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TRIASSIC SANDSTONE PETROLOGY OF TASMANIA: EVIDENCE FOR A TASMANIA-TRANSANTARCTIC BASIN

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(with eight text-figures and five tables)

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Similar fluvial sequences of Triassic age occur in Tasmania and the Transantarctic Mountains of Victoria Land. The Tasmanian reference section at Poatina consists of Lower Triassic quartzose fluvial sandstones overlain by Middle and Upper Triassic volcaniclastic fluvial sandstones and shale containing coal. Similar, but less well-exposed sequences, occur in many places in Tasmania and in southern Victoria Land. The hypothetical Tasmania–Transantarctic basin was similar in scale, configuration, and history to the Sydney foreland basin. Palaeocurrent data suggest that streams flowed along the axis of the basin from Antarctica to Tasmania. Lower Triassic sandstones were deposited by braided streams, but Middle and Upper Triassic stream deposits change from braided to meandering downstream toward Tasmania. Quartzose sandstones in the Lower Triassic were derived from northwestern Tasmania and the East Antarctic craton. The source of volcaniclastic sandstones in the Middle and Upper Triassic was a calcalkaline volcanic arc along the palaeo-Pacific margin.
Key Words: Triassic, Tasmania, sandstone petrology, foreland basin, Antarctica, Gondwana.

INTRODUCTION

Prominent features of the landscape of central and eastern Tasmania are the dolerite-capped cliffs of Triassic sandstone along the margins of plateaus. Similar plateaus demonstrating the same stratigraphic relationships are characteristic of parts of the Transantarctic Mountains along the Ross Sea. The similarity between these landscapes on opposite sides of the Southern Ocean is striking. Are the similarities superficial or are the rocks that characterise these landscapes closely related to each other in a reconstructed Gondwanan supercontinent? The Jurassic dolerites have a similar chemical signature that is unique to Tasmania and the Transantarctic Mountains. The Triassic sandstones, representing ancient river systems, are by their nature more complex. Our objectives are (1) to document the sandstone petrology of the stratigraphic section at Poatina, which serves as a reference section for the Triassic of Tasmania, (2) to identify major patterns in Triassic fluvial deposition, as indicated by environments of deposition, palaeocurrent patterns, and composition of sandstones as related to changing source areas, and (3) to relate the Triassic of the Tasmania basin to its palaeogeographic setting near the palaeo-Pacific margin of the Gondwanan supercontinent.

Reviews of the Triassic System in Tasmania include Banks (1973, 1978), Hale (1962), and Forsyth (1984, 1989). Maps and explanatory reports published by the Department of Mines and unpublished theses by students at the University of Tasmania have also contributed much to the knowledge of Triassic rocks in various parts of the state.

Fieldwork for the project was carried out from February to May 1980, with field checks in August 1982 and April 1988. A detailed petrologic analysis of Triassic sandstones was reported by Eggert (1983) in a Master's thesis at the Ohio State University. Additional information on measured sections and crossbedding data is detailed in this thesis, which is on file in the library at the University of Tasmania. Sample numbers refer to a collection of thin sections and slabs from 228 surface samples and 37 core samples housed in the Department of Geology, University of Tasmania.

STRATIGRAPHY

A variety of stratigraphic names has been applied to the Triassic rocks in Tasmania. Deposited in a single large fluvial system, most lateral differences in rock type are local facies variations. These facies changes and the difficulty of correlating stratigraphic units across fault blocks have resulted in a proliferation of local stratigraphic names. Formal stratigraphic names for Triassic units have not been applied on quadrangle maps of the Department of Mines since 1963. Instead, letters descriptive of rock types or facies, such as TRp (quartz sandstone), TRm (muddy fluvial plain facies), TRs (quartz and lithic-feldspathic sandstone and interbedded mudstone and siltstone) are assigned (Forsyth 1984). While portraying a useful description of rock units on a quadrangle map, these informal names are inadequate for regional discussions such as this.

From a descriptive standpoint, all Triassic rocks in Tasmania can be grouped into two lithostratigraphic units. The lower unit is characterised by quartzose sandstone and the upper unit by volcanic lithic sandstone and shale with coal toward the top of the section. Following Banks & Clarke (1973), we will use the nomenclature proposed by McKellar (1957) for the most complete and best exposed sequence of Triassic rocks in Tasmania, which is near Poatina along the northern margin of the Western Tiers (fig. 1). Because McKellar's descriptions and thicknesses are largely based on several cores, none of which fully penetrate the Triassic section, much confusion on the position of contacts at the surface exists. A proposal under consideration by the Department of Mines (S.M. Forsyth, personal communication) to obtain a complete core from a single borehole would be a great contribution to the knowledge of Tasmanian geology. The extensive mapping and palynologic studies of Triassic rocks underway by Forsyth (e.g. 1984, 1989), which are summarised in Forsyth (1989), will eventually lead to detailed correlations and perhaps a new stratigraphic nomenclature acceptable to everybody. A better knowledge of the microfloral sequence in Tasmania is essential to the interpretation of microfloras in Antarctica. Sections in the Transantarctic Mountains may be better exposed, but the intensity of Jurassic intrusions has seriously damaged the microfloral record (Collinson 1990b).

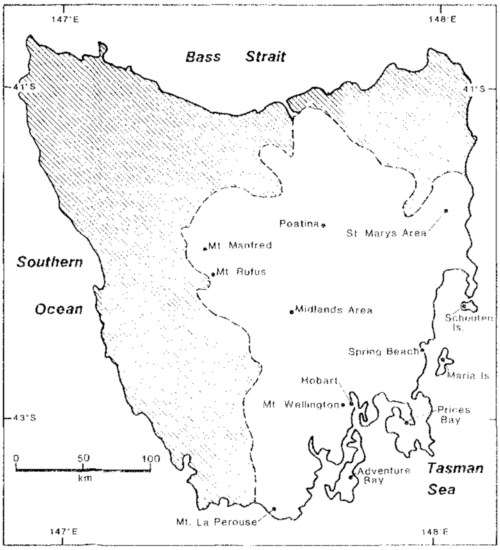

FIG. 1 — Map of Tasmania showing localities referred to in the text. Diagonal pattern outside of the area of known Triassic exposures.

The Parmeener Supergroup includes the Upper Carboniferous to Triassic sequence (Banks 1973). The Upper Parmeener Supergroup comprises the uppermost Permian and Triassic fluvial deposits. The lower part, including the Upper Permian and Lower Triassic, is composed predominantly of quartzose sandstone; the upper part, including the Middle and Upper Triassic, is dominated by shale and volcaniclastic sandstone. Coal occurs in both the Upper Permian and Upper Triassic. Late Permian floras are separated from Early Triassic microfloras by a widespread disconformity, with coal-bearing, somewhat feldspathic sandstone below and more quartzose sandstone with rare carbonaceous material above. Biostratigraphic control is not sufficient to determine whether this lithological break represents a hiatus across the Permian–Triassic boundary (Banks 1962, Banks & Naqvi 1967). The youngest unit with Permian fossils is the "Upper Freshwater Sequence", which is generally referred to as the Cygnet Coal Measures. Banks & Clarke (1987) interpreted these rocks to represent a sandy coastal plain sequence. In northeastern Tasmania, particularly in the area around St Marys, Middle Triassic fluvial sediments disconformably overlie Upper Permian marine beds, indicating a hiatus (Turner & Calver 1987). Regional truncation of Permian beds suggests slight tilting and erosion just before Middle Triassic deposition.

