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GEOLGY OF THE GLADBSTONE PEAK AREA
TARITINU MOUNTAINS
WESTERN SOUTHLAND NEW ZEALAND.

G. L. SCOTT, 1974
ABSTRACT

Volcanogenic sediments of the Lower Permian Takitimu Group in the Gladstone Peak area are mapped and sub-divided into seven lithofacies. Some of the lithofacies indicate a shallow marine near shore environment, others indicate subaqueous and possibly subaerial pyroclastic flows.

These volcanogenic sediments are cut by dykes, sills and plugs of predominantly basaltic composition and by a small diorite intrusion. The origin of the diorite intrusion is attributed to fractional crystallization and flow differentiation. Six rocks have been chemically analysed and their geochemistry is examined. Some of the component oxides (SiO₂, Fe₂O₃, CaO, Na₂O) in the volcanic rocks have been remobilized, redistributed and deposited elsewhere as authigenic minerals.

The Takitimu Group rocks and intrusives have been metamorphosed to zeolite facies and probably Prehnite - Pumpellyte facies in a low pressure type II terrain. There is a contact metamorphic aureole around the diorite intrusion. Some of the zeolites present would appear to require alkaline, mildly saline ground waters, relatively low activity of SiO₂ especially for thomsonite, high activity of H₂O, low chemical potential of CO₂ and a relatively high temperature (ca. 250°C) for their formation. The metamorphism is similar to that which prevails in the Tanzawa Mountains, Japan where the geothermal gradient is inferred to have been between 40-60°C/km.

The area is part of the Princhester Fault Block (new name) which is itself block faulted. It is likely that the dykes have intruded these Permian block faults. The strata in the Gladstone Peak area were later tilted. They characteristically dip gently toward the South-East and are interrupted by minor faults and cross-cutting veins.
ACKNOWLEDGEMENTS

I would like to acknowledge the help and advice given by my project supervisor, Dr. C.A. Landis, also assistance with petrography and metamorphism by Professor Coombs who suggested the project, assistance with palaeontological problems and stratigraphy by Professor J.D. Campbell, laboratory instruction from Dr. A. Reay and Mr. J.A. Sinton, interpretation of some geophysical data by Dr. J.A. Coggon, discussions with Mr. B.P. Houghton related to many aspects of Takitimu Geology Dr. Suggate of the N.Z. Geological Survey who kindly analysed a coal sample, and the rest of the Staff and students for their interest in this study all of which has been greatly appreciated. Field gear provided by A.M.O.T.I. and the contribution from the Benson Memorial Fund are also gratefully acknowledged.
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INTRODUCTION

This report is submitted as a partial requirement for a Post-graduate Diploma in Geology, Geology Department, University of Otago, New Zealand.

The Gladstone Peak area lies in the northern Takitimu Mountains in the upper reaches of the north branch Aparima River (see fig.1) and Kershaw Creek. The area is about ten square kilometres. Mapping was carried out using a blow-up section of the Gladstone Peak Sheet B2332 Series (Scale 1:15640) and an aerial photograph.

The area is dominated by Gladstone Peak and shows typical glaciated features - steep-sided valleys, truncated spurs, hanging valleys and moraines. Below bushline outcrop is almost absent, except in stream beds and in recent scree slopes. (ca. 1000m above sea level.) Road transport provided access as far as Stone But near the Aparima River, landrover or feet to Aparima But and a walking track to the Forest Service Aparima Forks Fiv. Nine days were spent in the field in February and five days in May, 1974.

Previous work prior to 1946 is summarized by Butch (1972). This includes work by Batten (1972) who first suggested that the Takitimu were made up of upper Palaeozoic rocks and Cox (1973) who mapped the northern Takitimu as far south as the Aparima River. McCraw (1947) mapped the Clare Peak area (2 km north of Gladstone Peak), Harper (1961) described rocks up the South branch of the Aparima River and Kennedy (1969) examined rocks from the Takitimu Group in the Wilanda Downs area near Chai. Butch (1972) described rocks in the Morley subdivision. Since the beginning of 1972, D.F. Houghton has been engaged in M.R. studies on the Takitimu Group. During December 1973 and February 1974, the writer did some reconnaissance work in the Takitimu Group under A.M.G.T.L.
Scale 1:250,000

Fig 1: Locality Map.
STRATIGRAPHY AND SEDIMENTOLOGY

A. Introduction.

The Takitimu Group crops out on the western limb of the Southland Syncline and is inferred to be Lower Permian in age (Waterhouse, 1967). The presently accepted Lower Permian stages and correlations are presented below modified after Waterhouse (1967) and Landis (1969).

<table>
<thead>
<tr>
<th>Russian Standard Sequence</th>
<th>N.Z. Stage</th>
<th>Stratigraphic Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Series</td>
<td>Stages</td>
<td></td>
</tr>
<tr>
<td>Lower</td>
<td>Hungarian</td>
<td>Bruxtonian</td>
</tr>
<tr>
<td></td>
<td>Lethua</td>
<td></td>
</tr>
<tr>
<td>Permian</td>
<td>Artinskian</td>
<td>Mangapirian</td>
</tr>
<tr>
<td></td>
<td>Takitimu</td>
<td>Group.</td>
</tr>
<tr>
<td></td>
<td>Salmonian</td>
<td>Telfordian</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Western terrain</th>
<th>Province</th>
<th>Eastern terrain.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takitimu Group</td>
<td>Southland</td>
<td>Waipahi Group.</td>
</tr>
<tr>
<td>Alabaster Group</td>
<td>Otago</td>
<td>Humbolt Group.</td>
</tr>
<tr>
<td>(Eglinton Volcanics and Skippers Fm.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brook Street Volcanics</td>
<td>Nelson</td>
<td>Lee River Group.</td>
</tr>
</tbody>
</table>

In the Gladstone Peak area, the Takitimu Group consists of pyroclastic, auteclastic and epiclastic volcanogenic rocks. These rocks are intruded by dyke swarms, volcanic plugs and a small plutonic intrusion. Seven sedimentary lithofacies have been recognised.

- Tuff breccia - tuff facies
- Reworked Sandstone facies
- Vent agglomerate facies
- Agglomerate facies
- Lignite facies
- Sandstone - Siltstone facies
- Graded Sandstone facies

Lithofacies are used because the lithologies in each facies are not distinctive enough to comprise normal formations or to map over large distances. Facies are distinguished from one another by sedimentological characteristics (e.g. cyclic repetition of beds with similar thickness, sorting, grain size, etc.). However, in the Gladstone Peak
area, the facies generally occur in the stratigraphic position in which they are listed above. (youngest at the top) Vent Agglomerate and Agglomerate facies occur outside of the measured section. The intrusions that cut the Takitimu Group sediments consist of low grade metamorphosed tholeiitic basalts, basaltic andesites, dolerites, angrite andesites, gabbros, diorites and quartz diorites. I propose to call these intrusions - the Gladstone Intrusives. Since these rocks intrude the Takitimu Group and are similar in lithology to those which intrude the Eglinton Volcanics (Grindley, 1953) they may be correlated with the McKay intrusives in the Eglinton Valley and also with other intrusives elsewhere in the Takitimu Mountains.

A new fossil locality was discovered just north of Gladstone Peak (see map in backcover) and three species were collected. One species is a key fossil and indicates a Tertiary age. The terminology used to describe volcanogenic sediments in this report is based on the nomenclature used by Wentworth and Williams (1932) and Fisher (1966).
B. Facies Description.

In order to understand the sedimentology and geological history of volcanic terrains, one must be able to sub-divide the sediments into recognisable units or facies. This has been done elsewhere with varying amounts of success. Noteworthy examples include the Espiritu Santo Islands (Jones, 1967) and the New Hebrides (Mitchell, 1970).

Graded Sandstone facies.

This facies is characterised by a repetition of a sequence of graded beds. The sequence is as follows: a thick, massive, poorly sorted basal unit (A) consists of size and density graded (sometimes reversely graded near the base) coarse sand-tuffs with angular fragments of fine volcanic breccia is overlain by a relatively thin, well-bedded unit (B) composed of fine to medium sand-tuffs. Sometimes a third unit (C) composed of very thin (ca. 2cms) mud-tuff lenses overlies (B). The average thickness of (A) is five metres while bedding in (B) only attains an approximate maximum thickness of ten centimetres. The total thickness of (B) is about one metre. The sequence then, runs (A),(B) sometimes (C),(A),(B) etcetera. The combination of (A) and (B) is inferred to be one pyroclastic flow. The contact between each sequence is generally sharp and sometimes slightly scoured. An abrupted grain size change occurs from fine sand-tuff to a coarse sand-tuff at this contact. (see Plate 4)

Thin Section description of sand-tuffs in this facies (034101, 034110, 034111.)

The sand-tuffs are comprised of subangular volcanic fragments and isolated crystals of euhedral plagioclase and augite. The volcanic fragments include -

(i) basalt with glomeroporphyritic plagioclase with ovoid alteration patches in a dark glassy groundmass altered to montmorillonoid clays; non-vesicular, anhedral normally zoned plagioclase phenocrysts; nontronite and Fe–Mg chlorite pseudomorphs after augite.

(ii) fine grained pigeonitic basaltic andesite with plagioclase microlites and an Fe–Mg chlorite mesostasis.
Plate 4. A. diffuse parallel lamination at the base of an inertia flow deposit. OU34152.
B. Unit (C) of the Graded Sandstone facies. OU34101
C. Units (A) and (B) of the Graded Sandstone facies. OU34114

Plate 5. Vitroclastic texture in a fine tuffaceous sandstone present in the Lignite facies and the Reworked Sandstone facies. X.200 P.F.L. OU34103.
(iii) porphyritic basalt with plagioclase and augite phenocrysts in a fine grained groundmass.

