

Middle Triassic Coastal Outwash Plain Deposits in Tank Gully, Canterbury, New Zealand

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Abstract

A homoclinal sequence of Middle Triassic rocks crops out in the southern flanks of Mt Potts between Tank and Rocky Gullies, Canterbury. The basal conglomerates and sandstones of this sequence were deposited by braided streams filling an early Triassic valley, cut into deformed older sandstones. The basal conglomerates and sandstones are conformably overlain by coal measures containing diverse megafossil plant assemblages typical of Late Anisian to Ladinian rocks of Gondwanaland. These coal measures are in turn conformably overlain by beach sandstones and shallow-marine siltstones containing Ladinian (Kaihikuan local stage) marine fossils. Two new formations are described, namely Bench Sandstone and Tank Gully Coal Measures, and a new fault, the Rocky Peak Fault, is located. The whole Triassic sequence was deposited on a narrow coastal outwash plain and shallow marine shelf adjacent to alpine fold mountains in a cool temperate to subantarctic climate and latitude. This interpretation of the Triassic palaeoenvironment supports the view that the Torlesse rocks of New Zealand were derived from land to the east.

INTRODUCTION

Fossiliferous rocks in Tank and Rocky Gullies were discovered relatively early in the geological exploration of New Zealand. Differences of opinion on the geological occurrence and age of the marine and plant fossils (detailed by Arber 1917) have remained unresolved up to the present, despite later work on the marine upper portion of the Triassic section in Rocky Gully (Campbell and Force 1972). From detailed mapping in Tank Gully, I here offer solutions to two of the most debated points. Firstly, the megafossil plants in the Tank Gully Coal Measures (new name) are of Aniso-Ladinian age and conformably underlie marine rocks containing Ladinian (Kaihikuan local stage) faunas. Secondly, the lowest rocks of the Triassic transgressive sequence are braided stream conglomerates and sandstones deposited in a valley cut into previously deformed sandstones. Despite the assertions of Kingma (1974), this is the first and only place in the Torlesse rocks of New Zealand where a pre-Ladinian angular unconformity can be seen and touched. The palaeoenvironmental interpretations of the sequence developed here strongly support the idea advanced by increasing numbers of authors (Coombs *et al.* 1976; Andrews *et al.* 1977) that the Torlesse rocks of New Zealand were derived from continental crust to the east.

Tank Gully is a deeply-incised watercourse draining from the western flanks of Mt Potts (2174 m) into the Clyde branch of the Rangitata River, Canterbury (Fig. 1). Forming a basement to the glacial outwash plain of the Clyde River and scree slopes and alluvial fans of Tank Gully, is a complex of very low grade metamorphic rocks, for which I here adopt the non-committal term "Torlesse rocks". The high level nomenclature of New Zealand rocks has recently attracted widely different opinions. My concept of "Torlesse rocks" is similar to the Torlesse Group of Suggate (1961), the Torlesse Zone, Alpine Assemblage, Rangitata Orogen of Carter *et al.* (1974), and the Torlesse Terrane, Alpine Domain, Rangitata Orogen and Canterbury Suite,

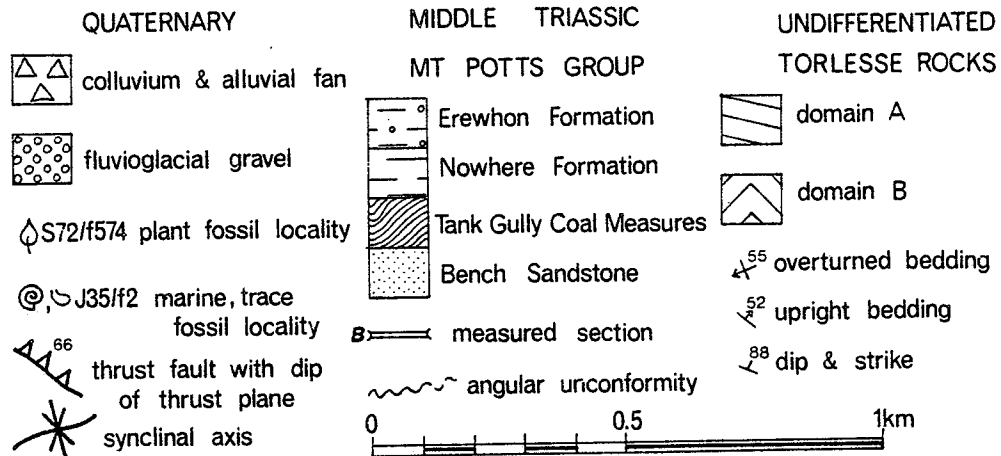
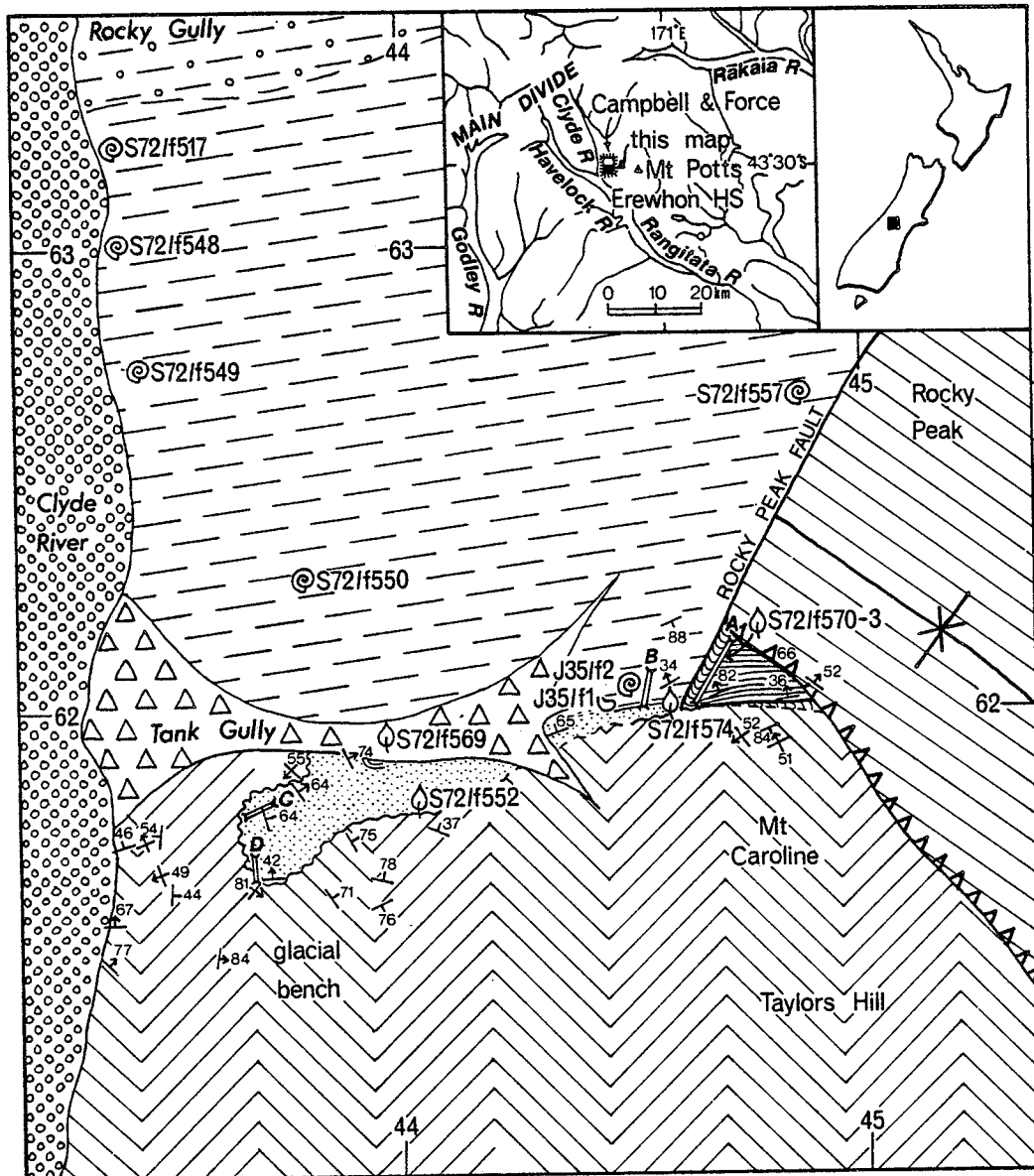


