

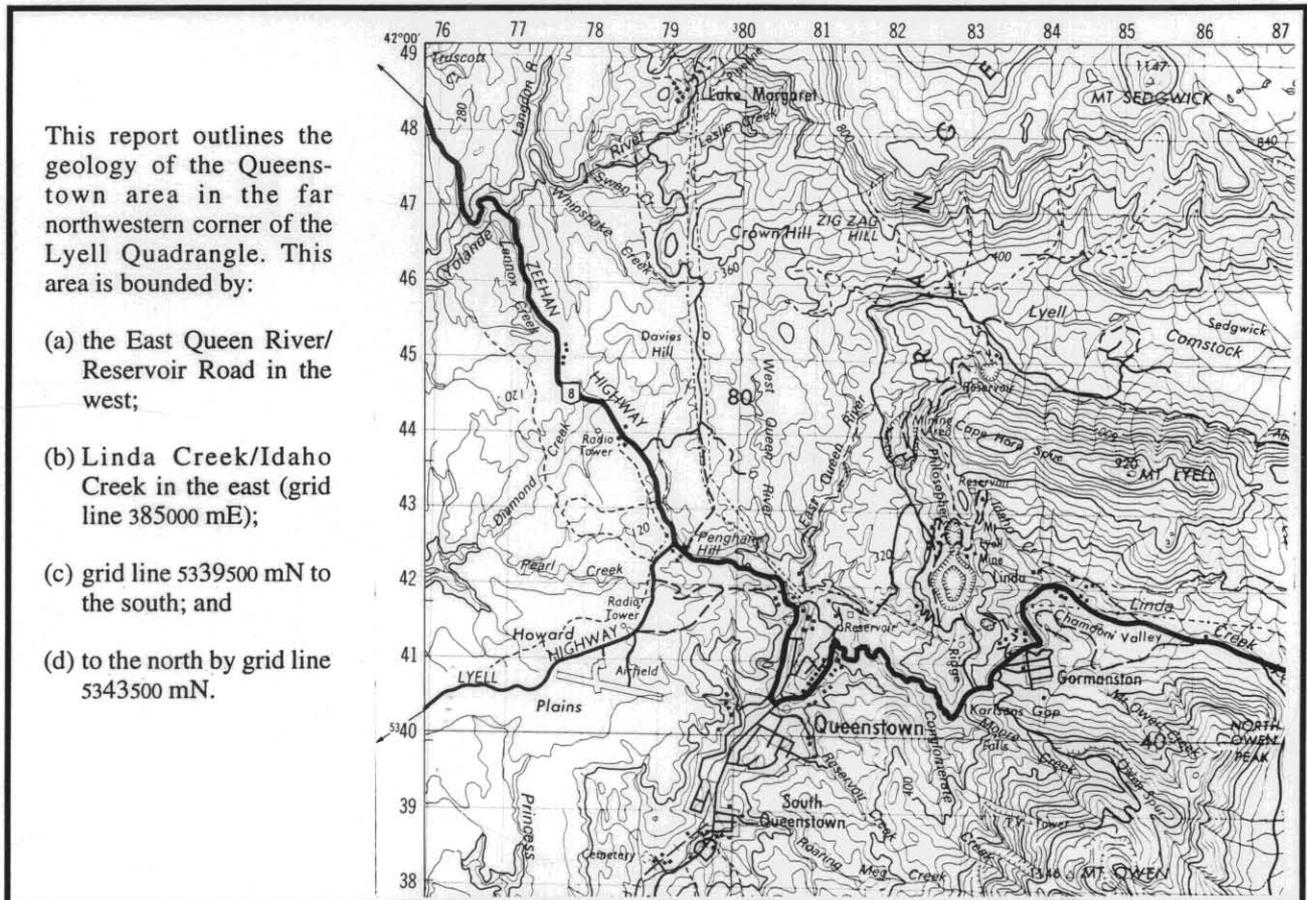
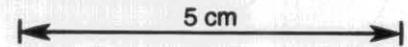


Mineral Resources Tasmania

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Notes on the geology of the Lyell Quadrangle between the East Queen River and Linda Creek

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STRATIGRAPHY

KING RIVER ASSOCIATION

Units of the King River association are usually laterally impersistent, steeply dipping, and trend NW to NNW. South of the Lyell Highway and north of grid 39500 mN very sparse facing data indicate that the units are folded about a horizontal NNW-directed synclinal axis located on the western flank of Little Owen Spur [823395]. The fabric of the rocks is dominated by a steep WNW-trending Devonian cleavage.

€kx

This laterally impersistent, steeply-dipping unit occurs as a strike section in Conglomerate Creek along the eastern

margin of Little Owen Spur [823395] and has a maximum thickness of about 120 metres. It is within the dominantly felsic feldspar-phyric pyroclastic rocks and agglomerate of unit €kvr and faces west.

The unit is well-layered and shows no obvious hydrothermal alteration. It consists of tuff, sometimes graded; siliceous and calcareous siltstone, which is commonly current bedded and displays convolute folding; laminated slaty mudstone; and agglomerate beds of up to 12 m in thickness. The unit is generally dark grey to black in colour with finer layers weathering dark green or white.

Typically, larger fragments within the pyroclastic deposits are vaguely defined and are commonly of altered feldspar porphyry with phenocrysts of altered feldspar and quartz grains with flecks of chlorite and carbonate in a fine matrix

of chlorite, feldspar, carbonate and micaceous material (Corbett, 1979).

To the west the ϵ_{kx} sequence passes upwards, with an increasing proportion of agglomerate, into the hydrothermally altered ϵ_{kvr} (of ϵ_{kvu}) of Little Owen Spur.

ϵ_{kvu} (hydrothermally altered ϵ_{kvp} and ϵ_{kvr})

This unit is of dominantly laterally impersistent felsic feldspar porphyry, felsic feldspar-phyric pyroclastic rocks and agglomerate, rare mudstone and sandstone, and some chlorite-rich intermediate/mafic layers. The feldspar porphyries are usually massive intrusions and extrusions, which are occasionally flow-banded or coarsely fragmental. East of Queenstown the rocks designated ϵ_{kru} are hydrothermally altered and include the Lyell Schists (Wade and Solomon, 1958), the structures of which have resulted from Devonian deformation, and lesser altered rock types. Hydrothermal alteration is readily recognised by the replacement of feldspar with phengitic-mica and quartz, and Na-depletion in comparison with the low-grade metamorphic assemblages of originally similar rock types (Solomon, 1964; Cox, 1981).

The northerly-trending ϵ_{kru} unit exposure is more than six kilometres long and up to 1.75 km wide, but it rapidly thins to the north and south. To the east, the belt of hydrothermally-altered rocks is faulted against members of the Owen Conglomerate, whereas to the west it is for the most part abruptly transitional with other units of the King River association.

Unit ϵ_{kx} of Conglomerate Creek [824400] grades upwards to the west into dominantly felsic feldspar-phyric agglomerate and tuff (ϵ_{kvr} of ϵ_{kvu}) of Little Owen. The textures of these grey-green to pale green laterally impersistent beds have been masked to varying degrees by hydrothermal alteration and the development of Devonian cleavage, and in a number of localities, particularly at the northern end of the Little Owen Spur [821406], the rocks grade into schist — the Lyell Schist (Wade and Solomon, 1958). The hydrothermal alteration is readily recognised by the replacement of feldspar with muscovite and quartz (Cox, 1981). Hydrothermal alteration extends west to a northerly-trending boundary along the western slopes of Little Owen Spur, and further west rock textures are modified by Devonian deformation alone.

Immediately west of ϵ_{kvu} on the Lyell Highway [821408] occur west-younging, felsic layers (up to 100 mm thick) of light green and grey graded tuff interbedded with felsic laminated tuff and usually grey feldspar-phyric agglomerate (ϵ_{kvr}) of a northerly-striking, steeply east-dipping sequence. This succession apparently stratigraphically overlies the ϵ_{kvu} unit to the west (Cox, 1981), which consists of hydrothermally altered, variably pyritised, layered felsic feldspar-phyric agglomerate and tuff. Further east, very thick and poorly-sorted dark grey agglomerate layers are common and contain usually angular clasts of up to some 350 mm diameter in a tuffaceous matrix. These massive agglomerates are evidently deposited from dense turbid currents. In areas where Devonian deformation has imparted a schistose structure to hydrothermally-altered siliceous volcanic

rocks, quartz rods and pyritised lenses, which are up to 800 mm in width and similar length, are common.

For most part the ϵ_{kx} unit of Conglomerate Creek is bounded on the east by northerly-trending felsic feldspar porphyry intrusive and extrusive rocks (ϵ_{kvp} of ϵ_{kvu}), which are hydrothermally altered along with other rock types of the King River association [830401] present between the ϵ_{kx} unit and the Owen Conglomerate to the east. At the boundary of the ϵ_{kx} unit is a steeply-dipping layer of massive, usually grey-green feldspar porphyry, which at Waterfall Creek [833401] includes a flow-banded horizon. This porphyry is separated from extensive northerly-trending pale green to grey felsic feldspar porphyry extrusive rocks to the east by steeply-dipping Lyell Schist consisting of pale green schistose felsic agglomerate with chlorite-rich zones. The felsic extrusives commonly display 5–25 mm thick vertical bands which have been flow folded, and the folds have axial surfaces of very variable trend. The extrusives, which show autobrecciation at some localities, contain phenocrysts of altered feldspar and uncommon embayed quartz grains in a matrix with textures that have resulted from Devonian deformation. Lyell Schist types similar to those downstream occur adjacent to the Owen Conglomerate at the base of the waterfall [835400] and include a steeply dipping intermediate layer which has been described (Corbett, 1979) as containing altered feldspar and chloritised pyroxene phenocrysts in a groundmass of intergrown quartz and feldspar with chlorite actinolite, epidote and sericite.

The feldspar porphyry extrusive rocks of Waterfall Creek extend north to a northerly-trending gully [830405] which is immediately east of the Lyell Highway. North of the Lyell Highway, at Philosophers Ridge [830412], grey and light green siliceous flow-banded impersistent extrusive rocks, sometimes displaying autobrecciation, occur in a generally NNW-trending, steeply-dipping sequence with schistose siliceous agglomerate and tuff. The extrusive rocks display folded bands with a very wide range of fold hinge and axial surface trends due to the superimposition of tight, short wavelength (>1 m), NW-trending Devonian folds upon flow folds developed during extrusion. The extrusives, as noted in thin section, commonly contain resorbed quartz phenocrysts and devitrified spherulites, and, in addition to hydrothermal alteration products, well-defined Devonian cleavage seams of micaceous material. Devonian deformation has also resulted in the development of ubiquitous quartz rods, quartz-rich boudins and pencil structures.

