Geology of the Kaikoura Area

M. S. Rattenbury
D. B. Townsend
M. R. Johnston
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Geology of the Kaikoura Area

Scale 1:250 000

M. S. RATTENBURY
D. B. TOWNSEND
M. R. JOHNSTON
(COMPILERS)

Institute of Geological & Nuclear Sciences 1:250 000 Geological Map 13

GNS Science
Lower Hutt, New Zealand

2006
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FRONT COVER

The Kaikoura Peninsula or Te Taumanu o Te Waka a Maui has an extensive shore platform cut into gently folded Late Cretaceous to Oligocene sedimentary rocks. The coastal cliffs are capped by beach deposits on raised marine terraces resulting from Late Quaternary uplift. In the background the Seaward Kaikoura Range rises from the active Hope Fault at the base of the range.

Te Taumanu o Te Waka a Maui, meaning the oarsman’s bench or thwarts of the canoe of Maui, is according to legend where Maui stood and cast his magical fish hook into the ocean. From his cast, he pulled up a giant fish, Te Ika a Maui, the North Island of New Zealand.

Photo CN 23908/19: D. L. Homer
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Toka Anau – Barney’s Rock or Riley’s Lookout

Toka Anau is a strategic landmark that historically has been used for spotting whales. The island lies within a kilometre of the steep western wall of the submarine Kaikoura Canyon and was used by Maori and early European whalers to sight breaching whales. The famed Paramount Chief Kaikoura Whakatau gave permission to Barney Riley to establish the first European whaling station in the district in 1857.

Photo: T. Kahu, Te Runanga o Kaikoura
The Kaikoura 1:250 000 geological map covers 18 100 km² of Westland, Nelson, Marlborough and northern Canterbury in the South Island of New Zealand, and straddles the boundary between the Pacific and Australian tectonic plates. The map area is cut by the Alpine, Awatere, Clarence, Hope and other major strike-slip faults, and includes a wide range of Paleozoic to Mesozoic rocks which form parts of eight tectonostratigraphic terranes. The early Paleozoic Buller and Takaka terranes, comprising sedimentary and volcano-sedimentary rocks respectively, are intruded by mid-Paleozoic granitic rocks of the Karamea Batholith and form the Western Province. This province is separated from the Eastern Province by Mesozoic plutonic rocks of the Median Batholith. North of the Alpine Fault, the Eastern Province comprises the Permian-Jurassic, predominantly volcano-sedimentary Brook Street, Murihiku, Dun Mountain-Maitai and Caples terranes. South of the Alpine Fault the Eastern Province comprises the Triassic-Early Cretaceous sedimentary Rakaia and Pahau terranes, collectively termed the Torlesse composite terrane.

The Eastern Province and Western Province were juxtaposed in Late Jurassic to Early Cretaceous time, and subsequently formed a comparatively stable basement to younger Cretaceous and Cenozoic sedimentation. Localised fault activity and elastic sedimentary basin development in the late Early to Late Cretaceous, and again in Late Cenozoic time, contrast with the deposition of widespread, passive margin limestone and mudstone in the Paleocene, Eocene and Oligocene. Late Cenozoic clastic sedimentation reflects development of the present oblique-compressional plate boundary and uplift of the Southern Alps and other ranges.

Quaternary glaciation deposited tills and glacial outwash gravels. During warmer interglacial periods, high sea levels cut flights of marine terraces that have been subsequently uplifted.

Mined mineral resources within the map area include alluvial gold, salt, coal, limestone, and rock aggregate. Recorded seeps and shows of oil and gas are sparse in the area; there has been no commercial hydrocarbon extraction, and the only petroleum exploration wells have been in the Murchison basin.

The Kaikoura map area is subject to severe natural hazards, including a high level of seismic activity from the Alpine, Awatere, Clarence, Hope and other active faults. These have potential for earthquake shaking, landsliding, liquefaction and ground rupture. Several large earthquakes with epicentres within or immediately adjacent to the map area have occurred within the last 160 years. Tsunami hazard may be from remote or local earthquakes or from submarine slumping, particularly within the Kaikoura Canyon immediately offshore. Storm-induced landsliding, rockfall and flooding are ongoing hazards.

