Mineral Resources Tasmania

Tasmania

Tasmanian Geological Survey Record 1996/10

AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

NGMA TASGO Project

Reconnaissance isotope chemostratigraphy of Neoproterozoic carbonate rocks in western Tasmania

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Abstract

A reconnaissance carbon and strontium isotope study of several Neoproterozoic–?Cambrian units in western Tasmania extends earlier chemostratigraphic work on the Togari Group of northwest Tasmania and provides new information on the age and correlation of the units.

The base of the Smithton Dolomite is mid-Ediacarian (c. 580 Ma) on $^{87}Sr/^{86}Sr$ evidence. Both C and Sr isotopes confirm that the Savage Dolomite is a correlate of the mid-Cryogenian (c. 700–650 Ma) Black River Dolomite of the Togari Group, except that equivalents of the upper part of the Black River Dolomite are missing. The Corinna Dolomite is a correlate of the Smithton Dolomite. Carbon isotopes are consistent with correlation of the Success Creek Group with the Black River Dolomite, but in the absence of corroborative unaltered $^{87}Sr/^{86}Sr$ results, the chemostratigraphic evidence is not compelling. High (typically Neoproterozoic) $\delta^{13}C$ values are found in parts of the upper Oonah Formation, but little more can be said about this unit, or the 'Cleveland–Waratah association', because of isotopic alteration, particularly of $^{87}Sr/^{86}Sr$.

Samples from the 'Cleveland–Waratah association' processed for acritarchs yielded no identifiable organic residues, because of thermal metamorphism. Future palynological and isotope-stratigraphic work on the Success Creek Group, Oonah Formation and 'Cleveland–Waratah association' rocks might be more profitably focused on less altered material not affected by Devonian granite-related metamorphism and metasomatism.

INTRODUCTION

Within the last decade, chemostratigraphy of carbon and strontium isotopes in marine sediments — principally carbonates — is being increasingly applied to Neoproterozoic correlation, aided by an expanding database of results and a recognition that preservation of original marine isotopic compositions appears to be commonplace in unmetamorphosed successions (Knoll *et al.*, 1986; Asmerom *et al.*, 1991; Kaufman *et al.*, 1991, 1992; Knoll and Walter, 1992; Narbonne *et al.*, 1994; Kaufman and Knoll, 1995). Because such isotopic compositions are assumed to reflect the primary isotopic compositions of global oceans, results can be compared from widely dispersed stratigraphic sections.

The pattern of secular variation in marine $\delta^{13}C$ and $^{87}Sr/^{86}Sr$ through the Neoproterozoic is now known in broad outline, and 'global curves' have been constructed purporting to show this variation through time (e.g. Kaufman and Knoll, 1995: fig. 1). The Neoproterozoic was characterised by long periods in which ^{13}C enrichment of marine carbonates, at +4 to +8‰ relative to PDB, was uniquely high. This is thought to have been related to increased burial rates of (^{13}C-depleted) organic carbon, causally related to an increase in the oxygen content of the atmosphere (Knoll *et al.*, 1986). In the Cryogenian (850–c. 650 Ma), three major negative excursions in $\delta^{13}C$ coincide with glaciations, the last two with the Sturtian and Marinoan/Varangian glaciations respectively (Kaufman *et al.*, 1991; Kaufman and Knoll, 1995). Marine $^{87}Sr/^{86}Sr$ was evidently very low (less than 0.7075) through the Cryogenian, while a monotonic rise (0.7075–0.7088) is seen through the 'Neoproterozoic III' (c. 650 Ma to

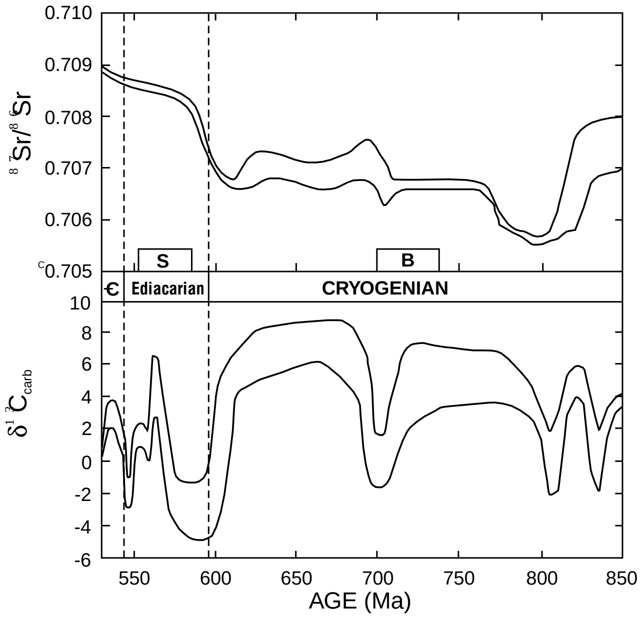

Figure 1

Secular change in $\delta^{13}C$, and $^{87}Sr/^{86}Sr$ of marine carbonates of Cryogenian to early Cambrian age (850–530 Ma), adapted from Kaufman and Knoll (1995). Note that numerical age calibration is poorly constrained, particularly in the 650–750 Ma interval. 'S': probable range of Smithton Dolomite, 'B': probable range of Black River Dolomite relative to isotope curves.

base Cambrian) to the high values of the Cambrian (over 0.7088) (Asmerom *et al.*, 1991; Kaufman *et al.*, 1993).

Of course, the chemostratigraphic method is equally applicable as an empirical correlation technique within and between basins, without reference to the documented 'global curves'.

This study extends into western Tasmania the work of Calver (1995; in press), who documented the chemostratigraphy and consequent age constraints of the Neoproterozoic Togari Group of northwest Tasmania. There are a number of carbonate-bearing Neoproterozoic (–?Cambrian) successions in western Tasmania, among them presumed correlates of the Togari Group. Absolute age constraints are mostly few and indirect, and our present understanding of several important relationships relies on broad lithostratigraphic correlation between spatially or structurally separated successions; see Seymour and Calver (1995) for a recent synthesis of age constraints relating to Neoproterozoic–Cambrian successions of western Tasmania.

Chemostratigraphy is one means of providing much-needed age constraints and of corroborating (or otherwise) correlations made in the past. This study is part of the Tasmanian National Geoscience Mapping Accord ('TASGO') Project, a co-operative research venture of Mineral Resources Tasmania, the Australian Geological Survey Organisation, universities and the mineral industry to generate new and diverse geological and geophysical datasets with which to re-evaluate Tasmania's mineral and petroleum potential, its geological history, and the timing of tectonic events.

In the Togari Group, two major carbonate units, the Black River Dolomite and the Smithton Dolomite, are separated by a unit of rift-related volcanic and clastic rocks, the Kanunnah Subgroup (Everard *et al.*, 1996) (fig. 2). On chemostratigraphic and other evidence, the Black River Dolomite is middle Cryogenian (c. 650–700 Ma), and a diamictite unit coinciding with a negative $\delta^{13}C$ excursion in the upper part of the Black River Dolomite may correspond to the Sturtian glacials (Calver, 1995; in press). The Smithton Dolomite is Ediacarian (Neoproterozoic III: c. 580–545 Ma) on $\delta^{13}C$ and $^{87}Sr/^{86}Sr$ evidence. The rift volcanic rocks of the Kanunnah Subgroup and its lithostratigraphic and lithogeochemical correlative, the Crimson Creek Formation (Brown, 1986; 1989*a*) thus appear to be temporally related to the breakup of Rodinia which happened soon after the Sturtian glaciation (Li *et al.*, 1996; Calver, in press).

Adabi (in press) has recently demonstrated the presence of little-altered, ^{13}C-enriched dolostones (+6 to +7‰) in the upper Success Creek Group and lower Crimson Creek Formation, consistent with a Neoproterozoic age for these units.

The present study is based on reconnaissance sampling, from outcrop and drill holes, of the Oonah Formation, the Savage Dolomite, the Corinna Dolomite, the Success Creek Group, the Crimson Creek Formation and the 'Cleveland–Waratah association'. A limestone unit near the base of the Smithton Dolomite was also sampled. The distribution of the rock units, and major sample locations, are shown in Figure 2.

The results of this study refine the age of the Smithton Dolomite as mid to late Ediacarian. The strontium and carbon isotope data show that the Savage and Corinna dolomites, formerly believed to be equivalent, are of different ages, while the data strongly corroborate correlation of the Savage Dolomite with the Black River Dolomite, the Corinna Dolomite with the Smithton Dolomite, and by inference the Bernafai Volcanics with the Kanunnah Subgroup. Carbon isotopes are consistent with correlation of the Success Creek Group with the Black River Dolomite, but $^{87}Sr/^{86}Sr$ ratios from the Success Creek Group are mildly to strongly radiogenic and therefore altered. The Oonah Formation contains some enriched (+4‰), typically Neoproterozoic $\delta^{13}C$ values, but again corroborative evidence from $^{87}Sr/^{86}Sr$ is lacking because of alteration. Carbon isotopic compositions from the 'Cleveland–Waratah association' seem to be too altered, or insufficiently distinctive, to give useful information. The isotopic alteration seen in the Success Creek Group, Oonah Formation and 'Cleveland–Waratah association' is probably a result of sampling in or near granite aureoles or in Devonian hydrothermal systems.