This unit contains all the known economic base metal deposits of the region (Hills, 1990) and has been termed the Mine Sequence (Cox, 1981). In this region the generally lenticular metal deposits are of similar trend to the units of the enclosing volcanic rocks. Much of the mineralisation is considered to have developed in a hydrothermal phase related to the volcanism, which resulted in disseminated pyrite-chalcopyrite, bornite-chalcopyrite, massive pyrite-chalcopyrite, and massive stratiform pyrite-galena-sphalerite-chalcopyrite mineralisation (Walshe and Solomon, 1981). Discussions continue as to the influence of later Devonian events, particularly in the evolution of enriched ore (Hills, 1990). The barite-chalcopyrite deposits are associated with lenses

[432832] of brecciated hematitic chert, chert (ch) and hematite/barite (hb) (Walshe and Solomon, 1981; Reid, 1975). The irregular lenses generally parallel the bounding Owen Conglomerate, and the hematitic deposits have been suggested to be metamorphosed pre-Owen Conglomerate gossan, both *in situ* and transported (Solomon, 1969). However, the Owen Conglomerate shows hematite and barite alteration at the margin, which suggests the outcome of a Devonian hydrothermal event (Hart, 1992). The dull-yellow chert is of very fine quartz, patchily recrystallised, and the hematitic chert contains minor amounts of muscovite, chlorite, fluorite, carbonate and barite (Markham, 1968).

€kvr

A measured section on the northwestern flank of Little Owen Spur (Corbett, 1979, fig. 8) is typical of the stratigraphy of the €kvr unit in this region. The section contains layers about 5–10 m thick of pale green ash flows, air-fall agglomerate and tuff, chlorite-rich dykes and possible flows, agglomerate layers with with chlorite-rich fragments and laminated tuff. The dominant rock type is feldspar-phyric agglomerate similar to that cropping out along the ridge of Little Owen Spur, where feldspar porphyry fragments attain 750 mm in length in some layers. The largest blocks of feldspar porphyry observed within felsic agglomerate are some 1000 mm in length. These are exposed in cuttings on the Queenstown–Reservoir road [811402] to the NE of the Reservoir andesite intrusion [815400].

The unit of dominantly felsic feldspar-phyric tuff and agglomerate at the western margin of Little Owen Spur extends north to the East Queen River [810425] and flanks the €kn unit to the northeast. To the east [810423], in the Queenstown mill area, unit €kvr consists of chlorite-rich intermediate agglomerate, which weathers to a mottled reddish-brown and grey. These intermediate volcanics envelope €ke at 420814 and extend south to around 407814. Immediately northeast of unit €kn occur [437820] felsic agglomerate, with feldspar-phyric pumiceous clasts, tuff, both crystal-vitric and crystal-lithic, and uncommon thin impersistent siltstone layers. In some tuff layers the presence of fragments of siltstone and collapsed pumiceous clasts indicate deposition by ash flow (Cox, 1981). In general, layering is steep and has a northerly strike but the enclosed clasts are usually elongate in the direction of the NW-striking steeply-dipping Devonian cleavage.

Layer facing data are uncommon, but unequivocal examples have been recorded in Conglomerate Creek [815408] northwest of Little Owen Spur, where truncations of layering within pyroclastic deposits indicate younging to the ENE.

€ke

Altered chlorite-rich intermediate occurrences (€ke) are common and are of diverse origins. In Conglomerate Creek [817407] north of Little Owen Spur chlorite-rich vesicular and autobrecciated flows crop out and are associated with intermediate agglomerate and tuffs (Corbett, 1979). Immediately north [812405] of the Reservoir andesite

intrusion are a number of uniformly thick chlorite-rich intrusions truncated to the south by an ENE-trending fault.

Near the mine mill a WNW-trending elongate occurrence [420814], some 100 m wide and more than 400 m long, consists of a chlorite-rich red and brown weathered succession of green to dark grey interlayered agglomerate, tuff and fine-grained porphyries (€ke). This intermediate sequence contains common phenocrysts of albite and relict clinopyroxene in some tuffs (Cox, 1981).

Within the hydrothermally altered, steeply-dipping sequences the origin of chlorite-rich rock types is difficult to determine. In the Philosophers Ridge/Tharsis area conformable chlorite-rich layers within crudely layered schistose felsic agglomerate and tuff are probably derived from intermediate/mafic pyroclastic rocks, whereas some chlorite-rich uniformly thick layers appear to be altered intrusive rocks [e.g. 413829], for they contain evenly distributed pseudomorphed feldspars and ferromagnesian phenocrysts.

€kvp

A massive felsic feldspar porphyry extrusive body (Corbett, 1979; Cox, 1979) straddles Conglomerate Creek at the Lyell Highway Bridge [810406]. The porphyry consists of altered feldspar phenocrysts and occasionally spherulites of altered pink feldspar in a matrix intergrowth of altered feldspar, quartz, chlorite and micaceous material. The porphyry displays generally westerly plunging columns with an average width of 250 mm, which are bounded by typical rippled and faintly ribbed cooling joints. Vesicles filled with micaceous material are flow elongated up to 15 mm in length approximately perpendicular to the cooling columnar joints. To the north the porphyry abuts, at a steeply dipping surface, a disturbed tuff in which there are shear zones. The sheared tuff includes chert lenses and is associated with a volcanic breccia which contains disoriented fragments many metres in length of banded feldspar porphyry.

€kb

Surrounding the Queenstown Reservoir [814399] is an elongate intrusive dark-green massive andesitic feldspar-pyroxene porphyry about 300 m wide and one kilometre long. The porphyry is medium-grained with variably altered plagioclase (mostly albite) and clinopyroxene phenocrysts in a groundmass of plagioclase and quartz with chlorite, actinolite and epidote (Corbett, 1979; Cox, 1979). The andesitic porphyry, which has a conchoidal fracture, is remarkably uncleaned in comparison with the surrounding rocks, where Devonian cleavage development has considerably modified the texture.

€kn

In the region north of the Lyell Highway a central 900 m wide belt within the King River association consists of dominantly massive green to grey chlorite-rich feldspar porphyries [820430]. The porphyries sometimes show flow banding of up to 20 mm thickness with occasional filled vesicles. The banding, which is due to changes in chlorite content, is steeply dipping and of northwest strike.

These feldspar porphyries extend southeast from the East Queen River. Their southwest margin against unit €kvr is a probable fault, whereas the nature of the northeast boundary is unknown.

Cox (1981) considers this unit to be dacitic, typically containing phenocrysts of partly altered albite (≤ 3 mm diameter), amphibole (≤ 2 mm) pseudomorphed by chlorite and calcite, and partially resorbed quartz (< 0.5 mm), which are set in a fine-grained groundmass intergrowth of quartz, albite, chlorite and phengite.

Northwest-trending impersistent layers of mudstone, siltstone and thin tuff beds, which are sometimes graded with indications of younging to the northeast [428818, 429823], appear to separate flows within the dacitic unit.

TYNDALL GROUP

€tu (€tc)

Northwest of the Queenstown mill [810421] iron-oxide impregnated, chlorite-rich, intermediate agglomerate of unit €kvr is overlain by a sequence (€tu) of siltstone, quartz-rich tuff and breccias, which is correlated with the Comstock Tuff of the Tyndall Group (Corbett *et al.*, 1974; Cox, 1981). The basal beds of this sequence are laminated and occasionally festoon current-bedded, dark grey siltstone. These basal beds are followed by light green and brownish-red, medium-grained to coarse-grained tuff, and crudely layered breccia containing angular slabs up to 2.5 m long of siltstone and tuff matching the lower beds of this sequence, angular fragments up to 600 mm diameter of intermediate feldspar porphyry and quartz-feldspar porphyry, and sub-rounded porphyry clasts of some 25 mm diameter in a coarse-grained tuffaceous matrix. The tuff is well bedded with layers up to 500 mm thick, and usually contains albite and quartz crystals in a feldspar-rich matrix with chlorite. The tuff has been described as also containing clinopyroxene crystals and secondary minerals of alkali feldspar, epidote, chlorite, tremolite-actinolite and carbonate (Corbett *et al.*, 1974). A sub-rounded grain of chalcopyrite was observed in a hand specimen of one of the tuff beds. The laminated, occasionally current-bedded siltstone and associated tuff beds evidently accumulated in a sub-aqueous environment, and the massive breccia with slabs of the underlying beds of this sequence and sub-rounded as well as angular porphyry clasts appears to have been deposited from sub-aqueous mass flows. This sequence of the Queenstown mill area attains some 150 m in thickness and is overlain with angular unconformity by the correlate of the Pioneer Beds (Oop).

DENISON GROUP

The Late Cambrian to Early Ordovician Owen Conglomerate belt extending north and south of Mt Owen [845384], and capping the other major peaks on the West Coast Range, consists of terrestrial siliceous, commonly hematitic and usually silicified conglomerate, and quartz sandstone (Oolu, Oolc, Ools, Ooc) passing up into dominantly marine quartz sandstone (Oos, Oop). Unit Oolc has been termed the Lower Owen, units Ools and Ooc have been referred to as the Middle Owen, and units Oos and Oop as the Upper Owen (Wade and Solomon, 1958). The overall fining-upward megasequence, with clasts of

dominantly Precambrian quartzite, indicates, in general, a southeasterly source for sediment-bearing currents around Mt Owen.

The western margin of the meridional Owen Conglomerate is faulted (Great Lyell Fault System) against the Cambrian volcanic rocks of the King River association. However the youngest member, the Pioneer beds (Oop), oversteps westwards onto Cambrian volcanics [e.g. 810420, 777344]. To the east the Owen Conglomerate is succeeded conformably by the younger sequences of the Gordon and Eldon Groups.