Keywords

Kaikoura; Marlborough; Westland; Nelson; Canterbury; 1:250 000 geological map; geographic information systems; digital data; bathymetry; Buller terrane; Takaka terrane; Karamea Batholith; Median Batholith; Median Tectonic Zone; Brook Street terrane; Murihiku terrane; Dun Mountain-Maitai terrane; Caples terrane; Rakaia terrane; Pahau terrane; Torlesse terrane; plutons; Greenland Group; Haupiri Group; Mount Arthur Group; Karamea Suite; Brook Street Volcanics Group; Dun Mountain Ultramafics Group; Livingstone Volcanics Group; Maitai Group; Tasman Intrusives; Rotoroa Complex; Teetotal Group; Separation Point Suite; Glenroy Complex; Richmond Group; Patuki mélangé; Esk Head belt; Coverham Group; Tapuaenuku Igneous Complex; Mandamus Igneous Complex; Wallow Group; Hapuku Group; Seymour Group; Eyre Group; Muzzle Group; Motunau Group; Awatere Group; Rappahannock Group; Tadmor Group; marine terraces; alluvial terraces; alluvial fans; scree; rock glaciers; moraines; till; outwash; landslides; peat swamps; Alpine Fault; Awatere Fault; Clarence Fault; Hope Fault; Marlborough Fault System; Quaternary tectonics; active faulting; economic geology; alluvial gold; salt; sub-bituminous coal; limestone; aggregate; groundwater; engineering geology; landslides; natural hazards; seismotectonic hazard; tsunami.
Figure 1  Regional setting of New Zealand, showing the location of the Kaikoura geological map and other QMAP sheets, active faults and major offshore features (as illustrated by the 2000 m isobath). The Kaikoura sheet lies on the boundary between the Australian and Pacific plates where the subduction in the Hikurangi Trough is transitional into continental collision in the Southern Alps of the South Island. The arrows indicate the direction and rate of convergence of the Pacific Plate relative to the Australian Plate. After Anderson & Webb (1994).
The geological map of the Kaikoura area (Fig. 1) is one of the national QMAP series produced by GNS Science. The series replaces the earlier 1:250 000 series geological maps covering the Kaikoura area (Lensen 1962; Bowen 1964; Gregg 1964). Since the publication of those earlier maps, important geological concepts such as plate tectonics, terranes and sequence stratigraphy have been developed, and a vast amount of new geological research has been undertaken. This research includes detailed mapping, at 1:50 000 scale, of large areas (e.g. Johnston 1990; Suggate 1984; Reay 1993; Challis & others 1994; Warren 1995), fault studies (e.g. Kieckhefer 1979), detailed investigations for economic and engineering projects, university theses, and published papers on tectonic, stratigraphic, petrological, geochemical and many other aspects of geology.

The QMAP series and database are based on detailed geological information plotted on 1:50 000 NZMS260 series topographic base maps. These data record sheets are available for consultation at GNS Science. The 1:50 000 data have been simplified for digitising during a compilation stage, with the linework smoothed and geological units amalgamated to a standard national system based on age and lithology. Point data (e.g. structural measurements) have not been simplified. All point data are stored in the GIS, but only selected representative structural observations are shown on the map. Procedures for map compilation and details of data storage and manipulation techniques are given by Rattenbury & Heron (1997).

Data sources

The map and text have been compiled from published maps and papers, unpublished university theses, GNS Science technical and map files, mining company reports, field trip guides, the New Zealand Fossil Record File in its digital form (FRED), and GNS Science geological resources (GERM) and petrological (PETLAB) digital databases (Fig. 2). Additional field mapping between 2000 and 2004 resolved some geological problems and increased data coverage in less well-known parts of the map area. Quaternary deposits, landslides and active faults have largely been mapped from aerial photos, with limited field checking. Offshore data have been compiled from published studies of the northern Canterbury-Marlborough region (Field, Browne & others 1989; Barnes & Audru 1999a,b; Field, Uruski & others 1997) and unpublished data from the National Institute of Water and Atmospheric Research. Data sources used in map compilation are summarised in Fig. 2 and are cited in the references together with other studies relating to the Kaikoura map area.

Reliability

The 1:250 000 map is a regional scale map only, and should not be used alone for land use planning, planning or design of engineering projects, earthquake risk assessment, or other work for which detailed site investigations are necessary. Some data sets incorporated with the geological data (for example the Geological Resources Map of New Zealand [GERM] data) have been compiled from old or unchecked information of lesser reliability (see Christie 1989).
Figure 2 Location of data sources used in compiling the Kaikoura map. Unpublished maps and reports, including mining company reports, are held in the map archive and files of GNS Science, Lower Hutt. Unpublished university theses are held in university libraries. All data sources are listed in the references.
REGIONAL SETTING

The Kaikoura geological map covers much of northern Canterbury, southern Marlborough and southern Nelson, including many of the northeastern mountains of the South Island. The map area is sparsely populated with the largest towns – Kaikoura, Hanmer and Murchison – servicing agricultural industries. The other main industries are tourism, fishing and exotic forestry. Much of the northwestern part of the Kaikoura map area is covered in indigenous forest and is under Department of Conservation (DoC) stewardship. DoC administers Nelson Lakes and Kahurangi national parks, Lewis Pass Scenic Reserve, Victoria, Hanmer and Lake Sumner conservation parks, Mt Richmond Forest Park and Molesworth Farm Park.

The Kaikoura map area straddles the boundary between the Australian and Pacific plates which are converging at about 40 mm per year (Fig. 1). This area also covers the plate boundary transition from subduction of the Pacific plate under the Australian plate (Fig. 3), exemplified in the southern North Island, to continental collision between the plates, manifest by uplift of the Southern Alps and other ranges of the South Island. Much of the plate boundary movement in the Kaikoura map area is accommodated by oblique, dextral strike-slip along the Alpine Fault and the Awatere, Clarence, Hope and other faults of the Marlborough Fault System (Van Dissen & Yeats 1991; Knuepfer 1992; Holt & Haines 1995).