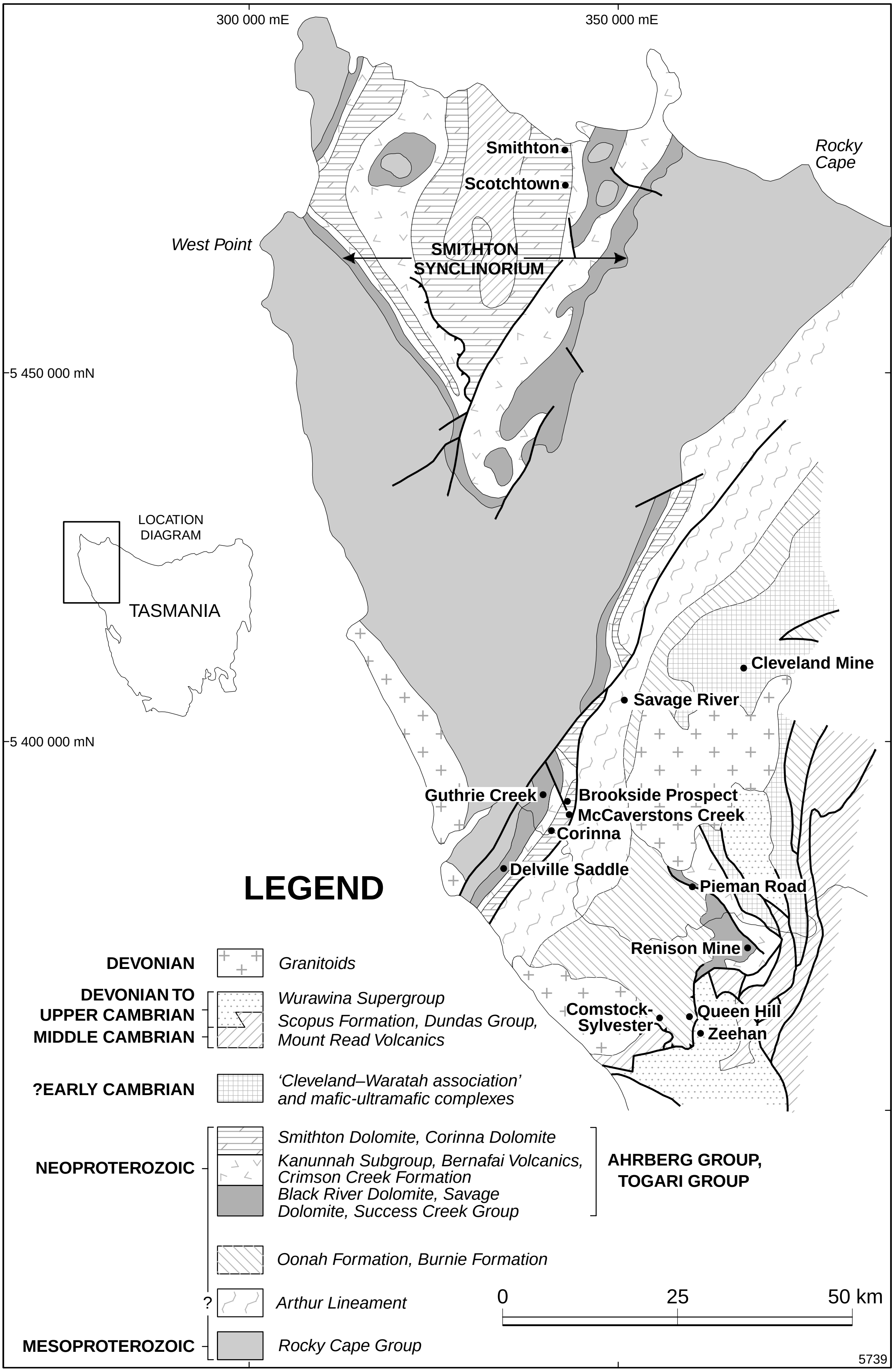

Figure 2

Geological sketch map of northwest Tasmania, showing main localities.

Alteration

Monitoring of diagenetic alteration of isotopic composition in carbonate rocks generally relies on a combination of petrographic, trace-element and isotopic criteria (Kaufman and Knoll, 1995; Kaufman *et al.*, 1993). Homogeneous, non-luminescent micrites or dolomicrites, or texturally well-preserved ooids and marine cements, that are low in organic carbon and insolubles, are the preferred material for analysis (e.g. Kaufman *et al.*, 1991; Kaufman and Knoll, 1995).

Post-depositional alteration typically gives rise to co-variant changes in trace-element and isotopic composition. Typically, $\delta^{13}C$, $\delta^{18}O$, Sr^{2+} and Na^{+} decrease, while $^{87}Sr/^{86}Sr$, Mn^{2+} and Fe^{2+} increase (Brand and Veizer, 1980, 1981; Veizer, 1983; Banner and Hanson, 1990). $\delta^{18}O$ and Mn/Sr are commonly used indices of diagenetic alteration in carbon and strontium isotope chemostratigraphic studies (e.g. Derry *et al.*, 1992; Kaufman *et al.*, 1993). Kaufman and Knoll (1995) consider that $\delta^{13}C$ in a given sample is likely to be unaltered if ^{18}O is greater than -10‰ and if Mn/Sr is less than 10. The $^{87}Sr/^{86}Sr$ ratio is more readily altered, and more rigorous limits are required — for example, Mn/Sr <1.5 and $^{87}Rb/^{86}Sr$ <0.001 for near-primary compositions (Kaufman *et al.*, 1993). In general these limits are empirically derived from large data sets and are chosen to yield consistent and concordant (and hence probably near-primary) $\delta^{13}C$ and $^{87}Sr/^{86}Sr$ data.

The $^{87}Sr/^{86}Sr$ ratio almost invariably increases with diagenetic alteration (Veizer and Compston, 1974). Thus, the lowest two or three values from a suite of closely associated samples, if in close agreement (± 0.0002) and if other criteria (above) are favorable, are likely to closely approach the original marine value (e.g. Derry *et al.*, 1989; Asmerom *et al.*, 1991). Limestone is a generally better material for $^{87}Sr/^{86}Sr$ chemostratigraphy than dolostone, as the process of dolomitisation entails loss of most Sr (Derry *et al.*, 1989; 1992).

Chronostratigraphic nomenclature

Current late Proterozoic chronostratigraphic/chronometric nomenclature needs a brief explanation. The Neoproterozoic Era (1000 Ma to base Cambrian) and constituent periods (Tonian, 1000–850 Ma; Cryogenian, 850–c. 650 Ma, and 'Neoproterozoic III' (c. 650 Ma–base Cambrian) have been set up (Plumb, 1991) with intra-Proterozoic boundaries defined as absolute dates. Final naming and definition of the third and last period ('Neoproterozoic III') is still to be determined, and its lower boundary (and thus also the upper boundary of the Cryogenian) is expected to be in a type section (as is the practice in Phanerozoic chronostratigraphy) rather than taken as an absolute date. There is currently no universally accepted, terminal Proterozoic time-rock unit of System rank, although various terms have been widely used.

Cloud and Glaessner (1982) formalised the Ediacarian System and Period, with a type section in the Adelaide Geosyncline extending from the top of the last Proterozoic glacial phase (the Marinoan glacials) to the base of the Cambrian. The widely-used term 'Vendian' may be partly older than the Ediacarian, as it extends from the base of the probably-correlative Varangian glacials in the northern hemisphere to the base of the Cambrian (Harland and Herod, 1975). The Adelaidean System and constituent series (Willouran, Torrensian, Sturtian and Marinoan) have been widely applied in mainland Australia (e.g. Preiss, 1987). Boundaries between these Series cannot be located with any precision away from their type localities (Preiss, 1987) but the terms 'Sturtian' and 'Marinoan' usefully differentiate the two main Adelaidean glacial phases. The base of the Cambrian, now defined at a Global Stratotype Section and Point in Newfoundland, is dated at c. 545 Ma (e.g. Jones, 1994).

METHODS

Following sampling protocols used in previous chemostratigraphic studies, fine-grained, texturally uniform carbonate rocks with a minimum of terrigenous impurities were selected in the field. Stable-isotopic analysis of the samples was undertaken at the Central Science Laboratory, University of Tasmania, and followed the usual method of phosphorolysis. Most samples were reacted at 50°C or for two days to allow for complete reaction. $\delta^{18}O$ values are corrected for reaction at 50°C using fractionation factors of 1.00925 for calcite (Wachter and Hayes, 1985) and 1.01066 for dolomite (Rosenbaum and Sheppard, 1986); and at 25°C, 1.01178 for dolomite (Rosenbaum and Sheppard, 1986). The precision is ± 0.1‰ for both O and C. The approximate percentages of carbonate were obtained from the CO_2 yields.

A number of samples were selected for $^{87}Sr/^{86}Sr$ analysis which was carried out at CSIRO, North Ryde. The $^{87}Sr/^{86}Sr$ ratios are normalised to $^{86}Sr/^{88}Sr$ = 0.1194 and to a Standard Reference Material 987 value of 0.710241. Splits of these samples were analysed by AAS for Mn and Sr at the Mineral Resources Tasmania geochemical laboratory, in order to provide an additional check on diagenetic alteration.

The small post-depositional increase in $^{87}Sr/^{86}Sr$ caused by decay of ^{87}Rb within the carbonate lattice was not determined, as this 'age correction' is insignificant relative to the uncertainties caused by diagenetic alteration (Calver, 1995). The Neoproterozoic $^{87}Sr/^{86}Sr$ signal is unlikely to be resolvable beyond the fourth decimal place because of diagenetic alteration (*cf.* Veizer, 1989).

Locations of all samples and the analytical results are tabulated in Appendix 1. Some localities are given as full AMG grid references.

SMITHTON DOLOMITE

The Smithton Dolomite is about 1500 m thick and consists of a 'lower member' (c. 500 m thick) of fine-grained dolostone and an 'upper member' (1000 m thick) of coarser-grained, crystalline dolostone and minor limestone (Calver, 1995).

Calver (1995) recovered little-altered $^{87}Sr/^{86}Sr$ values, suggesting an Ediacarian age, from limestone units within the 'upper member', but the 'lower member' in the area studied was found to consist entirely of dolomite in which $^{87}Sr/^{86}Sr$ tends to be somewhat altered, leaving this part of the succession relatively unconstrained in terms of strontium isotope chemostratigraphy.

About 20 m stratigraphic thickness of dark grey oolitic limestone occurs just above the base of the Smithton Dolomite in a small disused quarry near Scotchtown south of Smithton (fig. 2), and this occurrence was sampled in order to better constrain the age of the base of the formation. In thin section, the rock consists of brown-pigmented ooids 0.5–1 mm in diameter in an abundant sparry calcite cement. Ooids are uncompacted, suggesting very early diagenetic cementation. Ooid cortices are finely recrystallised microsparite but fine concentric layering is still preserved. Many ooid cores are replaced by spar. This sample (EC1) returned whole-rock analyses of $\delta^{13}C$ 0.5‰, $\delta^{18}O$ -6.3‰, and $^{87}Sr/^{86}Sr$ 0.7079.