McKellar (1957) assigned the following formational names to the Triassic succession exposed along the Western Tiers (in ascending order): Ross Sandstone, Cluan Formation, Tiers Formation, and Brady Formation. Although these formations were originally based on cores, an excellent reference section, graphically depicted in figure 2, is exposed along the Poatina highway ascending the Western Tiers (Banks & Clarke 1973). This highway did not exist at the time McKellar completed his work. The palynostratigraphy of this sequence is somewhat known from the work of Playford (1965) and can be correlated with other sequences in Tasmania (Forsyth 1984, 1989).

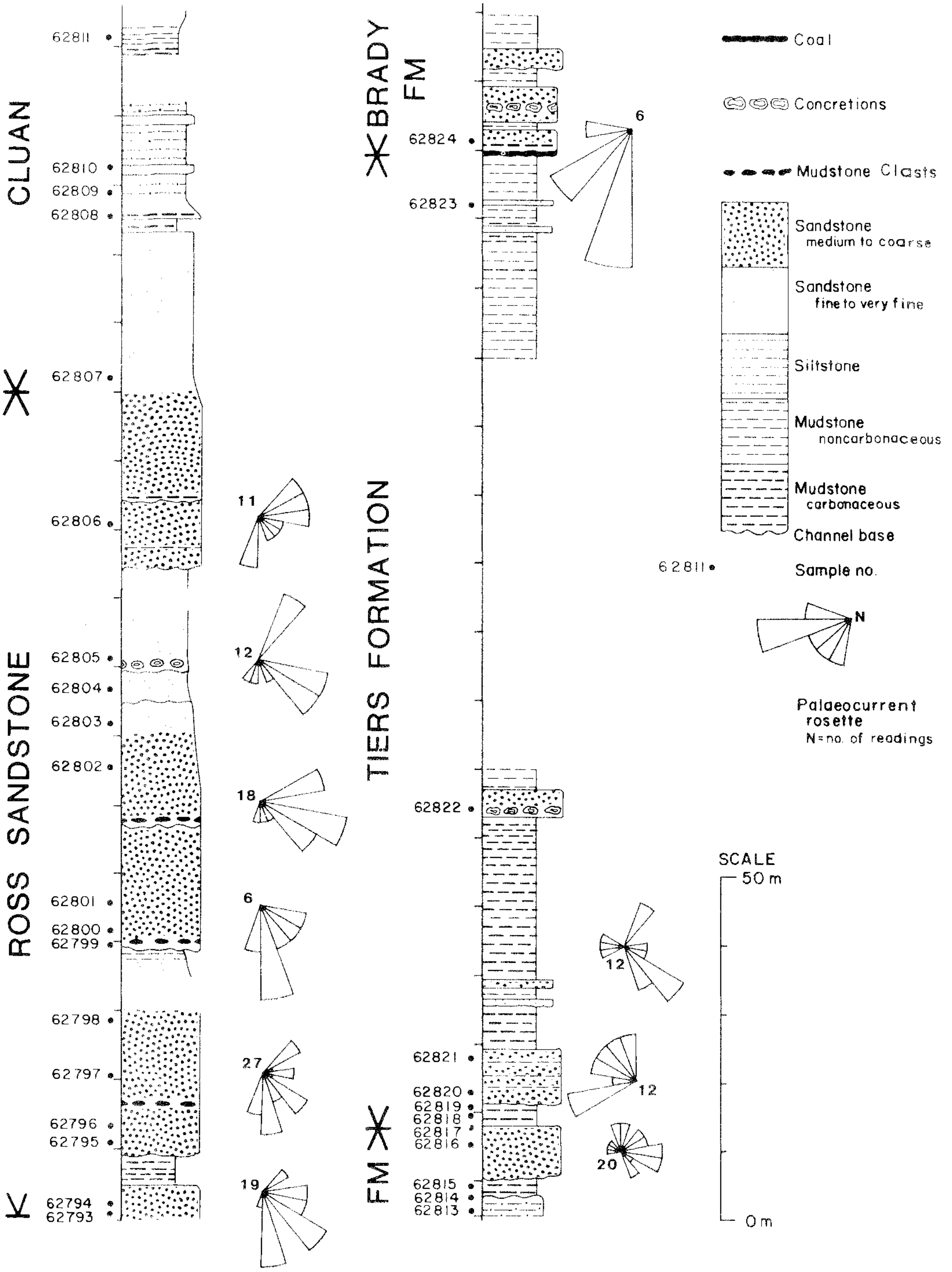

FIG. 2 — Triassic reference section along Western Tiers highway near Poatina. Sample numbers refer to the collections of the Department of Geology, University of Tasmania. Palaeocurrent rosettes are comparative; the frequencies counts for each class interval (20°) are converted to percentages of the total data set and these values are used as the radii lengths of the sectors. Plots were made by a computer program called "Sphere", which is being developed by Phil Ingram, School of Earth Sciences, Macquarie University.

McKellar (1957) described the Ross Sandstone as an "... impure, medium-grained quartz sandstone" marked by a line of cliffs along the face of the Tiers near Poatina. He noted that cores, which penetrated into the upper part of the formation, were entirely of sandstone and varied only in grain size. Our measured outcrop thickness of 170 m is less than the 650 ft (200 m) thickness reported by McKellar, which was based on 270 ft (83 m) of drill core plus an additional 380 ft (117 m) from "surface mapping".

The Ross Sandstone at Poatina disconformably overlies carbonaceous shale of the Jackey Shale, a correlate of the Cygnet Coal Measures. As noted by Forsyth (1984) in the Midlands area, the basal disconformity is no more pronounced than channel bases throughout the sequence. The formation is dominated by 5–20 m thick sandstone cycles separated by major channel scours. Mudstone clasts are commonly associated with these scours. Sandstones are coarse- to medium-grained, except near the tops of cycles where they may be fine-grained. Thin lenticular mudstones occur locally along bedding surfaces. Large-scale trough cross-bedding in sets averaging about 0.5 m thick predominates, but larger sets of tabular cross-bedding are also common. Cross-beds are commonly overturned. Finer-grained beds exhibit planar and ripple lamination.

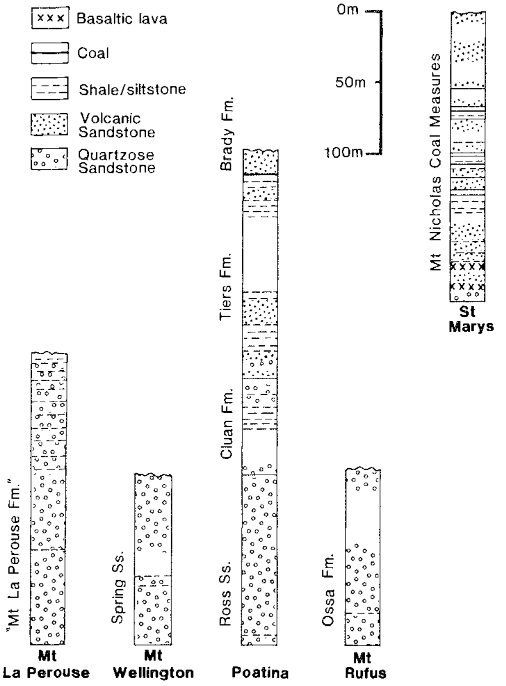

FIG. 3 — Selected stratigraphic columns in NE-trending traverse across Tasmania basin.