(iv) altered devitrified glassy fragments.

(v) vein rock fragment.

In general, the matrix is composed of altered plagioclase augite and glass. Bent plagioclase feldspars with undulose extinction also occur. (0034110)

Lignite

(Sandstone - Siltstone) facies.

The lithology of this facies is predominantly fine tuffaceous sandstone and contains thin, wavy, pyritized discontinuous lamellae of carbonaceous material. Some of this material occurs in troughs of symmetrical ripples where it can attain a maximum thickness of two centimetres. This phenomena is similar to flaser bedding (Reimick and Standerlich, 1963). Occasional beds have been deformed by bombs.

Thin section description of facies (0034153)

Fine tuffaceous sandstone consisting of rock fragments (ii), (iii) and (iv) of the Graded Sandstone facies. The rock contains up to 30% opaques probably in the form of carbon, pyrite and magnetite. The matrix consists of epidote, calcite and quartz.

Sandstone - Siltstone

(Lignite) facies.

This facies consists of alternating lamellae (5-10mm) of light grey weathered resistant very fine sandy vitric tuff and dark grey weathered muddy vitric tuffs. (see Plate 2a, 2b.) In outcrop the lamellae are undulatory and closer inspection through a slice of this rock reveals wedge shaped cross bedded fine tuffaceous sands interbedded with tuffaceous muds which thin out over a sandy crest and once again are reminiscent of flaser beds. flute structures, ball and pillow structures and load casts have been observed. Small asymmetric folds show consistent movement sence toward the north. Finely dispersed carbonaceous material appears in the sand. The facies is fossiliferous with at least one brachiopod species and transported prismatic fragments of atomodesma. The upper and lower contacts of this facies are sharp.

Thin section description of tuffaceous sands in this facies. (0034103)

The vitric tuffaceous sands are altered to clay minerals, talcrite and calcite. Glassy rock fragments and minor amounts of augite crystals are also present. Vitriclastic textures are typical. (0034103) (see Plate 5).
Plate 2. a. Sandstone Siltstone facies in outcrop. 
b. Section through Sandstone Siltstone facies showing flaser bedding, load casts and cross bedding.
Agglomerate facies. The Agglomerate facies is massive to poorly bedded and lies above pillow lava. It consists of amygdaloidal subangular to angular rock fragments about five to ten centimetres in diameter in a finer grained matrix of similar lithology. Although agglomerates probably predominate, breccias may be present as well including blocks and bombs. No pillow fragments were observed. The total thickness of this facies is estimated to be 30m. The agglomerates are heavily fractured, veined and cut by at least two dykes.

Vent Agglomerate facies. This facies has been positively identified on the ridge south of Gladstone Peak (see map in backcover) and is tentatively mapped elsewhere. It consists of a non-stratified scoraceous agglomerate and breccia which is poorly sorted and lies in a fine grained matrix of similar lithology to the volcanic fragments. Within this facies, a fine grained basalt occurs as xenoliths in porphyritic basaltic dykes.

Reworked Sandstone facies. The total exposed thickness of this facies is about 60m. It is characterised by a repetition of well bedded sediments (each bed about 5 to 40cms thick) composed of crystal-lithic and crystal-vitric medium to coarse tuffaceous sandstones. Occasionally at the base of each bed, larger fragments up to 10cms are present. Some of the beds are laminated, others are graded, most have semi-vertical burrows (5-10mm long) crosscutting stratification and other trace fossils similar to planolites (Chamberlain and Clark, 1973) are found as aruncate trails on bedding surfaces (see plate 1). Often very fine tuffaceous sands are interbedded with coarse grained thicker bedded tuffs. Large cobbles of volcanic breccia are sometimes found in the fine tuffaceous sands. Flame structures, cross lamination and cross bedding are common sedimentary structures. (see Plate 2)

Thin section description of fine tuffaceous sandstones in the Reworked Sandstone facies (GM34113 to GM34117). Isolated crystals of altered plagioclase (labradorite, ca. An$_{55}$), augite are predominant and are present as groups of plagioclase and/or augite in a clast.
Plate 1. Trails or burrows on a bedding surface in the Reworked Sandstones facies.
Yellow-brown devitrified glass is altered to \( \text{\textit{?}} \) palagonite, a zeolite from the analcime wairakite series and pumpellyite. The glassy fragments sometimes show axiolitic textures (see figs. 82 and 95, Ross and Smith, 1961) with characteristic elongate vesicles. (see Plate 3). A vitroclastic texture of glass shards is also common especially in the fine tuffaceous sandstones.

**Tuff breccia + Tuff facies.**

Very thick (10-50 m) massive pyroclastic rocks are characteristic of this facies. The size graded coarse sands tuffs which include fragments of volcanic breccia are interbedded with thinly bedded fine sand tuffs. Generally, the pyroclastic fragments are angular vesicular and are of one lithology though fragments of a different lithology may have been picked up from the underlying beds.

Thin section description of lithic-crystal sand-tuffs in OU34120.

Rock fragments similar to types (i), (ii) and (iv) of the Graded Sandstone facies exist in conjunction with rounded clastic fragments of euhedral augite and plagioclase. Analcime or wairakite partially replaces altered glass shards. The composition of the plagioclase clasts is calcic labradorite (ca. An\(_{50}\)). Pyroxene in the groundmass is completely altered to Fe-\( \text{\textit{Mg}} \) chlorite, calcite and garnet. Axiolitic textures are also common. (see Plate 3)

![Plate 3. Axiolitic texture in a fine tuffaceous sandstone.](image-url)
C. Palaeontology.

A new fossil locality occurs just north of Gladstone Peak (Fossil record number 562) in the upper part of the Sandstone Siltstone facies (see measured section and map in the backcover). The fossils were transported. The followed were collected and identified:

**Peruvispira imbricata** (Waterhouse)

**Terrakea sp.**

**Atomodesma sp.**

**Peruvispira imbricata** (Waterhouse) is a key fossil for the Braxtonian stage (Waterhouse, 1967) and these rocks may be correlated with the uppermost Takitimu Group and lower Productus Creek Group.

**Plate 6.** *Terrakea sp.* and *Atomodesma sp.* in a fine tuffaceous sandstone in the Sandstone Siltstone facies. Notice the preservation of punctae in the *Terrakea sp.*

*Scale to Plate 7*
Plate 7. *Peruvispira imbricata* (Waterhouse) with its carinae ornamented with delicate, well preserved threads.
D. Recognition of subaerial and subaqueous volcanogenic sediments

The following table summarises the structural and textural differences between subaerial and subaqueous debris flows. (after Piccoli, 1966; Parsons, 1968; Fisher, 1960; Fiske, 1963; Ross and Smith, 1961 and Kato et al., 1971.)

<table>
<thead>
<tr>
<th>Subaqueous Pyroclastic flow from predominantly subaqueous source.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a. low temperature type (100°C)</td>
</tr>
<tr>
<td>Thick massive units (a) (upto 600m) overlain by well bedded units (b) with sedimentary structures.</td>
</tr>
<tr>
<td>Both (a) and (b) are density graded and reverse graded at the base.</td>
</tr>
<tr>
<td>Only one lithology represented in lithic clasts.</td>
</tr>
<tr>
<td>Whole or broken mineral grains and abundant glass and shards. Pumice lapilli common.</td>
</tr>
<tr>
<td>Non-welded glass shards with random orientation.</td>
</tr>
<tr>
<td>Basal unit (a) consisting of massive lapilli tuffs and tuff breccias overlain by very fine grained laminated tuffs (b). Lower contact of (a) is scoured; lower contact is sharp. Lower unit of (a) is massive, density graded; upper unit (b) normal and reverse graded with sedimentary structures.</td>
</tr>
<tr>
<td>Both units (a) and (b) are lithology similar to each other.</td>
</tr>
<tr>
<td>Non to slightly vesicular angular glass fragments.</td>
</tr>
<tr>
<td>Flow structures (see Smith, 1968).</td>
</tr>
<tr>
<td>Lower and upper part of flow unit (a plus b) mainly glass but in the central part, it carries more abundant crystals.</td>
</tr>
</tbody>
</table>

There can be a mixture of sources between types 1 and 11, i.e. subaerial and subaqueous.
II. Shallow water pyroclastic flow derived from a subaerial source. Volcanic debris flow.

Unsorted layers with interbedded fine-grained, thinly bedded moderately sorted layers.

Heterolithologic clasts.

Sedimentary structures in the thin beds.

Size variation in fragments. Many fragments are recognisable as lava fragments as shown by remnants of flow structure.

Calcite and zeolite cement common.

Generally thinly bedded, well stratified, mod. sorted sediments interbedded with better sorted volcanic sandstones and conglomerates; sedimentary structures.

Fragments rounded; pumice and glass shards rare; well rounded mineral fragments and groundmass of sand-silt size.

Heterolithologic

Leaf and wood fragments present.

IV. Subaerial pyroclastic flows (including ignimbrites)

Lacks bedding close to source tends to become stratified away from vent.

Poorly sorted thick units (10m)

Monolithic

Vesicular glassy material and broken pumice fragments.

Non-welded and welded. Basaltic glass shards commonly showing devitrification to palagonite.

Veapour phase minerals common e.g. cristobalite, potassium feldspar, eral.

V. Subaerial epiclastic volcanic debris flows (Lahars)

Angular-subrounded grains sometimes with giant blocks.

Heterolithologic

Lithic fragments typical.

Fusine glass shards rare Many broken mineral grains at varying stages of alteration.

Poorly sorted. Bedding well to poorly developed.

Anyone of these features cannot be used to characterize a particular type of flow; they must be applied as a whole.
Graded Sandstone facies.