Oolc

The oldest successions of the Owen Conglomerate in this region consist dominantly of coarse siliceous conglomerate interbedded with grey or pink quartz sandstone within NW-trending fault-bounded areas as, for example, around 850390 (Oolc) and 845405 (Oolc?). In general both pebbles and quartz grains are sub-rounded to rounded. Pebbles are of vein quartz, quartzite, quartz schist and chert. Clasts usually form a continuous framework and are not matrix supported.

The succession around 850390, about one kilometre northwest of Mt Owen Peak, is approximately 260 m thick and fully exposed in the Telecom Road, where beds dip west to southwest. The lowermost beds are at the northern, shallow-dipping fault margin, whereas the youngest uppermost beds are adjacent to the southern, steeply-dipping fault margin. The oldest series of beds is about 63 m in thickness and dominantly consists of sequences of bedded conglomerate and well-bedded sandstone. The conglomerate sequences consist of 500 mm thick beds, with siliceous pebbles (average length 30 mm) aligned parallel to bedding, separated by medium-grained quartz sandstone lenses of up to 100 mm thick and two metres in length. The dominantly sandstone sequences are of medium-grained quartz sandstone beds, about 200 mm thick, separated by thin conglomerate layers with commonly imbricate pebbles (average length 35 mm) which are usually siliceous, although occasional hematitic ones occur. These oldest sequences are followed by a 95 m thick sequence of dominantly pebble (average length 20 mm) conglomerate with very coarse-grained sandstone beds up to 3.5 m thick.

Towards the base of this conglomerate sequence occur beds up to 1.5 m thick with an average clast length of 70 mm, whereas towards the top beds up to 3.5 m thick contain clasts of an average 40 mm length. The conglomerate clasts are usually too spherical to show imbricate structure. At the top of this dominantly pebble conglomerate sequence occurs a 300 mm thick hematite-rich sandstone, followed by 22 m of cobble (average length 75 mm) conglomerate containing two boulder (average diameter 400 mm) conglomerate horizons. Twelve metres of pebble (average length 50 mm) conglomerate with medium-grained quartz sandstone lenses, usually less than 100 mm thick, follow. These beds are succeeded by some 42 m of pebble (average length from 20 to 25 mm) conglomerate in beds of some 100 mm in thickness usually separated by medium-grained quartz sandstone lenses of less than 150 mm thickness; then a 24 m thick sequence in which the lower beds are of rippled, medium-grained quartz sandstone layers of up to

300 mm in thickness separated by mudstone leaves grading upwards into a mudstone-dominated series with rippled, very fine-grained quartz sandstone beds less than 50 mm thick. The topmost bed of the succession is a pebble (average length 30 mm) conglomerate. Clasts often display imbricate structure in a matrix of coarse quartz grains, and are usually siliceous although hematite-rich fragments occur.

Sequences with grey and yellow silicified massive cobble conglomerate horizons characteristic of the Oolc unit occur at 835397 (Oomu) and in a fault-bounded belt extending from Mt Owen Peak to 830393, where dominantly yellow and grey silicified massive pebble and cobble conglomerate includes thin grey medium-grained quartz sandstone lenses.

Exposed within the NW-trending fault-bounded belt of Owen Conglomerate (Oolc?) around 845405 are conglomerate sequences typical of the Oolc unit. Towards the northern boundary cobble conglomerates are massive with thin pink medium-grained quartz sandstone lenticles. The conglomerate cobbles, which are up to 200 mm in diameter, are sub-rounded and are set in a matrix of medium-grained quartz sand. Sandstone layers become more common in the younger sequences towards the southern fault boundary where pebble (average length from 25 to 40 mm) conglomerate is interbedded with current-bedded coarse-grained sandstone in layers averaging 500 mm in thickness.

A steeply-dipping, northerly-trending sequence similar to that of the Oolc unit underlies the western region of the fault-bounded Tharsis Ridge [830430]. The sequence consists of dominantly yellow to light brown, pebble/cobble conglomerate with current-bedded sandstone lenses.

Throughout these fault-bounded successions the coarseness of the deposits, continuous framework of the clasts of the various beds, and the common lateral impersistence of the layers are consistent with deposition as alluvial fans (Banks *in* Spry and Banks, 1962, pp. 154-160). Down-current directions around 850390, given by imbricate pebble structures and occasional current bedding, are dominantly to the northwest, indicating a southeast source in the Tyennan region which is underlain by rock types matching most of the Oolc clasts.

Ools

Younger than unit Oolc, unit Ools is well exposed along the Mt Owen Telecom Road [835405] where it dips gently south. The oldest beds of the unit are faulted against unit Oolc? to the north, whereas the youngest beds to the south are followed conformably by unit Ooc and younger beds of the Owen Conglomerate. The Ools succession is approximately 220 m thick. Lower sequences, about 155 m thick, consist of pink fine-grained to medium-grained quartz sandstone with usually grey or pink silicified, siliceous pebble conglomerate. The 65 m thick upper part of the Ools unit is dominantly grey and light pink silicified, siliceous pebble conglomerate with pink medium-grained quartz sandstone. Clasts in the conglomerate are usually sub-rounded and of vein quartz, quartzite, quartz-schist and chert, forming a continuous framework with a matrix of

medium to coarse-grained quartz. The sandstones are well-sorted and grains are usually sub-rounded to rounded.

The oldest sequence in the Telecom Road succession [835405] consists of 25 m of dominantly fine-grained current-bedded quartz sandstone with some coarse-grained sandstone and laterally impersistent one pebble-thick conglomerate horizons, followed by 25 m of fine-grained and medium-grained quartz sandstone beds, often graded, of thicknesses from 10 to 100 mm. This sandstone sequence is succeeded by a conglomerate-dominated horizon of approximately 15 m thick consisting of pebble (average length 16 to 32 mm) conglomerate beds up to one metre thick, and beds of vaguely laminated fine-grained sandstone. Approximately 65 m of fine-grained sandstone follows, with thin pebble (average length to 20 mm) conglomerate beds up to 200 mm thick and commonly displaying imbricate structure. Following is a 30 m thick laminated quartz-rich siltstone/very fine-grained sandstone sequence. The youngest series of unit Ools is 60 m thick and is of dominantly pink pebble (average length to 25 mm) conglomerate with fine-grained and medium-grained quartz sandstone horizons of up to 9 m in thickness.

A southerly dipping conglomerate/sandstone sequence (Oolu) at Razorback [832419] is similar to the upper section of the Ools unit. Steeply-dipping, northerly-trending, hematite-rich beds of sandstone and conglomerate (Oolu) underlying the eastern region of the fault-bounded Tharsis Ridge are probably of the Ools unit.

A southwest dipping sequence (Oomu) of usually pink sandstone/conglomerate in a NW-trending, fault-bounded belt some 0.7 km northeast of Mt Owen Peak is well exposed in the Telecom Road [847390]. The lower 40 m of this 145 m thick sequence consists of dominantly massive, medium-grained quartz sandstone, in which liesegang ring structures are notable. Interlayered, laterally impersistent thin beds of pebble (average length 6 mm) conglomerate and medium-grained quartz sandstone, and uncommon 20 mm thick mudstone lenses, occur as lenses up to 300 mm thick. This lower sequence is faulted against an upper sequence of approximately 100 m thickness consisting of massive or poorly laminated fine-grained quartz sandstone beds up to 2 m thick, with 20 mm thick pebble (average length 20 mm) conglomerate lenses. Hematite-rich sandstone and conglomerate beds are present. This fault-bounded Owen Conglomerate sequence may be correlated with unit Ools.

Down-current directions of the Telecom Road succession [835405], given by current bedding in the sandstone beds and imbricate structures in the conglomerate layers, are dominantly to the northwest, indicating the same source as unit Oolc — the Tyennan region, which consists of rock types matching most of the Ools clasts. For the most part, the depositional environment appears to be similar to that of the Oolc unit in which alluvial fans accumulated. However meristome trails near the top of the succession point to the development of a marine environment (Solomon *in* Spry and Banks, 1962, p.157).

Ooc

Unit Ooc, approximately 12 m thick, follows unit Ools conformably and consists of erosion-resistant, dominantly

large pebble conglomerate, which forms a distinctive mappable horizon. Clasts of the conglomerate are usually sub-rounded and are of vein quartz, quartzite, quartz schist and chert. The conglomerate clasts form a continuous framework with a matrix of sub-rounded to rounded quartz sand grains.

The basal bed of this unit on the Mt Owen Telecom Road [836403] is a 0.5 m thick grey pebble (average length 20 mm) conglomerate followed by one metre of dominantly red hematite-rich fine-grained quartz sandstone layers and 10.5 m of yellow and white silicified, siliceous pebble (average lengths 20 and 35 mm) conglomerate beds, in which the pebbles are usually aligned parallel to bedding but occasionally display imbricate structure. Near the top of the sequence thin well-cleaved mudstone layers occur within the conglomerate.

Continuous outcrop of unit Ooc extends from the Mt Owen Telecom Road [836403] to the southeast and to the southwest faulted margin of Mt Owen, where a fault-bounded occurrence of yellow pebble conglomerate, similar to that of unit Ooc, is surrounded by Lyell Schist.

Although clast compositions of the Ooc conglomerate and sandstone are the same as the underlying Owen Conglomerate sequences, indicating that much has been derived from the Tyennan region to the east, imbricate structure within the conglomerate suggests down-current directions to the southeast.

Oos

Along the Mt Owen Telecom Road [840400] unit Ooc is followed conformably by the SW-dipping unit Oos, which is some 243 m thick and consists of dominantly brown, pink and grey quartz sandstone beds, often hematite-rich, with minor mudstone and siliceous granule to small-pebble conglomerate. Sedimentary deformation structures and trace fossils are common.