Carbon and strontium isotopic composition of this sample are considered close to the original marine values because of the good textural preservation, the early diagenetic age of the cement, the high strontium content (1202 ppm) and very low Mn/Sr (0.03). $\delta^{13}C$ is consistent with a stratigraphic position at the base of the Smithton Dolomite (see fig. 6.7 of Calver, 1995). The $^{87}Sr/^{86}Sr$ result of 0.7079 suggests that the base of the formation is younger than basal Ediacarian (when marine $^{87}Sr/^{86}Sr$ is considered to have been close to 0.7072: Narbonne *et al.*, 1994; Kaufman *et al.*, 1995). This result is consistent with the proposed monotonic rise in Ediacarian marine $^{87}Sr/^{86}Sr$ (Kaufman *et al.*, 1995), as little-altered results from the 'upper member' are 0.7082 and, higher up, 0.7085 (Calver, 1995).

The Smithton Dolomite thus shows a similar range in depositional $^{87}Sr/^{86}Sr$ to middle Ediacarian successions of mainland Australia, such as the Ungoolya Group of the Officer Basin or the Wonoka Formation of the Adelaide Geosyncline (Calver, 1995; Calver and Lindsay, in press). However carbon isotope profiles of the mainland successions differ from that of the Smithton Dolomite, perhaps because the intracratonic mainland basins were partly isolated from the world ocean (see Calver, 1995). Semi-isolated basins can evolve distinct $\delta^{13}C$ compositions while retaining global-ocean $^{87}Sr/^{86}Sr$ because of the much longer residence time, and lack of biological isotopic fractionation of strontium (Calver, 1995).

CORINNA AND SAVAGE DOLOMITES

Introduction

In the Corinna district, west of the Arthur Metamorphic Complex, the Ahrberg Group (Turner *et al.*, 1991) unconformably overlies rocks correlated with the Rocky Cape Group (Spry, 1964; Turner, 1990). The Ahrberg Group consists of the 'Donaldson Formation' (conglomerate, quartzwacke, siltstone) succeeded by the Savage Dolomite, then the Bernafai Volcanics (Turner *et al.*, 1991; Turner, 1992). These units pre-date the main deformation and metamorphism in the Arthur Lineament. The Corinna Dolomite (Turner *et al.*, 1992) is a separate, fault-bounded unit which is shown as a correlative of the Savage Dolomite on the Corinna 1:50 000 scale geological map (Turner *et al.*, 1991). However, the two units show some lithologic dissimilarities (Shannon, 1988).

The Ahrberg Group has been correlated with the Togari Group of the Smithton Synclinorium, on the basis of formation-level lithostratigraphy and occurrence of chemically similar rift tholeiites in both the Kanunnah Subgroup and the Bernafai Volcanics (Turner *et al.*, 1992). One objection to this correlation — arising from the perception that the Togari Group post-dated the deformation in the Arthur Lineament, unlike the Ahrberg Group (Turner, 1989; 1990) — seems to have been overcome, with the recent recognition of a much younger, Cambrian age for this deformation (Turner *et al.*, 1992; Turner, 1993).

As a test of the Savage Dolomite–Black River Dolomite correlation, the Savage Dolomite was sampled and analysed in this study, and the Corinna Dolomite was also sampled in an attempt to settle the alternative ideas as to its age and correlation.

Lithostratigraphy

The Savage Dolomite was sampled in drill holes from Delville Saddle, south of the Pieman River, and from outcrops near Guthrie Creek, north of the Pieman River. The formation is about 800 m thick, dips steeply and faces southeast (Turner *et al.*, 1991). Outcrop in road cuttings near Guthrie Creek is massive, off-white dolomicrite or dolo-microsparite. Possible domical and stratiform stromatolites occur in a road cutting 550 m north of Guthrie Creek (at 340 620 mE, 5 391 360 mN). The dolomite typically has highly irregular, stromatactis-like vughs (e.g. at 340 580 mE, 5 391 270 mN) or fracture-fills (340 200 mE, 5 390 850 mN) lined with a dark grey, 1–2 mm thick isopachous dolomite cement and filled with fine-grained dolomite or silica. A unit of dark grey to black, thin-bedded shale and cherty mudstone crops out in the lower part of the formation in road cuttings immediately south of Guthrie Creek.

In the Delville Saddle drill holes the formation is predominantly massive grey dolomicrite or dolomicrosparite, with lamination discernible in places, and rare intraclastic and oolitic beds. A flat-pebble conglomerate with banded (laminated) intraclasts, like that seen near the base of the Black River Dolomite in the Arthur River (Calver, 1995), occurs at 301–303' in DS6381.

The Corinna Dolomite was sampled from Works Tasmania drill holes from the bed of the Pieman River at Corinna, from drill holes at the Brookside prospect, from a drill hole at the silica mine, and from outcrop near the Corinna Road and McCaverstons Creek. The dolomite is massive, and no bedding is recorded on the Corinna map sheet (Turner *et al*., 1991). The unit is fault-bounded, at least on the western side, and the structure may be complex in view of an inlier of Bernafai Volcanics in the northern part of the outcrop belt (Turner *et al*., 1991). No attempt has been made, therefore, to put the Corinna Dolomite samples in stratigraphic order.

The rock is typically a massive, off-white to pale grey, finely crystalline dolostone. Grain size tends to be slightly coarser than in the Savage Dolomite. Fractures and vugs are filled with sparry quartz, and disseminated fine-grained quartz may also be present.

Isotope stratigraphy

The Savage Dolomite is moderately enriched in ^{13}C, all samples having $\delta^{13}C$ between +2 and +5.5‰. There is a suggestion of a slight rise in least-altered (heaviest) $\delta^{13}C$ from 4 to 5.5‰ upward through the formation (fig. 3). Oxygen isotopic compositions are also relatively heavy, averaging about -3‰ with a maximum of 0‰. There is a weak covariance of $\delta^{13}C$ and $\delta^{18}O$ (fig. 4).

The Corinna Dolomite samples all have $\delta^{13}C$ distinctly lower than the Savage Dolomite, with a range of -0.5 to +1.5‰ (excluding an outlier at -0.5 ‰). Oxygen isotopic compositions are similar or only slightly lower, averaging about -4‰ (fig. 4).

The most ^{18}O-enriched samples from each formation were analysed for $^{87}Sr/^{86}Sr$. The sample from the Savage Dolomite (DS6385-3) came from near the top of the formation and yielded 0.7075; the sample from the Corinna Dolomite (8761-1) gave the significantly higher value of 0.7085.

Age and correlation

Carbon and oxygen isotopic compositions of the Savage Dolomite closely match those of the lower half of the Black River Dolomite (fig. 3). The fall in $\delta^{13}C$ to negative values in the upper part of the Black River Dolomite, in association with a unit of diamictite (the Julius River Member), appears to be absent in the Savage Dolomite. This is consistent with the absence of known diamictite in the Savage Dolomite and suggests non-deposition or erosion at the top of the Savage Dolomite.

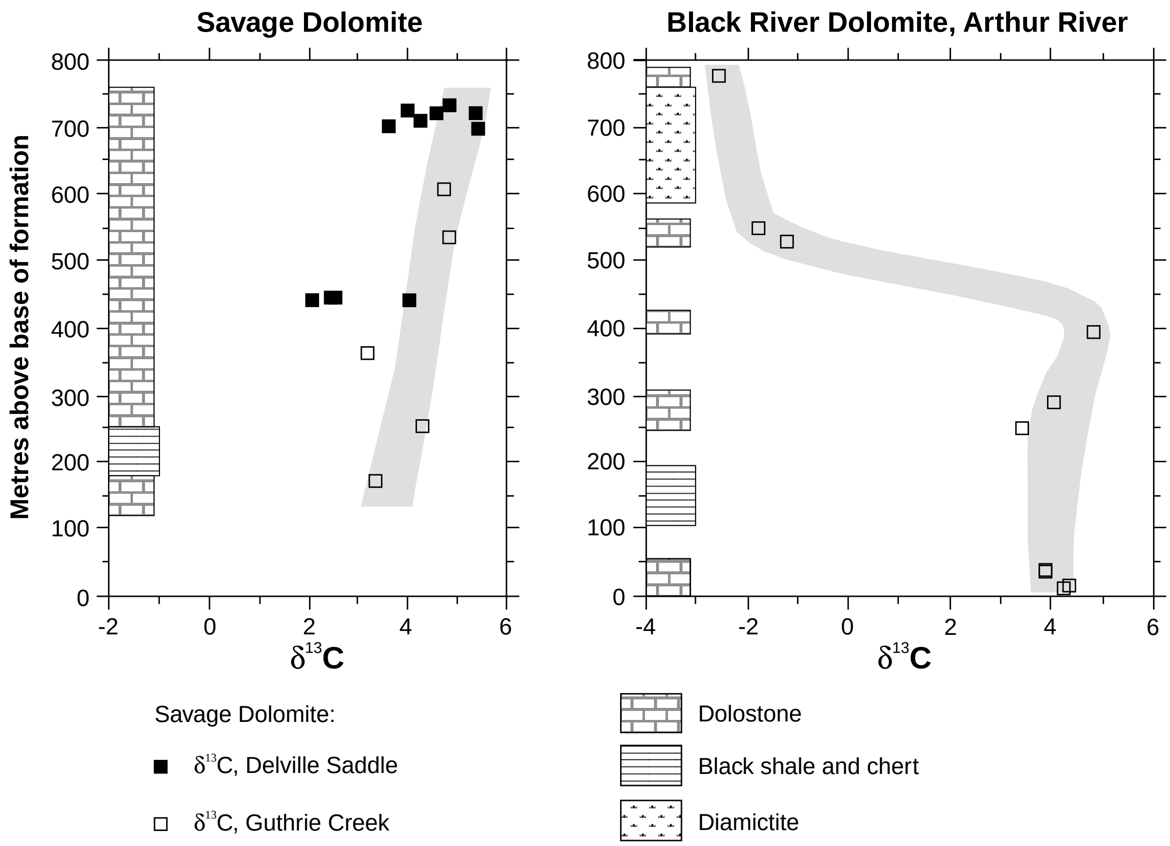

Figure 3

Lithologic column of Savage Dolomite and $\delta^{13}C$ data; and Black River Dolomite, Arthur River section, with $\delta^{13}C$ data, from Calver (1995). Shaded areas represent probable primary marine $\delta^{13}C$ signal.