FIG. 1—Geological interpretation map of Tank Gully. Grid after 1:63,360 map S72 "Godley". Measured sections in Figure 4.

Rangitata Sequence, both of Andrews *et al.* (1977). The fossiliferous Triassic rocks in Tank Gully have been named the Mt Potts Group by Campbell and Force (1972). Rare prehnite indicates that both the Mt Potts Group and the undifferentiated Torlesse rocks are low in the prehnite-pumpellyite metagreywacke facies of regional metamorphism (Coombs 1960; Force 1974). Petrologically both the Mt Potts Group and the undifferentiated rocks are typical of the quartzo-feldspathic Canterbury Suite rather than the volcanoclastic Wakatipu Suite (Andrews *et al.* 1977; Force 1974).

Numbers prefixed by P refer to catalogued specimens and thin sections in the Petrology Section, N.Z. Geological Survey.

UNDIFFERENTIATED TORLESSE ROCKS

These rocks differ from the Mt Potts Group in containing conspicuous shale breccias but no roundstone conglomerates. In thin section (P40549-53) they show more tightly-packed, angular sandstone grains, rarer mudstone matrix and grains, less common plant material and slightly more feldspar. Two separate areas of these undifferentiated rocks, here called domains A and B, are probably distinct in structure, age and sedimentary environment.

Domain A. This includes the magnificent exposures of the southeastern wall of Rocky Peak in the headwaters of Tank Gully (Figs. 1, 2A). To the northwest, domain A is separated from fossiliferous Mt Potts Group by the Rocky Peak Fault (new name). This almost vertical, northeast-trending fault is the fault mapped in Rocky Gully by Campbell and Force (1972). Heavily ferruginized, crushed rock of the fault trace has been weathered out to form a deep vertical groove in the northwest ridge of Rocky Peak. A reverse fault continuation of this fault separates domain A from both domain B and coal measures of the Mt Potts Group. This southern segment of the fault trace contains a thick slice of soft weathered clay, possibly a weathered mylonite. The hanging wall of domain A sandstone dips at 66° northeast over the clay. The overlying unit of shale and siltstone contains ripple marks, load casts and graded beds, indicating that they are not overturned. From this facing and the repetition of beds higher in the southeast wall of Rocky Peak (Fig. 2A), it seems that the rocks of domain A are folded into a northwest-trending syncline.

A stratigraphic section of the southwest limb of this syncline begins with massive, cleaved and quartz-veined sandstone above the Rocky Peak Fault. This is overlain by a thick unit of siltstone and black carbonaceous shale in normally graded sets about 10 cm thick. Higher within this unit is a sequence of interfingering sandstone beds. These are overlain by a siltstone unit and then massive sandstone in the core of the syncline (Fig. 2A).

No fossils were found in rocks of domain A. It is possibly Late Triassic, as *Monotis* has been found at several localities to the north and west (Campbell and Warren 1965).

Domain A rocks are similar to sedimentary associations of Torlesse rocks described from other areas, by Andrews (1974), Andrews *et al.* (1977) and Bradshaw (1972). These rocks show no evidence of palaeosols, well-preserved plant fossils, coal beds or brackish to shallow marine fossils, so they are unlikely to have been deposited in shallow marine deltas, as proposed by Andrews (1974). The evidence of traction currents and channel-like facies are equally compatible with deposition on outer continental shelves, slopes and rises, as described by Shepard and Dill (1966) and Heezen and Hollister (1971). The dark, shaly unit of domain A was not formed by contourite currents, as described by Bouma and Hollister (1973) because the ripples are separated by clay skins rather than heavy mineral placers. This unit shows thin T₃ Bouma (1962) sequences, probably deposited from gentle turbidity currents on the outer fan areas of a large submarine fan. The overlying lenticular sandstones were probably the