The basement geology of the Kaikoura map is dominated by quartzofeldspathic sedimentary rocks of the Rakaia and Pahau terranes (Bradshaw 1989), of dominantly Mesozoic age, that amalgamated to form the Torlesse composite terrane (Fig. 4). Northwest of the Alpine Fault the basement rocks include the early Paleozoic sedimentary and volcanogenic rocks of the Buller and Takaka terranes (Cooper 1989), and mid-Paleozoic to Early Cretaceous igneous intrusions of the Karamea and Median batholiths (Tulloch 1988; Mortimer & others 1999). The Permian to Jurassic volcanic and sedimentary Brook Street, Murihiku, Dun Mountain-Maitai and Caples terranes occur in south Nelson.

Covering mid- and Late Cretaceous, Paleogene and Neogene sedimentary rocks have been mostly removed by erosion, particularly in the central part of the map area. The sedimentary rocks resulted from an initial period of widespread erosion followed by marine transgression and subsequent regression in the early to middle Cenozoic. The Neogene development of the modern plate boundary through New Zealand, and associated convergence, resulted in uplift and further erosion. Widespread Quaternary terrestrial sedimentation reflects continuing uplift and erosion, with glaciation having a major influence on sedimentation.

Figure 3 Block model of the Kaikoura map area and surrounding regions showing active faults at the surface and the position of the subducting Pacific Plate under the Australian Plate defined by earthquake hypocentres (mostly concentrated on the upper surface of the subducting plate). After Barnes (1994b), Eberhart-Phillips & Reyners (1997).
Figure 4 Pre-Cenozoic basement rocks of New Zealand, subdivided into tectonostratigraphic terranes and batholiths; after Mortimer (2004). Cretaceous to Oligocene rocks of the Northland and East Coast allochthons were emplaced as a series of thrust sheets in the Miocene.
Figure 5 Shaded relief model of QMAP Kaikoura illuminated from the northwest. The model has been generated from a digital terrain model built from 20 m contour and spot height data supplied by LINZ (on land) and bathymetric contours supplied by NIWA (offshore). Major faults are arrowed and significant physiographic features are labelled.
GEOMORPHOLOGY

Main Divide ranges

The ranges and mountains at the northernmost end of the Southern Alps (Fig. 5), rise southeast of the Alpine Fault and form the “Main Divide” drainage boundary between the east and west coasts of the South Island. The mountains include a complex array of mostly north-trending ranges with numerous peaks over 2000 m, culminating at Mt Franklin (2340 m) in the Kaikoura map area. The higher range crests are generally bare rock and lack permanent snowfields or glaciers (Fig. 6).

Kaikoura ranges

The northeastern Kaikoura map area is dominated by the northeast-trending Inland and Seaward Kaikoura ranges (Figs 5, 7) that reach their greatest elevation in Tapuae-o-Uenuku (2885 m) and Manakau (2608 m) respectively. These ranges and lower ranges to the northwest are influenced by the major dextral strike-slip Alpine (Wairau), Awatere, Clarence and Hope faults, which traverse long straight valleys with intervening low saddles and aligned river segments. Except in the Wairau valley, remnants of Cretaceous-Pliocene covering rocks are preserved in fault-angle depressions on the southeastern sides of the faults. The summit heights of the ranges are generally concordant, reflecting uplift of relatively planar Late Cretaceous and later erosion surfaces cut in the basement rocks of Torlesse composite terrane. The distinctive peaks of Mt Tapuae-o-Uenuku and Blue Mountain result from more erosion-resistant igneous rock intrusions and associated hornfelsing of the Torlesse composite terrane country rock.

Hanmer Basin

Hanmer Basin is a rhomb-shaped topographic depression (Figs 5, 8) 15 km by 7 km at about 300 m elevation, surrounded by ranges up to 1500 m elevation. The Waiau River enters the basin area from the west, joins with the smaller Hanmer River, and drains through a gorge on the south side. Active traces of the Hope Fault are present on the northern side of the western part of the basin, are absent from the central area, and reappear on the southern side of the eastern part of the basin. This basin formed at a releasing bend between the right-stepping western Hope River and Conway segments of the dextral strike-slip Hope Fault. Seismic and gravity studies indicate Quaternary sediment fills the basin to a depth of more than 1000 m (Wood & others 1994).

Figure 6  Lake Constance and Blue Lake (far right) at the head of the Sabine River resulted from landslide dams in a deglaciated valley, and the smaller, unnamed tarn in the foreground fills a glacial cirque. The unvegetated greywacke-dominated Mahanga Range (middle distance) and the schistose Ella Range (behind) were occupied by glaciers until the early Holocene.

Photo CN25744/19: D.L. Homer.
Figure 7 The Inland Kaikoura Range is bounded to the southeast by the major Clarence Fault, which has an average Holocene right-lateral slip rate of 4-7 mm/yr (Pettinga & others 2001). The fault separates Early Cretaceous Pahau terrane (left) from Late Cretaceous to Miocene sedimentary and igneous rocks (right). The high peaks on the skyline are Mts Alarm (2877 m) and Tapuae-o-Uenuku (2885 m).

Photo CN4938/5: D.L. Homer.

Figure 8 The Hanmer Basin is a depression caused by a right step in the dextral strike-slip Hope Fault. The western Hope River segment of the fault (lower left) branches into many splays on the northern side of the basin (middle left). The Conway segment of the fault begins near the Waiau gorge (middle right) and follows the Hanmer River eastwards towards the coast. The basin sediments are over 1 km thick and are probably all Late Quaternary in age.