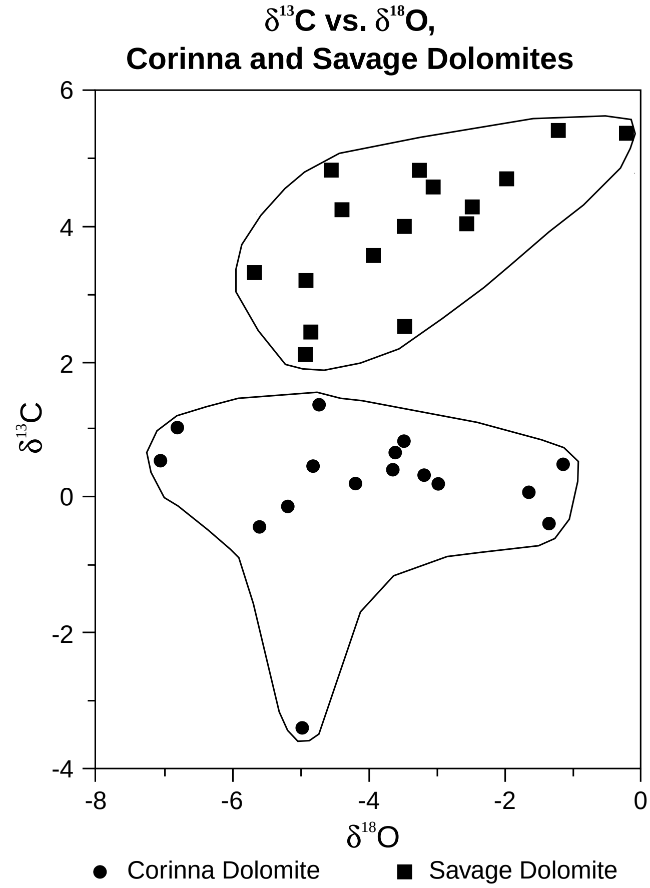

Figure 4

$\delta^{13}C$ – $\delta^{18}O$ crossplot of Savage Dolomite and Corinna Dolomite samples.

The $^{87}Sr/^{86}Sr$ result supports this correlation. Given that this result (0.7075), like most dolostones, is likely to be somewhat altered (i.e. higher than the original value), a pre-Ediacarian (i.e. pre-600 Ma) age is indicated. The result is lower than any obtained for the Smithton Dolomite (0.7079–0.7085; see below, and Calver, 1995) but is typical of dolostone from the Black River Dolomite. The sample plots within the field of Black River Dolomite in terms of $^{87}Sr/^{86}Sr$–Mn/Sr covariation (fig. 5).

Carbon and strontium isotopes thus provide convincing evidence for correlation of the Savage Dolomite with the Black River Dolomite. The unit of black mudstone and chert in the lower part of the Savage Dolomite may correlate with a similar unit in the lower part of the Black River Dolomite in the Arthur River area (fig. 3).

On isotope-stratigraphic and other evidence (Calver, 1995; in press) the Black River Dolomite is mid-Cryogenian (c. 700–650 Ma) in age. The Savage Dolomite is considered to be younger than the Oonah Formation, which has a maximum age (based on K-Ar dating of detrital muscovite) of 708 ± 6 Ma (Turner, 1993), and is probably older than the Sturtian glaciation which may be represented by the diamicitite in the upper part of the Black River Dolomite. The age of the Sturtian Glaciation is poorly constrained numerically but is probably around 650 Ma (Walter *et al.*, 1995; W. V. Preiss, pers. comm.; 1995).

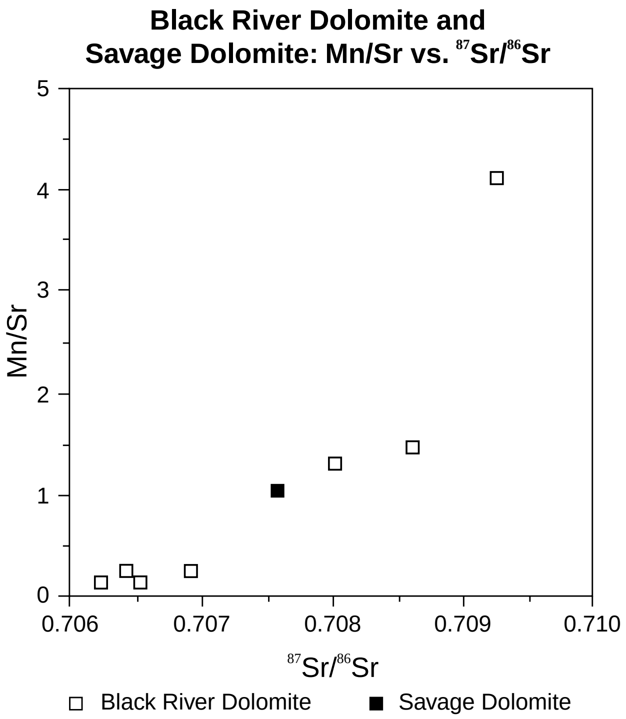

Figure 5

Plot of $^{87}Sr/^{86}Sr$ vs. Mn/Sr, Black River Dolomite and Savage Dolomite.

The distinctly lower $\delta^{13}C$ of the Corinna Dolomite compared to the Savage Dolomite might arguably be a result of alteration, consistent with the slightly coarser grain size and closer proximity of this unit to the Arthur Metamorphic Complex. However, such alteration (recrystallisation in the deep-burial environment) would be expected to affect, first and foremost, oxygen isotopic compositions, because of high temperatures and the much greater abundance of exchangeable oxygen than carbon in diagenetic fluids. Oxygen isotopic compositions of the two formations are not significantly different (fig. 4), so an original (primary) difference in $\delta^{13}C$ is strongly implied. Indeed, $\delta^{18}O$ in the Corinna Dolomite remains quite enriched, and $\delta^{13}C$ is therefore likely to be little-altered (*cf.* Kaufman and Knoll, 1995).

Carbon and oxygen isotopic compositions of the Corinna Dolomite closely match those of the 'lower member' of the Smithton Dolomite, which are +1 to -2‰ ($\delta^{13}C$) and -3 to -7‰ ($\delta^{18}O$) (Calver, 1995). The single $^{87}Sr/^{86}Sr$ result of 0.7085 is consistent with such a correlation, assuming the sample is somewhat altered (higher than the original value). Little-altered limestone in the 'lower member' of the Smithton Dolomite has $^{87}Sr/^{86}Sr$ of 0.7079 (see above), but the dolostone of the 'lower member', considered variably altered in $^{87}Sr/^{86}Sr$, ranges from 0.7084 to 0.7099 (n = 7; Calver, 1995).

Both carbon and strontium isotopes therefore provide good evidence for correlation of the Corinna Dolomite with the Smithton Dolomite, which is of mid to late Ediacarian age (Neoproterozoic III: c. 580–545 Ma) on chemostratigraphic evidence (see above).

It can be inferred from these correlations that the Bernafai Volcanics, interposed between the Savage Dolomite and Corinna Dolomite, is a correlative of the Kanunnah Subgroup of the Togari Group. Such a correlation has been previously proposed on the basis of basalt lithogeochemistry (Turner *et al.*, 1992; Crawford, *in* Turner, 1992).

The correlations proposed here have two further implications:

- The easternmost of two north-striking dolomite units west and north of the Savage River mine, shown as Savage Dolomite correlative on recent compilations (e.g. Everard and Richardson, 1995), is also a correlative of the Smithton Dolomite. This unit is called the 'Doodle Dolomite and Corinna Slate' by Shannon (1988).

- As this succession appears to face east, the 'Tunnelrace Volcanics' adjoining this unit to the east (Shannon, 1988) may be Cambrian in age. Similarly, on the Corinna 1:50 000 scale map sheet, unit Pdg (slaty siltstone with minor chert) and/or the Tunnelrace Volcanics [342 000 mE, 5 387 000 mN] could be Cambrian.

A Cambrian age and correlation with the Dundas Group has been suggested for the volcanic rocks in the Brookside area [342 900 mE, 5 391 600 mN], based on the presence of chromite grains and dacitic clasts in epiclastic rocks (Crawford, *in* Henham, 1990). These rocks are considered to be Bernafai Volcanics rather than Tunnelrace Volcanics (Henham, 1990).

SUCCESS CREEK GROUP AND CRIMSON CREEK FORMATION

Introduction

The Success Creek Group in the Renison Bell–Pieman Road area comprises about 1000 m of sandstone, shale and minor dolostone, and is conformably overlain by the Crimson Creek Formation, a succession of mafic-volcaniclastic sandstone, shale and basalt, 5000 m or more in thickness (Brown, 1986). There are few direct age constraints. However, correlation with the Black River Dolomite and Kanunnah Subgroup of the Togari Group seems reasonably well-established, on the basis of the broad similarity of the lithostratigraphic succession, basalt lithogeochemistry, and the occurrence of the stromatolite *Baicalia* cf. *B. burra* as clasts in both the Black River Dolomite and the Success Creek Group (Williams, 1978; Brown, 1986). This correlation implies a mid-Cryogenian age for the Success Creek Group and a late Cryogenian–early Neoproterozoic III age for the Crimson Creek Formation (Brown, 1989*a*; Calver, 1995; Calver, in press; and see previous section).

Renison mine geologists have long assumed a Lower Cambrian age for the Crimson Creek Formation, following Solomon (1965), and a single Cambrian acritarch has been reported from the formation (Vidal *in* Cooper and Grindley, 1982). The Crimson Creek Formation is lithologically very similar to fossiliferous, Middle Cambrian correlatives of the Dundas Group (Findlay, 1993), and a Cambrian age for both the Crimson Creek Formation and the Success Creek Group has recently been proposed (R. H. Findlay, pers. comm.).