The Ross Sandstone and its equivalents are early Early Triassic (Scythian) in age (Forsyth 1989). This resistant sandstone unit ranges between 100 m and 200 m thick, forming prominent cliffs throughout the Tasmania basin. The lower 125 m of the Triassic System (Davidson 1969) on Mt La Perouse and the Mountain Lodge Member of the Springs Sandstone on Mt Wellington (Banks 1978) fit the above description of the Ross Sandstone (see stratigraphic sections in figure 3). The Ossa Formation, which overlies the Upper Permian coal measures in the northwestern part of the Tasmania basin (e.g. Mt Rufus and Mt Manfred sections), is also similar, but generally coarser grained.

The name "Cluan Formation" was assigned to fine- to medium-grained quartzose sandstone interbedded with dark-grey shale and siltstone overlying the Ross Sandstone. McKellar reported a 460 ft (142 m) thickness based on cores, which is greater than the 113 m thickness that we measured along the Poatina highway. The lower 65 m is dominated by fine-grained quartzose sandstone. The upper 48 m contains some medium- to coarse-grained quartzose sandstone, but is dominated by fine- to medium-grained volcaniclastic sandstone. Carbonaceous mudstone and siltstone become more abundant upward in the section. Sandstone units are trough cross-bedded. The Cluan is assigned a late Early to early Middle Triassic (Scythian–Anisian) age based on the correlation suggested by Forsyth (1989). Fine-grained sandstones that form the top of Mt La Perouse also may be equivalent (fig. 3).

The Tiers Formation was described as a grey-green, khaki-weathering shale and "felspathic" sandstone, differing from the overlying Brady Formation in a lack of coal seams (McKellar 1957). Sandstone units are generally thinner than in the underlying formations and are interbedded with greenish-grey and grey carbonaceous siltstone and shale. Root casts and fossil plant material are common and coalified logs occur locally. The slope-forming, crumbly character of the formation is due to the predominance of mudstone and the easily weathered volcanic lithic component of the sandstone. Thin beds of quartzose sandstone occur near the base of the formation in the cores and in the transition between the Cluan and Tiers Formations along the Poatina highway. McKellar (1957) picked one of these quartzose units in the cores as the base of the Tiers, giving a total thickness of 280 ft (86 m) for the formation. This thickness is close to the 97 m thickness in the section along the Poatina highway, which is poorly exposed. The Tiers Formation is Middle Triassic (Anisian-Ladinian) in age (Forsyth 1989). Forsyth (1984) described Tiers-equivalent units on the Oatlands Sheet.

McKellar (1957) described the Brady Formation as consisting of fine- to medium-grained "felspathic" sandstone, dark-grey shale, and coal seams ranging in thickness from 0.5 ft (15 cm) to 5 ft (1.5 m). The dominant rock types are greenish-grey and grey carbonaceous siltstone and shale. Sandstones are typically greenish-grey or greenish-brown, reflecting alteration of the volcanic component. The thicker sandstone bodies are channel-based and fine upward. Basal scours contain intraformational clay-pellet conglomerate and quartz, quartzite, and granitic clasts. Fossil plant material is common and silicified wood occurs locally. Based on the cores, McKellar (1957) noted a 540 ft (166 m) thickness for the formation. Only the lower part of the formation is well exposed along the Poatina highway (fig. 2). The base of the formation was selected at the base of the lowest coal seam. Sandstones in the Poatina cores are generally volcaniclastic. Sandstone samples from our measured section of the Mt Nicholas Coal Measures in the St Marys area (fig. 3), from the New Town Coal Measures in Hobart, and from coal-bearing beds on Schouten Island are indistinguishable from those of the equivalent Brady Formation. Forsyth (1984) has correlated these units with volcanic lithic arenite, lutite and coal measures in the Oatlands area. In the St Marys area two basaltic lava flows in the lower part of the Upper Parmeener Supergroup give radiometric ages of 233 ± 5 Ma (Calver & Castleden 1981). Palynological analysis suggests an Anisian or Ladinian age for horizons above and below the basalts (Forsyth 1980). Tuffs near the top of the coal-bearing sequence near Bicheno in northeastern Tasmania have been dated at 214 ± 1 Ma (Bacon & Everard 1981, Bacon *et al.*, in Forsyth 1989), which places these beds within the Late Triassic according to the DNAG time-scale (Palmer 1983).

TRIASSIC DEPOSITIONAL ENVIRONMENTS

Although marine fossils occur in parts of the Permian sequence, no conclusive evidence of marine conditions has been reported in the Triassic sequence of Tasmania. Forsyth (1989) noted spinose acritarchs, but these could have been reworked. He also pointed out that sedimentary structures in some Middle Triassic rocks are similar to the deposits of tidally influenced estuaries. Trace fossils in the Upper Narrabeen Group of the Sydney basin suggest a marine influence in sandstones deposited under fluvially dominated estuarine conditions (Thann Naing, Macquarie University, written communication, 1989). Although similar trace fossils have not been reported in the Triassic of Tasmania, they could easily have been overlooked, as they were in the comparatively well-studied Sydney basin.

The predominance of channel-form sandstones and the occurrence of terrestrial vertebrate fossils (Cosgriff 1974, Camp & Banks 1978) in the Ross Formation suggest predominantly fluvial conditions. The multistorey nature of sandstone units and the paucity of fine-grained flood-plain deposits support the conclusion that these represent braided stream deposits. Local mudstone-dominated intervals have been interpreted as lacustrine and flood-plain deposits (Forsyth 1984, 1989). Lateral accretion surfaces, apparent in at least one outcrop in the upper Cluan Formation, highly variable palaeocurrent data, and a predominance of fine-grained beds suggest a meandering stream environment for the rest of the Triassic section. The generally fining-upward nature of the sequence is probably related to such factors as erosive lowering of the source area and the corresponding reduction in gradient, and a change to more humid conditions as indicated by the preservation of organic matter and coal.

PALAEOCURRENT DIRECTIONS

Palaeocurrent directions for 11 localities of the Ross Sandstone and its equivalents are shown in figure 4. A more complete listing of palaeocurrent data is shown in table 1.

The resistant Ross Sandstone is the only Triassic unit in which palaeocurrent data are easily gathered regionally. Dispersal directions are consistently toward the southeast quadrant except along the central east coast (Spring Beach, Schouten Island, Maria Island), where they swing toward the east. The low variability of directions at each locality and over the region is consistent with the interpretation that the Ross Sandstone represents low sinuosity braided stream deposits on a southeasterly dipping palaeoslope. Palaeocurrent directions in the reference section at Poatina are generally in the southeast quadrant throughout the Ross Sandstone, but show increasing variability upward as the sequence becomes finer grained. Readings from the overlying volcaniclastic upper Cluan, Tiers and Brady Formations vary greatly. Forsyth (1984) noted a reversal from southeast to northwest in palaeocurrent directions between the quartzose sequence and the overlying lithic sandstone sequence in the Midlands. Directions in equivalent rocks in the St Marys area are highly scattered and do not give a preferred direction (Turner & Calver 1987).