This facies is inferred to be deposited by subaqueous pyroclastic flows similar to type II (see table 1). Flows of this type may resemble the submarine inertia flows of Bott (1963) and the debris flow of Hampton (1972). The sharp contacts between flows implies rapid deposition.

One can envisage a pyroclastic flow, produced by a shallow marine eruption, consisting of a lower unit (a) formed by a submarine inertia flow. The submarine inertia flow may be genetically associated with and produce overriding turbidity currents and form unit (b) of the Graded Sandstone facies.

It is possible for these pyroclastic flows to pick up pyroclastic fragments from unconsolidated sea floor sediments and incorporate them into the flow. This may explain the heterolithic nature of the Graded Sandstone facies.

Shallow submarine eruptions are known to produce base surges (Moore, 1967). It is conceivable that the very fine grained material (Plate 46) in unit (c) as well as the upper part of unit (b) was produced by turbidity currents or slow settling of ash as a result of fallout from base surges. (see figure 2)

![Figure 2. Sedimentation mechanisms for the Graded Sandstone facies.](image)
Lignite facies.

The occurrence of "coal" on top of small scale symmetrical and asymmetrical ripples in very thinly laminated tuffaceous sediments with occasional deformation of beds by bombs argues strongly for a shallow water, near shore, near vent environment with sluggish current. The carbonaceous material could be transported out from the shore and during times of calm waters settle out in the trough of the ripples. Subsequently, tidal currents deposit coarser material, plant stems and marine fossils on top of the ripples surface preserving it for posterity. Marine fossils also occur below this facies strongly suggesting a regressive sea at least to this level.

Sandstone-siltstone facies.

Bedding in this facies is reminiscent of wavy bedding and flaser bedding (Reinick and Reinderich, 1963), features of which have been ascribed to an environment characterized by alteration of currents or wave action and slack water. They are characteristically but not exclusively found in sub-tidal or inter-tidal zones. The facies may also be interpreted as being deposited in a tidal zone. The small asymmetrical folds in the tuffaceous sandstone lamellae indicate either clumping during sedimentation or precontemporaneous sediment deformation due to an overriding pyroclastic flow.

Agglomerate facies.

This is ascribed to fragmentation of submarine lava as it comes in contact with sea water.

Elsewhere this type of facies commonly forms over pillow lavas and is similar to the hyaloclastite breccias described by Silvestri (1963).

Vent Agglomerate Facies.

The origin of this facies is self-explanatory. The pyroclastic sediments fill a vent with fragmented lava fragments and wall rock sediments torn off the side of the vent. It is possible that the presence of volcanic rock intruding these sediments may indicate that the lava was isolated from sea water (i.e. subaerial). Lava in vent in contact with sea water is unstable and it will brecciate explosively. However, lava may be preserved unbreciated in a vent below sea level.
Reworked Sandstone facies.

Debris flows (type IV, see table 1 and of Group 2, Sanders, 1965) and turbidity currents (cf. Group 1, Sanders, 1965) are interpreted as the sedimentation mechanism for the Reworked Sandstone facies. There were times when pyroclastic and epiclastic flows were generated as a result of a volcanic eruption. In the calm waters between eruptions, it may have been possible for spontaneous liquefaction to produce inertia flows which are similar to the debris flows (group 2, Sanders, 1965) in that they are characterised by massive bedding, sometimes reverse grading at the base; isolated large clasts and plane parallel laminae (see Plate 4) in the flow (Middleton and Hampton, 1973). Inertia flow or grain flow is capable of carrying large boulders (>20 cm or more) (Stauffer, 1967) and this mechanism may explain the occurrence of large boulders in the fine grained sediment.

Other sedimentary structures including laminated muds and interlaminated and rippled tuffaceous sands, silts and muds, and bioturbation as well as the association with the Sandstone Siltstone just below are suggestive of sub-tidal zones (Selley, 1970). The environment in which the Reworked Sandstone facies was deposited is inferred to be sub-tidal shallow marine.

Tuff breccia - Tuff facies.

Thick, poorly sorted, massive bed lacking internal lamination suggest that this facies was deposited either under subaerial conditions (type IV, see table 1) or under conditions below wave base.

If the Braxtonian fauna represent cold temperature forms (Waterhouse, 1967) and the Braxtonian is represented throughout the entire sequence stated, and if sediment was continually supplied, one may argue for a local sea level drop or regression. Previously it has been stated that regression has taken place up to the Lignite facies. Three possible alternatives are put forward for the relative movements of sea level for post-Lignite facies time. Either the sea level rises or it remains stationary or it drops. An overall regression and hence subaerial conditions are favoured for the above reasons.

Since the regional setting of the Tabitian Group represents a "festoon of islands" (Butch, 1972) with a
continuous supply of volcanogenic sediments, it is more likely that volcanogenic sediments produced by subaerial eruptions would be voluminous and resist erosion by the sea and hence some subaerial sediments would be preserved. Again for this reason, the writer favours sedimentation under subaerial conditions for the Tuff breccia - Tuff facies.

Assuming subaerial conditions did prevail, then the thin beds interbedded with the thicker beds are interpreted as once being air fall material that has settled out between different pyroclastic flows. An excellent mechanism to account for subaerial pyroclastic flow structures has been described by Fisher (1956).
E. Conclusions.

A shoreline is made up of volcanogenic detritus with three main depositional zones - a subaerial zone, intertidal zone and a submarine zone.

The subaerial zone consists of submarine pyroclastic flows and represents a regressive sequence so the source of these flows is likely to be partially subaerial. To explain the sequence of deposition in the broad inter-tidal, subtidal zones in the local column (represented by the lignite facies, Sandstone Siltstone facies and the Reworked Sandstone facies), a series of minor sea level changes are called upon. These may be brought about by local glacial effects in which sediment supply is restricted or by eustatic changes or by shifting tributaries along a lobate shoreline. (see fig. 9)

If there was a broad tidal zone, then the shoreline had a very gentle gradient.

There may be insufficient current action to rework the inter-tidal deposits and carry them out to sea. This may provide an environment further out at sea which is relatively free from volcanogenic detritus where carbonate may form.

If the lower Productus Creek Group (represented by the Letham and Mangawera Formations) are time equivalent to the Takitimu beds in the Gladstone Peak area, then the Productus Creek lithologies may represent tidal channel floor lag conglomerates with interlaminated fine sediments overlain by prograding carbonate banks.

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**Fig. 9. Diagram representing possible sea level changes in the local column.**
IGNEOUS PETROGRAPHY GEOCHEMISTRY AND VOLCANOLOGY

Takitimu Group and Gladstone Intrusives.

A Mineralogy

Augite

Augite occurs in both volcanogenic sedimentary rocks and volcanic rocks, largely as unaltered euhedral grains in the volcanics, in xenoliths with plagioclase in an andesite (OU34152) and as subrounded and broken clasts in the sediments. It alters to Fe-Mg chlorite, prehnite, pumpellyite and clay minerals. Augite is sometimes zoned and hornblende reaction rims are common especially in the plutonic rocks.

Biotite

Biotite is present as a primary mineral in minor amounts (ca. 2%) in a gabbro (OU34139).

Hornblende

Hornblende has only been observed in the plutonic rocks and in a contact metamorphosed sediment (OU34145). It occurs as a reaction rim with augite (OU34140) or it has formed a poikilitic texture (OU34143) or as an intercumulus mineral (OU34151) or as acicular needles in a pegmatoidal vein. Hornblende alters to calcite, Fe-Mg chlorite, prehnite and ? nontronite.

Plagioclase

Plagioclase is a ubiquitous mineral. It seems to be always twinned (Albite and Pericline laws) and is sometimes normally zoned. Compositions of plagioclase were determined using a flat stage Reichert microscope by measuring extinction angles normal to (010). Plagioclase is commonly seausuritized (i.e. altered to prehnite, pumpellyite, epidote, zeolites and calcite), and is often partially altered to albite and chlorite. Sometimes within plagioclase crystals, irregular dark inclusions can be found. They are thought to have originally been glass which is now altered to Fe-Mg chlorite and/or pumpellyite. Often these globules form sub-parallel to the composition zones in the crystal suggesting a preferential alteration. This same phenomena occurs in augite as well (OU34110).
Olivine.

Olivine occurs in basaltic andesite rock fragments in volcanogenic sediments (OU34132, OU34135, OU34136) where it shows characteristic alteration to Fe-Mg chlorite and iddingsite (see plate 8).

Plate 8. Olivine altered to Fe-Mg chlorite and iddingsite

X200. P.P.L. (OU34132)

Magnetite, Pyrite, Sphene, Apatite.

These minerals are constant accessories though they are not all present in any one rock. Magnetite has a granular habit in some diorites (OU34140) where it is probably formed as an alteration product of a mafic mineral. Sphene is present as light yellow euhedral crystals in a diorite (OU34144). Pyrite is present in an epiclastic sediment (OU34153) where it probably formed under reducing conditions, where as around the diorite intrusion on Kershaw ridge, it presumably formed from hydrothermal solutions. Apatite has been identified in at least one slide (OU34138) by its uniaxial negative optical property and its characteristic elongate crystal form. The crystals are abundant for an accessory (ca. 5%) and are relatively unaltered with respect to the rest of the slide.
B. Dykes and Sills.

(i) Petrography.

Classification of the dykes has been based on texture, colour index and mineralogy. Some of the basalts described below may be classified as basaltic andesites. Three rock types have been recognised in the dykes: basalts, dolerites and andesites.

Basalts.

Generally the plagioclases in the basalts have a composition more calcic than An$_{50}$, have intergranular or intersertal textures and a colour index greater than 40. Most of the dykes in the area are thought to be tholeitic basalts (see geochemistry.). Two types of basalt are recognised.