Photo CN14438/27: D.L. Homer.
Figure 9 Basin and range topography in the Waikari area, with Oligocene limestone outlining folds in the foreground. Late Cretaceous and Cenozoic rocks have largely been eroded off the Lowry Peaks Range in the left middle distance.

Photo CN3665/2: D.L. Homer.

Figure 10 The cliffed North Canterbury coastline results from ongoing tectonic uplift. These cliffs 4 km north of the Waiau River mouth are cut into Pahau terrane (left) and the unconformably overlying Neogene Greta Formation siltstone (right).

Photo CN19635/10: D.L. Homer.
Northern Canterbury basins and ranges

South of the Hope Fault, the ranges are lower in altitude and generally less rugged (Fig. 5). Between the ranges, the extensive intermontane Culverden, Cheviot and other basins are partly rimmed by Cretaceous-Miocene sedimentary rocks (Nicol & others 1995). These include the erosion-resistant Paleogene limestones that form distinctive landscapes near Waikari and Hawarden (Fig. 9). Sinkholes are locally developed where the limestone is flat-lying, such as the summit plateau of Mt Cookson and on the Kaikoura Peninsula. Where the Late Cretaceous to Miocene rocks have been stripped off relatively recently, the range crests are broad with little local relief. Some of the northeast-trending ranges are asymmetrical in transverse profile with reverse faults or thrusts on their generally steeper northwestern sides. The intermontane basins are filled with Late Quaternary gravel.

Coastal landforms

Much of the coast between the Clarence River mouth and Gore Bay consists of steep slopes and cliffs cut largely in Pahau terrane rocks (Fig. 10). At Kaikoura, the peninsula is composed of Late Cretaceous-Paleogene limestone and other rocks (front cover), and similar rocks form the smaller, but equally impressive Haumuri Bluffs south of Kaikoura. Paleogene rocks, capped by marine terraces, form the dominant exposures at the Conway River mouth and from the Hurunui River southwards. Slope failures are widespread, particularly in fine-grained rocks that are rich in montmorillonitic clays. More competent conglomerates and limestones form coastal cliffs and offshore rocks such as those at Needles Point (Fig. 11) and Chancet Rocks. Clifford Bay and the adjacent shallow Lake Grassmere occupy the northern end of the northeast-plunging Ward Syncline. Inland, along the syncline axis to the southwest, is the even shallower Lake Elterwater.
Figure 12 The active Alpine (Wairau) Fault crosses the northern end of Lake Rotoiti at St Arnaud, and continues northeast into the Wairau valley (distant). Neogene dextral strike-slip has juxtaposed Median Batholith, Brook Street, Murihiku, Dun Mountain-Maitai and Caples terrane rocks to the northwest (left) against Rakaia terrane and Esk Head belt rocks of the Travers, St Arnaud and Raglan ranges to the southeast (right).

Photo CN46400/16: D.L. Homer.

Figure 13 The Buller River flows south along the axis of the Longford Syncline to Murchison (centre distance). The thick Eocene to Miocene strata of the Murchison Basin have been tightly folded since the Late Miocene, completing a remarkably short but significant period of basin formation and deformation.

Photo CN4181/4: D.L. Homer.
Parallel to the coast, raised interglacial shorelines form narrow benches and terraces, the latter being more extensive between Haumuri Bluffs and the Waiau River. Intermittent narrow beaches of sand and gravel, commonly fringed or capped by sand dunes, also occur along the coast (Fig. 11).

Alpine Fault

The Alpine Fault is marked by a succession of low saddles, depressions, and aligned stream and river valleys. Between Tophouse and St Arnaud the fault traverses two low saddles (695 and 710 m; Fig. 12) that separate the Buller, Motupiko and Wairau rivers, which drain to the West Coast, Tasman Bay and Pacific Ocean, respectively. The fault prominently displaces a peninsula of moraine at the northern end of Lake Rotoiti. The Alpine Fault also marks a significant change in topography, especially south of St Arnaud; ranges to the southeast of the fault are typically 500 m higher than those to the northwest (Fig. 5), reflecting net Quaternary uplift.

Lakes

The largest lakes in the Kaikoura map area have formed in glaciated valleys behind terminal moraines, e.g. lakes Rotoiti (Fig. 12), Rotoroa, Sumner, Guyon and Tennyson. Most other lakes have resulted from landslide damming e.g. lakes Constance (Fig. 6), McRae and Matiri, and in many cases the landslides have fallen from previously glaciated and oversteepened valley sides, possibly triggered by earthquakes. Tarns occupying cirques are widespread in the higher mountains in the west.

Rivers

Large rivers traverse many parts of the Kaikoura map area and originate from the Main Divide, within or beyond the map area. Northwest of the Alpine Fault, the Buller River cuts through several mountain ranges from its source at Lake Rotoiti. Close to its source, the river flows westward through a gorge cut in granitic rocks of the Median Batholith before crossing the Murchison Basin. On entering the basin the river follows the axis of the Longford Syncline to Murchison (Fig. 13). Tributary valleys around Murchison commonly follow north-south trending faults and fold axes.