Adabi (in press) has demonstrated that least-altered carbonate rocks from the 'No. 1' and 'No. 3' dolomite units of the uppermost Success Creek Group, and a third carbonate horizon in the lower Crimson Creek Formation, have strongly ^{13}C-enriched compositions (+6 to +7‰), consistent with a Neoproterozoic, rather than Cambrian, age for these units.

Carbonate rocks in the upper part of the Success Creek Group host major stratabound iron sulphide-cassiterite deposits at Renison Bell, and minor carbonate rocks are also present in the lower Crimson Creek Formation. The mineralisation is of Devonian, magmatic-hydrothermal origin. A large number of drill core intersections are available, and two drill cores (S1134 and S1642) distant from known mineralisation were sampled in order to extend Adabi's work and, most importantly, to attempt to obtain meaningful $^{87}Sr/^{86}Sr$ results, which would be useful in further constraining correlation of the succession. Four additional samples from drill holes S705 and S835, kindly provided by M. Adabi (University of Tasmania), were analysed for $^{87}Sr/^{86}Sr$. A dolostone unit in the upper Success Creek Group was also sampled from outcrop on the Pieman Road.

Lithostratigraphy

The lithostratigraphy of the upper Success Creek Group–lower Crimson Creek Formation ('Renison Mine Sequence') is well known in the mine area. In downward stratigraphic order the sequence consists of (Morrison, 1982; Brown, 1986):

- Crimson Creek Formation (no top exposed): siltstone, lithicwacke, minor basalt, and rare carbonate;

- The 'No. 1 Dolomite': up to 25 m of grey, stylolitic, laminated dolostone;

- The 'Red Rock Member': up to 35 m of hematitic chert, mudstone, iron formation and conglomerate;

- The 'No. 2 Dolomite': 5 to 30 m of faintly laminated and pelletal dolostone, locally with stromatolites, oolites and possible evaporites;

- The Renison Bell Formation: up to 80 m thick, of quartz sandstone and minor conglomerate, fining up into siltstone, shale and nodular dolostone;

- The 'No. 3 Dolomite': up to 15 m of massive, locally laminated or pelletal, dolostone;

- The Dalcoath Formation, up to 800 m of shallow-marine quartz sandstone, siltstone and conglomerate. Near the top, the formation fines upward with siltstone and shale with nodular dolostone becoming predominant towards the contact with the No. 3 Dolomite.

The top of the No. 1 Dolomite is taken as the top of the Success Creek Group (Brown, 1986), although earlier workers and Renison mine geologists place the boundary at the top of the No. 2 Dolomite. The sequence is characterised by lateral facies variation, and strong changes in thickness and local splitting and wedging-out of units, including the three main carbonate horizons. Diachroniety of units is therefore to be expected. The three dolostone units are thought to have been deposited in intertidal-supratidal environments (Morrison, 1982).

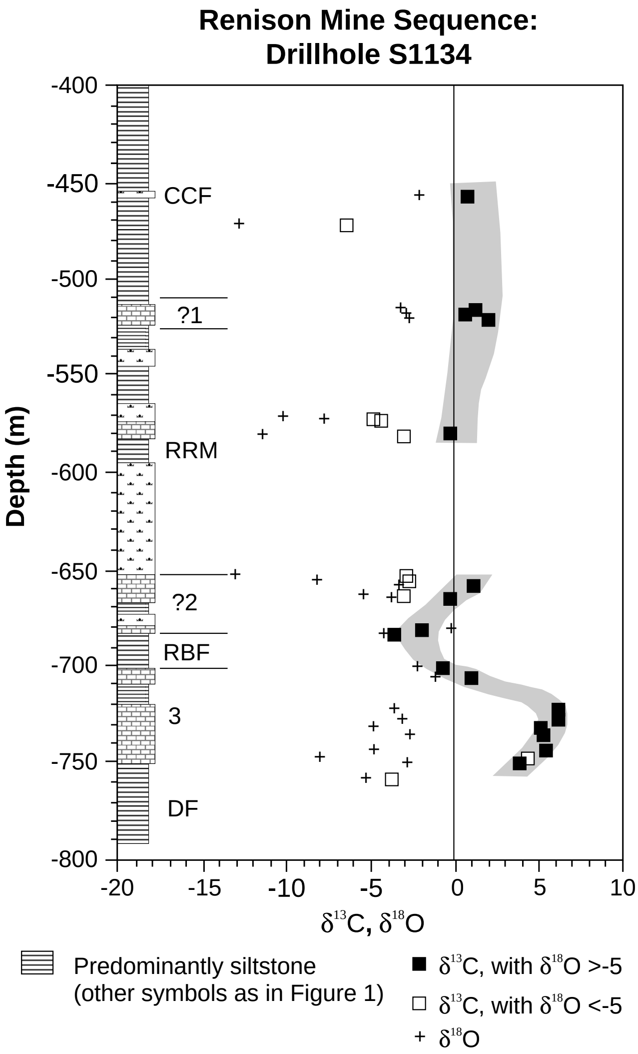

Figure 6

Lithologic column of Renison Mine Sequence in drillhole S1134, with $\delta^{13}C$ and $\delta^{18}O$ data. Shaded area represents probable primary marine $\delta^{13}C$ signal. CCF: Crimson Creek Formation; 1: No. 1 Dolomite; RRM: 'Red Rock Member'; 2: No. 2 Dolomite; RBF: Renison Bell Formation; 3: No. 3 Dolomite; DF: Dalcoath Formation.

Drill holes S1134 and S1642 have been logged by Renison geologists, and their stratigraphic assignations, in terms of the above scheme, together with simplified graphic logs, are provided in Figures 6 and 7.

Drill hole S1134, located 3.5 km northwest of the mine area, intersected a relatively thick No. 3 Dolomite, in two splits (fig. 6). The Renison Bell Formation correlate is thin — only 20 m (thicknesses are not corrected for dip of bedding relative to core axis). The ?No. 2 Dolomite occurs as two splits, separated by conglomerate and siltstone assigned to the Red Rock Member. The Red Rock Member is very thick (c. 150 m in total) and includes a seven metre thick dolostone unit towards the top. A probable No. 1 Dolomite is present, and there are two further, thin dolostone units in the lower part of the succeeding Crimson Creek Formation.

Drill hole S1642, located three kilometres southwest of the mine area, intersected 6.2 m of dolostone assigned to the No. 3 Dolomite, succeeded by about 90 m of Renison Bell Formation (fig. 7). The No. 2 Dolomite is relatively thick (43 m) and unusual in

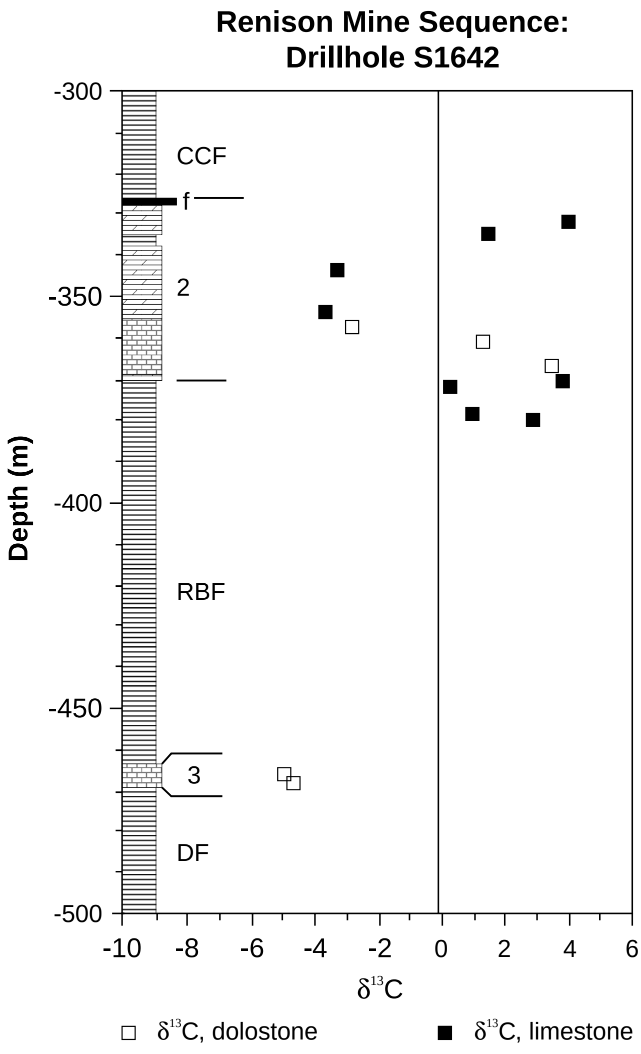

Figure 7

Lithologic column of Renison Mine Sequence in drillhole S1642, with $\delta^{13}C$ and $\delta^{18}O$ data. Abbreviations as Figure 6.

consisting predominantly of impure limestone. Younger units, including the No. 1 Dolomite, are faulted out.

An outcropping carbonate unit about eight metres thick was sampled on the Pieman Dam Road, about 14 km northwest of the Renison mine. The unit consists of massive, pale yellow-brown fine-grained dolostone, and is overlain by red mudstone, chert, and ferruginous granule conglomerate, correlative with the Red Rock Member. The unit may therefore be correlative with the No. 2 Dolomite or some higher horizon.

Isotope stratigraphy

In drill hole S1134, dolostones of the lower split of the No. 3 Dolomite display a concordant and well-defined trend in $\delta^{13}C$, increasing from +4‰ to +6‰ upward through 31 m of section. The upper split, at +1 to -1‰, appears to be part of a steeply declining trend. All samples are relatively pure, fine-grained dolostone, almost all have relatively high $\delta^{18}O$ (-1 to -5‰), and carbon isotopic compositions are therefore likely to be close to original values. One discordant $\delta^{13}C$ result of -3.8‰ from the uppermost Dalcoath Formation, below the No. 3 Dolomite, comes from irregular diagenetic nodules in which carbonate may be partly derived from ^{13}C-depleted organogenic CO_2 in early diagenesis — a process typical of carbonate nodule growth (e.g. Irwin *et al*., 1977).