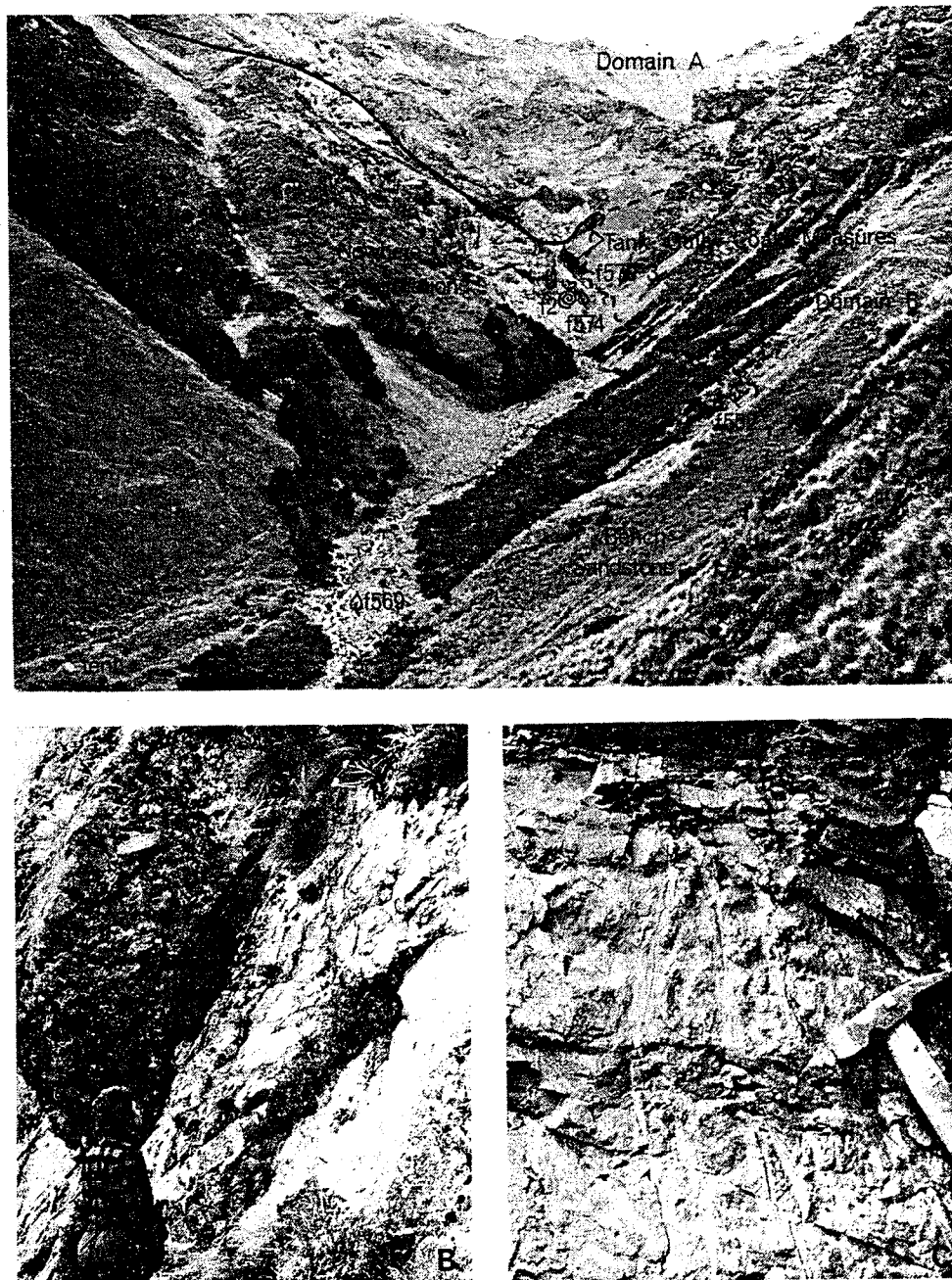


FIG. 2.—Geology of Tank Gully; A, looking up Tank Gully from glacial bench to the southwest; B, angular unconformity between conglomerate of Bench Sandstone and massive, jointed siltstone of domain B of undifferentiated Torlesse rocks, at base of section of Figure 4D; C, long fossil roots penetrating 90 cm from overlying coaly layer, in main outcrop of Tank Gully Coal Measures (Figure 4A).

braided channels of the suprafan lobe. Applying the submarine fan model developed by Walker (1975a, 1975b) even further, the overlying siltstone unit can be interpreted as the non-channelled suprafan area and the uppermost sandstone as the inner fan

channel. Thus the domain A section probably records the progradation of a large submarine fan on the continental rise.

Domain B. This crops out irregularly from under a mantle of snow grass, scree slopes and alluvial fans south of Tank Gully. Domain B is separated from domain A by the Rocky Peak Fault and forms an angular unconformity with the overlying Mt Potts Group. The exact structure of this domain was not determined, but the scattered attitudes and widespread overturning suggest that it is complex. The thrust fault figured by Park (1904, pl. 31, fig. a) lies within this domain on the northern ridge of Mt Caroline.

The domain as a whole has a greater proportion of sandstone than domain A, but is also similar to sedimentary associations of Torlesse rocks described from other areas. Sandstone units are exceptionally thick and massive, and contain thin horizons of intraformational shale breccia. There are also thick units of shale and sandstone beds in fining-upwards sets, 0.5 to 1 metre thick.

Only a few trace fossils, like those figured by Andrews (1974, Fig. 11c), were found in the shales high above central Tank Gully. These are undiagnostic with respect to both age and environment of the unit.

Domain B is tentatively regarded as a Permian deeper continental shelf deposit by comparison with a wide area of Torlesse rocks to the south and east. These rocks have more carbonate in their matrix and a seemingly lower metamorphic grade, also noted in domain B, than most of the Torlesse rocks (Gair 1964; Landis and Bishop 1972). There are several localities in these rocks with *Atomodesma* fragments, a brachiopod assemblage (S91/f501) and an assemblage of fusulines, corals and crinoids (S117/f666 and f667, in Campbell and Warren 1965). Kauffman and Runnegar (1975) have interpreted *Atomodesma* as shelf dwelling benthos, most prolific in shallow water. The sparseness of fossils in most of these rocks suggests a relatively deeper shelf palaeoenvironment.

MT POTTS GROUP

The Mt Potts Group (Campbell and Force 1972) unconformably overlies domain B of undifferentiated Torlesse rocks in Tank Gully. It is a transgressive Triassic sequence forming an apparently homoclinal sequence in the western flanks of Mt Potts between Tank and Rocky Gullies. The group now contains, in order of succession, the Bench Sandstone, Tank Gully Coal Measures, Nowhere Formation, Erewhon Formation and Rocky Gully Formation (Fig. 3).

BENCH SANDSTONE (new name)

Mappable Features. Coarse brown-grey or greenish weathering sandstone with angular, white flecks (quartz grains) is the most characteristic rock type. Boulder conglomerates are also common, especially towards the base of the formation.

Name. The formation is named from the glacial bench at an elevation of 900 m (3000 ft) south of Tank Gully.

Type Locality. The best area for reference in mapping proved to be the 14 m section (Fig. 4C) exposed at an elevation of 880 m (2900 ft) on the northwest spur of the glacial bench (Godley 1:63 360 map, grid reference 438617).

Thickness. A maximum thickness of 300 m for the formation may be calculated from the map (Fig. 1), by assuming that it forms a homoclinal valley fill deposit with a dip and strike averaged from 15 readings. The formation thins to 65 m in central Tank Gully and to probably less than 40 m opposite the main outcrop of Tank Gully Coal Measures.

Lithology. Thick conglomerates with rounded boulders up to 30 cm in diameter are characteristic of the base of this unit (Figs. 2B, 4D). However, for much of this

formation, well-dispersed granules and pebbles are generally less than 3 cm in diameter with occasional beds of cobbles up to 8 cm. All the clasts observed were sandstone, shale or alternating sandstone and shale, similar to rocks of domain B of the undifferentiated basement.

The sandstone consists of medium to very-coarse-grained, very-poorly-sorted, subangular quartz and rock fragments. In thin sections (P40548, 40554-8) the prominence of well-rounded and slightly ferruginized mudstone grains, some muddy matrix, carbonaceous material and less conspicuous feldspar grains distinguish these sandstones from those of the undifferentiated basement. The more detailed petrography of these sandstones has been discussed by Force (1974).

Siltstone is rare in the Bench Sandstone. It is generally quite carbonaceous and somewhat bioturbated.