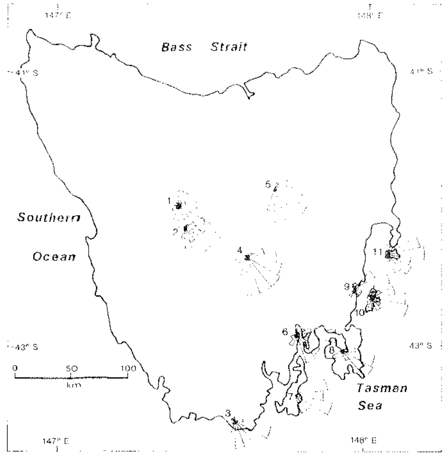

FIG. 4 — Map of Tasmania showing palaeocurrent rosettes for the Ross Sandstone and equivalent units. Localities from E–W are: (1) Mt Rufus, (2) Mt Manfred, (3) Mt La Perouse, (4) Oatlands, (5) Poatina, (6) Mt Wellington, (7) Adventure Bay, (8) Prices Bay, (9) Spring Beach, (10) Maria Island, (11) Schouten Island. Compiled only for localities where data comprise 25 or more readings (see table 1). The rosette for the Oatlands locality (4) was reconstructed from data presented by Forsyth (1984). Palaeocurrent rosettes are comparative; the frequencies counts for each class interval (20°) are converted to percentages of the total data set and these values are used as the radii lengths of the sectors. Plots were made by "Sphere", as fig. 2.

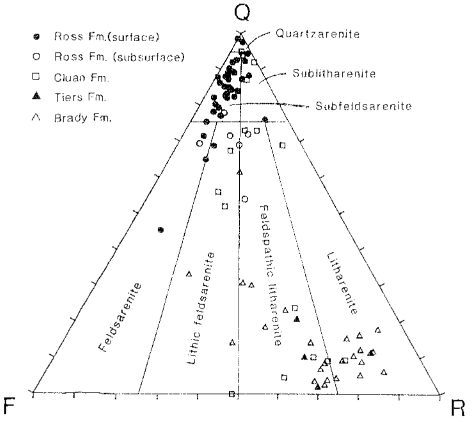

FIG. 5 — Triangular diagram showing compositional differences between formations (Folk et al. *1970).*

PETROGRAPHY

Modal analyses of the detrital component of 91 fine- to medium-grained sandstone samples are listed in tables 2 to 5. These are compared in the triangular diagram (fig. 5). Samples for point counting were selected from the more than 300 samples and thin sections from throughout the Tasmania Basin. As is apparent at outcrops, sandstones from the lower part of the Triassic section are very different in composition from those in the upper part of the section. This change occurs abruptly in the Poatina section within the Cluan Formation with the introduction of volcanic grains (fig. 6). Quartzose sandstones dominate the Ross and lower Cluan Formations and their stratigraphic equivalents. Sandstones in the Upper Cluan, Tiers, and Brady Formations and their stratigraphic equivalents contain many of the same types of grains, which are, however, overwhelmed by the volcaniclastic component. Quartzose sandstones occur rarely in the upper sequence and are easily differentiated from those in the lower sequence by the presence of volcanic lithic grains.

Ross and Lower Cluan Formations and Equivalents (Quartzose Sequence)

The quartzose sandstones of the Ross and Cluan Formations and their equivalents are characterised by low ratios of plagioclase to total feldspar (P/F), polycrystalline quartz to total quartz (Qp/Q) and volcanic lithic fragments to total rock fragments (V/R). The average composition of sandstones in the Ross Formation and its equivalents (table 2) falls into the subfeldsarenite field in the classification of Folk *et al.* (1970). As is apparent on the triangular plot (fig. 5), subsurface samples contain a higher percentage of feldspar and rock fragments and fall into the lithic feldsarenite field. These components apparently have been removed by weathering. The average compositions of subsurface samples from the Ross and lower Cluan Formations are not significantly different, but they fall into different fields, lithic feldsarenite and feldspathic litharenite.

TABLE 1
Palaeocurrent Data from Tasmania

Locality*	Formation	Age	N	VM	VS	SD
Poatina	Cluan	L Triassic	50	56†	20	90
Poatina	Ross	L Triassic	102	122	74	45
Mt Manfred	Ossa	L Triassic	33	117	82	37
Mt Rufus	Ossa	L Triassic	53	118	56	63
Woods Quoin	Ross	L Triassic	18	113	88	31
New Norfolk	Ross	L Triassic	20	139	45	80
York Plains	"Volc. lithic"	U Triassic	23	8†	22	91
Schouten Is.	Ross	L Triassic	53	102	74	46
Spring Beach	Ross	L Triassic	32	82	69	52
Maria Is.	Ross	L Triassic	32	85	81	37
Mt Wellington	Springs	L Triassic	63	116	56	63
Prices Bay	Ross	L Triassic	56	127	74	48
Adventure Bay	Ross	L Triassic	29	102	90	26
Mt La Perouse	"La Perouse"	L Triassic	59	114	64	34

N = number of readings, VM = vector mean in degrees, VS = vector strength in percent, SD = azimuth standard deviation in degrees.
* Localities shown on figure 1, except for Woods Quoin, New Norfolk and York Plains, which are in the Midlands area. † Not a meaningful direction.

Monocrystalline quartz grains are mostly subrounded to subangular and equant. Two-thirds are nonundulose. Included are (1) euhedral biotite or muscovite, (2) disseminated, randomly oriented rutile needles, (3) stubby light-green apatite, (4) rounded vacuole-shaped or euhedral tourmaline, and (5) euhedral zircon. Non-mineral inclusions include common curvilinear vacuole trains and abundant disseminated vacuoles. Some monocrystalline quartz grains with abundant vacuole inclusions also have vermicular chlorite inclusions; these grains are presumably of vein origin.

Polycrystalline quartz grains display elongated original crystals that have polyhedral outlines, smooth crystal–crystal boundaries, and many show interfacial angles of 120° at triple junctions of crystal unit boundaries. Elongate polycrystalline quartz grains are subangular to angular, whereas equant grains are more commonly subrounded to well rounded. Mineral inclusions are less abundant than in monocrystalline grains and are primarily randomly oriented muscovite or biotite.

Feldspar grains include microcline and orthoclase. Plagioclase grains are typically sodic andesine (An_{30-40}). One-third or fewer of all plagioclase grains are Carlsbad-twinned. They are commonly subrounded. No zoned grains were observed.

Rock fragments, in order of decreasing relative abundance, include: (1) sedimentary-metasedimentary grains, and subordinate (2) volcanic-hypabyssal, (3) metamorphic, and (4) plutonic varieties. Sedimentary rock fragments are subrounded to well-rounded mudstone and siltstone of intrabasinal origin, and slate. Only a few volcanic rock fragments were identified and none were vitric; these were probably derived from older volcanic rocks. Metamorphic rock fragments are low in relative abundance, but are ubiquitous. Most common are schistose polycrystalline quartz grains composed of elongate original host crystals with crenulated and sutured crystal–crystal boundaries; muscovite, biotite, or chlorite inclusions are oriented parallel or subparallel to the long axes of quartz grains. Plutonic rock fragments are rare and identified by micrographic or myrmekitic textures.