The course of the Awatere River and sections of the Clarence, Waiau and Wairau rivers have been strongly influenced by movement of the active faults of the Marlborough Fault System and related uplift of adjacent ranges. The Clarence River flows south from its source near Lake Tennyson, then east and northeast along the traces of the Elliott and Clarence faults, and then southeast through a gorge at the northern end of the Seaward Kaikoura Range to the coast.

The Conway, Waiau and Hurunui rivers have each cut several antecedent gorges through the ranges of northern Canterbury and have wide braided channels where they traverse the intervening basins to reach the Pacific Ocean. Most of the rivers are flanked by sets of terraces carved into glacial outwash gravel or formed by aggradation. Many of the outwash gravel surfaces can be traced inland to terminal moraines on both sides of the Main Divide.

Offshore physiography

The offshore physiography of the Kaikoura map area is dominated by four elements: the continental shelf, the continental slope, the Hikurangi Trough and the Chatham Rise. The continental shelf has a smooth sea floor at shallow depth (<400 m) that tapers from about 50 km wide in the north to about 10 km wide near Kaikoura Peninsula (Fig. 5). Immediately south of the peninsula, the spectacular Kaikoura Canyon is deeply incised into the shelf to within c. 500 m of the shoreline (Lewis & Barnes 1999). At the head of the canyon, the sea floor falls away abruptly so that only 4 km offshore the water is 1000 m deep. This deep canyon is responsible for interruption of the north-flowing Southland current, and the coincidence of the Subtropical Convergence Zone with the Chatham Rise (Lewis & Barnes 1999) leads to the local upwelling of plankton which attracts marine life such as whales, seals, and dolphins (Childerhouse & others 1995). South of the canyon near the Kaikoura map boundary the continental shelf broadens to 30 km width. The Conway Trough and Hurunui Canyon are incised into the Canterbury continental shelf.

The edge of the continental shelf abruptly gives way to the continental slope. The slope is incised by many canyons and small basins, which are predominantly controlled by fault movement (Field, Uruski & others 1997; Barnes & Audru 1999a). Directly east of Kaikoura Peninsula the Kowhai sea valleys form a series of narrow ridges and canyons that cut into the slope (Fig. 5). The continental slope is bounded to the east by the northeast-trending Hikurangi Trough, which reaches depths of 2500 m within the Kaikoura map area and 3500 m off the East Coast of the North Island (Lewis & Barnes 1999). Southeast of the trough, the continental slope (here known as Mernoo Bank) climbs to the Chatham Rise, part of a submerged continental plateau (Barnes 1994b). The Mernoo Bank is incised by the Pukaki, Pegasus and Hurunui canyons.
Figure 14 Tectonostratigraphic relationships within and between basement terranes. Stratigraphic units not appearing on the Kaikoura map are marked with an asterisk.
Cambrian to Cretaceous basement rocks, including volcanic, metasedimentary, granitic and ultramafic rocks, outcrop over 70% of the Kaikoura map area. The basement rocks are overlain by remnants of Late Cretaceous and Cenozoic, terrestrial and marine, sedimentary and igneous rocks, preserved in basins around Murchison and throughout eastern Marlborough and northern Canterbury. In the east these younger rocks contain local volcanic sequences. Quaternary fluvioglacial and alluvial deposits are widespread but Quaternary marine rocks occur only locally.