Relationships. Bench Sandstone overlies domain B of undifferentiated Torlesse rocks with an angular unconformity which may be observed at two localities overlooking lower Tank Gully, at another locality overlooking the Clyde River (Fig. 2B) and also a few hundred metres downstream from the main outcrop of Tank Gully Coal Measures in central Tank Gully. The variation in thickness of the Bench Sandstone suggests that it may be filling a basement valley with a relief of at least 250 m.

Tank Gully Coal Measures overlie the Bench Sandstone with a sharp, conformable contact in a (?) rotated block on the southern bank of central Tank Gully and

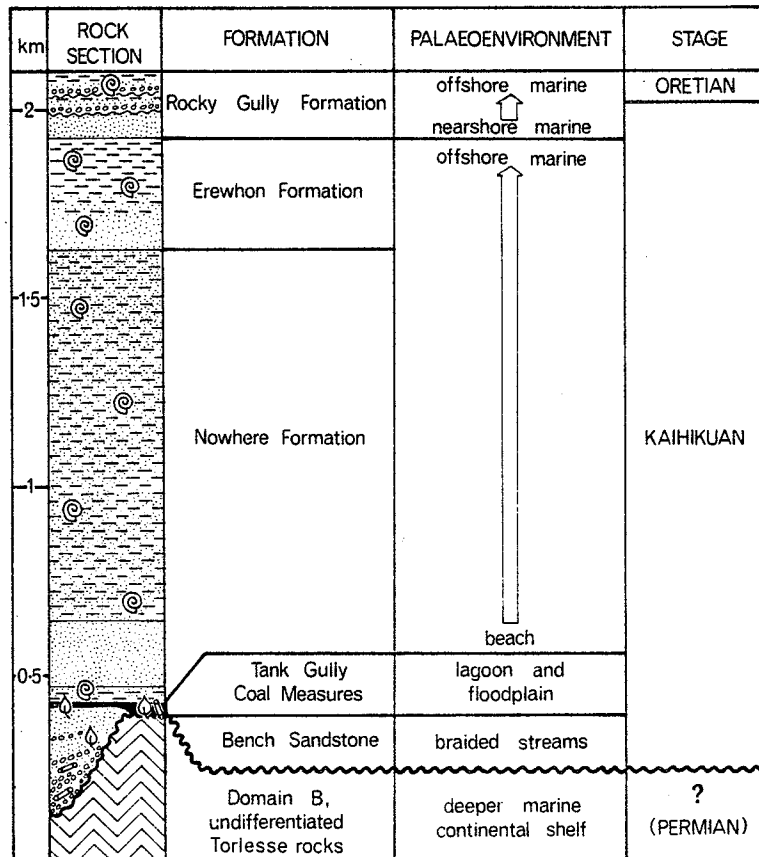


FIG. 3—Geological relationships of the Mt Potts Group and adjacent rocks. Lithological key as for Figure 4.

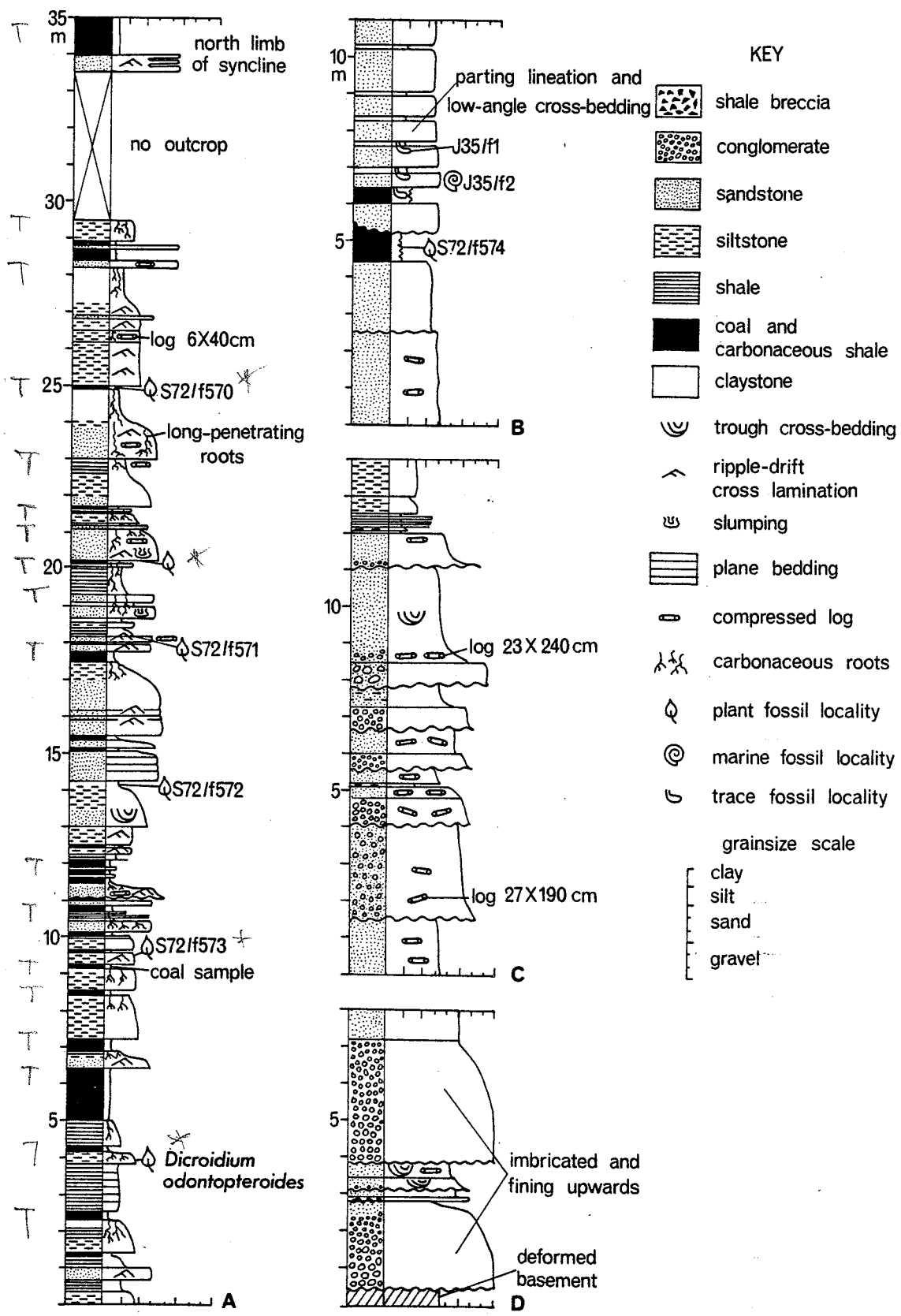


FIG. 4—Columnar sections of the Mt Potts Group. Locations marked on Figure 1; A, main outcrop of Tank Gully Coal Measures; B, section through uppermost Bench Sandstone (4.3 m), Tank Gully Coal Measures (2 m) and basal Nowhere Formation (4.6 m) on northern bank of Tank Gully; C, middle Bench Sandstone on broad spur south of Tank Gully; D, basal Bench Sandstone overlooking the Clyde River.

also in a continuous sequence through coal measures into the basal Nowhere Formation (Fig. 2B) a few hundred metres upstream.