Fine grained basalt. (OU 34106, OU34107, OU34108, OU34109, OU 34112, OU34123, OU34128, OU34113.)

These basalts are microporphyritic with a fine grained groundmass of plagioclase microlites and an augite-chlorite asessastasis. The microphenocrysts are predominantly plagioclase though augite sometimes appears. Magnetite is an accessory mineral. Plagioclase is often saussuritized and augite is partially altered to Fe-Mg chlorite. Prehnite and epidote are sometimes present as vesicles in these rocks.

Porphyritic basalts. (OU34100, OU34102, OU34104, OU34113, OU34122, OU34124, OU34129.)

There are two types of porphyritic basalt. One has a glassy groundmass and the other has a fine grained groundmass. Both types are glomeroporphyritic and contain plagioclase and augite phenocrysts. Zoned plagioclase is rare. Alteration products are similar to the fine grained basalts.

Dolerites. (OU34121, OU34130, OU34134, OU34137.)

The dolerites are not common and are usually found in the centre of thick dykes. All the samples collected are remarkably fresh. The dolerites consist of coarse (up to 3mm) zoned plagioclase (ca. An$_{50}$, calcic labradorite) and zoned augite set in a medium-grained groundmass of plagioclase (ca. An$_{50}$), augite and magnetite. Some of the plagioclases are poikilitic. Augite has a sub-ophitic texture and is altered to stilpnomelane and quartz.

Augite Andesites. (OU34125, OU34133, OU34138.)

The Andesites described here have a typical pilosaxitic texture and a colour index less than forty. They are glomeroporphyritic with saussuritized plagioclase phenocrysts and augite phenocrysts. The very fine grained groundmass is made up of the same mineralogy with magnetite. Neither hypersthene nor potassium feldspar have been observed.
5. Dykes, and Sills.

(ii) Nature of Emplacement.

Two phases of dyke emplacement are tentatively recognised. Most of the dykes are offset by faults however have been observed to approach a fault obliquely intrude along the fault a short distance then continue along the original trend on the other side of the fault. Clearly, the faulting has occurred between the two phases of dyke emplacement. Commonly, the second phase of dyke emplacement is made up of andesite dykes. The age of the minor faulting is inferred to be Permian.

In order for magma in a dyke to reach the surface, the lithostatic load must exceed the weight of the magma column and the frictional resistance to flow (McBirney, p465, 1963). If, because of the relative lightness of the overlying rocks, this condition is not fulfilled, the magma will be intruded laterally. The presence of pillow lavas in the study area suggest that some magma has reached the surface. In order for magma to breach the sedimentary layer, it seems necessary to appeal to some initiating event, such as block faulting or strong seismic shocks (McBirney, 1963). Block faulting has been attributed to the disruption of the Takitimu Group sediments (see section on Structure.) and it seems likely that this may be a mechanism by which lava can reach the surface.
C. Kershaw Plutonic Intrusion.

(i) Description.

The plutonic intrusion on Kershaw Ridge is composed predominantly of diorite though the diorites become more mafic toward the intrusive margin. An augite andesite occurs around the periphery and probably represents a chilled margin. The intrusion itself is about 200m in diameter. Leucocratic quartz, oligoclase, hornblende pegmatoidal veins cut the more mafic rocks. Xenoliths of andesite occur in the diorite and flow banding is also present. (see plate 9) The grain size of each mineral in one flow band is approximately constant however where flow banding does not occur, the grain size of hornblende and plagioclase varies from about one to four millimetres. Mafic and leucocratic patches are also common in the diorites away from the flow bands.

Plate 9. Flow banding in the diorites in the Kershaw Plutonic Intrusion.

The banding is generally semi-vertical though cumulate textures are poorly developed. On the western side of the intrusion veins composed of quartz, calcite, chlorite and dolomite occur inside augite andesite dykes. (CU34147). Pyrite mineralization is concentrated in the augites andesites around the outside of the intrusion and is probably associated with hydrothermal activity during its emplacement.
C. Kershaw Plutonic Intrusion.

Fig. 5. Distribution of structures described in text for the Kershaw Plutonic Intrusion.

(ii) Petrography.

Three basic rock types occur. Propylites, gabbros and diorites.

Propylites (altered augite andesites)

(OU34127, OU34145, OU34149, OU34150, OU34152.)

Pyroxenes are completely altered to Fe-Mg chlorite, calcite, stilpnomelane, pumpellyite and sphene. Plagioclase almost completely altered to albite, calcite epidote. Quartz is present though it is not known whether it is primary or secondary. Pyrite is also present.

Gabbros. (OU34139, OU34140, OU34143.)

These rocks are typically coarse grained, labradorite augite-bearing plutonic intrusives which have a colour index greater than 40. Some leucogabbros are also present. Twinned labradorite (An$_{46}$) and augite are the dominant minerals present in these rocks and sub-ophitic and hypidiomorphic textures are common. The minerals are fairly fresh, however epidote has formed in a microgranular groundmass in OU 34139. Biotite is also present and magnetite is a constant accessory. OU34140 and OU34143 are leucogabbros in which pyroxene has reacted to form poikilitic hornblende.

Diorites. (OU34142, OU34143, OU34144, OU34148; OU34151.)

Zoned oligoclase (An$_{54}$) and hornblende are the typical minerals in this coarse grained rock. Some of the leucocratic veins cutting the gabbros are rich in oligoclase (ca. An$_{74}$). Hornblende in OU34143 shows a poikilitic texture enclosing plagioclase microlites. OU34141 is a quartz diorite composed predominantly of zoned plagioclase with interstitial quartz and mafic minerals altered to Fe-Mg chlorite, calcite and prehnite. Hornblende reaction rims occur in the andesite xenoliths and also sometimes occur in the diorite host (OU3414...
C. Kershaw Plutonic Intrusion.

(iii) Nature of Emplacement.

The distribution of features in the Kershaw intrusion (i.e. flow banding, pegmatites, xenoliths, etc.) are very similar to the structures in the Mount Johnson Intrusion, Quebec, Canada (Shattacharji and Nehru, 1972). The gradational character of the diorites to the gabbros on Kershaw Ridge suggests that this igneous body has been differentiated. Vertical flow banding suggests that the magma was moving upward or downward during the time of consolidation.

Shattacharji and Nehru produced an experimental model which showed that a solid-fluid mixture moved through a pipe-like conduit; a solid plug core was surrounded by a marginal fluid in the experiments. With continued crystallization, the marginal fluid underwent flow differentiation. Coarser material moved toward the walls of the inner solid plug and a transitional zone developed characterized by poikilitic textures between this coarser material and the periphery of the intrusion.

The velocity profile of the solid plug became blunted and hence accounted for the absence of layering in the solid plug. The high shear gradient and fluctuating velocity-pressure conditions along the plug walls occasionedally ripped off xenoliths from the core. Grain size variations appear to be a result of concentration gradients of volatiles, and flow movements during crystallization and emplacement.

A five stage emplacement model was proposed for the Mount Johnson intrusion as follows:

1.) fractional crystallization and intrusion of a partly differentiated magma giving to the formation of an inner crystalline core with immobilized fluid.

2) flow of a solid plug with marginal fluid.

3) concentration of volatiles inward toward the walls of the solid plug

4) rapid crystallization of plagioclase under a partial vapour pressure of gases in the fluid and flow differentiation on route in the marginal fluid during transport.

5) marginal shearing of the plug and development of flow lineation, flow banding, xenolithic structures, etc. in the high shear zone under the variable pressure-velocity conditions present during intrusion.

The writer favours a similar mode of emplacement for the Kershaw Plutonic Intrusion.
D. Geochemistry.

Six chemical analyses of Takitimu rocks were determined from the Geology Departments XRF (Na2O by atomic absorption) four of the rocks analysed are from the Kershaw Plutonic Intrusion: one analysis is from an andesite dyke and the other is a sediment analysis.

Table 2.

<table>
<thead>
<tr>
<th></th>
<th>0U34115</th>
<th>0U34130U154</th>
<th>0U152</th>
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<th>0U139</th>
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<tbody>
<tr>
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<td>dyke</td>
<td>And.</td>
<td>And.</td>
<td>dlor.</td>
<td>gab.</td>
</tr>
<tr>
<td>SiO₂</td>
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<td>50.70</td>
<td>48.05</td>
<td>45.50</td>
<td>41.60</td>
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<tr>
<td>Al₂O₃</td>
<td>16.93</td>
<td>17.00</td>
<td>19.60</td>
<td>17.75</td>
<td>18.30</td>
</tr>
<tr>
<td>Fe₂O₃</td>
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<td>4.98</td>
<td>5.06</td>
<td>14.40</td>
<td>12.62</td>
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<td>FeO</td>
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<td>6.12</td>
<td>5.19</td>
<td>6.61</td>
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<tr>
<td>T. Fe₂O₃</td>
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<td>10.31</td>
<td>9.40</td>
<td>19.45</td>
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<td>MgO</td>
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<td>3.70</td>
<td>4.95</td>
<td>7.30</td>
<td>5.20</td>
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<td>5.22</td>
<td>8.22</td>
<td>11.34</td>
<td>11.15</td>
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<td>6.69</td>
<td>3.64</td>
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<tr>
<td>K₂O</td>
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<td>0.49</td>
<td>0.52</td>
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<td>H₂O</td>
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<td>2.98</td>
<td>3.46</td>
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<td>TiO₂</td>
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<td>1.10</td>
<td>1.02</td>
<td>0.68</td>
<td>0.70</td>
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<tr>
<td>SnO</td>
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<td>0.17</td>
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<tr>
<td>PbO₅</td>
<td>0.28</td>
<td>0.24</td>
<td>0.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>102.16</td>
<td>98.36</td>
<td>98.34</td>
<td>102.07</td>
<td>99.44</td>
</tr>
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</table>

Estimated Modal Analyses

<table>
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<tr>
<td>SiO₂</td>
<td>Lab</td>
</tr>
<tr>
<td>plagioclase</td>
<td>35</td>
</tr>
<tr>
<td>augite</td>
<td>20</td>
</tr>
<tr>
<td>hornblende</td>
<td>30</td>
</tr>
<tr>
<td>chl.</td>
<td>30</td>
</tr>
<tr>
<td>epi.</td>
<td>5</td>
</tr>
<tr>
<td>pre.</td>
<td>5</td>
</tr>
<tr>
<td>pump.</td>
<td>2</td>
</tr>
<tr>
<td>anal.</td>
<td>3</td>
</tr>
</tbody>
</table>

Abreviations

N & P Av. And. = Mason & Poldervaart Average Andesite

* The rock name is based on field and thin section description and it is assumed that the rock has subsequently been partially metamorphosed.
The most striking feature of the analysed rocks as compared to the Mason and Poldervaart's basalt and andesite are the low SiO₂ contents, the high iron contents of the coarse grained plutonic rocks and the high Na₂O content of the andesite dyke analysed. As the analyses stand, OU34125 OU34131 OU34154 are similar to Mason and Poldervaart's average tholeiite. If these analyses are recalculated for water contents of 1%, then the SiO₂ contents approach an andesite for OU34131 and a tholeiite for OU34154.