The basal 50.5 m of unit Oos on the Mt Owen Telecom Road section consists of interbedded mudstone and quartz sandstone with thin siliceous conglomerate layers. Mudstone occurs in layers up to 0.5 m thick, often with siliceous siltstone/fine-grained sandstone lenses, and as lenses up to 5 mm thick in coarse-grained and very coarse-grained quartz sandstone layers, varying in thickness from 200 mm to 0.5 metres. Well-bedded medium-grained to coarse-grained quartz sandstone with usually thin siliceous pebble (average length 5 mm) conglomerate dominates horizons up to four metres in thickness. The sandstone beds sometimes display festoon current bedding and occasional trace fossils of tubular burrows. The basal beds are succeeded by approximately 16 m of pebble (average length 7 mm) conglomerate layers up to 1.6 m thick, separated by 200 mm thick medium-grained quartz sandstone beds. Overlying this conglomerate-dominated sequence is 100 m of fine-grained to medium-grained quartz sandstone in beds characterised by ripple lamination and common bioturbation structures. Following is a 32 m thick sequence of dominantly mudstone, with layers up to 0.7 m thick of medium-grained quartz sandstone, which is succeeded by 30 m of well-bedded, usually hematite-rich, medium-

grained quartz sandstone with common bioturbated surfaces. The uppermost beds of unit Oos consist of 14 m of dominantly coarse-grained quartz sandstone with common grains of hematite, overlain by about 1.5 m of siliceous pebble (average length 15 mm) conglomerate beds with a matrix of medium-grained sand with sparse hematite. These conglomerate beds are folded and extend southeast along the spur crest [853394].

Underlying, in part conformably, the youngest unit Oop of the Owen Conglomerate at Pioneer Ridge [835420] is some 81 m of a succession typical of the stratigraphic horizon covering the whole of the area immediately west of Linda, and which is correlated with unit Oos. The steeply-dipping lowermost beds, approximately 12 m thick, are juxtaposed at the Lyell Fault System against Cambrian Lyell Schist to the west, and consist of alternating beds up to 150 mm in thickness of grey and white silicified, siliceous pebble (average length 7–15 mm) conglomerate and grey, medium-grained quartz sandstone with scattered small pebbles. Then follows 18 m of grey and white siliceous pebble (average length 15–35 mm) conglomerate beds of 350–600 mm thickness interlayered with grey festoon current bedded medium-grained quartz sandstone in 20–30 mm thick beds. These beds are overlain by approximately 41 m of grey, usually festoon current bedded, medium-grained quartz sandstone beds which have an average thickness of 200 mm, and in many of which trace fossils of tubular burrows are preserved. The youngest sequence of beds of unit Oos at this locality is 10 m thick and consists of interlayered grey and white, bioturbated, festoon current bedded or planar laminated coarse-grained quartz sandstone, with occasional surfaces of scattered yellow siliceous pebbles, in beds of up to 700 mm thick.

Throughout unit Oos on the Mt Owen Telecom Road [840400] and Pioneer Ridge [835420] clasts form a continuous framework and are of vein quartz, quartzite, quartz schist and chert. Conglomerate clasts are usually sub-rounded and sand grains are sub-rounded to rounded.

As in the underlying Owen Conglomerate units the compositions of the clasts of the Oos sedimentary unit are matched by the rock types of the Tyennan region to the east. In contrast to the older units, however, the down-current directions of the Telecom Road [840400] and Pioneer Spur [835420] successions of Oos, as given by current bedding in the sandstone beds, are radial. This radial current pattern, together with the common bioturbation and tubular burrow structures, indicate a frequently reworked shallow-marine depositional environment.

Oop

This sequence is the youngest unit of the Owen Conglomerate and is known as the Pioneer Beds (Wade and Solomon, 1958). Generally, the Pioneer Beds consist of grey and yellow quartz sandstone and silicified siliceous conglomerate, with chromite-rich orthoquartzite layers, and pink to yellow basal conglomerate. Trace fossils are present in the sandstone beds. A short distance to the east of the Great Lyell Fault System [835419; 850395] the Pioneer Beds conformably overlie unit Oos, whereas within some 100 m of the Fault System on the eastern side [833419; 834400] angular unconformities have been noted

where unit Oop rests on older upturned beds of unit Oos. West of the Great Lyell Fault System the Pioneer Beds (Oop) overlie, with angular unconformity, the Cambrian volcanic rocks [810419; 814416; 812410; 807406; 814406]. In common with other units of the Owen Conglomerate in this region, the usually sub-rounded clasts within the conglomerate are of vein quartz, quartzite, quartz-schist and chert, and form a continuous framework within the silicified deposits. Sandstone is usually well sorted with sub-rounded to rounded quartz grains.

Some 200 m east of the Great Lyell Fault System on Pioneer Spur [836419], well-exposed south-dipping Pioneer Beds, approximately 25 m thick, conformably overlie unit Oos. The Oop succession at Pioneer Spur, which is typical of this stratigraphic horizon in the whole of the area immediately west of Linda, has a basal 2 m thick sequence of light yellow silicified siliceous pebble (average length 20 mm) conglomerate with up to 20 mm thick grey medium-grained quartz sandstone partings. The conglomerate layers usually contain angular hematite-rich fragments amongst the sub-rounded siliceous clasts set in a comparatively hematite-rich, medium-grained quartz sand matrix. The basal sequence is followed by 12 m of dominantly grey/yellow siliceous pebble (average length 10 mm) conglomerate with grey and yellow medium-grained quartz sandstone partings and beds up to 0.5 m in thickness. Tubular burrows are present in some of the festoon current-bedded sandstone layers. A 1.5 m thick poorly-bedded grey siliceous pebble (average length 20 mm) conglomerate follows, and is succeeded by some 3.5 m of interbedded coarse-grained and medium-grained quartz sandstone beds, which vary in thickness from 15 to 40 mm and commonly display festoon current bedding. The uppermost sequence of the Pioneer Beds is about six metres thick and consists of grey and yellow siliceous pebble (average length 10 mm) conglomerate beds up to 200 mm thick, which are interlayered with grey current-bedded medium-grained quartz sandstone beds up to 100 mm thick. Abruptly but conformably overlying the Pioneer Beds is a Gordon Group sequence of mudstone and clay derivatives of limestone.

In the western parts of Pioneer Spur nearer to the Great Lyell Fault System, unit Oop overlies unit Oos with spectacular angular unconformity, which is well exposed along the southwest flank of Pioneer Spur and at Cooley Creek Haulage [834417] (Wade and Solomon, 1958), where angular differences between the beds above and below the unconformity are up to 130°. Although the angular unconformity is usually remarkably planar and with no evidence of induration or pre-existing joint planes in the underlying upturned rocks, uncommon scours up to 3 m wide and 1.5 m deep occur. These are filled with pink siliceous pebble (average length 20 mm) conglomerate with some hematite-rich fragments and grey and pink very coarse-grained quartz sandstone beds. The scour infill conformably underlies the basal conglomerate sequence of the Pioneer Beds. In the nearest occurrence of the angular unconformity to the Great Lyell Fault System on the southwest flank of Pioneer Spur, pebbles of the basal conglomerate of the Pioneer Beds are pressed into the underlying beds, indicating that they were unconsolidated although coherent at the time of deposition of unit Oop.

On the eastern side of the Great Lyell Fault System, at the top of Moore Creek Waterfall [835400] some 2 km south

of Pioneer Spur, the overlying Pioneer Beds (Oop), which dip southeast, show angular unconformable relationships of up to 20° with the underlying Oos unit, which also dips southeast. The surface of the unconformity is irregular, with underlying scours up to one metre wide and 0.3 m deep. The basal bed of Oop at this locality is a one metre thick light pink siliceous pebble (average length 20 mm) conglomerate followed by two metres of grey current-bedded coarse-grained quartz sandstone and siliceous siltstone, with some layers containing tubular burrows (up to 10 mm in diameter) and one bed showing soft sediment slump deformation. These sandstone/siltstone beds are followed by a yellow siliceous pebble conglomerate and a dominantly quartz sandstone sequence. Some eight metres topographically higher occurs conglomerate, which is partly obscured by scree shed from a coarse-pebble conglomerate of unit Oolc underlying a spur to the south. This conglomerate is similar to the basal conglomerate of unit Oop, and may be the same horizon displaced by a small hidden fault. The comparatively erosion-resistant basal conglomerate forms a pronounced topographic feature which can be traced along the southern flank of the spur followed by the Mt Owen Telecom Road to the headwaters of Moore Creek [850395]. Although there are discontinuities in outcrop at this locality, the basal conglomerate of unit Oop appears to conformably overlie the uppermost siliceous pebble (average length 15 mm) conglomerate beds of unit Oos, which extends along the spur crest [853394].

Units of Oomu do not occur west of the Great Lyell Fault System, which includes the fault-bounded sequences of Oomu at Tharsis Ridge [830430], Razorback [832419] and Waterfall Creek [832401]. However attenuated correlates of the Pioneer Beds (Oop) occur preserved in structural lows near Queenstown [807406; 811411] and around the Queenstown mill [810419; 814416; 812410] (Cox 1981).

The Pioneer Beds correlate at 807406 consists of a 150 mm thick yellow siliceous pebble (average length 20 mm) conglomerate, which rests unconformably on rocks of unit Ckvp , followed by five metres of interlayered current-bedded and ripple-bedded medium-grained quartz sandstone and siliceous siltstone. This Oop unit correlate is overlain conformably by Gordon Group limestone. A similar sequence of Oop, but thinned by a strike fault to one metre in thickness, occurs at 811411, where the 150 mm thick basal siliceous pebble (average length 10 mm) conglomerate rests unconformably on Comstock Tuff (Ctc).

The correlate of the Pioneer Beds at 814406 is well exposed along the south bank of Conglomerate Creek, and consists of a southwest dipping sequence of interlayered grey current-bedded medium-grained and coarse-grained quartz sandstone and laminated siliceous siltstone in beds varying from 0.8 to 6 m thick. The Oop correlate rests unconformably on intermediate agglomerate of unit Ckvr . Immediately below the unconformity a limonite-rich lateritised zone up to one metre thick is present. A similar iron oxide rich zone is developed northwest of the Queenstown mill at 807406, where the correlate of the Pioneer Beds rests unconformably on unit Ctc . At this locality coarse-grained quartz sandstone beds within the Oop correlate are notably rich in chromite grains.

The Pioneer Beds and correlates are of the same general composition as the underlying Owen Conglomerate units, indicating a Tyennan Region source. However, some horizons are comparatively rich in chromite grains, which are presumably derived from western ultramafic occurrences, with quantities considerably greater than recorded from sandstone of unit Oos and near the top of unit Ools on the Mt Owen Telecom Road (Bottrill, 1986). The down-current directions, indicated by current bedding in the sandstone beds of the Pioneer Spur succession, give a radial pattern similar to that of unit Oos on the Mt Owen Telecom Road, which suggests a continuation of the reworked, shallow-marine depositional environment proposed for unit Oos.

