), proposed that the upper intertidal to supratidal sequences building the Gordon Group represent a prograding tidal flat depositional environment. Upward shifts in eustacy cause rhythmic overlain sets to be deposited upon the older prograding tidal flat sequence (**Figure 15**).

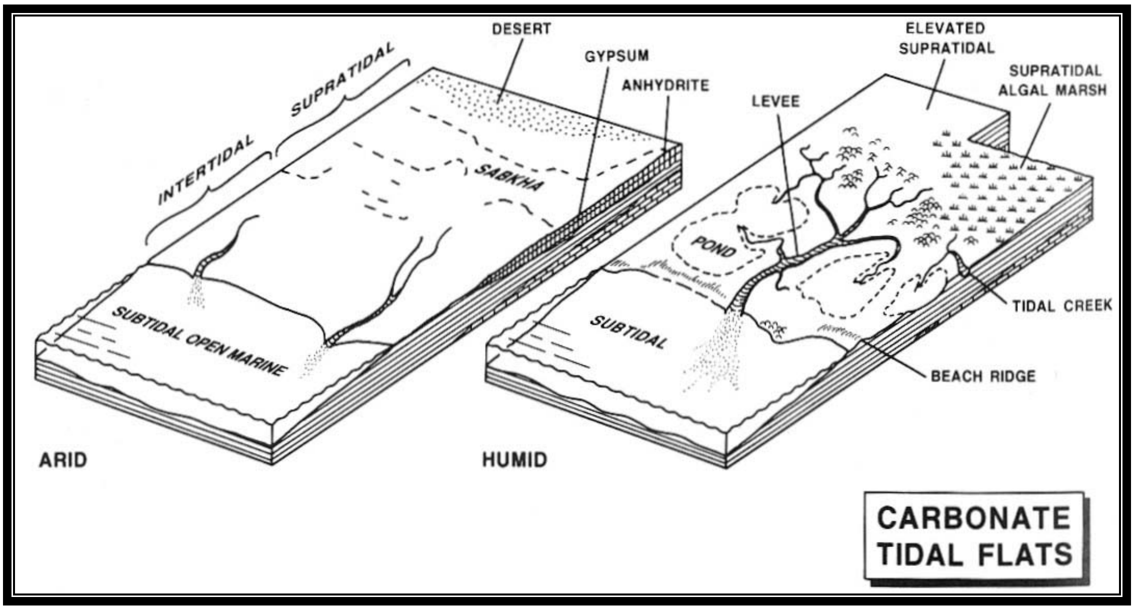


Figure 13: Block diagram showing the main morphological elements of a carbonate tidal flat. Left: a hypersaline tidal flat with few channels bordering a desert and developing evaporite deposits (based on modern Persian Gulf – Abu Dhabi); Right: normal-marine tidal flat with many creeks, or channels, and ponds in a humid to sub-humid setting (based on modern Mexico Gulf – Bahama Bank), (*from* Pratt *et al.* 1992).