In the lavas and sediments of the Ordovician Molong Geanticline, N.S.W., (Smith 1968), where CaO is high, Na₂O is correspondingly low. Where CaO is low, Na₂O is nearly always high with respect to the average tholeiite and andesite of Mason and Poldervaart. A similar pattern is observed in the analysed rocks in the Gladstone Peak area. In the case where Na₂O is high, albite may be the alteration product. The high CaO contents in the analysed rocks compared to the standard tholeiites are interpreted to mean that this component has been mobile and probably introduced from nearby altered rocks during metamorphism and calcium aluminosilicates such as prehnite, pampellyite, and /or epidote have been formed.

According to Smith (1968), Al is the least variable component and the amount of total iron is probably related to the original composition in the burial metamorphosed rocks. If these variables are applied here then there is a discrepancy interpreting the original composition. The high total iron contents suggest a tholeiitic basalt while the alumina contents are closer to Mason and Poldervaart's average andesite.

Textural evidence, colour indices, mineralogy, and the ACF diagrams (see figs. 6) suggest that some of the dykes and the sediments were originally basaltic. The mineralogy of the analysed rocks also suggests that they were originally basalts, gabbros and diorites but they have subsequently been metamorphosed. This alteration probably explains the anomalous SiO₂, Fe₂O₃, Na₂O and CaO contents.
A. Introduction.

The volcanic and volcaniclastic rocks in the Gladstone Peak area have been metamorphosed to Zeolite facies and probably prehnite pumpellyte facies in a low pressure type II terrain (Akiyoshiro 1973, Table 11-1 p.296). The inferred geothermal gradient and mineralogy is similar to that which prevailed in the Tanzawa Mountains, Japan (Seki et al. 1969) and to the Butte Lake area, British Columbia (Surdam 1973), where the metamorphic sequence is related to rising temperature resulting from both burial and intrusion of magma. Both areas (i.e. Tanzawa and Butte Lake) are characterised by the presence of albited plagioclase, epidote, prehnite, pumpellyte and wairakite.

The following metamorphic minerals are present in the Gladstone Peak area.

- Actinolite
- Albite, Oligoclase
- Carbonates
- Chlorite
- Epidote
- Garnet
- Carbonaceous Material
- Smectite
- Prehnite
- Pumpellyte
- Quartz
- Stilpnomelane
- Zeolites

**Aalcime - Wairakite Mineral Series**
- Laumontite
- Stilbite
- Mesolite
- Thomsonite
B. Mineralogy.

Actinolite.
Two localities are known for actinolite. It occurs in a lithic-vitric and lithic-crystal tuffaceous sandstones as a partial replacement after clastic augite (OU34105, OU34116). The actinolites are pleochroic \( \gamma = \text{yellow green} \alpha = \text{pale green} \) and have low extinction angles. (see Plate 10)

Plagioclase.
Albite commonly occurs as a replacement after clastic plagioclase feldspar, and coexists with Mg-Fe chlorite, calcite, prehnite, pumellyte and epidote in vesicles and groundmass (OU34102). In OU34145 albite oligoclase appears in veins. Oligoclase was tentatively identified by its extinction angle and refractive index which was greater than Canada balsam.

Carbonates.
Calcite and dolomite have been identified by optical and X-ray diffraction techniques. Calcite is found in almost every slide. It occurs as a partial replacement of plagioclase, augite, hornblende, as a partial vesicle filling with quartz, epidote or chlorite, as a partial replacement of glass (OU34103) and as a vein filling with chlorite, quartz and dolomite (OU34147). Dolomite occurs in veins in andesite dykes on the western side of the Kershaw plutonic intrusion.

Chlorite.
Chlorite is present in all altered rocks within the study area. Following the identification method of Albee (1962), two chlorites can be recognised; an iron chlorite and an Fe-Mg chlorite. All primary phases appear to alter to Fe-Mg chlorite which is the most abundant chlorite. Sometimes discrete monomineralic patches of Fe-Mg chlorite are seen either as an alteration product of augite or olivine. It is also present in vesicles, veins and as an alteration product of volcanic glass. The volcanic glass is vesicular or pumiceous, though the vesicles are sometimes difficult to distinguish from spherulites. Two types of vesicle can be recognised (see Plates 11 and 12).
Plate 11. Devitrified glass with spherules altering to chlorite. Notice the different types of alteration of the spherules and the plagioclase microlites preserved in the altered glass. X200 P.P.L. (0U34105)

Plate 12. Devitrified glass showing maltese crosses in the spherules. X200 X.P. (0U34105)
Plate 10. Actinolite forming as an alteration product around clastic augite grains. X400 E.P. (OU34105)

Plate 13. Garnet or hydrogarnet in a patch of Fe-Mg chlorite X200 P.P.L. (OU34126)
Carbonaceous Material.

Thin lamellae of carbonaceous material occur in pyritized, wavy lenses in a fossiliferous tuff (OU34153). A sample of this material was sent to Dr. R.P. Suggate of the N.Z. Geological Survey, Lower Hutt to be analysed. The results are set out below.

Coal analysis – Air dried basis (%)

<table>
<thead>
<tr>
<th>Moisture</th>
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<tbody>
<tr>
<td>Ash</td>
<td>9.0</td>
</tr>
<tr>
<td>Volatile Matter</td>
<td>8.7</td>
</tr>
<tr>
<td>Fixed Carbon</td>
<td>78.9</td>
</tr>
<tr>
<td>Calorific Value</td>
<td>12960 BTU/lb (30.14 MJ/kg)</td>
</tr>
<tr>
<td>Sulphur</td>
<td>2.0</td>
</tr>
<tr>
<td>Swelling No.</td>
<td>0</td>
</tr>
</tbody>
</table>

The coal is similar in composition to a semi-anthracite though the moisture content is too high in the calorific value is too low for such a low volatile coal (R.P. Suggate pers. comm.) He concluded that the sample is weathered. He also stated that it is not possible to tell the depth of burial from the sample.

Another sample was cleaned with HF and Xrayed. Descriptive parameters were the same as those used by Landis (1971)

Height/Width ratio  
d_{002} A  
at 1/3 height  
3.57

These results correspond approximately to graphite – d_{2} (Table 1, Landis 1971) and are similar to the Fox River semi-anthracite (Table 3, Landis 1971). The conditions under which the coal was formed may be inferred from fig. 5 Landis (1971) and it suggests that the coal was metamorphosed to upper prehnite pumpellyite – lower prehnite actinolite facies in a temperature range 300-350°C.
Epidote.

Epidote is a common metamorphic mineral partially replacing plagioclase, glass, matrix in sediments and groundmass in volcanic rocks as well as occurring in vesicles and veins. The grains have rectangular, longitudinal sections and six sided cross-sections. Data collected for epidotes are presented below.

Table 3.

<table>
<thead>
<tr>
<th>OU34</th>
<th>Pleochroic Scheme (Berek comp.)</th>
<th>d spacing (020)</th>
<th>Pistorite content</th>
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<tr>
<td>OU125</td>
<td>α = colourless to pale yellow</td>
<td></td>
<td>18% Fs</td>
</tr>
<tr>
<td></td>
<td>β = green yellow ca. 0.022</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>γ = pale green yellow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OU102</td>
<td>α = pale yellow</td>
<td>0.027</td>
<td>22% Fs</td>
</tr>
<tr>
<td></td>
<td>γ = yellow - 0.030</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OU139</td>
<td></td>
<td>2.818A</td>
<td>22-27% Fs</td>
</tr>
</tbody>
</table>

Garnet.

Garnet is tentatively identified as grossularite or hydrogrossular. Andradite has been found in or close to the Whitehill intrusives in the Takitimu Group (Houghton pers. comm.) however it occurs typically as a result of contact metamorphism (Deer et al., 1966). The garnet bearing volcanogenic sediments in the present study area are not present close to plutonic intrusions or contact metamorphosed.

Garnet is found in patches of Fe-Mg chlorite with minor amounts of spongy pumpellyite (OU34113, OU34115, OU34126). The pumpellyite in the chlorite patches is often distributed in lines presumably along former cracks or cleavages. (see plate3)

Smith (1969) has reported garnet in the prehnite - pumpellyite and actinolite zones in the volcanogenic sediments of the Tasman Geosyncline. It occurs there with chlorite and is known to replace glass in a volcanic breccia and to occur as a vesicle filling in basalts. Coombs (1970) states that garnet or hydrogarnet is also present in Taringaure sealite facies rocks imbedded in chloritic pseudomorphs.
Smectite. (Montmorillonoid).