Clearly angular unconformable relationships within the Owen Conglomerate units on the eastern side of the Great Lyell Fault System resulted from movements along the faults of the system, which confined units of Oomu of a total thickness greater than 760 m to an eastern depositional trough. Cessation of the fault movements prior to deposition of the Pioneer Beds allowed this thin sequence to be deposited as a blanket over the region, covering the Oomu trough deposits and spreading over the eroded plains of Cambrian volcanic rocks to the west (Corbett *et al.*, 1974).

GORDON GROUP

Ogu, Ogu'

The Ordovician Gordon Group correlate (*Ogu*), which consists of dominantly poorly fossiliferous impure grey-weathering micrite with usually black weathered clay derivatives (*Ogu'*), mudstone and siltstone, follows the Pioneer Beds and correlates (*Oop*) conformably. The limestone usually underlies flat-floored solution valleys and is for most part obscured by Quaternary deposits. However small outcrops of Gordon Group are often exposed near the occurrences of the Pioneer Beds.

Along the south bank of Conglomerate Creek [at 814406] is a well-exposed correlate of the Gordon Group, at least 50 m in thickness, which has been preserved as the faulted core of a NW-trending Devonian syncline. The lowermost layers of this southwest-dipping succession overlying unit *Oop* correlate are adjacent to a disturbed zone which parallels bedding; these layers comprise grey micritic limestone extensively weathered to a blue-black clay. Fine-grained calcarenite beds with tubular burrows, dolomitised light brown patches and seams, and dark grey stylolitic seams usually parallel to bedding are present stratigraphically higher in the generally micritic sequence. North of Conglomerate Creek, remnants of the correlate of the Gordon Group with associated blue-black clays (*Ogu, Ogu'*) occur at 807406, 811411, 814416, and 810419.

West of Linda, around Lyell Blocks [834432], Lyell Consols [835428] and King Lyell [835418] "copper clays" basal to the Gordon Group correlate are preserved in faulted synclinal valleys and adjacent to occurrences of Pioneer Beds underlying WNW-trending spurs. These derivatives of the basal beds (Solomon, 1969; Markham, 1968) attain more than 100 m in thickness and consist of red, grey and brown clay derived from calcareous mudstone. At the contact with the Pioneer Beds,

concentrations of sub-rounded waterworn grains and pebbles of native copper have been recorded in boreholes, together with spherical grain aggregates of ore minerals such as bornite and chalcocopyrite. At the Lyell Blocks the clays are mixed with large angular fragments of Cambrian volcanic rocks and Owen Conglomerate in a fault zone. The copper clays appear to be deposits associated with both indigenous and transported gossans (Solomon, 1969; Markham, 1968). Planar colour variations in the dominantly dark grey clays at King Lyell appear to have been determined by original bedding surfaces, for they are of an orientation similar to that of a dark grey laminated mudstone/impure micrite sequence resting conformably on Pioneer Beds on the southern flank of Pioneer Spur. The basal clay derivatives occasionally reveal evidence of disturbance [as in the creek at 840419; 837417 south of Linda], where steeply-dipping as well as flat-lying Pleistocene(?) gravel and sand-filled veins separate slightly rotated large blocks of dark grey cohesive clay. The blue-black clay deposits (*Ogu'*) exposed along Mount Creek [847410] contain west-striking sequences of grey impure micrite and fine-grained calcarenite with bioturbated beds including trace fossils of tubular burrows. Many of these limestone layers contain thin (usually <10 mm thick), light brown dolomitic seams and dark grey stylolitic seams, which appear to parallel bedding.

IGNEOUS DYKE

Di ?

An approximately vertical dyke of dark grey/black clay, which is up to two metres wide, is exposed along the Mt Owen Telecom Road [at 850391] about 0.9 km northeast of Mt Owen Peak. The northwest strike of the steep dyke is generally parallel to that of the enclosing bedded silicified siliciclastic rocks, which dip moderately southwest. There is no lateral displacement of the country rocks along the dyke, which contains an angular fragment of the surrounding unmetamorphosed quartzite which is some 300 mm thick and more than one metre long and oriented parallel to the dyke walls. The clay of the dyke is notably poor in silica and may well have resulted from the weathering of lamprophyre, which has been recorded as intruding the Lyell Schists, particularly around 828419 (Sutherland and Corbett, 1974). As the dyke does not appear to have been involved in any folding, and because no remnant structural textures, such as cleavage, occur within the dyke clay, the intrusion is considered to be post the fold deformation of the Devonian.

STRUCTURE

CAMBRIAN

Within the King River association (*Ɛku*) and the younger Tyndall Group (*Ɛtu*) correlate of this region common strike faulting, which is usually associated with later Devonian deformation, the lateral impersistence of the units, and the sparseness of facing data do not allow a full determination of structural relationships between the units. The fabric of the rocks is dominated by a steep WNW-trending Devonian cleavage, and no earlier microtectonic features have been noted. In the west of the region units of the King River association and the Tyndall Group correlate are overlain with angular unconformity by

a correlate of the Pioneer Beds (Oop) of the Owen Conglomerate (Oou – Denison Group), whereas to the east the King River association is juxtaposed against members of the Owen Conglomerate along faults of the Great Lyell Fault System, which has been considerably deformed by later Devonian folding and faulting (Wade and Solomon, 1958; Cox, 1981; Arnold and Carswell, 1991).

Thinned correlates of the Pioneer Beds occur in the structural lows caused by Devonian folding and Devonian or later faulting near Queenstown [807406; 811411] and around Queenstown mill [810419; 814416; 812410] (Cox, 1981). At and immediately south of Conglomerate Creek [at 814406] and northwest of the Queenstown mill [at 807406] the Pioneer Beds correlate, which is overlain conformably by Gordon Group limestone (Ogu), occurs within WNW-trending Devonian synclines and rests unconformably on the older rocks. At Conglomerate Creek the underlying rocks are intermediate agglomerate of unit €kvr, whereas northwest of the Queenstown mill they are correlates of the Comstock Tuff (€tC) and display an angular unconformity with the overlying Pioneer Beds greater than 50°.

A short distance east of the Great Lyell Fault System (e.g. 100 m at Pioneer Spur [836419]) the unit of Pioneer Beds rests conformably on the older unit Oos of the Owen Conglomerate (Denison Group), which attains a thickness greater than 760 m within a meridional trough. This depositional trough is narrow, as members of the Owen Conglomerate other than the unit Oop do not extend beyond the Great Lyell Fault System to the west and are absent some 8 km east where a thin correlate of the Pioneer Beds (Oop') rests with angular unconformity on Precambrian quartzite and schist. Within 100 m of the western faulted trough margin at Pioneer Spur the Pioneer Beds (Oop) vary from being conformable with the older underlying Oos unit to an angular difference of up to 130°. At this locality reconstruction of the Oos layers prior to deposition of the flat-lying Pioneer Beds shows an overfolded syncline with an axial surface dipping 35°W and trending N-S, paralleling the Great Lyell Fault System. No joints or cleavages were developed during this early folding and unit Oos was soft enough for penetration by pebbles from the younger Pioneer Beds. Nevertheless beds of unit Oos were sufficiently coherent for them to be mechanically competent, and flexed with orthogonal thicknesses unchanged. Similar fault-associated folds occur on the eastern side of usually steeply west-dipping faults (Reid, 1975) of the Great Lyell Fault System along the other spurs northwest of Linda [840420]. The folds are consistent with having resulted from east-side down fault drag, although they have been variously attributed to reverse faulting or thrusting (Wade and Solomon, 1958; Arnold and Carswell, 1991). To the south, however, at the waterfall on Moores Rivulet [835400], unit Oos was not folded prior to the deposition of unit Oop, but there is an angular unconformity of up to 20° and compared with the more complete Oos succession at the headwaters of Moore Creek [850395], significant erosion had occurred.

The angular unconformable relationships between unit Oop and older rocks and early folds of the Oos unit confined to such a narrow zone on the eastern side of the Great Lyell Fault System clearly resulted from movements along faults of the system prior to deposition of the Pioneer

Beds blanketing the region. The fault movements resulted in the development of a narrow (<8 km) meridional depositional trough in which accumulated >760 m of Oomu units.

POST-CAMBRIAN/PRE-DEVONIAN

The thin blanket of Pioneer Beds is followed conformably by the deposits of the Gordon and Eldon Groups, but whereas the shallow-marine carbonates of the Gordon Group appear to have been deposited with uniform thickness over the region, the shallow-marine succession of mudstone, siltstone and quartz sandstone of the Eldon Group increases from the average thickness by some 2.5 km at a depocentre about 4 km east of that of the Oomu basin (see Calver *et al.*, 1987). The close proximity of the depocentres of the Oomu and Eldon basins suggests a structural relationship with, apart from a time break spanning deposition of the Pioneer Beds and the Gordon Group, a continuity of the regional stress fields responsible for the development of the basins. Such a relationship indicates that Early Silurian extension faulting required for basin deepening resulted from reactivation of an underlying listric sole fault, which during the Late Cambrian governed the formation of the Oomu basin. Diagrammatic sections of the structural developments of the depositional basins based on known examples (McClay *et al.*, 1991) are given in Figure 1. The models presented require a total horizontal E-W hanging wall extension of only 500 m over a width of 8 km during the Late Cambrian, and some 1500 m extension over a width of 7 km in the Early Silurian. It should be noted that the proposed structural development of the Late Cambrian and Early Silurian depositional basins accounts for the occurrences of large fault-bounded and detached masses of unit Oomu within Mt Read Volcanics in the Great Lyell Fault System.