Minor constituents include mica concentrated on bedding planes. Biotite is more common than muscovite. The more abundant heavy minerals are angular, isotropic garnet and well-rounded to subrounded tourmaline grains that are pleochroic in green, dark blue, brown and zoned green-brown. Other heavy minerals include well-rounded or euhedral zircon, zoisite, clinozoisite and subrounded magnetite-ilmenite grains.

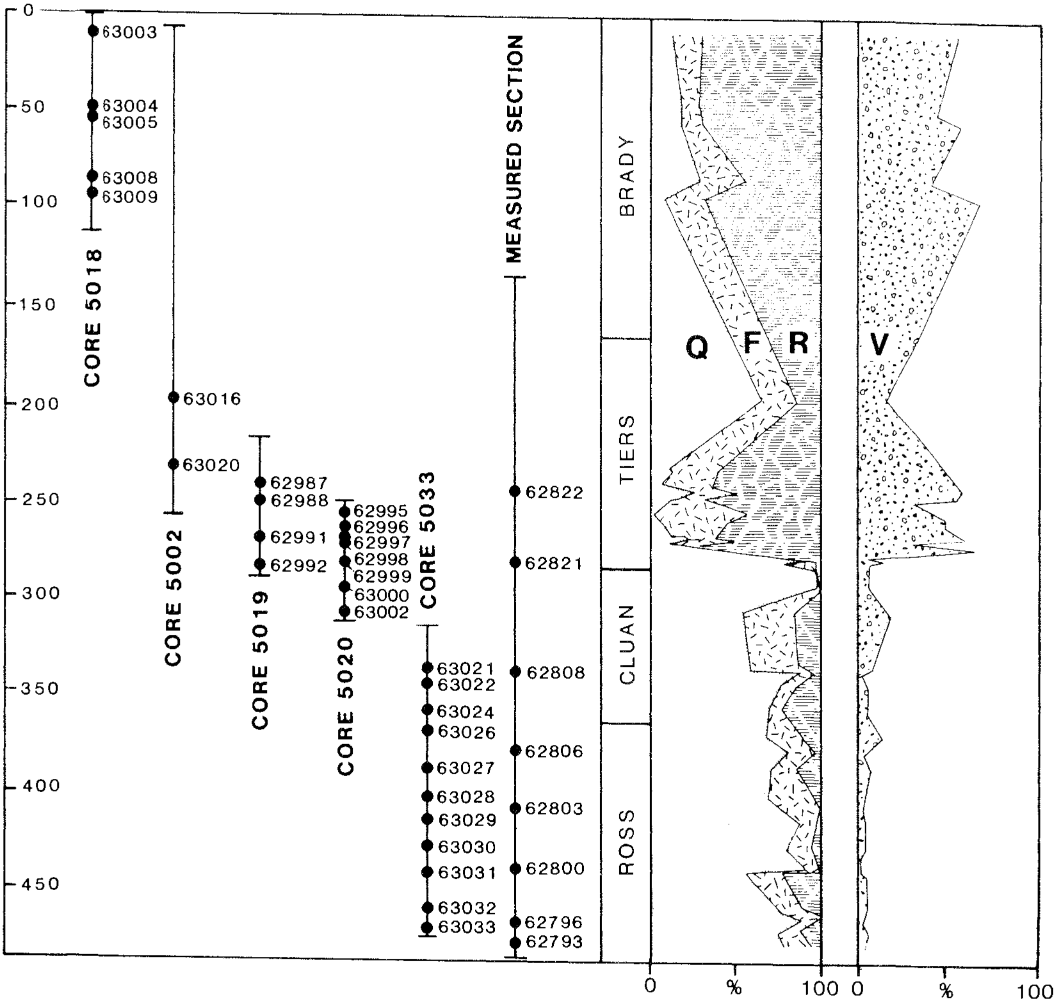

FIG. 6 — Graphic presentation of modal analyses of Poatina cores and measured section, showing percentages of quartz (Q), feldspar (F) and rock fragments (R) in column on left and percentage of volcanic (V) rock fragments compared to total rock fragments in column on right. Sample numbers refer to the collections of the Department of Geology, University of Tasmania.

Matrix and cement include small amounts of clay (2–3%), particularly in core samples. Clay cement consists of illite, kaolinite and minor chlorite and smectite and occurs as (1) recrystallised detrital mudstone fragments and clay matrix, (2) rims on detrital grains, (3) pore-lining and pore-filling cement, (4) feldspar grain replacements. Calcite occurs locally as anhedral intergranular pore-lining cement and as a feldspar and quartz grain replacement.

Upper Cluan, Tiers, Brady Formation and Equivalents (Volcaniclastic Sequence)

Volcaniclastic sandstones are characterised by abundant volcanic rock fragments. In contrast to the underlying quartzose sequence, volcaniclastic sandstones have high ratios of plagioclase to total feldspar (P/F), volcanic rock fragments to total rock fragments (V/R), and polycrystalline quartz to total quartz (Qp/Q)). The average compositions of the