CAMBRIAN TO CRETACEOUS

The basement rocks of the Kaikoura map area, of Gondwanaland origin, have been divided into the largely early Paleozoic Western Province and the late Paleozoic to Mesozoic Eastern Province (Landis & Coombs 1967). The volcano-sedimentary and mafic intrusive rocks are mapped in tectonostratigraphic terranes (Figs 4, 14; Coombs & others 1976; Bishop & others 1985; Bradshaw 1993; Mortimer 2004) within which traditional lithostratigraphic formations and groups are recognised. The Western Province contains the Buller and Takaka terranes (Cooper 1989) that amalgamated in the mid-Devonian (collectively termed the Tuhua composite terrane). The Eastern Province in the Kaikoura map area comprises the Brook Street, Dun Mountain-Maitai, Murihiku, and Caples terranes west of the Alpine Fault and the Rakaia and Pahau terranes (collectively the Tuhua composite terrane). The Eastern Province in the Kaikoura map area comprises the Brook Street, Dun Mountain-Maitai, Murihiku, and Caples terranes west of the Alpine Fault and the Rakaia and Pahau terranes (collectively the Tuhua composite terrane). The Eastern Province in the Kaikoura map area comprises the Brook Street, Dun Mountain-Maitai, Murihiku, and Caples terranes west of the Alpine Fault and the Rakaia and Pahau terranes (collectively the Tuhua composite terrane). The Eastern Province in the Kaikoura map area comprises the Brook Street, Dun Mountain-Maitai, Murihiku, and Caples terranes west of the Alpine Fault and the Rakaia and Pahau terranes (collectively the Tuhua composite terrane). The Eastern Province in the Kaikoura map area comprises the Brook Street, Dun Mountain-Maitai, Murihiku, and Caples terranes west of the Alpine Fault and the Rakaia and Pahau terranes (collectively the Tuhua composite terrane). The Eastern Province in the Kaikoura map area comprises the Brook Street, Dun Mountain-Maitai, Murihiku, and Caples terranes west of the Alpine Fault and the Rakaia and Pahau terranes (collectively the Tuhua composite terrane). The Eastern Province in the Kaikoura map area comprises the Brook Street, Dun Mountain-Maitai, Murihiku, and Caples terranes west of the Alpine Fault and the Rakaia and Pahau terranes (collectively the Tuhua composite terrane). The Eastern Province in the Kaikoura map area comprises the Brook Street, Dun Mountain-Maitai, Murihiku, and Caples terranes west of the Alpine Fault and the Rakaia and Pahau terranes (collectively the Tuhua composite terrane). The Eastern Province in the Kaikoura map area comprises the Brook Street, Dun Mountain-Maitai, Murihiku, and Caples terranes west of the Alpine Fault and the Rakaia and Pahau terranes (collectively the Tuhua composite terrane). The Eastern Province in the Kaikoura map area comprises the Brook Street, Dun Mountain-Maitai, Murihiku, and Caples terranes west of the Alpine Fault and the Rakaia and Pahau terranes (collectively the Tuhua composite terrane). The Eastern Province in the Kaikoura map area comprises the Brook Street, Dun Mountain-Maitai, Murihiku, and Caples terranes west of the Alpine Fault and the Rakaia and Pahau terranes (collectively the Tuhua composite terrane). The Eastern Province in the Kaikoura map area comprises the Brook Street, Dun Mountain-Maitai, Murihiku, and Caples terranes west of the Alpine Fault and the Rakaia and Pahau terranes (collectively the Tuhua composite terrane). The Eastern Province in the Kaikoura map area comprises the Brook Street, Dun Mountain-Maitai, Murihiku, and Caples terranes west of the Alpine Fault and the Rakaia and Pahau terranes (collectively the Tuhua composite terrane). The Eastern Province in the Kaikoura map area comprises the Brook Street, Dun Mountain-Maitai, Murihiku, and Caples terranes west of the Alpine Fault and the Rakaia and Pahau terranes (collectively the Tuhua composite terrane). The Eastern Province

Buller terrane

Early Ordovician sedimentary rocks

The Buller terrane, comprising the Greenland Group (Gg) within the Kaikoura map area, occupies a few square kilometres near Marua Saddle. The group consists of well-to poorly bedded, greenish-grey quartzose sandstone and mudstone (Stewart 1974). The rocks are intruded by Late Ordovician-Carboniferous Karamea Suite granite in the northwest and faulted against Miocene conglomerate to the southeast. Greenland Group sandstone typically contains abundant detrital quartz, minor sodic plagioclase and subordinate volcanic and sedimentary rock fragments (Nathan 1976; Roser & others 1996). The group has been interpreted as a turbidite succession within a submarine fan deposit (Laird 1972; Laird & Shelley 1974). Graptolites from near Reefton, 30 km west of the Kaikoura map area, are early Ordovician (Cooper 1974). K-Ar and Rb-Sr ages from near Reefton, 30 km west of the Kaikoura map area, are early Ordovician (Cooper 1974). K-Ar and Rb-Sr ages from near Reefton, 30 km west of the Kaikoura map area, are early Ordovician (Cooper 1974). K-Ar and Rb-Sr ages from near Reefton, 30 km west of the Kaikoura map area, are early Ordovician (Cooper 1974). K-Ar and Rb-Sr ages from near Reefton, 30 km west of the Kaikoura map area, are early Ordovician (Cooper 1974). K-Ar and Rb-Sr ages from near Reefton, 30 km west of the Kaikoura map area, are early Ordovician (Cooper 1974). K-Ar and Rb-Sr ages from near Reefton, 30 km west of the Kaikoura map area, are early Ordovician (Cooper 1974). K-Ar and Rb-Sr ages from near Reefton, 30 km west of the Kaikoura map area, are early Ordovician (Cooper 1974). K-Ar and Rb-Sr ages from near Reefton, 30 km west of the Kaikoura map area, are early Ordovician (Cooper 1974).

Takaka terrane

A small area of the Takaka terrane outcrops in the Kaikoura map area along the Alpine Fault, near Lake Daniells. Further north the terrane is concealed by Tertiary rocks in the Murchison Basin (see section C-C’), but is well exposed in Northwest Nelson, where the type localities of the Haupiri and Mt Arthur groups are located (Rattenbury & others 1998). Southwest of the Kaikoura map area, the terrane progressively narrows and is truncated by the Alpine Fault (Nathan & others 2002).

Middle Cambrian to Late Ordovician sedimentary rocks

In the vicinity of Lake Daniells, volcanicogenic sedimentary rocks with conglomerate and minor basaltic flows are correlated with the Haupiri Group of Northwest Nelson (Münker & Cooper 1999; Nathan & others 2002). Three informal units (Nathan & others 2002) are recognised, comprising dolomitic mudstone and ankeritic sandstone with minor conglomerate (Ehr), polymict pebble to granule conglomerate (Eha), and grey laminated dolomitic mudstone and sandstone with widespread interlayered felsic volcanic rocks (Ehh). In Northwest Nelson the group has been assigned a Middle-Late Cambrian age (Münker & Cooper 1999).