GREAT LYELL FAULT SYSTEM

Faults of this generally northerly-trending system developed in the Late Cambrian associated with the formation of the meridional Oomu depositional basin, and the Early Silurian with the deepening of the Eldon basin (fig. 1; cf. Hills, 1990; Arnold and Carswell, 1991). The faults, which juxtaposed rocks of the King River association and the Denison Group, were modified and considerably distorted during the Devonian deformation, particularly in the second fold phase, for the contortions of the fault trends match adjacent Devonian second-phase folds of members of the Denison Group (Calver *et al.*, 1987). Despite the complex movements that have taken place along the faults (Cox, 1981), the deformation zones of sheared rocks associated with them are relatively narrow. The fault deformation zones, which contain crushed material derived from the surrounding rocks, are foliated parallel to the fault walls. The fault shear zones were formed prior to the development of axial cleavages of the Devonian second fold phase, which are superimposed on the shear foliation of the fault zones. These relationships are present at the southern boundary of the fault-bounded Tharsis Ridge outlier of unit Oomu [at 831428], where the steep fault varies in strike from 110° to 180° within a couple of metres and the associated 100 mm thick deformation zone contains sheared rocks of the King River association, with some entrained pebbles derived from the Owen Conglomerate which are moulded to and foliated parallel with the fault wall. Superimposed on this shear zone are

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5 cm

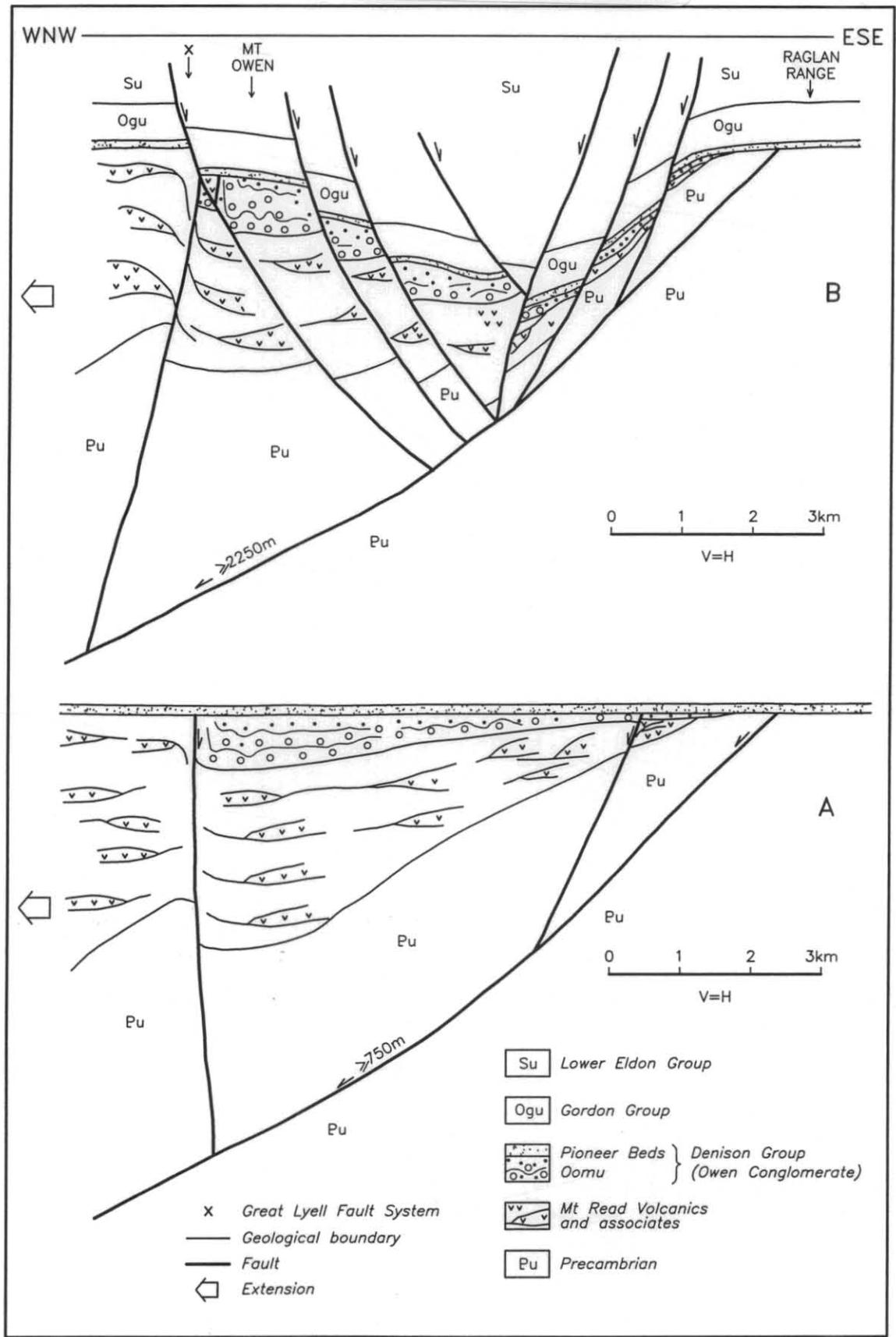


Figure 1

- (a) Late Cambrian (pre-Pioneer Beds) development of Oomuu depositional basin by extension of hanging wall of 750 m along listric sole fault.
 - (b) Early Silurian development of Su depositional basin by extension of hanging wall of 2250 m along re-activated listric sole fault.
- Models based on known examples (McClay *et al.*, 1991).

steeply-dipping synchronous axial cleavages of 140° and 170° strikes of the Devonian second fold phase. Similar narrow fault shear zones with the foliation paralleling the fault wall are well displayed at numerous sites, such as on Pioneer Spur [833420] where the steep fault varies in strike from 40° to 165°, and around the Oomu outlier at 833402 where the trace of the steep bounding fault is circular. Uncommonly, the steep deformation zones are comparatively broad along stretches of the contorted faults of the Great Lyell Fault System, as at 833397 where the shear zone of a steep fault trending from 70° to 120° is many metres wide and consists of sheared rocks of both the juxtaposed King River association and the Owen Conglomerate. This shear zone contains phyllonitic rocks with laminae moulded parallel to the fault wall and entrained lenses, up to a metre in length, of sheared quartz sandstone and siliceous pebble conglomerate.

DEVONIAN DEFORMATION

The general rock distribution of the region results from Devonian folding and faulting superimposed on Late Cambrian and Early Silurian depositional basins and associated structures which governed their development (Wade and Solomon, 1958; Cox, 1981). The first Devonian deformational phase produced NNW-trending upright folds with low plunge and a half wavelength of up to 2.5 km, and reactivated earlier faults. A second Devonian deformational phase is characterised by WNW to NW-trending faults and associated upright folds with steeply dipping axial surfaces, and of usually smaller wavelength than those of the first phase. These deformations significantly modified earlier structures and even considerably distorted faults of the Great Lyell Fault System. Later deformation includes a rare development of E-W trending upright folds of small wavelength, and a shortening along cleavage of the Devonian second deformational phase by buckling with NE-trending axial surfaces.

FIRST PHASE

Within the laterally impersistent units of the King River association very sparse facing data occasionally show reversals. South of the Lyell Highway the steeply-dipping unit Ckx in Conglomerate Creek [823395] faces west and, to the west, passes gradationally upward into unit Ckvr (of Ckvu) of Little Owen Spur. In Conglomerate Creek to the northwest [815408], however, facing in unit Ckvr is to the east. This reversal in facing suggests folding of unit Ckvr about a horizontal NNW-directed synclinal axis located on the west flank of Little Owen Spur [820400]. This probable NNW-trending syncline (Cox, 1981) and other reversals of facings noted within the units of the King River association appear to belong to the Devonian first phase of deformation, despite the absence of features in the fabric of the rock units that can be attributed to this deformational phase, as the fabric is dominated by a steep NW-trending cleavage developed during the second deformational phase.

Meso-structures developed in the first deformational phase are in evidence within the Owen Conglomerate at the eastern margin of the Great Lyell Fault System, and are associated with a resumption of movement during folding along this boundary. At the rim of Moore Creek Waterfall

[835400], which is a few metres east of the NE-trending Great Lyell Fault, the basal layers of the Pioneer Beds have been rotated to parallel the strike of the fault and to dip 55°SE. Similarly, some three metres east of the easternmost northerly-trending fault of the Great Lyell Fault System at Pioneer Spur [833419], the basal conglomerate has been upturned to dip some 80°E and strike approximately parallel to the fault. Micro-structures associated with this deformation are rare, but a related cleavage is developed in unit Oos near the Great Lyell Fault System at Batchelors Quarry on the spur [832427] between Idaho Creek and Lyell Consols (Cox, 1979). At this locality a patchily developed cleavage varying in strike from 0° to 30° and with a vertical to 85°W dip transects Late Cambrian (pre-Pioneer Beds) overfolds with axial surfaces dipping moderately west, and is intersected by a pervasive second deformational phase vertical cleavage of 135° strike. Where both the earlier and later cleavages are present steeply-plunging rods and needles are developed within the beds.

SECOND PHASE

Superimposed on the northerly-trending Devonian first phase folds is a later Devonian fold deformation characterised by WNW to NW-trending folds with a smaller wavelength of usually a few hundred metres. These later folds, which have upright to steeply-dipping axial surfaces, are commonly associated with similarly trending reverse faults and thrusts. The folding has significantly deformed all earlier structures, including faults of the Great Lyell Fault System.

The second phase folds are well developed in the structurally competent and erosion-resistant units of the Owen Conglomerate, but are usually not as obvious within the structurally incompetent volcanic units of the King River association, although faults of similar trend to those associated with the second phase folds of the siliceous clastic successions displace the volcanic units. Despite the lack of recognition of second phase folds in the volcanic rocks, the structural fabric of the King River association is governed by a spaced to penetrative WNW to NW-trending foliation associated with a well-developed mineral lineation of steep plunge, which developed during the Devonian second fold phase.

Folds and associated faults

Second phase folds and associated similarly trending faults are best observed within the Owen Conglomerate in the WNW-trending structural low between Mt Lyell and Mt Owen immediately west of Linda [840420] (Wade and Solomon, 1958; Cox, 1979, 1981; Arnold and Carswell, 1991), which has been referred to as the Linda Disturbance. Commonly, cover deposits have been removed by erosion baring hinges of anticlines along spur crests. The WNW-trending folds of a wavelength of 300 to 400 m are upright and flexural, with uniform orthogonal thicknesses of the silicified siliceous beds of sandstone and conglomerate throughout the folds. Valleys separating the spurs are sited along the ESE-trending faulted synclinal troughs often occupied by overlying remnants and derivatives of the Gordon Group. Along the Gormanston Spur [837413] the broad hinge zone within the Owen Conglomerate of the crest tightens to the ESE where,

before plunging some 16°ESE beneath the younger Gordon Group, it is represented by two anticlinal culminations about 30 m apart. The folds are associated with ESE-trending reverse faults of up to a few metres displacement and varying in dip from 67°N to 70°S. Similarly, the fold hinge zone of Pioneer Spur bifurcates to the ESE at 838418. At this locality the anticlines, which are separated by a steep ESE-trending fault and are some 45 m apart, plunge 25°ESE beneath derivatives of the Gordon Group exposed in Linda Creek [839418].