Palaeontology. There are many horizons of compressed logs in the Bench Sandstone. Two of the larger specimens are 240 cm. by 23 cm and 190 by 27 cm. According to Walton's (1936) compression theory, the compressed width is equal to the original diameter. Some of these show clearly-marked growth rings. A badly torn fossil leaf of *Linguifolium steinmannii* has also been found in coarse sandstone at locality S72/f552. Such plants are better known in the overlying Tank Gully Coal Measures.

Depositional Environment. The Bench Sandstone is most likely a coarse-grained, braided stream deposit. This is suggested by the upward-fining cycles within the unit (Fig. 4C, D), by the abundant compressed logs within both the Bench Sandstone and the nearby Tank Gully Coal Measures, and a Trask sorting coefficient of 1.83, calculated by measuring 500 pebbles from the top of the basal conglomerate of the formation (Fig. 4D; compare other coefficients for various environments given by Emery 1955).

Upward-fining sequences in the lower part of the Bench Sandstone (Fig. 4D) are dominated by 2-3 m thick, clast-supported, massive, conglomerates (facies Gm of Miall 1977). At the base of these conglomerates, well-rounded boulders may reach 30 cm across, but most are of cobble grade, fining up to pebble grade only in the upper few centimetres of the bed. Trough and planar crossbedded sandstones (facies St and Sp of Miall 1977) are relatively thin and inconspicuous. According to Miall massive gravels are deposited by the migration of longitudinal bars. However, the exceptional thickness of these examples, their homogeneity and proximity to ancient valley basement, suggests other interpretations. Perhaps they were deposited by flash floods, in the manner envisaged by Scott and Gravlee (1968) as an unsorted "viscous subaqueous rock flow" or as "large gravel waves". The sandstones were probably formed by smaller bedforms at low or waning flood stage, perhaps in part as thin veneers and aprons around large bars. Sedimentologically the lower Bench Sandstone is very similar to braided stream deposits of the Scott type of Miall (1977).

Higher within the Bench Sandstone (Fig. 4C) massive conglomerate beds are thinner, with smaller cobbles (up to 10 cm across). They form thick, upward-fining cycles with crossbedded and massive, pebbly, sandstone (facies St, Sp and Sh of Miall 1977). Finer sediments (facies Fl of Miall 1977) include light-coloured, fine-grained siltstone interlayered with carbonaceous siltstone and also some orange-grey silty claystone. The cyclic relation of conglomerate to sandstone in this part of the section suggests that the conglomerates are channel lag deposits, later overrun by various kinds of in-channel bars. Siltstone and mudstone probably accumulated in quiet water in the lee of bars or in anabranches cut off during low stage. Such thick cycles suggest that most deposition occurred during the waning phase of episodic flooding, as explained by Conaghan and Jones (1975). The sedimentary sequence of this part of the Bench Sandstone is most like braided stream deposits of the Donjek type of Miall (1977).

In nature there is a complete intergradation between braided streams of outwash plains and steeper alluvial fans. The Bench Sandstone is unlikely to have been deposited in an alluvial fan because it lacks mudflow deposits, which Beatty (1963) and Fahnestock (1963) regard as diagnostic of alluvial fans. Mudflow deposits may be laterally extensive, lobate in plan and have coarse levees and snouts. They have a characteristic fabric of very poorly sorted, angular boulders, derived locally and completely supported in a muddy matrix. Unlike stream deposits, they lack an erosional base and a sandy top (Steel 1974; Steel *et al.* 1975). One of the beds interpreted here as a flood deposit (at 8 m in Fig. 4C), has some similarities to a mudflow. However, the matrix is coarse sandstone, not mudstone, and the pebbles are small and well-rounded.

The sedimentary structures and lithologies of the Bench Sandstone compare best with those of the higher portion of low gradient glacial outwash plains, especially those of the Alaskan Gulf coast described by Boothroyd (1972), Gustavson (1974) and Fahnstock and Bradley (1974). These flank a 6000 m high, fold mountain range of similar composition to domain B of undifferentiated Torlesse rocks. In the Alaskan outwash fans, clasts of the size found in the basal Bench Sandstone are transported less than 2 km from their source and those of the size found in the central Bench Sandstone about 20 km (Bradley *et al.* 1972).

Braiding in streams may be produced by steep gradients, sparse vegetation, coarse unconsolidated material in and around the channel area, and highly variable discharge (Morisawa 1968). As there are no mudflows in the Bench Sandstone, it seems unlikely that the channel gradient was steep. Lush vegetation and deeply weathered soils can prevent bank and source area erosion to such an extent that even very high mountains may be drained by meandering streams that supply only sand and silt to the sea (Garner 1959). This was obviously not the case with the Bench Sandstone. Although there is abundant evidence that the adjacent alluvial plain was heavily wooded, the fossil soils in the nearby coal measures are only poorly developed and there is no deeply weathered mantle on the basement unconformity. It is likely that much of the source area for the Bench Sandstone was rocky, barren and ineffective in regulating runoff. The Bench Sandstone was certainly developed as a system of successively unconsolidated channels, but it is doubtful whether this factor is sufficient to cause braiding in itself. Coarsely cyclical sedimentation suggests that the key to braiding of the Bench Sandstone was highly variable discharge. This may have been caused by the orographic effect of a high mountain range, ice damming, snow melt or monsoons. Only monsoons seem unlikely, considering the grey, little weathered sandstone matrix compared with the mineralogically similar pebbles, and the low diversity flora and fauna in immediately overlying units.

The combined evidence of angular unconformity, basement relief of at least 250 m, little weathering of matrix compared to pebbles, conglomeratic flood cycles formed within a low gradient, wooded floodplain and similarities with the Alaskan Gulf coast, suggests that the Bench Sandstone was derived from a mountainous area very close at hand, in a cool temperate to subantarctic climate and latitude.

TANK GULLY COAL MEASURES (new name)

Mappable Features. This formation may be mapped by the presence of thin coal seams. It is also characterised by carbonaceous mudstone and siltstone and by very light orange or purple quartzose sandstone, usually in beds less than one metre thick.

Name. The Tank Gully Coal Measures correspond only to the upper portion of the "Tank Gully Formation" of Campbell and Force (1972).

Type Locality. The 30 m type section (Fig. 4A), exposed on the northern side of central Tank Gully (Godley 1:63,360 map, grid reference 447621), is in the largest single outcrop of the Tank Gully Coal Measures.

Thickness. The maximum observed thickness is 30 m in the type locality. Thinner coaly sequences are seen about 20 m downstream where 2 m of coal and carbonaceous shale lies conformably between the Bench Sandstone and Nowhere Formation (Fig. 4B), and some distance downstream where 8 m of coal measures overlie a (?) rotated block of Bench Sandstone on the southern bank of Tank Gully.