Nontronite or Fe

montmorillonite is common and occurs as a complete replacement of felsic minerals in volcanogenic sediments. The smectite (OJ34115) has been identified by X-ray techniques (Carrol 1970). It has a low peak (13.5 Å) on a diffractogram which has shifted to a lower peak (ca.16 Å) when it was glycolated. Nontronite is pleochroic yellow green, has a predominant second order yellow interference tint, indistinct extinction and commonly shows structures inherited from other minerals (see Plate 14). Prehnite.

Prehnite can be found in most of the volcanlastic and volcanic rocks. Its typical form is a radial group of sheaf-like crystal aggregates. It is characteristically length fast with straight extinction. Prehnite occurs as a partial replacement of plagioclase, hornblende and is usually intergrown with Fe-Mg chlorite or ? oxychlorite (cf. Johnstone Plate 9, 1973); it also occurs in the matrix of volcanogenic sediments and in vesicles and veins. Pumpellyite.

Pumpellyite is abundant in the volcanlastic sediments. It is typically pleochroic light green, and has a spongy habit though bladed and fibrous forms are also present. Pumpellyite forms as an alteration product after plagioclase, augite, glassey matrix and possibly prehnite. (OJ34102, Plate 15).

Quartz.

No clastic quartz has been observed in the volcanogenic sediments, though it does appear as a primary mineral in one andesite, in diorites and in pegmatoidal veins in the plutonic rocks on Korahaw ridge. Usually it occurs as a secondary mineral in vesicles and veins in volcanogenic sediments and volcanic rocks.

Plate 15. Fibrous pumpellyite coexisting with albite, Fe-Mg chlorite, and prehnite. Elsewhere in the slide epidote occurs. X200 P.P.L. OU34102.

Plate 15. Fibrous pumpellyite coexisting with albite, Fe-Mg chlorite, and prehnite. Elsewhere in the slide epidote occurs. X200  P.P.L.  0U34102.
Stilpnomelane.

Stilpnomelane seems to be restricted to altered andesites and basalts (OU34102,OU34121,OU34134,OU34133). In the volcanic rocks it tends to replace mafic minerals and plagioclase, and occurs with pumpellyite, epidote, chlorite and sometimes quartz. The mineral itself is a dark yellow brown colour and forms radial and subparallel fibrous aggregates. The strong colour suggests a ferristilpnomelane (Hutton,1956).

Zeolites.

The zeolites were identified by optical and X-ray methods. A zeolite from the analcime -wairakite series has been identified in the following rocks (OU34103,OU34110, OU34113,OU34120,OU34126). This zeolite occurs with prehnite, pumpellyite and epidote. It generally fills cavities and sometimes partially replaces glass. OU34103 is composed predominantly of altered glass shards and $\gamma$ and $\delta$ are consistent with wairakite. $\gamma > 1.496$.

Baumontite is reported from only one locality (Kershaw ridge) where it occurs in amygdales in an andesite dyke (OU34146).

Stilbite has been found in two localities; one in a pyroclastic sediment as a pore filling (OU34113) and as a vein filling near OU34100.

Mesolite and thomsonite occur together in vesicles in volcanic fragments in volcaniclastic sediments (OU34135,OU34136). Thomsonite occurs alone as a partial replacement of plagioclase and mesolite coexists with prehnite in vesicles in the same rocks. Mesolite forms a radial arrangement of fibres and has very low birefringence while thomsonite shows a similar form but has a higher birefringence(first order white) and is characterised by intergrowths of fibres which are length fast and length slow. The following data was obtained for mesolite (OU34135)

Refractive index

\[ \gamma = 1.501 \pm 0.002 \]

Cell dimensions (A) (from diffractogram)
cont'd...

<table>
<thead>
<tr>
<th>Cell dimensions</th>
<th>A</th>
<th>(from diffractogram)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a₀ = 18.760</td>
<td></td>
<td>Mesolite A.S.T.M. card 13/173</td>
</tr>
<tr>
<td>b₀ = 19.23</td>
<td></td>
<td>a₀ = 56.3</td>
</tr>
<tr>
<td>c₀ = 7.03</td>
<td></td>
<td>b₀ = 6.55</td>
</tr>
</tbody>
</table>

The discrepancy in the cell dimensions may be due to an error in the measurements from the diffractogram.

Measurements in degrees from quartz (100) peak to the following peaks

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
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<tr>
<td>(400)</td>
<td>22.746</td>
</tr>
<tr>
<td>(040)</td>
<td>23.192</td>
</tr>
<tr>
<td>(111)</td>
<td>27.103</td>
</tr>
</tbody>
</table>
C. Metamorphic Assemblages.

Matrix and mineral replacement.

chl - Cc - epi - pump
qtz - Ab - Cc - pre - pump.
qtz - Cc - chl - epi
chl - Cc - gross
chl - pump - + gross
qtz - Ab - stilp
qtz - Cc - epi - stilp
Ab - epi
chl - epi
Ab - chl - pre ± epi
Ab - chl - pre - pump - stilp ± epi

Amydales

pre - chl
Cc ± qtz
Cl - chl ± pre
chl - Cc - pump ± epi
qtz - pre - chl
qtz - pre - pump
chl - nontr - pre
qtz - chl - Cc ± epi
qtz - Cc - epi
pre - pump - stilp
chl - pre - Cc
Me - Th - chl - pre
Me - chl - pre
Lau
An
St

Veins

qtz - Ab - epi
qtz - pre
qtz - epi - pre
qtz - dol - Cc - chl
pre - An
St

Abbreviations:

qtz - quartz   epi - epidote   An - analcime
Cc - calcite   stilp - stilpnomelane   Me - Mesolite
chl - chlorite  gross - grossularite  Th - thomsonite
pre - prehnite  nontr - nontronite  Lau - laumontite
pump - pumpellyite  dol - dolomite  St - stilbite
D. Metamorphic Conditions.

Assemblages of authigenic silicate minerals can be correlated to some extent with
(i) original bulk composition of host rock (or sometimes glass), especially in marine and fresh water tuffs although this correlation decreases with increase in depth (Hay, 1966).
(ii) activities of ionic species in solution including pH and salinity.
(iii) $fO_2$
(iv) chemical potential of $CO_2$ and $H_2O$
(v) geothermal gradient
(vi) $p$ total - $p$ fluid relations
(vii) mineral phases in host rock
(viii) rate of reaction
(ix) equilibrium conditions.

Original bulk composition.

The bulk composition of a low grade metamorphosed rock will be a close approximation to the original composition provided the metamorphic reactions in the rock are isochemical (Smith, 1968). The component oxides in one sediment analysed in the Gladstone Peak area are similar to that of a tholeiitic basalt (Table 2) Coombs (1971) suggests that the bulk compositions of most volcanic rocks and volcanogenic sediments tend to project on to and just below the Ca - zeolite - chlorite join on an ACF diagram (see Fig.6). The nesolite - thomsonite assemblage would imply a silica deficient environment or a low activity of $SiO_2$ (Coombs et al., 1959).

Activities of ionic species in solution.

According to Sardan (1973), the observed distribution patterns of hydrous calcium - aluminosilicates can be explained in terms of ionic equilibria. The stability of prehnite, epidote and wairakite can be related to the activities of $Ca^2+$, $SiO_2$ and $H^+$. (see Fig.7) It appears then, that the overlap of key mineral phases such as wairakite and epidote in the Gladstone Peak area may be related to the variability of the activities of ionic species in the aqueous phase:
Fig. 7. Activity diagram depicting phase relations of hydrous calcium aluminosilicate minerals, slightly modified after Surdam (1973).

pH and salinity.

In a simple hydrologic system characterised by free flow, the salinity, solubility and pH should increase with depth. These factors can account for first appearance of zeolites at depth in a buried sequence of rocks (Hay, 1966; Hay and Iijima, 1968).

Zeolitization in the Pleistocene Honolulu Group, Hawaii occurs in alkaline ground waters (Hay and Iijima, 1968). In the Honolulu Group, a sequence of potassium rich to sodium rich zeolites occurs in ultrabasic tuffs namely phillipsite, chabazite, thomsonite, gonnardite, natrolite, analcime.

In the Irkutsk Basin of Coal Measures, U.S.S.R. laumontite and thomsonite are forming at a pH of 9 or more at depths ranging from 3m to 230m - as an upper limit (Korporolin, 1964, Table 1 p.538). He stresses that the alteration in the terrigeneous sandstone, siltstones and gravels is dependent on the chemical composition of the ground waters and grain size. Coarser grained rocks have larger pores and hence are easier to alter.

Potassium feldspar is absent where zeolites are abundant in mildly saline waters (Hay, 1966). Four Takitimu Group sediments (0U34110, 0U34111, 0U34117, 0U34120) were stained with sodium colbaltinitrite and failed to reveal any potassium feldspar.
Cont'd...