The folds of the siliceous Owen Conglomerate of Pioneer Spur are typical of the Devonian deformation phase in that they are flexural, unflattened and upright. A fold of this deformation phase of unusual style occurs in Cooley Creek [833417] at the southern flank of the spur. The fold, which is upright and flattened, has a wavelength of two metres. This fold plunges 5°NW and is within a structurally incompetent sequence of interbedded mudstone and originally muddy conglomerate. The beds display transposition with pebbles entrained in a steep axial surface schistosity. The effects of the superimposed Devonian second phase fold on the overfolded siliceous Oos unit, which was deformed in the Late Cambrian, and the Great Lyell Fault System can be observed WNW along Pioneer Spur [833420]. Similar observations on interference structures can be made at Linda Spur [834424], and at 832430 where resulting folds within unit Oos, which are of some 30 m wavelength and have NW-trending axial surfaces, plunge approximately vertically. Nearby, at 832427, is a fine exposure of a fracture (100°/62°S) of this deformation phase along which Lyell Schist has been thrust over unit Oos of the Owen Conglomerate.

Within the structural high of Mt Owen, cover deposits have been removed from the Pioneer Beds in the NW-trending synclinal trough along Moore Creek [840397] some 200 m above the stratigraphic correlate in the structural low of the Linda Valley to the north. The style of the syncline is reflected in a minor syncline [at 837398] which plunges 10°NW and has an axial surface dipping 80°SW. Immediately southwest of this locality the southern limb of the syncline is faulted against unit Oolc which dips steeply southwest. This steeply SW-dipping reverse fault trends northwest and is associated with a 60 m wide deformation zone containing schistose volcanic rocks and mudstone with a NW-trending transposition foliation dipping about 60°SW. The fault shear zone narrows rapidly within 300 m to the southeast to about a metre in width. Scissor faults with up to 300 mm thick crush breccia have developed in the axial surfaces of tightly appressed folds plunging 12°WNW within the syncline trough in Moore Creek [846395]. Displacements along the scissor faults, although small, result in a complicated distribution pattern of the layers of the Pioneer Beds on the dip slopes of Moore Creek. At 850396 the adjacent anticline to the Moore Creek syncline is within the pebble conglomerate layers of unit Oos, stratigraphically immediately below the coarser basal conglomerate of the Pioneer Beds. This fold varies to the northwest along its length from upright with no plunge and 10 m wavelength parasite folds, to an anticline plunging 5°NW with an axial surface dipping 80°SW and parasite folds of two metre wavelength at 845398.

In the Mt Owen structural high the oldest unit of the Owen Conglomerate, unit Oolc of Mt Owen Peak, is some

1600 m above its anticipated depth at Linda. Structural displacements have been dominated by transportation along NW-trending faults bounding the slices of SW-dipping sequences varying in age from the oldest to the youngest units of the Owen Conglomerate. These bounding structures appear to be similar in character to the reverse fault at the southwest boundary of the associated NW-trending Moore Creek syncline [837397]. Usually the faults have notable shear zones and dip steeply southwest [837397, 848388], but at 853391 the fault, with its shear zone, dips some 25°SW.

At the western margin of the meridional belt of the King River association near Queenstown [807406; 811411; 813407] and around the Queenstown mill [810419; 814416; 812410], the correlate of the unconformably overlying Pioneer Beds (Oop) is topographically lower than occurrences at Linda [840420] by about 120 m, and at Moore Creek [840397] by some 320 metres. At these western localities unit Oop, and the conformably overlying Gordon Group sequences, are preserved in local structural lows (Cox, 1981) resulting from downfolding or faulting of the Devonian second deformation phase. In Conglomerate Creek [813407] the steeply-dipping northeastern limb of an upright NW-trending syncline of unit Oop and limestone of the Gordon Group is exposed, and it is bounded to the southwest by a NW-trending fault. A more complete, though faulted, portion of a syncline hinge zone is outlined by steeply-dipping to overturned beds of unit Oop and Gordon Group limestone at 810419.

Folds are uncommon within the usually structurally incompetent members of the King River association, presumably because of the comparative lack of marker layering in the often massive volcanic units. However in a lenticular unit extending from Philosophers Ridge [830415] to Waterfall Creek [831400] hydrothermally altered quartz-rich volcanic rocks exhibit banding of variable thickness (from millimetres to 0.5 m) (Cox, 1981), which is generally steeply dipping and north trending, although original flow folding is common. These banded volcanics display tight meso-folds of the Devonian second deformation phase, with WNW-trending axial surfaces steeply dipping to the SSW. Hinge lines of the WNW-trending folds vary from usually vertical to a shallow plunge to the WNW or ESE due to the superimposition of the Devonian on the earlier flow folds (fig. 2). Similar WNW-trending Devonian folds are observed within a chlorite-rich horizon about 250 m west of Philosophers Ridge (Arnold, unpublished data, 1985).

The distribution of units of the King River association is related, in part, to the presence of NW-trending faults. These faults [e.g. 818420] appear to be continuations of similarly trending reverse dislocations associated with the Devonian second phase folds within the competent siliciclastic layers of the Owen Conglomerate to the east. Quartz veins, up to a few metres wide, are often present in the fault deformation zones (Cox, 1979). In a number of highly siliceous units, structurally within the region of dominantly King River association, arrays of silica-rich gash veins are common. At Tharsis Ridge [830430] well-developed arrays of fibrous quartz gash veins occur within N-trending and steeply-dipping layers of the Owen Conglomerate outlier. Variations in the bulk of the generally flat-lying gash veins along the length of the

siliciclastic occurrence range from 5% to 50% of the total rock volume, indicating differential vertical volume changes. Although the gash veins are post the formation of the cleavage of the Devonian second fold phase, their bulk volume variations may well correspond with fold and fault vertical displacements during this deformation phase within the competent Owen Conglomerate east of the corridor of incompetent volcanic rocks at the western margin of Tharsis Ridge.

Related fabric elements

The fabric elements of the remarkably competent siliceous sandstone and conglomerate beds of the Owen Conglomerate are usually depositional (e.g. traction and current laminae, imbricate pebble patterns, etc.) and are not notably affected by tectonic deformation. At the interfaces of the siliceous and occasional mudstone beds in the uncommon pinch-ins of Devonian second phase minor fold hinge zones, conglomerate pebbles may be aligned parallel to the axial surface, and in rare occurrences where the conglomerate matrix was originally muddy, pebbles are entrained within a transpositional axial schistosity [Cooley Creek, 833417]. In general, cleavage is not obvious in the siliceous sequences, but closely-spaced axial fracture cleavage is patchily developed within sandstone layers where the WNW to NW-trending second phase folds are of comparatively short wavelength [e.g. 836423; 836418; 850395]. During this second fold phase an axial cleavage also formed in the beds of the younger Gordon Group, as well as in the occasional mudstone layer within the Owen Conglomerate successions, where the cleavage is of a slaty nature and is fanned about WNW to NW-trending minor fold axial surfaces, converging in anticlines and diverging in synclines [e.g. 844409].

Within the volcanic rocks of the King River association the structural fabric elements are of a spaced to penetrative WNW to NW-trending foliation associated with a well developed mineral lineation of steep plunge (Wade and Solomon, 1958), which developed during the Devonian second fold phase (Cox, 1979; 1981). Commonly in the Lyell Schist, other volcanic rocks and occasionally adjacent siliceous clastic rocks of the Owen Conglomerate, the foliation consists of surfaces or cleavage sets of two different strikes and dips some 20° to 28° apart, which gives a lenticular appearance to the outcrops in both plan and vertical section. Under the microscope the cleavage surfaces occur as layer silicate films forming a diamond pattern. In vertical section, Cox (1979) reported that microfractures were sites for mineral growth and alignment, with mineral assemblages consistent with metamorphic temperatures of between 275° and 350°C at water pressures of about 2 kb. He described grains of quartz and feldspar with beards of quartz and platy mineral fibres streaming into the acute angles of the cleavage diamonds and constituting the steeply-plunging lineations seen in hand specimens. Cox (1981) calculated extensions of up to 150% in the lineation direction during plane strain, whilst there was up to 60% shortening perpendicular to the WNW to NW fold trend.

The synchronous nature of the cleavage surfaces comprising the lenticular foliation of particularly the volcanic rocks can be evaluated at Philosophers Ridge [830415] and Pioneer Spur [833419]. Within the flow

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banded felsic unit of Philosophers Ridge the two trends of cleavage surfaces, both in plan and section, are approximately symmetrical in attitude with respect to the WNW-striking and steeply-dipping axial surfaces of the well-developed minor folds of the Devonian second deformation phase (fig. 2a). Figure 2a demonstrates clearly that not one of the surfaces of the foliation developed before the second phase folding, for none show the spread of poles of folded cleavage. Similar foliation characteristics of the Lyell Schist can be determined some 200 m east of Philosophers Ridge at Pioneer Spur, where the schist is separated by a steep fault, with an associated 0.5 m thick shear zone, from the Owen Conglomerate to the east. The fault is of the Great Lyell Fault System and swings in strike some 60° due to folding corresponding to half a flexural anticline in the eastern siliciclastic Pioneer Beds. The cleavage surfaces, which constitute the schist foliation, recorded at field stations spread across the spur, are symmetrically developed with respect to the WNW-trending axial surface of the Pioneer Spur fold, and there is no correspondence of the spread of cleavage poles matching the change in fault strike. Evidently, all the cleavage surfaces of the Lyell Schist were developed during the Devonian second fold phase (fig. 2b).

Typically, where Owen Conglomerate beds are adjacent to King River association units, field comparisons can be made between the second fold phase single cleavage set of particularly the finer grained beds of the siliciclastic successions and the synchronous cleavages of diamond pattern of the volcanic rocks. An example occurs on the south bank of Conglomerate Creek [813407], where within a limb of a WNW-trending fold the axial slaty cleavage of the Pioneer Beds contrasts with axial lenticular foliation of the underlying intermediate agglomerate of unit C_{Kvr} . Exceptionally, lenticular fractures are developed locally in the siliceous Owen Conglomerate, which correspond in trends of the constituent surfaces to those of the foliation of the adjacent Lyell Schist [e.g. 830420; 835400; 830392; 830428].