Lithology. Coarse sandstone is found in the Tank Gully Coal Measures, but medium- to fine-grained sandstone is much more common. In thin section (P40546, 40559-62) sandstone of this formation is distinguished by more abundant rock fragments and muddy matrix, both altered to carbonate and sericite, by local diffuse

ferruginization and by carbonaceous layers and strata-transgressive streaks after fossil roots and leaves. These features indicate some development of fossil soils, but in all other details these sandstones are similar to those of the Bench Sandstone.

Siltstone and claystone mixtures form the most voluminous rock type. These are usually somewhat leached, so that plant fossils are represented by impressions with a slight oily iridescence and no cuticular material.

Massive black mudstones commonly with carbonaceous roots in place, contain the best preserved fossil plants. These fossils have been graphitized, at least on their surface, so that they have a distinct silvery sheen. Similar styles of preservation have been noted by Harris (1946, p. 33) and by Hamilton *et al.* (1970).

Coal seams are generally thin and outcrop poorly. They are largely clayey and dull, with some bright layers, often with a silvery graphitic sheen along cleat and joint faces. Analysis of the coal (no. 19/958 of the N.Z. Coal Research Association and N.Z. Geological Survey) shows it to be anthracite. Such a low-moisture, low-volatile coal of high calorific value is generally in accord with the metamorphic grade of the enclosing rocks (see Suggate 1974).

Relationships. The main outcrop of the Tank Gully Coal Measures is an in-faulted block with no clear relationship to underlying and overlying formations (Fig. 1). The southern margin can be mapped by a distinctive change from black to light grey clays in the scree slope. The true nature of this boundary is unknown. The northeast boundary with domain A of undifferentiated Torlesse rocks is formed by the reverse fault continuation of the Rocky Peak Fault. Near the northwest margin of the outcrop is a close-limbed, rounded syncline plunging 32° at azimuth 036° magnetic. The western limb of this fold has been faulted out against the basal Nowhere Formation but probably has not been moved any considerable distance. The eastern limb forms most of the outcrop. A complementary anticline with a faulted-out crest forms the southern edge of the outcrop.

A few metres southwest of this main outcrop, a coaly sequence 2 m thick is sandwiched conformably between the Bench Sandstone and the Nowhere Formation (Fig. 4B). At locality S72/f574, this coaly sequence contains a similar megafossil flora to that of the main outcrop of the Tank Gully Coal Measures.

Palaeontology. The easiest way to collect plant fossils in Tank Gully is to smash loose boulders in the gully bed. This gives the most comprehensive species list (Fig. 5), but poor stratigraphic resolution of the fossil plant associations. My own collections by this method supplemented those of A. C. Beck, G. W. Grindley and J. A. Townrow. In 1975 I also made a sequence of collections from the main outcrop of Tank Gully Coal Measures (S72/f570-3) and collected some poorly-preserved fossil plant fragments from the thin coaly sequence to the southwest (S72/f574).

The fossil plant collections fall into at least two distinctive types of associations, the *Linguifolietum* and *Dicroidietum odontopteroidium* of Retallack (1977b).

Linguifolium is often very abundant in low-diversity assemblages, which also include *Ginkgophytopsis* and *Desmiophyllum*. This repeated abundance of *Linguifolium* supports Steinmann's (1920) suggestion that *Linguifolium* was deciduous. The abundance of compressed logs, leaf coal and carbonaceous roots penetrating up to 90 cm of sediment in the portion of the Tank Gully Coal Measures containing the *Linguifolietum* (Fig. 2C), suggests that it was a swamp woodland vegetation. It appears to have grown closer to the sea than the *Dicroidietum odontopteroidium* because it occurs higher within the marine transgressive sequence of the Mt Potts Group. Such a conclusion is also supported by its occurrence near Benmore Dam and Long Gully, and by the widespread occurrence of *Linguifolium* in marine rocks of the Murihiku Supergroup, in New Zealand (Retallack 1977a). This association is unlikely to have been a mangrove, because it has nowhere been found intimately associated with marine fossils.

	S72/f552	S72/f574	S72/f570	S72/f571	S72/f572	S72/f573	S72/f569
<i>Neocalamites carrerei</i>							
<i>Sphenopteris</i> sp.							
<i>Cladophlebis indica</i>							
<i>Lobifolia dejerseyi</i>							
<i>Dicroidium dubium</i> var. <i>tasmaniense</i>							
<i>D. eskense</i>							
<i>D. incisum</i>							
<i>D. lancifolium</i> var. <i>lancifolium</i>							
<i>D. odontopteroides</i> var. <i>argenteum</i>							
<i>D. odontopteroides</i> var. <i>moltenense</i>							
<i>D. odontopteroides</i> var. <i>odontopteroides</i>							
<i>D. odontopteroides</i> var. <i>remotum</i>							
<i>D. prolongatum</i>							
<i>D. zuberi</i> var. <i>papillatum</i>							
<i>D. zuberi</i> var. <i>sahnii</i>							
<i>Johnstonia dutoitii</i>							
<i>J. stelzneriana</i> var. <i>stelzneriana</i>							
<i>Pteruchus johnstonii</i>							
<i>Pilophorosperma</i> sp. cf. <i>P. costulatum</i>							
<i>P.</i> sp.							
<i>Sphenobaiera robusta</i>							
<i>Desmiophyllum elongatum</i>							
<i>D.</i> sp. cf. <i>D. indicum</i>							
<i>D.</i> sp.							
<i>Ginkgophytopsis lacerata</i>							
<i>Linguifolium arctum</i>							
<i>L. lilleanum</i>							
<i>L. steinmannii</i>							
<i>L. tenison-woodsii</i>							
<i>Carpolithus mackayi</i>							
roots with rootlet bundles							
forking grooved log							
ptycnocytic wood							

FIG. 5—Plant megafossils and localities from the lower Mt Potts Group. Solid black boxes mark abundant species. Localities (specimen numbers) are S72/f552 (OU3761), S72/f569 (B121.1-31, B1068.1-25, B1091.1-66), S72/f570 (B1092.1-8), S72/f571 (B1093.1-2), S72/572 (B1094.1-3), S72/573 (B1095.1-15), S72/574 (B1096.1-4). Identifications after Retallack (in press).

In addition, *Linguifolium* also occurs at localities in Australia (Walkom 1925; Jones and de Jersey 1947), and Argentina (Menendez 1951) which were probably some distance inland of the Triassic coast. *Linguifolium* apparently grew in freshwater, coastal swamp woodlands, analogous to the *Casuarina* and *Melaleuca* forests of modern coastal lagoons in New South Wales described by Osborn and Robertson (1939) and Recher (1971).