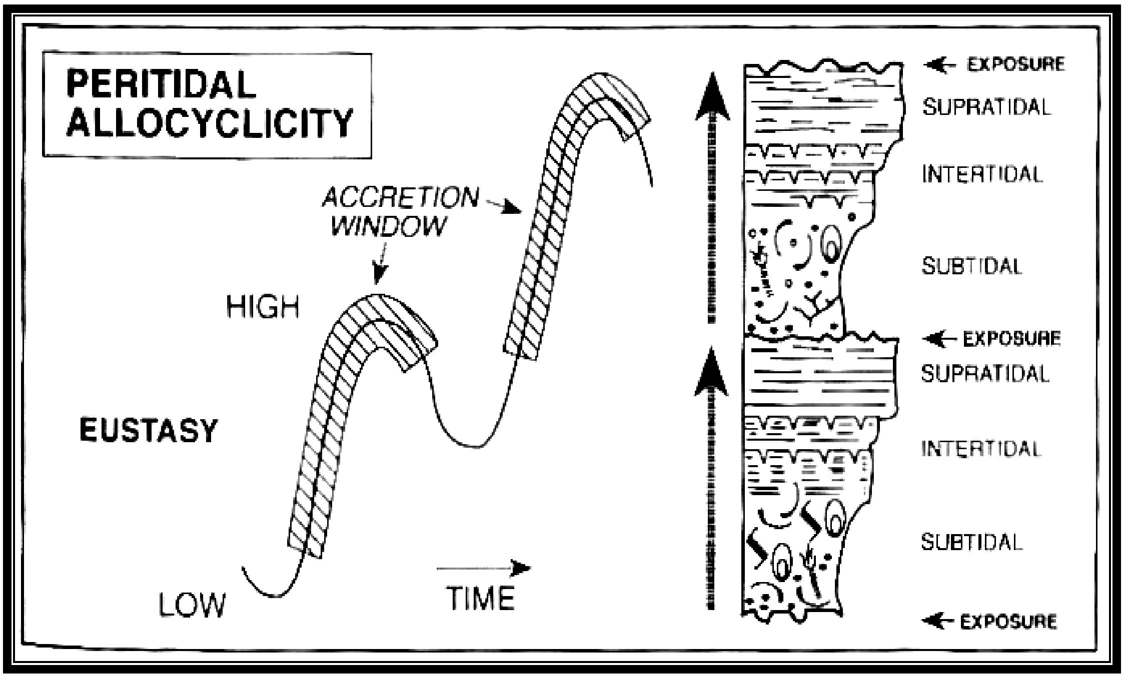


Figure 14: A diagram illustrating the relationship between fluctuating sea level and stacked metre-scale, peritidal, shallowing-upward successions. Sea level rise provides a window of opportunity for the succession to accrete as a prograding wedge, as a simultaneously aggrading sheet or as tidal flat islands. Sea level fall terminates accretion and results in sub-aerial exposure (*from* Pratt *et al.* 1992).