LATER FOLD DEFORMATION

Later deformation by folding is evident on Linda Spur [837423] where west-trending upright folds with horizontal hinges and 20 m wavelength are superimposed on the hinge zone of the WNW-trending Devonian second phase fold of the spur. Additional evidence of later deformation is afforded at many localities by mesoscopic kink folds of second deformation phase cleavage lithons. The usually north to northeast-trending and steeply-dipping kink fold bands vary in width from 20 mm within, for example, the cleaved Gordon Group limestone at Conglomerate Creek [813406], to some 0.7 m within the foliated hydrothermally-altered unit C_{Kru} [822405]. Further indications of adjustments to later movements are sometimes encountered in the volcanic rocks of the King River association, where both on microscopic and hand lens scale movement along one of the synchronous cleavage surfaces of the Devonian second fold phase foliation may have crenulated another, but there is no consistency as to which cleavage surface may display crenulation.

Regionally, throughout the Queenstown/Gormanston terrain, the results of later deformation have been assessed

5 cm

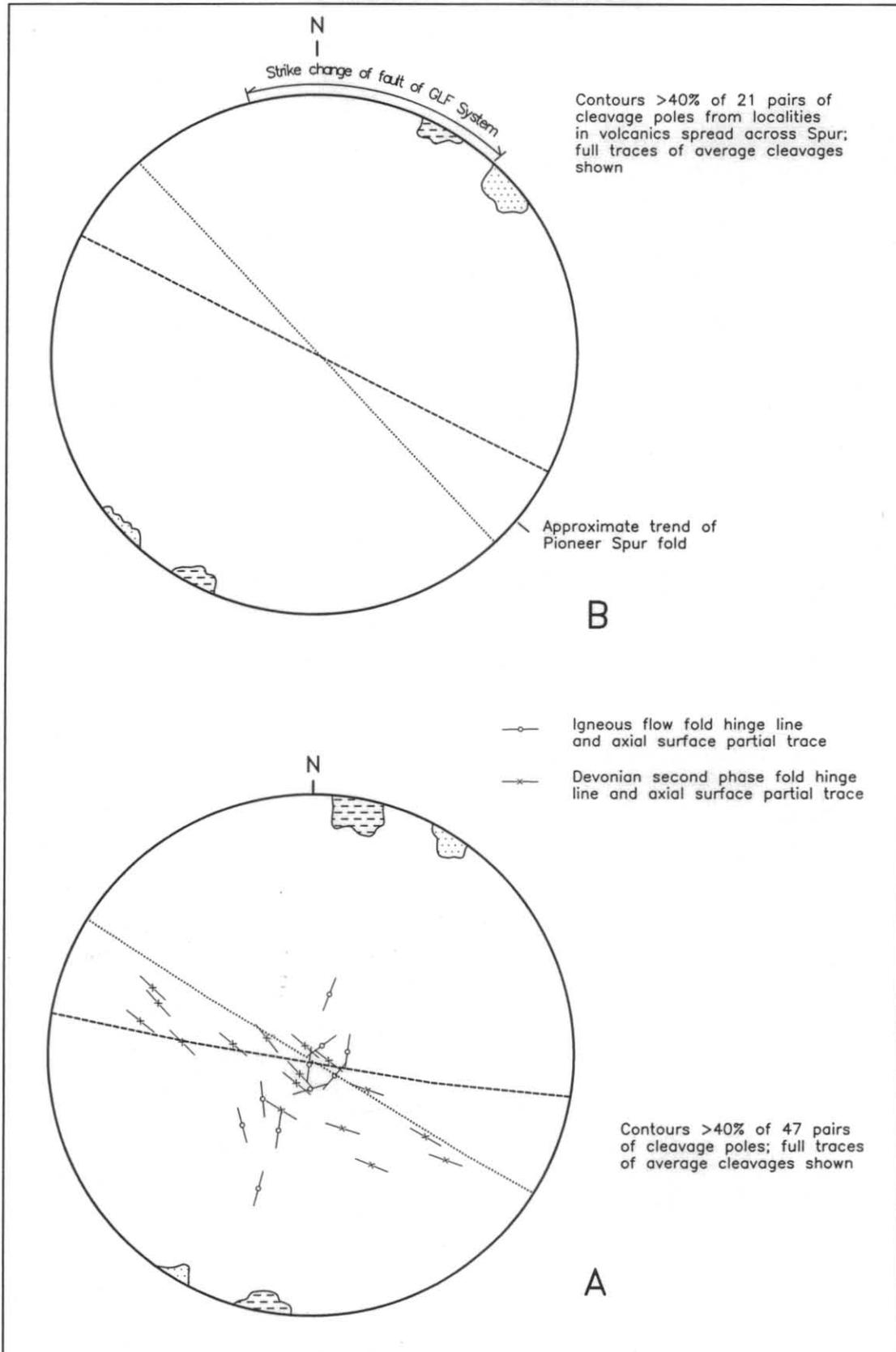


Figure 2

- (a) Philosophers Ridge felsic volcanic rocks. Equal area net plot of igneous flow fold hinge lines and partial traces of axial surfaces, Devonian second phase fold hinge lines and partial traces of axial surfaces, and contoured synchronous cleavage poles with full great circle traces of average cleavages of 47 pairs.
- (b) Pioneer Spur Lyell Schist. Equal area net plot of contoured cleavage poles of 21 synchronous pairs from localities spread across the trend of the Devonian second phase Pioneer Spur fold of the Owen Conglomerate to the east of the folded fault of the Great Lyell Fault (GLF) System. Note symmetrical distribution of cleavage poles about trend of upright Pioneer Spur fold.

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5 cm

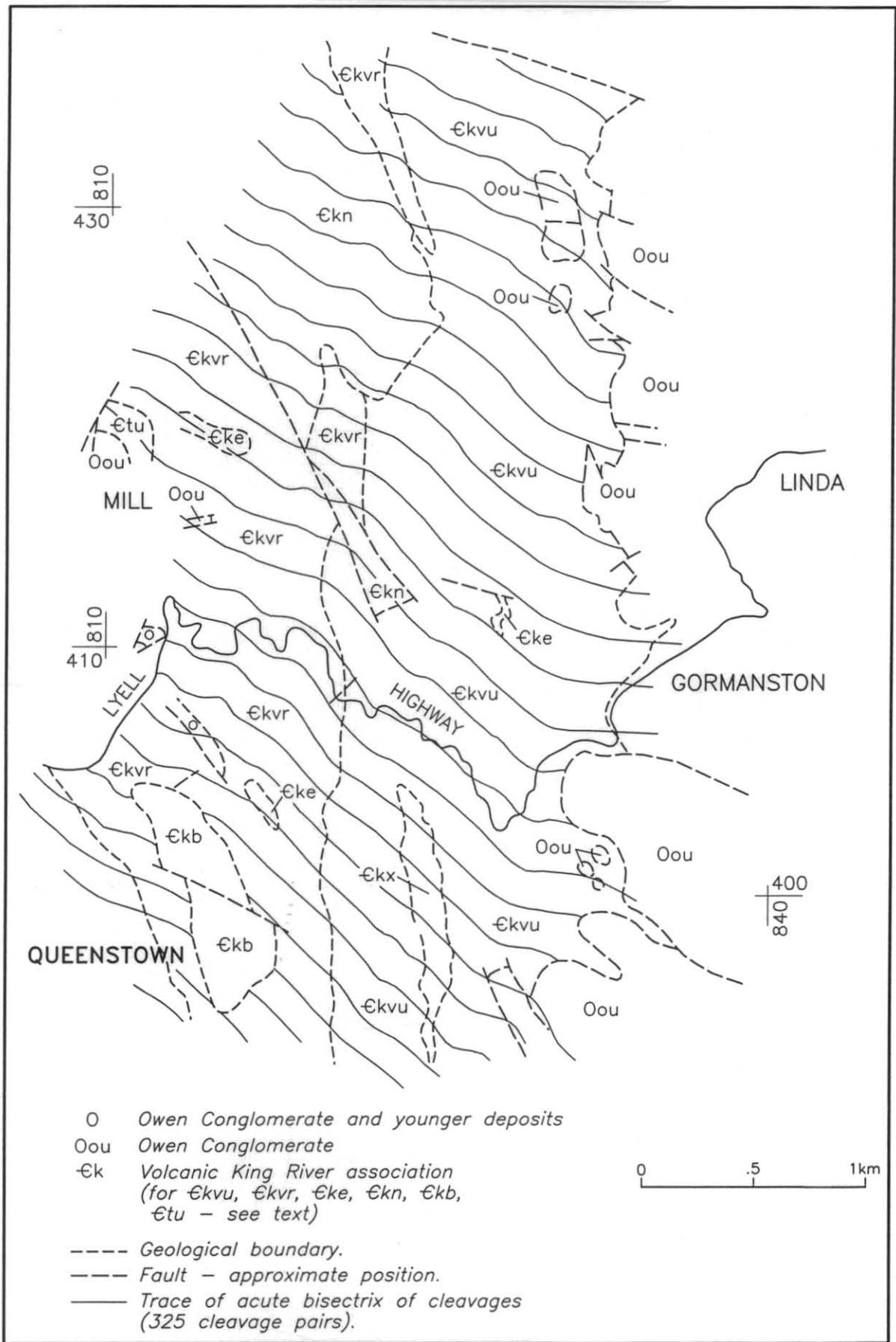


Figure 3

Map of Queenstown/Gormanston region showing geological boundaries of units of volcanic King River association and other selected units, with construction based on flexural folding about vertical axes of traces of acute bisectrices of 325 synchronous cleavage pairs showing WNW to ESE shortening of some 10%.

within the lenticularly foliated volcanic rocks of the King River association and adjacent lenticularly fractured Owen Conglomerate sequences. Construction (fig. 3) of the traces in plan of the acute bisectrix of the synchronous cleavage surfaces based on flexural geometry show buckling about vertical hinges and with north to northeast-striking axial surfaces, which are of similar trends to those of the spasmodically developed kink fold bands of the region. The extent of this buckling indicates an overall 10% E-W to ESE-WNW shortening.

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