In the Lake Daniells area the Mt Arthur Group overlies the Haupiri Group (Bowen 1964), separated by a detachment fault (R. A. Cooper in Nathan & others 2002). The Sluice Box Limestone (Oms) consists of recrystallised grey, commonly siliceous, limestone and minor sandstone with mudstone layers. Conodonts, trilobites and disarticulated brachiopods indicate a Late Cambrian to Middle Ordovician age (Cooper 1989). The formation is correlated with the Arthur Marble 1 and Summit Limestone formations of Northwest Nelson (Rattenbury & others 1998). The conformably overlying siltstone and minor quartz sandstone of the Alfred Formation (Omw) contains Late Ordovician (Gisbornian) graptolites and is correlated with the Wangapeka and Baldy formations in Northwest Nelson (Rattenbury & others 1998).

Karamea Batholith

Late Devonian to Early Carboniferous intrusive rocks

The Karamea Batholith extensively intrudes the Tuhua terrane in the northwest of the South Island and is dominated by the Karamea Suite of Late Devonian-early Carboniferous granites (Tulloch 1988; Muir & others 1994). The suite has S-type geochemistry, commonly containing muscovite and generally lacking hornblende. Within the Kaikoura map area the rocks are only exposed at Mt Newton and Mantell, north and south of Murchison respectively, but are inferred to underlie much of the Paleogene-Miocene strata of the Murchison Basin. At Mt Newton the suite comprises coarse-grained, inequigranular
biotite granite, locally with megacrystic K-feldspar, and fine-grained muscovite-biotite granite (Dkg). At Mt Mantell, biotite granodiorite and tonalite (Dkt) predominate (Stewart 1974). U-Pb dating of the Karamea Suite beyond the map area gave crystallisation ages of 388–358 Ma (Muir & others 1994, 1996).

**Median Batholith**

The rocks separating the Eastern and Western provinces include a range of mafic, intermediate and felsic plutonic intrusions, some extrusive equivalent rocks and several significant sedimentary units in and to the north of the map area. The Median Tectonic Zone (MTZ, Bradshaw 1993) was defined to include these diverse and, in places, structurally dismembered rocks. Mortimer & others (1999) recognised that the MTZ is more than 90% plutonic in origin and that much of the deformation was superimposed in the Cenozoic. Moreover the plutonic rocks extend beyond the western limit of the MTZ into parts of the Western Province and are viewed as part of an originally contiguous batholith, the Median Batholith (Fig. 4, Mortimer & others 1999; Mortimer 2004). The batholith is dominated by I-type plutonic rocks ranging from ultramafic through to felsic compositions (Mortimer & others 1999).

In the Kaikoura map area the Median Batholith is obliquely truncated by the Alpine Fault to the southeast, and the western contact is obscured under the Murchison Basin. Northwards from the Alpine Fault the Median Batholith becomes increasingly obscured by a cover of late Cenozoic rocks, dominated by the Moutere Gravel, although it re-emerges northeast of Nelson city. In Northwest Nelson the batholith intrudes the Takaka terrane (Rattenbury & others 1998). In the east the batholith is separated from the Brook Street terrane by the Delaware-Speargrass Fault Zone (Johnston & others 1987; Johnston 1990; Rattenbury & others 1998). The Median Batholith includes the Rotoroa Complex, Tasman Intrusives and Separation Point Suite. The latter two intrusive units are separated by the Flaxmore Fault. Adjacent sedimentary and volcanic rocks, ranging from subgreenschist to amphibolite facies metamorphic grade, are volumetrically minor and some have been derived from extrusive equivalents or erosion of the Median Batholith intrusive rocks.

**Late Triassic to Late Jurassic igneous rocks and associated sedimentary rocks**

The **Tasman Intrusives** group several Late Triassic to Late Jurassic plutons in the southeast of the Moutere Depression (Johnston 1990). The **Buller Diorite** (Tab), near Lake Rototiti, consists of medium-grained, commonly altered, diorite to tonalite (Fig. 15a) with sparse dikes of fine-grained diorite and quartz-rich pegmatites. The Buller Diorite characteristically contains plagioclase (oligoclase, andesine) and hornblende with minor interstitial quartz and accessory minerals. Southeast, towards the Delaware-Speargrass Fault Zone, it becomes progressively foliated with the development of alternating white to greyish-white, feldspar-rich and dark grey to black, biotite and hornblende-rich layers. Within the Delaware-Speargrass Fault Zone the diorite grades into the foliated **Rototiti Gneiss** (Tar) composed of quartz, plagioclase (oligoclase), K-feldspar, biotite, muscovite and porphyroblastic garnet. Radiometric dating of the Buller Diorite yielded Late Triassic ages of 225 Ma (K-Ar, Johnston 1990) and 228 Ma (U-Pb zircon, Kimbrough & others 1994). Other rock types within the Delaware-Speargrass Fault Zone include altered coarse-to fine-grained gabbro and minor pyroxenite of the **Seventeen Gabbro** (Jas) of Mesozoic age (Johnston 1990).

The **One Mile Gabbro** (Jao) consists of diorite, tonalite and hornblende gabbrogranite that are commonly altered (Tulloch & others 1999). The pluton intrudes the Rainy River Conglomerate in the east and is bounded by the Flaxmore Fault in the west. U-Pb dating of zircons indicates a 147 Ma (Late Jurassic) intrusive age (Kimbrough & others 1994).