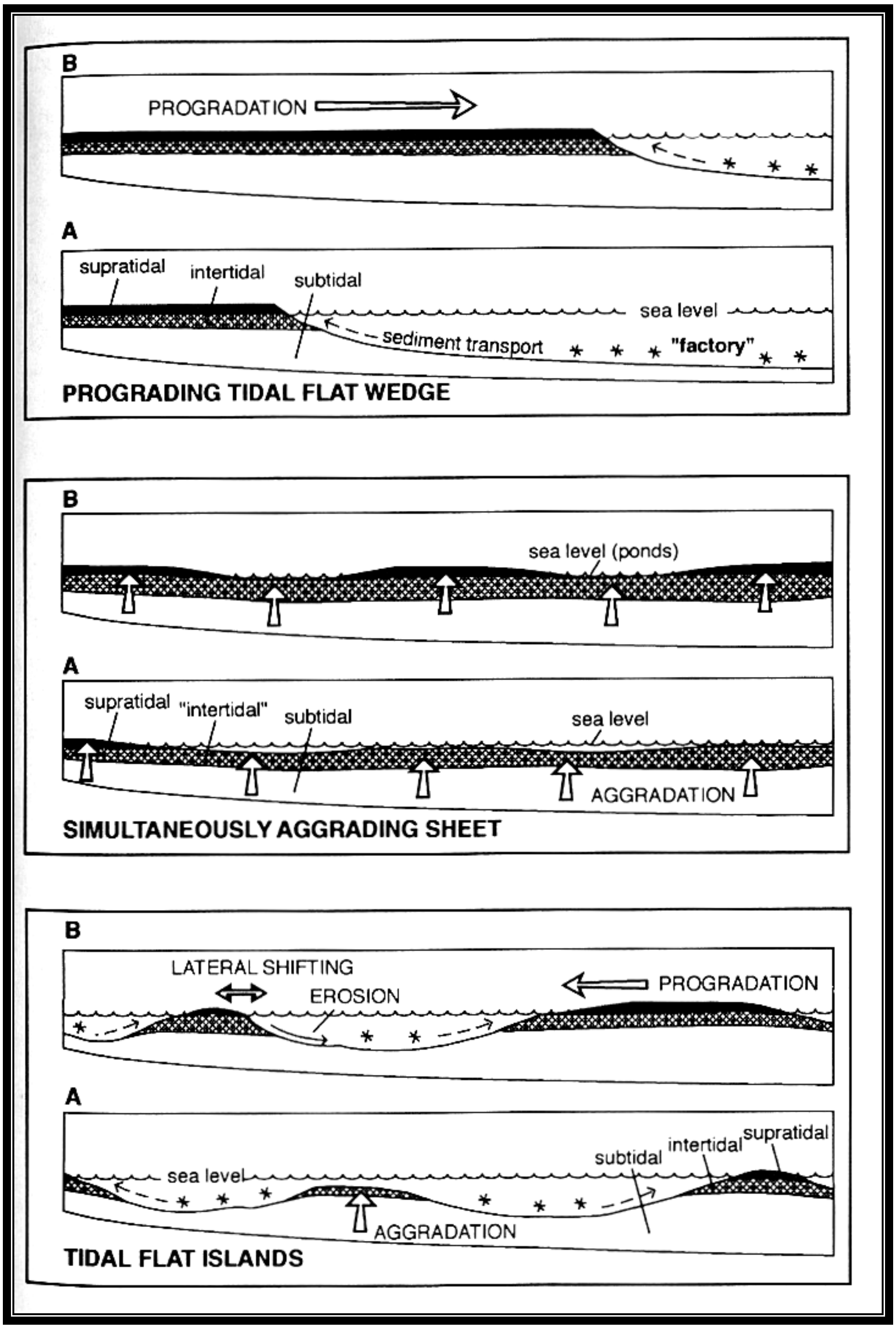


Figure 15: Diagrams illustrating various ways in which a metre-scale, peritidal, shallowing-upward succession can form. A prograding wedge is generated by sediment transported onto the tidal flat from the offshore carbonate factory. A simultaneously aggrading sheet accretes vertically to sea level and the whole platform becomes sequentially intertidal and then supratidal. Tidal flat islands nucleate and accrete by aggradation and progradation and shift in response to hydrographic forces (*from* Pratt *et al.* 1992).

Myrtle Formation sediments across Zeehan are overlain by open, energetic subtidal sediments of the lower Black Jacks Formation. Transition of intertidal to subtidal sediments defines a substantial increase in the sea level column, attributed to an incapacity of the carbonate factory to keep up with sea level rise, an increased rate of basinal subsidence or increased movement along active faults. Radiometric date determination on mineralised faults in the area by Banks, (1989), suggests dominant bi-modal populations at 475Ma and 455Ma. Movement along Oceana fault also fades into Silurian beds, (1962), suggesting propagation before or during deposition of the carbonates and probable reactivation during Devonian orogeny. A characteristic factor associated with calcarenites of the Ugbrook Formation and Black Jacks Formation at Oceana is the incidence with intraformational breccia, implying a near syn-diagenetic relationship, (epigenetic).

Intraformational breccias and conglomerates are laterally continuous lenses from Oceana Fault to Pyramid, and beyond?, that include several lithofacies and occur as soft sediment deformed, angular clasts. In rare instances, associated with upper parts of lenses, the breccio-conglomerate advances into intraformational edgewise limestone conglomerates, representing some distal transport. Similar movements are proposed on the Firewood Siding Fault during this period by Corbett, (1975), and along most other prominent northeast strike faults in the region (Banks, 1989).

High-energy shallow-subtidal sediments wane within the lower Blacks Formation to two brief occurrences of cycles aggrading to high intertidal and peritidal deposition (BJ1 & BJ2), representing increased carbonate factory production or decreased subsidence and faulting.

The upper and lower Black Jacks Formation are regionally divided by the relatively isochronous Lords Siltstone Member. The Lords Siltstone represents a period of uplift in the Tyennan region producing quartzose conglomeratic beds within the middle Benjamin Limestone Formation west of the Florentine Valley (Calver 1977), sandstone beds at Firewood Siding (Burrett 1995), and clay-rich siltstone at Oceana. The Lords event is a significant boundary marker within the Black Jacks Formation and probably corresponds to a short lived, epeirogenic event during the middle Trentonian (Late Caradoc), (Burrett 1995).