The writer concludes that the zeolites in the volcanogenic sediments in the Gladstone Peak area were formed in alkaline, mildly saline groundwaters. In the pleistocene rhyolitic tuffs of Lake Tecopa, California, a high salinity which would have the affect of lowering the $a_{H_2O}$ favours the formation of potassium feldspar (Sheppard and Gude, 1968).

$$\text{fO}_2$$

The epidote composition is related to $\text{fO}_2$ and bulk rock composition. High $\text{fO}_2$ and iron rich rocks (e.g. basalts) favour the formation of iron rich epidotes (Liou, 1973). The appearance of epidotes in the higher grade part of the zeolite facies and the lower grade part of the prehnite pumpellyite facies was suggested by Seki (1972, in Liou 1973) to be the result of the reactions:

\[
\begin{align*}
\text{Leu} + \text{hem} & = \text{epi} + \text{qts} + \text{Al}_2\text{O}_3 + \text{water} \\
\text{pre} + \text{hem} & = \text{epi} + \text{water}
\end{align*}
\]

Liou (1973) has shown that as $\text{fO}_2$ increases the break down of epidote occurs at progressively lower temperatures for some arbitrary pressure. The lower temperature stability of epidote is about 220°C at 1 - 6 kb. It is possible for $\text{fO}_2$ to become high enough to oxidise most available iron and inhibit their formation of pumpellyite containing essential FeO and favouring the production of pistoritic epidote (Smith and Jolly, 1972).

\[
\begin{align*}
\text{pump} & = \text{epi} + 2\text{H}_2\text{O} + \text{H}
\end{align*}
\]

Andradite reflects a high $\text{fO}_2$ (B.F. Houghton, pers. comm.).

Chemical potential of $\text{CO}_2$ and $\text{H}_2\text{O}$.

Zen (1961) showed that the zeolite facies requires relatively high $\mu_{\text{H}_2\text{O}}$ and low $\mu_{\text{CO}_2}$, for some arbitrary pressure and temperature. As $\mu_{\text{H}_2\text{O}}$ decreases at the same value of temperature and pressure, the apparent metamorphic grade increases (Coombs, 1971). Garnet can occur in a low $\mu_{\text{CO}_2}$ environment where it forms from the breakdown of prehnite (Strens, 1968; Coombs, 1970; Liou, 1971).

\[
\begin{align*}
5\text{pre} & = 2 \text{zois} + 2 \text{gross} + 3 \text{qts} + 4\text{H}_2\text{O}
\end{align*}
\]

Coombs (1970) suggests that the disappearance of prehnite should mark the upper temperature limit of the prehnite pumpellyite facies. (400°C at 2kb)
Since part of the Gladstone Peak area may represent lower grade prehnite pumppellyte facies, metamorphic minerals will have formed at somewhat lower temperatures than 400°C. Mesolite has been observed to coexist with prehnite. (OU34135) Coombs (1971) noted that Ca-zeolites can coexist stably with prehnite. According to Liou (1971) it is possible for calcium zeolites to form with prehnite in such a low /µ CO₂ environment where CaO is present in excess. (CaO/Al₂O₃ > 1).

**Geothermal gradient.**

Low grade metamorphism is, in general, degradation and hydration of a higher temperature primary mineralogy (Jolly,1972). A rise in temperature tends to form more strongly dehydrated silicate assemblages. On the basis of water content, alkali zeolites should be more stable than other zeolites at a high temperature. The assemblage thomsonite mesolite (OU34135) is stable at a temperature of approximately 250°C (Miyashiro and Shido,1970). If a sequence of zeolites with varying amounts of water in their structure occurs in veins, cavities or in the groundmass within a confined area, then the zeolites (as well as other hydrated calcium aluminosilicates) commonly appear in the sequence - earlier water rich phase to a later water poor phase. (All other factors being equal). This sequence usually occurs at depth in a pile of sediments and can be related to an increase in the temperature (Coombs et al.,1959). For example, thomsonite will form after diasprosite and stilbite after heulandite (Coombs et al. ; Carpenter, 1971).

The dehydration of analcime to albite occurs at about 500°C in the absence of quartz and at 200°C in the presence of quartz (Liou,1971). The reaction curve is determined by Liou(1971) is steep on a P-T plot. He suggests that analcime alone is more likely to be silica and water deficient at high temperatures compared with authigenic analcime which coexists with quartz. From experimental evidence, Liou (1970) has shown that wairakite has a temperature range 250° - 340°C at 1kb for P fluid = P total. The mineral assemblages and their temperature range are consistent with a low pressure type II metamorphic terrain (Liou,1971; Miyashiro, 1973) and are similar to those in the
Tanzawa Mountains, Japan (Seki et al., 1969) where the geothermal gradient is estimated to be 40-60°C/km.

$P_{\text{total}} - P_{\text{fluid}}$ relations.

In a porous permeable rock where $P_{H_2O} < P_{\text{load}}$, condition 1, in cavities where $P_{H_2O} = P_{\text{load}}$, condition 2, and under osmotic or disequilibrium conditions where $P_{H_2O} > P_{\text{load}}$, condition 3, may be possible to explain the overlapping of key metamorphic minerals. For example heulandite or prehnite may occur under condition 1, laumontite or pumpellyite respectively may occur under condition 2 (Coombe et al., 1959; Houghton in prep.). However heulandite or prehnite can also occur under condition 3 and laumontite and pumpellyite could occur under condition 1 in fissures and hence an overlap of mineral phases will be apparent.

Mineral phases in host rock.

It has become apparent that the mineralogy of the starting materials affect the resulting metamorphic mineral assemblages. "A wide range of apparent phase boundaries have been recorded for the same phase using different starting materials." (Coombs et al., 1959). The experimental work of Hinrichsen and Schurmann (1972) also show that a slightly different mineral assemblage forms if a different initial primary mineral assemblage is used. They show that Mg - pumpellyite has an upper stability range between 260 - 340°C at 3kb for $P_{H_2O} = P_{\text{total}}$ where $\% CO_2/\% H_2O$ is low. If Fe$^{+3}$ is present and $P_{H_2O} < P_{\text{total}}$, then the stability temperature will be lowered. The mineral assemblages that occur with increasing temperatures in their experiments are as follows

\[ \begin{align*}
\text{An} + \text{Di} \text{ join in an ACF diagram,} \\
\text{An} - \text{Di are the starting minerals} \\
\text{An} + \text{Di} &= \text{pre} + \text{chl} + \text{qtz} \quad 280^\circ C \\
\text{pre} + \text{chl} + \text{qtz} &= \text{pre} + \text{clz} + \text{chl} \\
\text{pre} + \text{clz} + \text{chl} &= \text{gloss} + \text{clz} + \text{chl} + \text{qtz} \quad \text{ca}330^\circ C \quad \text{at 5kb}
\end{align*} \]
Rate of reaction.

In the experiments of Hinrichsen and Schumann, the first low temperature assemblages that appear from anorthite diopside starting composition are prehnite, chlorite and quartz. From field experience by numerous workers throughout the world, zeolites tend to occur initially in a low $\mu$ CO$_2$ environment from a primary mineral assemblage such as anorthite and diopside. Hinrichsen and Schumann conclude that the rate of reaction in nature is slow. Starting composition and crystalline nature of the host rock may be critical here.

Zeolites may form directly from the alteration of immature, highly unstable volcanic glass particularly alkali silica poor glasses which react relatively rapidly at shallow depths compared to siliceous glass in the marine environment (Muller, 1961; in May, 1966).

**Equilibrium conditions.**

Where three authigenic tectosilicates appear together in a cavity, they may represent an equilibrium assemblage (Coombs et al., 1959; Miyashido and Shido, 1970). The assemblage mesolite, thomsonite, prehnite appears in a cavity in OU34135 does not preclude the existence of an equilibrium assemblage in the Takitimu Group sediments. The above mineral assemblage must imply changing composition of the depositing solution and/or changing P-T conditions for contemporaneous growth assuming the minerals form one after the other (Carpenter, 1971).
Fig. 6. Possible mineral assemblages represented on AFC diagrams (see Table 2). Diagrams after Coombs (1961) and Coombs (1971).

Zeolite Facies

Prehnite Pumpellyte Facies

Fig. 8 Sketch map showing distribution of key metamorphic minerals.
D. Paragenesis.

A Hypothesis.

It is possible to divide low grade metamorphic rocks into zones each characterised by the appearance of predominantly monomineralic patches or metadomains. In the original description (Smith, 1968) the metadomains in the Ordovician pyroclastic sediments and lavas, N.S.W., Australia were divided into three basic types; an epidote rich yellow-green domain, a pumpellyite-rich green domain and an albite chlorite rich grey domain with a lithology similar to spilites. The dimensions of the metadomains are mesoscopic (say 5-200 cms) and their boundaries are sharp (joint controlled), semi-sharp (change in mineralogy over a few millimetres) and transitional (change in mineralogy over several cms). Smith and Jolly (1972) used this domain concept to explain the mineral zoning in the Portage lava series of the Keweenawan Peninsula, northern Michigan. They found three zones; Lawmontite zone(zeolite facies), Pumpellyite zone and an Epidote zone(prehnite pumpellyite facies). The monomineralic domains occur along fractures and the alteration gradually changes with distance from the fractures. The Lawmontite and Pumpellyite zones have metadomains that were formed by hydration of primary minerals in the host rock while the Epidote zone formed by dehydration suggesting that the former zones are fluid sinks.

$P_{\text{fluid}} < P_{\text{total}}$ in the dehydration zone as a result of the decrease in hydration with depth. The distribution of a specific secondary mineral filling voids is greater than the distribution of the same phase replacing primary rock-forming minerals so that thomsonite may appear in voids in the Portage Lake tholeiites in the prehnite zone. This phenomena can be explained in terms of the relations between $P_{\text{fluid}}$ and $P_{\text{total}}$ (Coombs et al., 1959).

Houghton (in prep.) has further developed these ideas and defines two types of metadomain.
Metadomain type A - in and adjacent to vesicular zones in flows, the groundmass of permeable clastic rocks, minor joints and fractures and interstices of pillow lava sequences.

Metadomain type B - in and adjacent to shear zones and major fractures.