TABLE 2
Modal Analyses of Ross Sandstone and Equivalent Units*

Locality	Sample	Formation	Classification	Q	F	R	P/F	V/R	Qp/Q
				(expressed as % of framework grains)			(expressed as ratios)		
Mt Rufus	62785	Ossa	Subfeldsarenite	89.3	7.0	3.7	0.33	0.27	0.04
Mt Rufus	62784	Ossa	Subfeldsarenite	78.2	17.5	4.3	0.11	0.61	0.05
Mt Rufus	62783	Ossa	Subfeldsarenite	82.0	12.3	5.7	0.08	0.23	0.11
Mt Rufus	62782	Ossa	Subfeldsarenite	86.3	12.0	1.7	0.25	0.80	0.05
Mt Rufus	62781	Ossa	Subfeldsarenite	80.3	16.0	3.7	0.14	0.27	0.04
Mt Rufus	62788	Ossa	Lithic feldsarenite	68.7	22.0	9.3	0.42	0.17	0.05
Mt La Perouse	62764	La Perouse	Subfeldsarenite	84.4	10.0	5.6	0.16	0.82	0.01
Mt La Perouse	62761	La Perouse	Subfeldsarenite	92.0	6.0	2.0	0.66	0.15	0.01
Mt La Perouse	62760	La Perouse	Subfeldsarenite	88.0	9.7	2.3	0.20	0.85	0.01
Mt La Perouse	62759	La Perouse	Subfeldsarenite	88.3	9.0	2.7	0.18	0.62	0.04
Mt La Perouse	62773	La Perouse	Subfeldsarenite	83.3	11.7	5.0	0.85	0.46	0.13
Scouten Is.	62881	Unnamed	Sublitharenite	76.1	5.7	18.2	0.52	0.42	0.00
Schouten Is.	62887	Unnamed	Quartzarenite	97.6	0.8	1.6	0.50	1.00	0.08
Schouten Is.	62890	Unnamed	Subfeldsarenite	85.2	11.4	3.4	0.00	0.40	0.08
Schouten Is.	62894	Unnamed	Quartzarenite	98.5	1.5	0.0	0.00	0.00	0.00
Mt Manfred	62857	Ossa	Subfeldsarenite	87.9	11.7	0.4	0.09	0.00	0.10
Mt Manfred	62589	Ossa	Subfeldsarenite	92.6	4.7	2.7	0.09	0.00	0.03
Mt Manfred	62860	Ossa	Feldsarenite	45.4	46.8	7.8	0.50	0.43	0.08
Mt Manfred	62862	Ossa	Subfeldsarenite	82.2	15.4	2.4	0.24	0.00	0.38
Midway point	62856	Knocklofty	Feldsarenite	71.5	23.2	5.3	0.13	0.21	0.04
Mt Knocklofty	62973	Knocklofty	Subfeldsarenite	82.4	10.3	7.3	0.45	0.13	0.06
Mt Knocklofty	62972	Knocklofty	Sublitharenite	87.2	6.0	6.7	0.44	0.10	0.03
Mt Knocklofty	62971	Knocklofty	Sublitharenite	92.3	2.7	5.0	0.75	0.40	0.04
Mt Knocklofty	62969	Knocklofty	Subfeldsarenite	85.0	10.3	4.7	0.74	0.35	0.07
Mt Knocklofty	62966	Knocklofty	Subfeldsarenite	87.3	9.4	3.4	0.50	0.11	0.02
Mt Knocklofty	62965	Knocklofty	Lithic feldsar.	65.0	25.9	9.1	0.57	0.16	0.06
Mt Wellington	62945	Springs	Sublitharenite	94.4	1.0	4.6	0.00	0.07	0.04
Mt Wellington	62944	Springs	Subfeldsarenite	84.0	8.7	7.3	0.23	0.36	0.04
Mt Wellington	62943	Springs	Sublitharenite	87.3	6.0	6.7	0.11	0.10	0.06
Mt Wellington	62942	Springs	Sublitharenite	88.3	3.7	8.0	0.36	0.08	0.02
Mt Wellington	62941	Springs	Subfeldsarenite	90.3	7.7	2.0	0.65	0.83	0.04
Poatina	62806	Ross	Subfeldsarenite	79.4	15.6	5.0	0.04	0.27	0.06
Poatina	62803	Ross	Subfeldsarenite	75.8	20.2	4.0	0.20	0.25	0.04
Poatina	62800	Ross	Subfeldsarenite	89.1	7.0	3.9	0.23	0.17	0.09
Poatina	62796	Ross	Subfeldsarenite	89.1	8.6	2.3	0.23	0.43	0.04
Poatina	62793	Ross	Subfeldsarenite	77.1	16.3	6.6	0.32	0.25	0.07
Poatina core	63027	Ross	Lithic feldsarenite	69.0	15.7	15.3	0.46	0.47	0.11
Poatina core	63028	Ross	Feldsarenite	69.4	25.3	5.3	0.36	0.43	0.10
Poatina core	63029	Ross	Subfeldsarenite	82.7	12.3	5.0	0.32	0.66	0.08
Poatina core	63030	Ross	Subfeldsarenite	78.0	15.0	7.0	0.57	0.42	0.18
Poatina core	63031	Ross	Feldsp. litharenite	54.0	21.7	24.3	0.60	0.21	0.14
Poatina core	63032	Ross	Lithic feldsarenite	71.6	16.7	11.7	0.78	0.22	0.33
Poatina core	63033	Ross	Feldsp. litharenite	72.0	12.0	16.0	0.83	0.39	0.21
Average of surface samples			Subfeldsarenite	84.2	11.2	4.6	0.27	0.36	0.06
Average of subsurface samples			Lithic feldsarenite	71.0	17.0	12.1	0.56	0.40	0.16
Average of all samples			Subfeldsarenite	81.6	12.4	6.0	0.32	0.34	0.08

Q = quartz, F = feldspar, R = rock fragment, P/F = plagioclase/total feldspar, V/R = volcanic rock fragment/total rock fragment, Qp/Q = polycrystalline/total quartz.

* Based on 300 or more data points for each sample.

TABLE 3
Modal Analyses of Cluan Formation*

Locality	Sample	Formation	Classification	Q	F	R	P/F	V/R	Qp/Q
				(expressed as % of framework grains)			(expressed as ratios)		
Poatina	62808	Cluan	Sublitharenite	87.2	4.9	8.0	0.27	0.12	0.06
Poatina core	62999	Cluan	Feldsp. litharenite	73.1	12.3	14.6	0.23	0.75	0.09
Poatina core	62992	Cluan	Sublitharenite	92.0	0.6	7.4	0.80	0.13	0.04
Poatina core	63000	Cluan	Quartzarenite	95.0	2.3	2.7	0.14	0.75	0.04
Poatina core	63002	Cluan	Lithic arkose	52.0	27.7	20.3	0.53	0.72	0.23
Poatina core	63021	Cluan	Lithic arkose	56.0	27.3	16.7	0.61	0.26	0.17
Poatina core	63022	Cluan	Feldsp. litharenite	73.0	9.3	17.7	0.50	0.32	0.11
Poatina core	63024	Cluan	Litharenite	69.0	4.7	26.3	0.50	0.22	0.14
Poatina core	63026	Cluan	Lithic arkose	67.3	18.7	13.9	0.27	0.82	0.17
Average composition				73.8	12.0	14.2	0.33	0.45	0.12

* Abbreviations and explanations as table 2.

upper and lower Cluan Formation (table 3) both fall into the feldspathic litharenite field, but they are generally at opposite ends (fig. 5). The average compositions of the Tiers and Brady sandstones (table 4) falls into the litharenite field. Surface and core samples are not significantly different.

Rock fragments are dominated by epiclastic volcanic-hypabyssal grains. These are equant or elongate and subangular to well rounded, with a few angular grains. Grains are intermediate to felsic in composition and are identified by microlitic plagioclase feldspar inclusions that result in felted and pilotaxitic textures. Plagioclase feldspar microlites occur in a light to dark-brown or brown-green matrix. The matrix is in some cases devitrified, chloritised or oxidised. Aphanitic fragments that have relict fabrics resembling those of feldspar microlites in devitrified glass groundmass were identified as volcanic fragments. Dark-brown fragments of vitric crystalline tuffaceous material occur sparsely, and are recognised by bubble-wall textures characteristic of volcanic glass shards. Basaltic fragments are associated with Triassic basalt flows in the Mt Nicholas Coal Measures north of St Marys. Other rock fragments include small but consistent proportion of schistose grains containing biotite, muscovite, or chlorite. Plutonic grains, typically with intergrowths of monocrystalline quartz with orthoclase, plagioclase, or microcline, are sparse but more abundant than in the underlying quartzose sequence.

Feldspars are dominated by plagioclase, ranging in composition from calcic oligoclase to sodic andesine (An_{35}). These are equant to elongate and angular to subrounded. The grains are typically fresh, but some contain vacuoles. Many grains show albite twinning, and about one-third of these display Carlsbad twinning as well. Many display well-developed oscillatory zoning. Microcline, orthoclase and microperthite occur in relatively minor amounts.

Quartz grains occur in relatively low abundance in most samples from the Tiers Formation and equivalents. A notable difference is the presence of angular to subrounded volcanic quartz grains. These exhibit straight extinction, display bipyramidal cross-sections, and some are embayed.