The Upper Black Jacks Formation, characterised by shallow subtidal conditions, conformably overlays the Lords Siltstone and represents a renewed autocyclic transition associated with transgression of sea level. The occurrence of the Lords

Siltstone at the lower boundary is testament to probable syn-sedimentary reactivation of faults in the region accounting for some of the displacement. Occurrences of shallow subtidal lithofacies are known to continue to the upper Gordon Group boundary however the majority of Zeehan sections expose a peritidal interlude during the Late Trentonian / Early Ashgill (Burrett 1995). Up to five PACs of rapidly aggraded sediment are likely to represent brief tidal flat development in the Zeehan area. The peritidal member is absent in the Myrtle section although is recognised at Greives Siding and Pyramid. Burrett, (1995), proposed Myrtle sediments may have been deeper during the time, corresponding with an open channel-way. Glover, (1996), considered the additional condition of related faulting, due to a sudden appearance of the lithofacies at Greives Siding.

At Oceana the upper peritidal members are heavily veined and broken in core samples although the nature of this boundary is considered gradational. Calcarenite beds diminish in grainsize and thickness through calcisiltite to pale-grey dominant dolomicrite. Stromatolites are present with minor domal development in combination with pervasive development of birdseye vugs. This shallowing member may correlate to the Overflow Creek Formation at Mole Creek (Burrett 1995).

Blissett, (1962), defined the upper boundary of the Gordon Group as conformable – disconformable to the overlain Crotty Quartzite. This boundary is proposed as a disconformity which represents resurgent uplift during the Ashgill, rapidly shedding sheet siliciclastics across the Gordon Group, connected with the Benambran Orogeny of New South Wales during the Late Ordovician (Llandovery), (Banks 1959; 1989). Sediments are characterised by a diverse assemblage of faunas which represent a littoral to sub-littoral depositional environment. The dominance of well-sorted units with intermittent conglomerates and turbidites suggests deep-water, near-shore, unstable shelf-type sediment deposition. Eldon Group sediments accumulated until disruption by the Middle Devonian Tabberabberan Orogeny (Blissett 1962). Regional folding consisted of three phases associated with dominant axial plane directions and resulted in the common occurrences of Eldon Group sediments in the axial regions of synclinoria and Denison Group sediments in the axial regions of anticlinoria (Blissett 1962).

3.7 Dolomitisation

Dolomite is a common product of carbonates at Oceana indicating syn-genetic and epigenetic types. Syngenetic dolomites are generally associated with supratidal hardgrounds in modern carbonate analogues to depths of 1m (Tucker 1981). Intertidal examples seen in thin section occur as small, colourless subhedral to euhedral rhombs. Well-developed euhedral and subhedral matrix dolomite is indicative of slow recrystallisation rates and hence, can include penecontemporaneous or early diagenetic processes.

Epi-genetic dolomites are discernible in carbonates at Oceana occurring in thin section as large (<1mm – 3mm) compositionally zoned rhombohedra recrystallised with fine subhedral matrix dolomite. Matrix dolomite, scattered zoned rhombohedra and cavity cement are commonly ferroan in composition both partially and completely replacing the original rock. Epigenetic processes considered by Tucker, (1981), (in section 4.3.9), and Kahle, (1965), suggest the role of Mg leaching and absorption by clays as an important process in the complete replacement of adjacent limestones, due to the Mg 'cage' effect. This is the case at Oceana where dolomite replaces ~1m either side of the Lords Siltstone Member, and was observed at Greives Siding by Glover, (1996), as a replaced and weakly mineralised zone. The large constituent of argillaceous dominated beds throughout the intertidal zone, Myrtle Fm, presents an additional source of Mg absorbers.

Epi-genetic dolomitisation is hard to define to one particular paragenetic phase due to the extensive influence of tectonism at Oceana. Post-diagenetic dolomitisation is associated with faults, 'fresh' fractured beds, joints and mineralisation phases. Structure related dolomites will be discussed in Chapter 4.