Results from the lower split of the ?No.2 Dolomite appear to define a negative excursion in $\delta^{13}C$ to around -2‰; in the upper split a return to +1‰ is seen. In the upper part of the upper split, $\delta^{18}O$ (and to a lesser extent, $\delta^{13}C$) steeply decline towards the contact with the overlying fractured, chloritic, hydrothermally altered conglomeratic unit. These carbon isotopic compositions (-2 to -3‰) may have been altered by hydrothermal fluids moving through the overlying unit, presumably a pathway for Devonian magmatic hydrothermal-dominated fluids.

Carbon isotopic compositions of the three higher dolostone horizons — within the upper Red Rock Member, the ?No. 1 Dolomite, and within the lower Crimson Creek Formation — define a more or less concordant trend at 0 to +2‰, if samples with depleted (less than -5‰) $\delta^{18}O$ are ignored. The interpreted relatively unaltered samples have $\delta^{18}O$ tightly clustering around -2 to -3‰. The shaded area in Figure 6, representing the inferred $\delta^{13}C$ signal, is based only on samples with relatively high (>-5‰) $\delta^{18}O$.

In drill hole S1642 the ?No. 3 Dolostone is very strongly depleted in $\delta^{18}O$ (-18 to -19‰); accordingly the carbon isotopic compositions (-5‰) are likely to reflect Devonian hydrothermal overprint and be meaningless for chemostratigraphy. Unfortunately the carbonate rocks from the No. 2 Dolomite are also quite strongly ^{18}O-depleted (dolostone around -8‰; limestone around -15‰). Only samples from the base and top of the unit, with $\delta^{13}C$ at +4‰, may be relatively unaltered in $\delta^{13}C$. ^{13}C-depleted samples (c. -3‰) from the middle of the unit are quite impure (only 10–38% carbonate) and unlikely to reflect primary marine values.

Samples from near the base, middle and top of the dolostone unit on the Pieman Dam Road are all just under 4‰ in $\delta^{13}C$, and being relatively $\delta^{18}O$-rich (-1 to -3‰), are considered likely to retain near-primary carbon isotopic compositions.

Six limestone samples from S1642 were analysed for $^{87}Sr/^{86}Sr$. The ratios are all strongly altered (0.718–0.738) (Appendix 1.2). Four dolomicrite samples, provided by M. Adabi, were also analysed. These were selected from a large sample set, as having the highest $\delta^{18}O$ (around 0‰), high $\delta^{13}C$, and low Mn/Sr (Appendix 1.2). Unfortunately the dolostones also have $^{87}Sr/^{86}Sr$ ratios (0.714–0.716) that are higher than any likely marine value, but not as altered as the limestones. Evidently, the more soluble limestones were more susceptible to partial dissolution-reprecipitation in the hydrothermal environment and consequent contamination with radiogenic strontium. The selected dolostones, with stable isotopic compositions apparently unaffected by hydrothermal processes, nonetheless appear to have somewhat altered strontium isotopic compositions, at least in part because of their inherently very low Sr contents (c. 100 ppm). There remains a possibility that the dolostones are relatively unaltered in $^{87}Sr/^{86}Sr$, and non-marine.

Age and correlation

Results from drill hole S1134 confirm Adabi's (in press) finding of ^{13}C-enriched carbonate rocks (+4 to +6 ‰) in the No. 3 Dolomite, which he found in drill hole S835 3.8 km west of the Renison mine. Beyond this the $\delta^{13}C$ results, taken as a whole, are ambiguous. On sparse data, there is a broad negative excursion to c. -2‰ around the ?No. 2 Dolomite in S1134. It is possible that there is a correlative negative excursion of more limited stratigraphic extent in the middle of the thick No. 2 Dolomite in drill hole S1642, but the samples are too altered for this to be certain. Adabi (in press) records $\delta^{13}C$ of c. +3‰ in the No 2 Dolomite of S705, but here the unit, at 2.6 m thick, is much thinner than usual (Stephenson and Bond, 1981). The three carbonate horizons higher up in S1134, including the ?No. 1 Dolomite, have carbon isotopic compositions (0 to +2‰) different from the No. 1 horizon in S705 (+4 to +6‰: Adabi, in press).

The apparent inconsistencies are probably an inevitable result of diachroniety and lateral impersistence of the carbonate horizons, which in any case have recorded only a very incomplete part of the chemostratigraphic 'signal'. A more intensive and systematic sampling programme may capture more of the signal and reveal consistent patterns of secular $\delta^{13}C$ change, and assist in local correlations if individual units could be isotopically characterised. A concomitant sedimentological study should be carried out to monitor any facies overprint and seek marine/non-marine indicators.

The $\delta^{13}C$ of the No. 3 Dolomite in drill holes S835 (Adabi, in press) and S1134 is very similar to the upper Savage Dolomite (and the correlative middle Black River Dolomite). The negative excursion above the No. 3 Dolomite in S1134 may correspond to the negative excursion seen in the upper Black River Dolomite, but without corroborative data from Sr isotopes the chemostratigraphic evidence is not compelling. Lithostratigraphic and biostratigraphic evidence remains stronger on this point. Clasts containing the stromatolite *Baicalia* cf. *B. burra* occur in the Red Rock Member (Brown, 1986) and in the upper Black River Dolomite (Griffin and Preiss, 1976). Diamictites in the Red Rock Member (e.g. 537–546 m; 568–573 m in S1134) closely resemble the diamictite of the Julius River Member of the upper Black River Dolomite. Significantly, iron-formation is known from Sturtian (but not the younger Marinoan) glacigene sequences (Preiss, 1987), consistent with a correlation of the Red Rock Member with the Sturtian glacials.

OONAH FORMATION

Introduction

Reconnaissance sampling was undertaken of carbonate rocks in the upper part of the Oonah Formation from drill holes west of Zeehan. The Oonah Formation, a thick, monotonous succession of interbedded quartzite and black shale, passes up into an 'upper Oonah' succession of laminated siltstone, black shale, dolomite, limestone, and spilitic volcanic rocks north and west of Zeehan. The 'upper Oonah' is host to a number of Devonian vein, skarn and replacement-tin deposits in this area.

Turner *et al*. (1992, 1994) considered the Oonah Formation to be a thick, distal, basinal equivalent of the Forest Conglomerate (the impersistent basal unit of the Togari Group, underlying the Black River Dolomite). These authors implicitly considered the Oonah to pass conformably up into the Success Creek Group. However Brown (1986) — who had access to outcrop now flooded by Lake Pieman — considered the relationship to be unconformable, with more phases of deformation in the Oonah suggesting a substantial time break. R. H. Findlay (pers. comm. 1996) recently suggested a Cambrian age for the Oonah Formation.

Radiometric constraints suggest a mid to late Cryogenian age for the Oonah Formation. K-Ar ages have been obtained from slate (690 ± 10 Ma), and from detrital muscovite (708 ± 6 Ma) (Adams *et al*., 1985; Turner, 1993). A dolerite intrusion in a lithologic correlate of the Oonah has features suggestive of synsedimentary intrusion, and is dated by K-Ar at 725 ± 35 Ma (Crook, 1979).

Limestone outcrop has been recorded in the Burnie Formation, a correlate of the Oonah (Green, 1977), near Ridgely in northwest Tasmania. A concerted effort was made to relocate this outcrop, with no success.

Lithostratigraphy

Three drill holes (G57, G60 and G61) from Queen Hill, one kilometre west of Zeehan, and two holes (Sylvester 1 and 2) from the Comstock–Sylvester area a few kilometres further west, were sampled. The upper Oonah is characterised by marked lateral variation and isoclinal folding, with facing reversals often observed in drill holes. There are broad, irregular melange zones (Crossing, 1990). Thus, no attempt has been made to place the analyses in stratigraphic sequence. Sideritised gypsum evaporites are recorded by Anderson (1986). Summary logs, in part from company exploration reports (Young, 1980*a*, *b*; Crossing, 1990), are as follows (with sampled units in bold type):

G57

0–184 m	Interbedded black shale and quartzite
184–241 m	Volcanic conglomerate
241–250 m	Black siltstone
250–273 m	**Predominantly massive, pale grey, fine-grained, veined dolostone**
273–307 m (EOH)	Carbonate-rich lithic tuff-agglomerate

G60

0–228 m	Volcanic rocks: carbonate-rich mafic tuff and agglomerate
228–268 m	**Predominantly massive, pale grey, fine-grained, veined dolostone**
268–301 m (EOH)	Carbonaceous shale, siltstone and tuff

G61

0–250 m	Interbedded quartzite and black shale
250–284 m	**Dolostone, recrystallised dolostone, dolostone breccia**
284–308 m (EOH)	Shale, agglomerate

Sylvester 1

0–69 m	Carbonaceous siltstone and shale
69–86 m	**Interbedded limestone and shale**
86–118 m	Sandstone and shale
118–137 m	Melange
137–189 m	Skarn, sandstone, melange (Tenth Legion Thrust at base)
189–193 m	Cambrian gabbro

Sylvester 2

0–83 m	Melange (Oonah Formation)
83–396 m	Faulted interval of lithic arenite and mudstone (Cambrian Dundas Group?)
396–427 m	Interbedded siltstone and sandstone; **dolostone at 406-408 m** (Oonah Formation)
427–464 m	Interbedded siltstone and sandstone
464–475 m	**Dolostone**
475–483 m	Siltstone/mudstone
483–500 m	**Dolostone**
500–535 m (EOH)	Mudstone, melange, lithic arenite