Houghton (in prep.) has recognised two zones which have been applied elsewhere in the Takitimu Group. His two zones are presented below however the third zone is introduced as an extension of the metadomain concept developed by RF. Houghton and may explain the metamorphic assemblages below the prehnite pumpellyite facies in deep piles of volcanoclastic sediments in the Takitimu Group and elsewhere. The following zones have been slightly modified after Houghton (in prep.)

<table>
<thead>
<tr>
<th>Zeolite Zone 1</th>
<th>Zeolite metadomains (type A)</th>
<th>Prehnite metadomains (type B)</th>
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<tr>
<td>Facies</td>
<td>prehnite bearing metavolcanic and volcanoclastic sediments and shallow plutonic horizons</td>
<td></td>
</tr>
<tr>
<td>Prehnite</td>
<td>prehnite metadomain (type A)</td>
<td>Epidote metadomain (type B)</td>
</tr>
<tr>
<td>Pumpellyite Zone 2</td>
<td>Ab-chl pump bearing</td>
<td>Pre = Epidote</td>
</tr>
<tr>
<td>Facies</td>
<td>metavolcanic, volcaniclastic and plutonic horizons</td>
<td></td>
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</tbody>
</table>

The epidote metadomain type A in Zone 3 may be developed in the Gladstone Peak area however it is rare and only a few thin sections are known where epidote occurs, predominantly over other metamorphic minerals, the groundmass of volcanogenic sediments (e.g. OU34153). In Zone 3, the epidote metadomain type A is converted to albite near major fracture zones and the Ca$^{2+}$ remaining is available for the epidote metadomain type B in Zone 2. The reactions of converting Zone 3 have been determined by Liou (1973). The equilibrium temperature for this reaction is high (amphibolite facies) but Liou states that this temperature will be drastically reduced if albite and chlorite are present.
These phases are present in the proposed zone.

Albite occurs sporadically below the prehnite pumpellyite zone in the Tasman Geosyncline, Australia and not at all in the lower biotite zone (Smith, 1969). The albite metadomain type B proposed could explain albite bearing veins above and below the prehnite pumpellyite zone in Australia and zone 2 in the Takitimu Group.

In the lower Palaeozoic Tamworth Group, N.S.W., albite epidote assemblages are cementing minerals in volcanogenic arenites. Pyroxene is unaltered, actinolite and biotite are lacking and the "hornfelsic textured" rocks (a typical texture for a metadomain) form part of an albite epidote facies (Packham and Crook, 1960). The rocks in N.S.W. are formed under conditions in which Packham and Crook call "epigenetic diagenesis". These rocks are burial metamorphosed. The albite epidote facies of Packham and Crook may be correlated with Zone 3 just described. Packham and Crook have related their epidote facies with the greenschist facies. "The greenschist facies of regional metamorphism has equivalents in the albite epidote hornfels facies of contact metamorphism and in the albite epidote facies of diagenesis proposed herein".

It is likely then that an albite epidote assemblage occurs below burial metamorphosed rocks or beside contact metamorphosed rocks characterised by the assemblages prehnite and/or pumpellyite and that the former assemblage can be explained in terms of the metadomain concept.

The following diagram is a summary of the metadomain concept recently developed.

![Metadomain Concept Diagram](image)
Based on reconnaissance work, the Takitimu Mountains are sub-divided into fault blocks. Within each of these there is structural continuity. The Gladstone Peak area is part of a fault block and is characterised by homoclinal beds which strike north-east and dip gently to the south. The proposal is to call this fault block - The Princhester Fault Block after a stream in the northern Takitimu Mountains (B.P. Houghton pers. comm.).

South of the Gladstone Peak area, there is another suite of rocks characterised by steep eastward dipping beds. The contact between the two rock suites is inferred to be a fault which I suspect to run up the South Branch of the Aparima River. The eastern unnamed boundary fault has been mapped by Grindley (1953); the northern fault boundary has been mapped and named the Takitimo fault (Grindley, 1953) while the western boundary is unknown.

Within the Gladstone area of the Princhester Fault Block, there are numerous cross-cutting veins and minor faults which displace dykes only a few metres. The major faults (see map in backcover) are inferred since the strike of bedding changes abruptly across these faults. The variation of dip of the beds may reflect local rearrangement in their attitude due to minor faulting. The minor faults completely offset some dykes while other dykes cut across these faults of probable Permian age. The major inferred faults are likely to be oriented parallel to the predominant steep westward dipping Permian dykes.

There is no evidence for folding in the Gladstone Peak area.

Quaternary.

Moraines are present in the upper reaches of Kershaw Creek while terraced glacial outwash occurs further downstream. Recent scree covers most of the valley walls and Takitimu Group sediments occur as alluvium on the valley floors.
SUMMARY, CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK.

The lower Permian Takitimu Group sediments in the Gladstone Peak area have been deposited predominantly under marine conditions. Seven lithofacies are recognisable and their environments of deposition have been interpreted. They range from shallow water marine to below wave base to a possible subaerial environment. Indications for shallow water include small ripples, thin laminae, beds deformed by bombs and interspersed carbonaceous material. An overall regressive sequence is favoured. Bedding in general is remarkably continuous (see frontispiece) and it is concluded that the facies show a similar lateral continuity. Extensive palaeocurrent data will be useful in delineating the orientation and nature of the shoreline.

Fossils in this area may be more abundant than previously realized. A search along strike in the beds that the fossils are now known to occur may prove to be fruitful.

The graded sandstone facies has been interpreted to have been the result of deposition from pyroclastic flows. The temperature of these flows can be determined by measuring remanent magnetisation on magnetite grains in the sediment (Kato et al., 1971).

The majority of the dykes and the sills are basaltic in composition and generally dip steeply to the west. Their emplacement may be attributed to movement along planes of weakness in the volcanogenic sediments eg. bedding planes, unconformities and faults.

The Kershaw plutonic intrusion is likely to be a later feature since it cuts the volcanogenic sediments. Its origin is ascribed to fractional crystallization and flow differentiation. The cumulate textures in the plutonic intrusions are not well defined however if flow differentiation is a mechanism for the intrusion of this body then cumulate textures may have been disturbed. Using the chemical data as it stands, this intrusion is ultrabasic however it is more likely that some of the SiO₂, CaO, Fe₂O₃, Na₂O have been remobilised and distributed elsewhere as authigenic minerals during low grade metamorphism. Textural and mineralogical evidence suggests that the rocks were originally gabbros and diorites.
The Takitimu Group rocks in the Gladstone Peak area have been metamorphosed to zeolite and prehnite pumpellyite facies. Waikakite tends to occur with prehnite, pumpellyite and sometimes epidote suggesting that these rocks are transitional between zeolite and prehnite pumpellyite facies or metamorphism is complicated by local heat sources (such as dyke swarms) so that the rocks may have been metamorphosed to zeolite facies regionally but that the zeolite facies is overprinted by or overlaps with the prehnite pumpellyite facies at least locally, or that the presence of all three minerals; prehnite, epidote and waikakite, may be related to the relative activities of ionic species (Hendis, pers. comm.). (see fig. 7). Other factors may be involved as well. eg. P total – P fluid relations.

More data is needed to map the metamorphic zones and metamodains and the rock types in the Kershaw Intrusion.

This region was probably characterised by a geothermal gradient similar to the Tanbaca Mountains, Japan (40–60°C/km) which resulted in a metamorphic low pressure type II terrain.

Structurally, the area is characterised by gently dipping monoclinal beds which are interrupted by steeply dipping faults.

A possible sequence of events that could have occurred in the Gladstone Peak area might have been

Volcanism
Sedimentation
Dyke intrusion with associated fracturing and faulting
Plutonic intrusion with associated hydrothermal activity.
Continued metamorphism since the sedimentation period and a climax post plutonic intrusion.
Post – metamorphic faulting.
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Zen E-an 1961. The Zeolite Facies; An Interpretation.  
A.J.S. 259, 401-409.


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<td>34100</td>
</tr>
<tr>
<td>2</td>
<td>sand - tuff</td>
<td>34101</td>
</tr>
<tr>
<td>3</td>
<td>porphyritic basalt</td>
<td>34102</td>
</tr>
<tr>
<td>4</td>
<td>fine vitric tuff, sand.</td>
<td>34103</td>
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in a lithic tuffaceous sandstone
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<td>Diorite with andesite xenoliths</td>
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<td>Lazurite augite in andesite dyke</td>
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<td>Propylite</td>
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</table>
**MEASURED SECTION THROUGH X Y Z**

**DESCRIPTION**

Very thick (10-50m) massive units lacking internal lamination.

Interbedded with finer grained tuffs.

Repetition of well bedded sediments made up (40 cms) of medium tuffaceous sandstones. Some beds are laminated, others are graded, and most are burrowed

Pyritized, fine tuffaceous sandstones containing thin (ca. 2 cms) wavy lenses of semi-anthracite. *Atumodesma sp.*

Plant fragments and *Pterodactylus imbricata* (Waterhouse)

Repetition of a sequence of graded beds. The sequence runs A, B, sometimes C, A, B, etc. where A is a massive, poorly sorted basal unit, B is a thin well bedded unit of sand-tuffs, and C is a very thin (ca. 2 cms) lensoidal unit.

Upper and lower contacts of each sequence are sharp.

**REFERENCE**

- Tuff breccia
- Thick breccia
- Thin breccia (ca. 2 cms)
- Dyke
- Asymmetric ripples
- Carbonaceous lense.

**SCALE 1:500**

**FACIES NAME**

TUFF-BRECCIA TUFF

**INTERPRETATION**

Pyroclastic Flows

(? Subaerial or Subaqueous)

Reworked Sandstone Facies

Sub-tidal

Lignite Facies

Near shore, shallow marine

Sandstone Slitstone Facies

Inter-tidal

Graded Sandstone Facies

Subaqueous Pyroclastic Flows

Where A, B, C represents one flow.