Minor constituents make up less than 1% of total framework grains. Of these, biotite is the most abundant, occurring mainly along bedding planes and cross-bedding laminae.

Matrix and cement comprise clay matrix (typically about 5%), calcite and clay cements, and less commonly laumontite and quartz. Calcite occurs extensively as an anhedral intergranular pore-filling cement and as a replacement mineral in plagioclase, quartz and volcanic rock fragments. Clay cements consist of chlorite and smectite with subordinate amounts of illite and kaolinite. Clay cement abundances are the opposite of those in the underlying quartzose sequence. Clay cements occur as (1) pore-lining, (2) hydration rims on plagioclase grains and volcanic lithic fragments, and (3) grain replacements. Authigenic quartz is present

TABLE 4
Modal Analyses of Tiers and Brady Formation and Equivalent Units*

Locality	Sample	Formation	Classification	Q	F	R	P/F	V/R	Qp/Q
				(expressed as % of framework grains)			(expressed as ratios)		
St Marys	62848	Mt Nicholas	Litharenite	15.5	15.2	69.3	0.81	0.71	0.12
St Marys	62847	Mt Nicholas	Litharenite	16.4	11.6	71.9	0.58	0.78	0.29
St Marys	62846	Mt Nicholas	Feldspathic litharenite	4.0	25.7	70.3	0.85	0.82	0.08
St Marys	62845	Mt Nicholas	Feldspathic litharenite	2.7	27.0	70.3	0.96	0.89	0.25
St Marys	62844	Mt Nicholas	Feldspathic litharenite	3.7	29.0	67.3	0.91	0.68	0.09
St Marys	62843	Mt Nicholas	Feldspathic litharenite	30.9	33.6	35.5	0.72	0.65	0.03
St Marys	62841	Mt Nicholas	Feldspathic litharenite	30.3	31.7	38.0	0.93	0.61	0.02
St Marys	62839	Mt Nicholas	Feldspathic litharenite	18.7	34.0	47.3	0.96	0.66	0.08
St Marys	62838	Mt Nicholas	Litharenite	9.3	19.3	71.3	1.00	0.65	0.14
St Marys	62837	Mt Nicholas	Feldspathic litharenite	14.4	24.7	60.9	0.98	0.86	0.09
St Marys	62836	Mt Nicholas	Litharenite	10.6	15.9	73.5	1.00	0.92	0.03
St Marys	62833	Mt Nicholas	Lithic feldsarenite	33.3	45.7	21.0	0.92	0.93	0.14
St Marys	62831	Mt Nicholas	Feldspathic litharenite	14.3	44.3	41.3	0.99	0.95	0.01
St Marys	62829	Mt Nicholas	Litharenite	5.3	16.9	77.8	0.98	0.99	0.31
Hobart	62939	New Town	Litharenite	6.3	10.6	83.1	0.71	0.62	0.36
Hobart	62938	New Town	Feldspathic litharenite	8.7	24.0	67.3	0.85	0.96	0.19
Hobart	62937	New Town	Feldspathic litharenite	7.0	25.9	67.1	0.91	0.74	0.19
Schouten Is.	62883	Unnamed	Litharenite	11.5	11.2	77.2	0.94	0.81	0.69
Schouten Is.	62884	Unnamed	Litharenite	18.0	6.2	75.7	1.00	0.66	0.25
Poatina core	63003	Brady	Litharenite	9.0	14.7	76.3	0.65	0.65	0.37
Poatina core	63004	Brady	Litharenite	11.8	10.5	77.7	0.80	0.48	0.47
Poatina core	63005	Brady	Litharenite	12.3	13.4	74.3	0.81	0.70	0.38
Poatina core	63008	Brady	Feldspathic litharenite	23.3	26.7	50.2	0.53	0.65	0.16
Poatina core	63009	Brady	Litharenite	4.5	23.3	72.4	0.72	0.86	0.07
Poatina core	63016	Tiers	Feldspathic litharenite	61.6	19.2	19.2	0.62	0.58	0.17
Poatina	62822	Tiers	Feldspathic litharenite	20.9	24.8	54.2	0.87	0.78	0.14
Poatina core	63020	Tiers	Feldspathic litharenite	10.4	28.2	61.4	0.69	0.75	0.35
Poatina core	62987	Tiers	Feldspathic litharenite	2.1	29.0	68.9	0.74	0.81	0.16
Average for Brady and equivalents			Litharenite	13.4	22.5	64.1	0.85	0.76	0.20
Average for Tiers			Feldspathic litharenite	11.1	27.3	61.5	0.77	0.78	0.22

* Abbreviations and explanations as table 2.

in minor amounts as a pore-filling cement. Laumontite occurs as pore-filling cement and grain replacements of plagioclase and volcanic rock fragments.

PROVENANCE

Quartz grains, heavy minerals, the predominance of potassium feldspar, and paucity of volcanic rock fragments in Lower Triassic sandstones suggest a varied source of plutonic, metamorphic, and sedimentary rocks. Palaeocurrent dispersal (fig. 4) and coarsening of sandstones toward the northwest in the Mt Manfred and Mt Rufus sections suggest a source area in the northwest where a variety of suitable Precambrian and lower Palaeozoic basement rocks are exposed.

The predominance of intermediate to silicic volcanic grains in the Middle and Upper Triassic sequence and the occurrence of silicic tuffs in northeastern Tasmania (Bacon *et al.*, in Clarke & Forsyth 1989) suggest the possibility of an active volcanic source, probably to the east. Palaeocurrent data do not show any obvious trends, but the possible reversal described by Forsyth (1984) in

TABLE 5

Similarities in the Upper Palaeozoic–Early Mesozoic Geology of Tasmania and Victoria Land*

(1) Trough-shaped basins, probably of fault origin.
(2) Late Carboniferous glacials rest unconformably above early Palaeozoic granites or folded and metamorphosed sedimentary rocks with great relief locally.
(3) Sedimentary cycle began in Late Carboniferous with glacials and ended in Jurassic with tholeiitic vulcanism.
(4) Coal measures in Permian and Middle to Upper Triassic.
(5) Lower Triassic dominated by quartzose sandstone with little volcanic contribution.
(6) Middle and Upper Triassic dominated by volcaniclastic sandstone.
(7) Lower Triassic deposited by braided streams.
(8) Middle and Upper Triassic deposited in part by meandering streams.
(9) Jurassic intrusion of dolerite and extrusion of tholeiitic basalt.

* Tasmanian relationships are summarised in Clarke & Forsyth (1989) and antarctic relations in Collinson *et al.* (1986, 1987).