A variety of *Dicroidium* leaves, with less abundant *Sphenopteris*, *Sphenobaiera*, *Desmiophyllum*, *Linguifolium* and fructifications, was recovered from the lower Tank Gully Coal Measures (S72/f573). Compressed logs up to 9.6 by 65 cm and roots up to 4 cm

wide were associated with these remains. These plants probably formed a woody vegetation somewhat lower in stature but with a more complex structure, than the *Linguifolietum*. As suggested above, the *Dicroidietum odontopteroidium* probably colonised more inland areas than the *Linguifolietum*. This explains why *Dicroidium* is so rare in the largely marine Triassic rocks of New Zealand.

Neocalamites forms an almost monospecific association in some boulders in the gully bed. It may have formed dense thickets around streams, lakes and marshes, like modern equisetaleans. For the purposes of strict association analysis, it is probably best to regard *Neocalamites* as one of the structural elements (a synusium) of the *Dicroidietum odontopteroidium*.

Depositional Environment. The larger eastern and the thinner western outcrops of the Tank Gully Coal Measures were probably deposited in two different sedimentary environments.

The eastern, or main outcrop was probably deposited as a succession of river floodplains. This is suggested by the generally fine grain size, coal, even bedding, well-preserved fossil plants, logs and palaeosols. There are no marine fossils or extensive flaser-bedded siltstones which would indicate tidal flat conditions, nor any larger, deltaic-channel, sandstones.

The several fining-upwards cycles (Fig. 4A) are thinner than, and lack the characteristic sedimentary structures of, point bar cycles (Allen 1970a; Duff 1967). These sandy beds are more likely crevasse splay and flood deposits. A "crevasse" is a local breach in the levee through which rushing flood waters deposit miniature deltas of sand and mud. Successive crevasse splays commonly form large interfering sets which build wide natural levees (Allen 1970b; Hatch *et al.* 1971, p. 119). Individual stratigraphic sections generated by such flood deposition may be quite variable (McKee *et al.* 1967).

Fossil soils in the sequence appear to be barely modified floodplain sediments with mild leaching (the ochric epipedon of Buol *et al.* 1973) some streaky purple and orange mottling (cambic horizon) and prominent carbonaceous roots. Some of the massive, slickensided, black claystone containing fossil roots may have been argillic horizons, but, judging from the nature of the associated soils, a primary depositional origin is more likely. I could see no evidence for cryoturbation or other permafrost structures. All these soils are probably alluvial soils (of Stace *et al.* 1968) or fluvents (Boul *et al.* 1973), for which pedogenic modification of the land surface was constantly interrupted by episodic sedimentation at intervals of less than one hundred years.

The palaeoenvironment of the main outcrop of the Tank Gully Coal Measures is analogous to topographic level three of the Donjek River, described by Williams and Rust (1969). Its hydrophytic sedge-horsetail and better drained vetch-willow plant associations, may also be analogous to the *Neocalamites* and *Dicroidium* synusia of the *Dicroidietum odontopteroidium*.

In the Tank Gully Coal Measures, the *Linguifolietum* evidently grew in soils of the more sandy upper portion of the section. Within Torlesse rocks, this plant association does not seem to have preferred such a substrate, as it seems to have grown in coaly clay near Benmore Dam and in silts at Long Gully (Retallack 1977a). Some of the sand in the upper portion of the Tank Gully Coal Measures may have been wind-blown from unstabilised beach sands of the Nowhere Formation.

There is a notable lack of pebbles in the Tank Gully Coal Measures. These would be expected from the flooding of a stream powerful enough to deposit the lower Bench Sandstone. It is likely that forested river flats were only developed during deposition of the less-conglomeratic upper Bench Sandstone.

In contrast with the main outcrop, the two western outcrops of the Tank Gully Coal Measures probably accumulated in a coastal lagoon or lake. At plant locality

S72/f574 (Figs. 1, 4B), the formation consists mainly of interbedded greasy, slickensided, organic claystone and 10 cm bands of hard, dark grey mudstone. Fossil plant remains are largely fragments of *Linguifolium*, commonly curled and clumped at irregular angles to the bedding planes. The coaly sequence contains one lenticular sandstone channel and is overlain by sandstones of the basal Nowhere Formation containing marine shell fragments (at locality J35/f2), trace fossils (J35/f1) and shale breccia. No fossils were found in a similar 8 m thick sequence of interbedded coal, carbonaceous shale, siltstone and sandstone on the southern bank of Tank Gully further downstream.

NOWHERE FORMATION

In the southwest spur of Rocky Peak is a steeply dipping homoclinal section of the Nowhere Formation (Campbell and Force 1972) overlying the Tank Gully Coal Measures (Fig. 2A). Fragmentary marine fossils found at the very base of this section (J35/f2; Otago University, Geology Dept., specimens 14194-6) include a relatively well-preserved trioniid bivalve. A more diagnostic Kaihikuan fauna, higher in the section (S72/f550), includes the bivalves *Bakevelloides*, *Balantioselena*, *Daonella*, a trioniid and a cardiid, and the brachiopods *Alipunctifera kaihikuana* and a lingulid (I. G. Speden, pers. comm., 1976). Similar faunas have been found at other localities within the Nowhere Formation (Campbell and Force 1972). I have reconstructed these faunas (Fig. 6) from observations of Force (in Campbell and Force 1972), and Speden (in Gair *et al.* 1962), functional morphological work of Stanley (1970, 1972) and my own examination of the specimens at Otago University. The newly discovered burrows in the basal Nowhere Formation may have been inhabited by swimming prawns (Retallack, in press), such as the Triassic *Antrimpos* (figured by Glaessner 1969).

The prominent massive sandstone in the long ridge of Nowhere Formation (Fig. 2A) is very fractured and veined, but a clear parting lineation can be seen on some weathered surfaces. In thinner beds of sandstone this forms a very low-angle cross-bedding, more likely deposited on a barrier bar than a duned beach. It seems likely that the Nowhere Formation is a beach and nearshore marine deposit.

EREWHON FORMATION

The Erewhon Formation (Campbell and Force 1972), consists of marine sandstones and siltstones in normally graded units, with the whole formation also fining upwards. My reconstruction of its brachiopod-dominated fossil assemblages (Fig. 6) is based largely on the observations of Campbell and Force (1972) and the illustrations of Trechman (1918), Wilckens (1927) and Marwick (1953). Stevens' (1972) suggestion that *Daonella* was a free swimmer is supported by the morphological criteria provided by Stanley (1970). Fleming *et al.* (1971) have discussed the ichthyosaurian remains from the Erewhon Formation. I agree with Force (1974), that the Erewhon Formation was deposited in an offshore marine prodelta.

ROCKY GULLY FORMATION

Conglomerate and plant fragments in this offshore marine formation (Campbell and Force 1972) may have been introduced through rejuvenation of the source terrain and shallowing of the shelf. The "rusty" clasts and concretions, mentioned by Campbell and Force (1972) certainly seem to have been derived from nearby land. The upper portion of the formation contains Oretian (approximately lower Carnian) fossils.