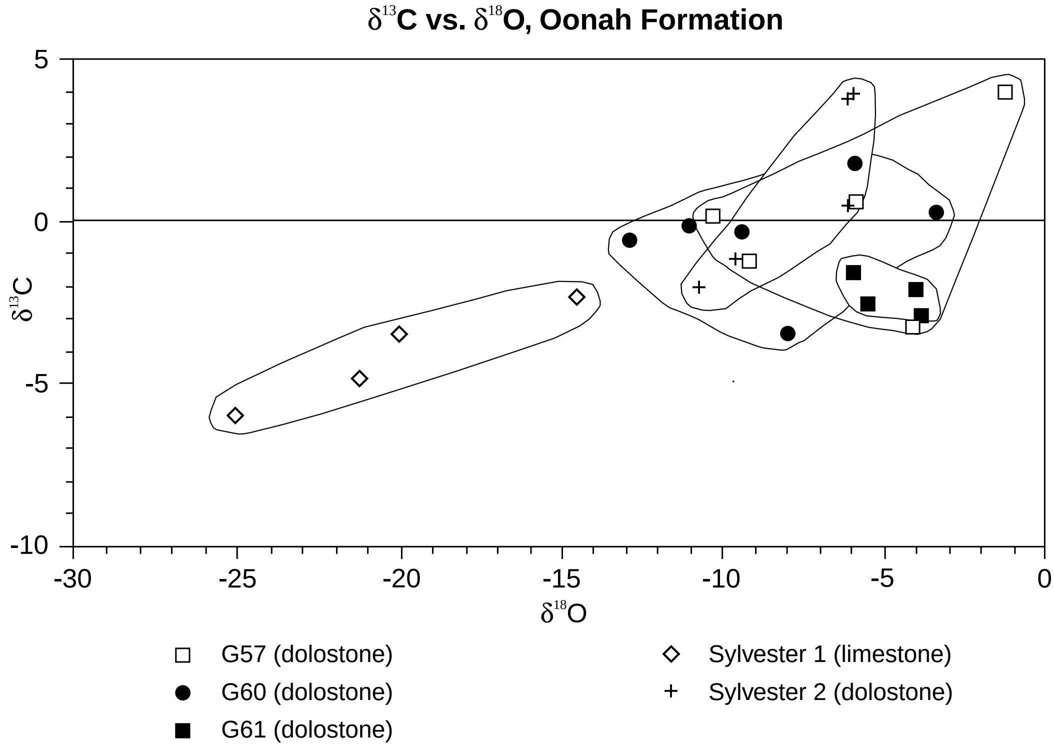

Figure 8

$\delta^{13}C$ – $\delta^{18}O$ crossplot of Oonah Formation samples.

Isotope stratigraphy

The stable isotopic compositions obtained from the Oonah Formation are marked by a wide range of $\delta^{13}C$ values (-6 to +4‰) and are moderately to very strongly depleted in ^{18}O (-3 to -25‰). There is a loose δ^{13}CC–$\delta^{18}O$ covariation in most drill holes (fig. 8), suggesting that all but the most ^{18}O-enriched samples have altered $\delta^{13}C$. Samples with $\delta^{18}O$ greater than -6‰ are probably little-altered in $\delta^{13}C$; these samples range from +4‰ (G57, Sylvester 2) to -3‰ (G57, G61). The heaviest values are characteristically Neoproterozoic (i.e. unlikely to be Cambrian).

Two limestone samples from Sylvester 1 yielded altered, radiogenic $^{87}Sr/^{86}Sr$ results (0.712 and 0.717) that probably reflect some degree of interaction with Devonian hydrothermal fluids.

'CLEVELAND–WARATAH ASSOCIATION'

Introduction

A three-part conformable stratigraphic succession in the Cleveland area consists of the Deep Creek Volcanics (dominantly spilitic basalt with minor sediments, probably over 600 m thick), the Hall Formation (shale, tuff, limestone, chert and basalt, about 100 m thick), and the Crescent Spur Sandstone (muscovitic greywacke, mudstone and chert, over 350 m thick) (Collins, 1983).

The succession is generally considered to be Cambrian in age, but the rocks are unfossiliferous and age constraints are tenuous. Basalts from the Deep Creek Volcanics and Hall Formation exhibit geochemical affinities to ocean floor basalt (Collins, 1983) and are thought to be genetically related to the ultramafic-mafic 'Layered Pyroxenite-Dunite' (LPD) association of western Tasmania (Brown and Jenner, 1988, Brown, 1989*b*). In turn the age of the ultramafic complexes is constrained by a U-Pb zircon age of 517 ± 6 Ma (late Early Cambrian) from a tonalite from the Heazlewood Ultramafic Complex, probably representing the crystallisation age of the last magmatic phase of the ultramafic association (Turner, 1993; Black, 1994). The ultramafic-mafic complexes, together with the 'Cleveland–Waratah association', are thought to be allochthonous remnants of an oceanic fore-arc, obducted onto passive margin in the late Early or early Middle Cambrian (Berry and Crawford, 1988; Brown and Jenner, 1988). However, an oceanic forearc provenance is not consistent with the muscovitic, quartzose composition (i.e. continental provenance) of the Crescent Spur Sandstone. The 'Cleveland–Waratah association' is one of the more enigmatic Tasmanian rock associations in terms of age and genesis.

Limestone units in the Hall Formation host the sulphide-cassiterite replacement deposits of the abandoned Cleveland mine. An unmineralised drill core intersection of the Hall Formation was sampled for isotopic analysis and for acritarchs.

Lithostratigraphy

Limestones were sampled in the 515–548 m depth interval in diamond drill hole C1290. Impure limestone is interbedded with tuffaceous shale, black mudstone and pale grey chert. Much of the limestone appears to be of detrital, possibly turbiditic, origin. Graded units are 100 to 300 mm thick and consist of lithoclastic, impure calcarenite or calcisiltite passing up into laminated cherty mudstone or, rarely, impure micritic limestone. There is some evidence for early cementation at 545–548 m (sharp tops to carbonate beds, greater purity, overburden stylolites). The sequence youngs down-hole.

Results

The micritic limestone and calcisiltite are -1 to -3‰ in $\delta^{13}C$ and are uniformly, rather strongly depleted in $\delta^{18}O$ (-15 to -16‰). The strong ^{18}O depletion, probably a regional metasomatic signature associated with Devonian granite intrusion, suggests that the carbon isotopic compositions are probably also somewhat altered. In view of this, and because the $\delta^{13}C$ values are not particularly distinctive, no useful chemostratigraphic information can be deduced. No attempt was made to analyse for $^{87}Sr/^{86}Sr$ because of the altered stable isotopic compositions.

Twelve shale and chert samples from between 565 m and 330 m depth in drill hole C1290 were processed by Laola Pty Ltd for acritarchs using a method developed by K. Grey. A preliminary examination by K. Grey (Geological Survey of Western Australia) showed no recognisable preservation of organic microfossils, apparently because of thermal metamorphism.

CONCLUSIONS

The $^{87}Sr/^{86}Sr$ of the limestone at the base of the Smithton Dolomite, together with previous results from the middle to upper parts of the formation (Calver, 1995; in press), forms part of an upward-increasing trend (0.7079–0.7085) consistent with a middle to upper Ediacarian age (c. 580–545 Ma) for the Smithton Dolomite.

The Savage Dolomite and Corinna Dolomite are not correlative. Carbon and strontium isotopes support correlation of the Savage Dolomite with the mid-Cryogenian Black River Dolomite of the Smithton Basin (except that temporal equivalents of the upper part of the Black River Dolomite, including the Julius River Diamictite, are absent). Carbon and strontium isotopes support correlation of the Corinna Dolomite with the Smithton Dolomite. Earlier schemes correlating the Togari and Ahrberg Groups, based on lithostratigraphy and basalt geochemistry, are strongly corroborated by isotope chemostratigraphy. Confirmation of the presence of a Smithton Dolomite correlative (Corinna Dolomite) is, however, new, and one consequence of this is that Cambrian rocks may be present in units adjoining the Corinna Dolomite on the eastern side.

The application of chemostratigraphy to units in the Dundas Trough (Success Creek Group, Oonah Formation, 'Cleveland–Waratah association') has been less successful, in part because of pervasive alteration of $^{87}Sr/^{86}Sr$. $\delta^{13}C$ evidence is consistent with correlation of the upper Success Creek Group with the upper Savage Dolomite and middle to upper parts of the Black River Dolomite, as expected on the basis of lithostratigraphy, stromatolite biostratigraphy and basalt lithogeochemistry. However no corroborative evidence from $^{87}Sr/^{86}Sr$ could be obtained because of pervasive alteration. Further work is required to fully understand the secular $\delta^{13}C$ signal of the many thin, probably diachronous dolostone units of the upper Success Creek Group and lower Crimson Creek Formation.

Carbonate rocks in the upper Oonah Formation exhibit a range of little-altered $\delta^{13}C$ values (-3 to +4‰), the upper end of this range being characteristic of Neoproterozoic (but not Cambrian) carbonates. Other than this, results from the Oonah Formation (and the Cleveland–Waratah sequence) are of little chemostratigraphic significance without $^{87}Sr/^{86}Sr$ data unaffected by later events.

A more successful outcome from the Dundas Trough units would probably follow from sampling in areas unaffected by Devonian hydrothermal activity, which appears to be the cause of pervasive radiogenic contamination of $^{87}Sr/^{86}Sr$ and much resetting of stable isotopic compositions. Unfortunately, natural outcrop of these thin carbonates is rare in western Tasmania, necessitating a reliance in the present study on the mineralised areas for which a plethora of drill core is available. Likewise, sampling for acritarchs in such units as the 'Cleveland–Waratah association' needs to be undertaken from fresh outcrop or drill core distant from granite.

ACKNOWLEDGEMENTS

Mohammad Adabi (University of Tasmania) is thanked for discussions, and for providing his four least-altered dolostone samples from the Renison Mine Sequence, together with stable isotope and trace-element data, for $^{87}Sr/^{86}Sr$ analysis. Chris Mroczek and core store staff at Renison Ltd are thanked for access to Renison drill core. Aberfoyle Exploration are thanked for permitting access to Oonah Formation drill core at their Zeehan store. Kath Grey (Geological Survey of Western Australia) examined palynological residues from the Cleveland hole. Isotopic analyses were carried out by Christine Cook (CSL) and Steve Craven (CSIRO), and paid for by the Australian Geological Survey Organisation. Tony Yeates and Geoff Green are thanked for constructive reviews.