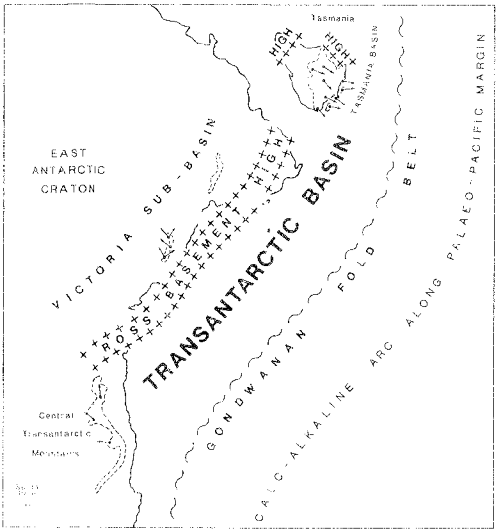

FIG. 7 — Map of palaeo-Pacific margin of the Gondwanan supercontinent including the Ross Sea coastline of East Antarctica and Tasmania. Positions of hypothetical tectonic features are based mainly on sedimentary evidence. Arrows indicate Early Triassic palaeocurrent directions. For Antarctica these are derived from information in Barrett & Kohn (1975), Barrett & Fitzgerald (1985), Barrett (1968), Collinson & Elliot (1984), Collinson et al. *(1983) and unpublished field data of the authors.*

the Midlands supports the existence of an easterly source. Basaltic grains in sandstones associated with basaltic lava flows in the Mt Nicholas Coal Measures near St Marys were locally derived.

Non-volcanogenic components of the upper volcaniclastic sequence suggest the continued presence of a basement source. Large clasts in the southeast and in the Midlands (Forsyth 1984, Clarke & Forsyth 1989), including quartz feldspar porphyry and lithics containing Permian fossils, suggest a new source area to the east. Basement uplift occurred in the Late Permian or Early Triassic in northeastern Tasmania (St Marys section, fig. 3) where the uppermost Permian and Lower Triassic are missing along a disconformity (Forsyth 1989).

PALAEOGEOGRAPHY

In most Gondwanan reconstructions (e.g. DeWitt *et al.* 1988), Tasmania is off the Victoria Land coast, in line with the Transantarctic Mountains (fig. 7). The Transantarctic basin, which paralleled the Transantarctic Mountains, consisted of an intracratonic sub-basin in Victoria Land and a foreland basin that were separated at times by basement highs. Evidence for a foreland basin is based on palaeocurrent dispersal and provenance relationships in the Central Transantarctic Mountains, and an intensely folded sedimentary sequence in West Antarctica (Collinson *et al.* 1981, Vavra *et al.* 1981, Collinson 1990a). The hypothetical Ross basement high blocked drainage into the Victoria sub-basin until Middle Triassic, when volcaniclastic sediment from a volcanic arc along the palaeo-Pacific margin spilled over the high.

A major problem in interpreting and comparing the Tasmania and Transantarctic basins is that the present extent of Triassic outcrops represents only a fraction of their original distribution (fig. 7). If these outcrops are part of a larger Transantarctic–Tasmania basin, they should have similar geologic histories and fit into an overall basin model. Anyone who has studied these rocks in both regions is struck by their similarity (table 5).

The Permian in Tasmania, except for the presence of coal measures, is different from that of Victoria Land. The marine cycles that contain an abundant shelly fauna in Tasmania are unknown in Antarctica. If these two regions are part of the same basin, Tasmania occupied the marine end of a basin that emptied into the palaeo-Pacific Ocean.

Triassic correlations between Antarctica and Tasmania are shown in figure 8. The correlatives of the Ross and Cluan in the Transantarctic Mountains are the Feather Conglomerate and lower part of the Fremouw Formation, both of which are prominent cliff-forming, quartzose, braided stream deposits (Barrett & Kohn 1975, Barrett & Fitzgerald 1985, Collinson 1990b). These formations overlie Permian coal measures along a prominent erosion surface. Palaeocurrents suggest that streams flowed northward toward the Tasmania Basin (Collinson *et al.* 1987). The Tiers and Brady Formations are similar to the volcaniclastic upper part of the Fremouw and Falla Formations in the central Transantarctic Mountains, and the Lashly and Section Peak Formations in Victoria Land. These units contain coal or carbonaceous shale. Palaeocurrents remain northward toward the Tasmania Basin, but a transition occurs from braided streams in the upper part of the basin to meandering streams in the lower part of the basin toward Tasmania (Collinson *et al.* 1987).

The hypothetical Transantarctic–Tasmania basin was similar in size and many features to the Sydney–Bowen basin, which was also occupied by an extensive river system during the Triassic, and is classified as a foreland basin (Conaghan *et al.* 1982, Veevers *et al.* 1984). The Sydney–Bowen basin is bordered by the craton to the west, which contributed quartzose sandstone from the erosion of Devonian sandstones and metamorphic and granitic rocks of the Lachlan fold belt. On the east the active New England orogen contributed primarily lithic sandstone with an important penecontemporaneous volcanic component. Major drainage was axial and emptied into the palaeo-Pacific ocean.

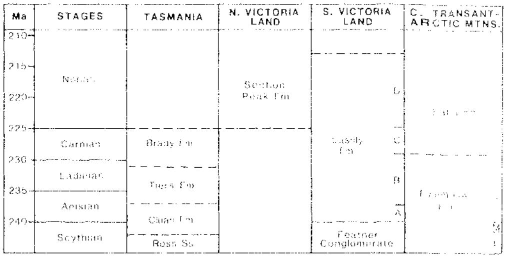

FIG. 8 — Time–stratigraphic chart comparing Tasmania to Antarctica. Based on DNAG time-scale (Palmer 1983).

Using the Sydney–Bowen basin as a model, the Tasmania basin is interpreted as being part of a much larger intracratonic basin that extended landward into the Victoria Land portion of East Antarctica. This basin was bounded to the west by the craton of East Antarctica and southeastern Australia. Precambrian to lower Palaeozoic rocks in the Ross and Tasman orogens on the palaeo-Pacific margin of the Gondwanan craton, including basement highs in Tasmania, were the major sources of quartzose sediment in the Permian and Early Triassic. A calcalkaline volcanic arc, which bordered the Gondwanan palaeo-Pacific margin from eastern Australia to West Antarctica, was the source of volcaniclastic sediment that flooded the basin in Middle Triassic time. Other than local uplift, there is no direct evidence of a fold belt comparable to the New England or West Antarctic orogens in Tasmania or Victoria Land. However, folding, thrusting and uplift of a volcaniclastic apron of sediment from the volcanic arc along the palaeo-Pacific margin would explain the sudden flood of volcaniclastic sediments into these regions.

CONCLUSIONS

The Triassic sequence of Tasmania, best represented by the continuous stratigraphic section at Poatina, consists of a lower quartzose sandstone (Ross and lower Cluan Formations) overlain by an upper volcaniclastic sandstone and mudstone (upper Cluan, Tiers and Brady Formations). The quartzose sequence was deposited by braided streams and the volcaniclastic sequence by meandering streams. Palaeocurrent dispersal in the quartzose sequence was toward the southeast and east. Present data are insufficient to establish palaeocurrent patterns for the volcaniclastic sequence. The source area for the quartzose sequence was in northwestern Tasmania and the Gondwanan craton west of Tasmania. The primary source for the volcaniclastic sequence was a calcalkaline volcanic arc east of Tasmania along the palaeo-Pacific margin. The Triassic sequences in Tasmania and the Victoria Land sector of the Transantarctic Mountains are greatly similar, suggesting that they were once part of the same, but much larger basin. The Transantarctic–Tasmania basin was similar to the Sydney–Bowen basin in size, configuration, and history. They were both foreland basins that developed on the Gondwanan craton in front of a fold-thrust belt inside the calcalkaline volcanic arc that bordered the palaeo-Pacific margin.

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