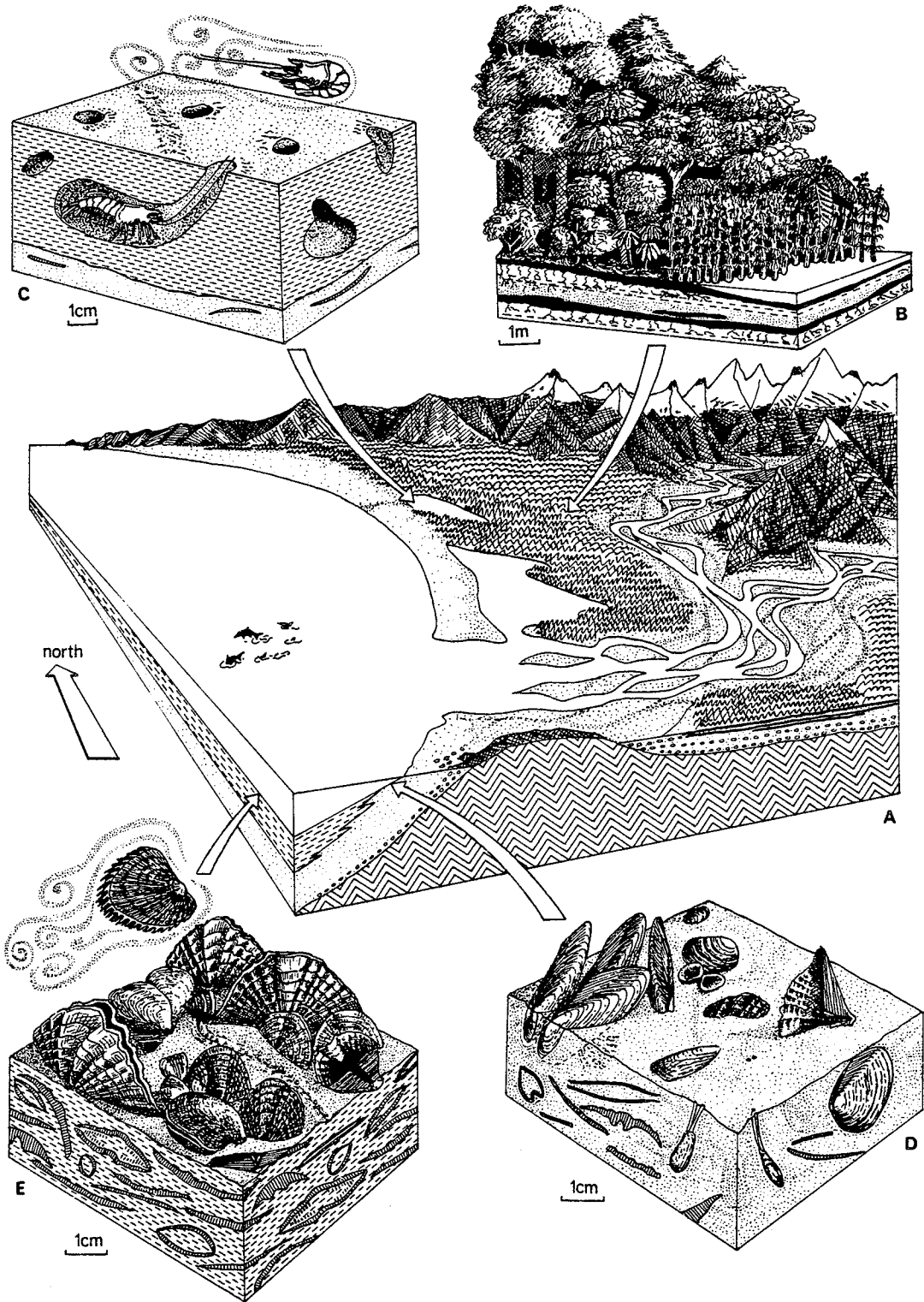


FIG. 6—Reconstructed Triassic environment of the lower Mt Potts Group.

RECONSTRUCTED TRIASSIC ENVIRONMENT OF THE MT POTTS GROUP

The reconstruction (Fig. 6) summarises conclusions from each of the preceding sections for a time within the Ladinian when the sands of the lower Nowhere Formation were winnowed by ocean waves and tides. The following account describes the likely panorama, processes and climate.

The imposing snow-capped mountain range is formed of folded Permian sandstones and shales, weathered to an impressive jumble of sawtooth ridges and peaks. Penetrating the mountain front are extensive tracts of unvegetated outwash gravels. For much of the time, small permanent streams weave through the stranded gravel bars, carrying smaller pebbles, sand and mud further along the broad braided channels towards the sea. Occasionally the outwash plain is swept by powerful floods, which scour the bankful channel and wooded banks with turbulent streams of gravel, sand and water. At these times, large gravel waves course the bankful channel, and sand and silt are spread widely through the wooded floodplain. After the initial flood surges, large gravel waves are dumped within the channel, and sandy layers deposited over the wooded floodplain are capped by mud settling from ponded floodwaters.

The more inland portion of the coastal plain is wooded by broadleaf vegetation, largely *Dicroidium*, but also including *Sphenopteris*, *Sphenobaiera*, *Desmiophyllum* and *Linguifolium*. Small channels, oxbow lakes and ponds are fringed by thickets of *Neocalamites*. Nearer the coast are extensive, low diversity, deciduous woodlands largely of *Linguifolium* plants. This coastal plain vegetation was prolific enough to produce thin beds of peat within periods of less than 100 years, judging from the relatively immature fossil soils preserved under them.

The carbonaceous muddy substrate and fresher water of coastal lagoons and lakes evidently excluded most marine animals. However, some burrowing crustaceans thrived there, separated from the sea by irregular, unstabilised, barrier bar sands. The shifting nearshore sands are colonised by lingulid brachiopods and a variety of epibyssate and shallow burrowing bivalves. In less disturbed offshore areas, brachiopods form extensive shellbeds. The slower sedimentation rate offshore has also resulted in a greater accumulation of swimming bivalves (*Daonella*) and ichthyosaurian bones in a given volume of sediment.

The Ladinian climate during deposition of the Mt Potts Group appears to have been cool temperate. This is suggested by the presence of deciduous plants, prominent seasonal growth rings in fossil logs and marine shellfish, sedimentological similarities with the Alaskan Gulf Coast, and New Zealand's usual position in Gondwanaland reconstructions (Smith *et al.* 1973, Figs. 9, 17A). For the following reasons the climate was probably neither tropical nor subantarctic. There is no evidence of cryoturbation in the fossil soils. The slight reduction of feldspar content and larger number of weakly ferruginised mudstone grains in sandstones compared with pebbles of the Bench Sandstone and compared to domain B of Torlesse rocks is probably the result of moderate weathering. This is less than would be expected in a tropical climate but more than expected in a periglacial climate. Considering the abundance of logs and roots, climate was no colder than that tolerated by modern taiga or cold woodland communities described by Strahler (1969). On the other hand, both the fossil flora and fauna found in Tank Gully have few species and marked morphological conservatism compared to other, presumably tropical, Ladinian fossil assemblages of the world (discussed by Neaverson 1955).

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