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[26 August 1997]

APPENDIX 1
Analytical data

1.1 Locational and stable-isotopic data

Sample	Depth (m) or AMG co-ordinates	Mineralogy*	% carb[§]	$\delta^{13}C$	$\delta^{18}O$
SMITHTON DOLOMITE					
Scotchtown quarry					
EC-1	[341 200 mE, 5 472 100 mN]	L	106	0.51	-6.31
SAVAGE DOLOMITE					
Drillhole DS6381 [333999 5380755]					
DS6381-1	270’	D	58	2.11	-4.92
DS6381-2 dark	302’	D	65	2.44	-4.83
DS6381-2 pale	302’	D	41	2.53	-3.48
Drillhole DS6383 333648 5380361]					
DS6383-1	193’	D	49	4.01	-2.55
Drillhole DS6385 [334423 5380723]					
DS6385-1	480’6“	D	69	4.82	-4.52
DS6385-2	405’6“	D	40	3.99	-3.47
DS6385-3 dark	370’	D	72	4.57	-3.05
DS6385-3 pale	370’	D	59	5.37	-0.19
DS6385-4	290’	D	61	4.24	-4.36
DS6385-5	240’	D	34	3.59	-3.94
DS6385-6	182’	D	49	5.41	-1.22
Outcrop samples					
S4	[340 330 mE, 5 391 080 mN]	D	94	4.28	-1.26
S6	[340 470 mE, 5 391 270 mN]	D	85	3.18	-3.73
S7	[340 620 mE, 5 391 370 mN]	D	92	4.83	-2.04
S8	[340 690 mE, 5 391 470 mN]	D	94	4.72	-0.76
S9	[340 200 mE, 5 390 860 mN]	D	100	3.34	-4.47
CORINNA DOLOMITE					
Drillhole 87-56 [339 900 mE, 5 386 880 mN]					
87-56-1	22.50	D	34	0.07	-1.63
Drillhole 87-57 [339 830 mE, 5 386 860 mN]					
87-57-1	29.70	D	51	0.39	-3.62
Drillhole 87-58 [339 870 mE, 5 386 840 mN]					
87-58-1	31.40	D	55	-0.15	-5.17
Drillhole 87-59 [339 850 mE, 5 386 810 mN]					
87-59-1	33.80	D	53	0.18	-2.94
Drillhole 87-60 [339 800 mE, 5 386 830 mN]					
87-60-1	37.40	D	50	0.42	-4.80
Drillhole 87-61 [339 750 mE, 5 386 860 mN]					
87-61-1	34.20	D	51	0.48	-1.14
Drillhole SMC-2 [342 602 mE, 5 390 369 mN]					
SMC2-1	79.00	D	71	0.82	-3.45
Drillhole BRK-2 [342 880 mE, 5 391 635 mN]					
BRK2-1	6.70	D	93	-3.40	-3.75
BRK2-2	17.30	D	89	0.63	-2.37
BRK2-3	21.00	D	95	0.18	-2.96
BRK2-4	28.80	D	101	1.35	-3.52

Sample	Depth (m) or AMG co-ordinates	Mineralogy*	% carb[§]	$\delta^{13}C$	$\delta^{18}O$
Drillhole BRK-5 [342862 5391682]					
BRK5-1	9.00	D	98	0.31	-1.96
Outcrop samples					
S10	[341 700 mE, 5 389 100 mN]	D	103	0.50	-5.82
S11	[342 650 mE, 5 390 770 mN]	D	94	-0.44	-4.40
S13	[342 600 mE, 5 390 820 mN]	D	92	-0.42	-0.15
S14	[342 780 mE, 5 390 730 mN]	D	76	1.03	-5.59
SUCCESS CREEK GROUP					
Drillhole S1134 [367292 5373655]					
S1134-1	457.00	D	88	0.87	-2.07
S1134-2	471.85	D	6	-6.31	-12.81
S1134-3	516.50	D	93	1.24	-3.20
S1134-4	519.20	D	95	0.72	-2.89
S1134-5	521.50	D	65	2.05	-2.66
S1134-9	653.70	D	83	-2.84	-13.15
S1134-10	656.30	D	93	-2.74	-8.24
S1134-11	659.20	D	89	1.19	-3.24
S1134-12	663.40	D	33	-3.06	-5.48
S1134-13	665.90	D	95	-0.27	-3.78
S1134-14	681.50	D	68	-1.97	-0.27
S1134-15	684.00	D	75	-3.58	-4.19
S1134-16	573.80	D	83	-4.45	-7.70
S1134-17	571.40	L	51	-4.79	-10.24
S1134-19	579.60	D	82	-0.30	-2.91
S1134-20	580.70	D	63	-3.07	-11.36
S1134-21	702.00	D	94	-0.78	-2.19
S1134-22	707.30	D	96	1.04	-1.16
S1134-23	722.00	D	102	6.15	-3.66
S1134-24	727.70	D	103	6.24	-3.18
S1134-25	731.60	D	99	5.17	-4.91
S1134-26	736.50	D	99	5.32	-2.66
S1134-27	743.40	D	101	5.43	-4.80
S1134-28	748.00	D	99	4.32	-8.07
S1134-29	751.00	D	99	3.85	-2.82
S1134-30	758.80	D	81	-3.81	-5.38
Drillhole S1642 [368210 5369139]					
S1642-1	466.00	D	75	-4.99	-18.31
S1642-2	468.10	D	65	-4.64	-18.97
S1642-3	357.60	D	10	-2.76	-16.44
S1642-4	361.10	D	89	1.29	-8.80
S1642-6	366.90	D	96	3.45	-8.38
S1642-7	370.50	L	105	3.87	-9.69
S1642-8	372.00	L	61	0.27	-14.45
S1642-9	380.00	L	52	2.92	-15.76
S1642-10	331.90	L	94	4.01	-15.64
S1642-11	334.80	L	78	1.55	-16.65
S1642-12	343.30	L	18	-3.28	-16.30
S1642-13	353.80	L	36	-3.62	-15.69

Sample	Depth (m) or AMG co-ordinates	Mineralogy*	% carb§	$\delta^{13}C$	$\delta^{18}O$
Outcrop samples					
LPD-2	[360 350 mE, 5 380 150 mN]	D		3.78	-2.69
LPD-3	[360 350 mE, 5 380 150 mN]	D		3.64	-2.88
LPD-5	[360 350 mE, 5 380 150 mN]	D		3.51	-1.17
OONAH FORMATION					
Drillhole G57 [360558 5361345]					
G57-1	253.50	D	65	-3.27	-4.08
G57-2	258.10	D	91	0.14	-10.30
G57-3	259.70	D	96	3.92	-1.19
G57-4	263.40	D	71	0.55	-5.87
G57-5	270.30	D	102	-1.28	-9.14
Drillhole G60 [360553 5361859]					
G60-2	231.10	D	91	0.21	-3.29
G60-3	232.40	D	86	-3.47	-7.91
G60-4	237.90	D	79	-0.41	-9.35
G60-6	254.60	D	96	-0.20	-10.98
G60-7	257.40	D	94	1.74	-5.88
Drillhole G61 [360800 5361700]					
G61-1	255.00	D	80	-2.58	-5.52
G61-2	258.40	D	90	-1.56	-5.94
G61-3	270.70	D	89	-2.15	-4.02
G61-4	274.90	D	81	-2.87	-3.83
Drillhole SY1 [357540 5360200]					
SY1-3	75.30	L	73	-4.86	-21.21
SY1-4	77.60	L	40	-5.99	-25.05
SY1-5	79.10	L	76	-2.39	-14.47
SY1-6	82.00	L	74	-3.45	-19.97
Drillhole SY2 [358889 5361368]					
SY2-3	407.20	D	92	0.41	-6.14
SY2-4	468.30	D	80	3.90	-5.90
SY2-5	472.80	D	100	3.67	-6.12
SY2-6	484.10	D	86	-1.29	-9.58
SY2-7	496.20	D	93	-2.12	-10.72
‘CLEVELAND–WARATAH ASSOCIATION’					
Drillhole C1290 [366 150 mE, 5 406 951mN]					
C2	519.00	L	53	-1.62	-15.24
C4	522.70	L	69	-1.38	-15.53
C6	532.30	L	54	-3.09	-15.50
C7	536.80	L	79	-2.70	-15.68
C8a	544.70	L	78	-2.89	-15.46
C8b	544.70	L	91	-2.34	-15.47
C9	547.70	L	76	-2.80	-15.96

*L = limestone; D = dolomite
§ % carb = approximate percent carbonate based on CO_2 yield after phosphorolysis

1.2 Trace-element and strontium isotope data

Formation	Sample	Mineralogy	Sr (ppm)	Mn (ppm)	Mn/Sr	IR (%)**	$^{87}Sr/^{86}Sr$
Smithton Dolomite	EC-1	L	1202	38	0.03	1.17	0.707877
Savage Dolomite	DS6385-3 pale	D	73	76	1.04	1.46	0.707578
Corinna Dolomite	87-61-1	D	36	37	1.03	0.79	0.708371
Success Creek Group	S1642-7	L	122	2850	23.36	7.31	0.729189
Success Creek Group	S1642-8	L	92	3420	37.17	41.4	0.723549
Success Creek Group	S1642-9	L	237	1018	4.30	25	0.737780
Success Creek Group	S1642-10	L	351	960	2.74	6.67	0.717555
Success Creek Group	S1642-11	L	218	1809	8.30	22.8	0.722752
Success Creek Group	S1642-13	L	79	1154	14.61	62.2	0.731765
Success Creek Group	S705-166.4	D	104	177	1.70	0	0.715713
Success Creek Group	S705-171.7	D	98	186	1.90	4.16	0.713763
Success Creek Group	S705-172.8	D	90	198	2.20	2	0.714515
Success Creek Group	S835-204.5	D	73	329	4.50	8.72	0.713550
Oonah Formation	SY1-3	L	555	1856	3.34	23.9	0.717078
Oonah Formation	SY1-4	L	681	305	0.45	58.1	0.712487

*IR(%) = insoluble residue