The **Big Bush Andesite** (Jeb) of the **Tectotal Group** (Johnston 1990) forms an 800 m wide strip in the upper Rainy River and consists of grey to greenish-grey, fine- to medium-grained andesite and overlying andesitic breccia. The andesite is largely massive but flows, up to 2 m thick, with dark, fine-grained margins are locally recognisable. It is characterised by andesine phenocrysts with a dominant trachytic texture. The breccia is predominantly unstratified although locally fragments are weakly aligned. The breccia grades eastwards, and probably stratigraphically upwards, into the c. 2000 m thick **Rainy River Conglomerate** (Jer). Within the conglomerate are rare sills or flows of porphyritic Big Bush Andesite. The lower 200 m of the Rainy River Conglomerate is dominated by andesitic breccia with layers of subrounded to rounded andesitic pebbles. This breccia grades upwards into very poorly sorted, greenish-grey conglomerate with a variety of clasts, up to 0.5 m across, in a fine- to coarse-grained grey or greenish-grey sandstone matrix (Fig. 15b). The clasts include andesite, felsic plutonics, basalt, and altered sandstone and siltstone. In places the clasts are dominated by diorite eroded from the underlying Buller Diorite (Tulloch & others 1999). The Rainy River Conglomerate contains rare, very thick sandstone beds locally with coal seams up to 0.4 m thick, and minor siltstone. The formation has undergone zeolite facies metamorphism and the coal is of high-volatile bituminous rank.

Clasts within the Rainy River Conglomerate are sourced from the Median Batholith and the Brook Street terrane, the closest terrane of the Eastern Province. No clasts from the Western Province have been identified. The ages of the Big Bush Andesite and Rainy River Conglomerate are not known, although they are constrained by the underlying Buller Diorite and the intruding One Mile Gabbrogranite (see above). U-Pb zircon dating of two quartz monzonite clasts from the Rainy River Conglomerate yielded 273–290 Ma (Early Permian) and 176–185 Ma (Early Jurassic) ages. A late Middle or Late Jurassic age is assigned to the Big Bush Andesite and Rainy River Conglomerate (Tulloch & others 1999).
The **Rotoroa Complex** comprises a layered intrusion consisting of gabbro, gabbronorite, norite, anorthosite, diorite and trondhjemite, and rare hornblende with lenses of amphibolite (Challis & others 1994). Relatively unaltered gabbronorite layered with anorthosite, hornblende gabbro, leucogabbro and biotite gabbro (Howard Gabbro, Jrh, Fig. 15c) occurs mainly in the east of the complex. Opaque mineral-rich plagioclase (typically An$_{60-70}$) gives the gabbro a dark appearance, even where it is highly feldspathic. Dioritic rocks are widespread, particularly in the west of the complex, and include gneissic mafic to leucocratic diorite, microdiorite, quartz diorite, and trondhjemite (Bræburn Diorite, Jra). Migmatite and gneissic intrusion breccia are common within the diorite and have resulted from the later intrusion of Early Cretaceous granitoids. Layering, defined by alternating felsic and mafic bands or by coarse and finer grained rocks, is common. Fine-grained, dark grey amphibolite and epidiorite of the **Kawatiri Amphibolite** (Jrk) are concentrated in the northwest of the complex. The amphibolite and epidiorite are composed mainly of hornblende and plagioclase, and are probably metamorphosed basalt and dolerite dikes and sills. The epidiorite is generally more felsic and has relict igneous textures. Shearing occurs in many places, and the rocks are locally schistose.

U-Pb zircon dating of gabbronorite from near Lake Rotoroa at 155 Ma indicates a Late Jurassic age for the Rotoroa Complex (Kimbrough & others 1993).

**Early Cretaceous intrusive rocks**

The **Separation Point Suite** is the dominant component of the Separation Point Batholith, here incorporated in the Median Batholith (Mortimer & others 1999). The granite-dominated suite intrudes Rotoroa Complex within the Kaikoura map area and intrudes rocks of the Takaka terrane northwest of the map area (Rattenbury & others 1998). In the map area the Tainui Fault separates the suite from Tertiary rocks of the Murchison Basin to the northwest (Suggate 1984). The suite is dominated by massive, equigranular biotite and biotite-hornblende granite with minor tonalite, quartz diorite and quartz monzonite (Ksg; Fig. 15d). In the southeast the suite is extensively
interlayered with the Rotoroa Complex along a northeast trend (Challis & others 1994). Quartz diorite occurs with intrusion breccias adjacent to un faulted contacts with the Rotoroa Complex. The suite is intruded by late-phase dikes and sills of fine-grained tonalite, aplite and granite pegmatite. Rb-Sr ages of 116 Ma (Aronson 1965) and 114 Ma (Harrison & McDougall 1980) and, from beyond the map area, U-Pb dating of zircons between 109 and 121 Ma (Kimbrough & others 1994; Muir & others 1994, 1997) indicate that the Separation Point Suite was emplaced in the Early Cretaceous.

The Glenroy Complex (Kg), dominated by coarse-grained biotite-hornblende granite, occurs east of the lower Glenroy River and around the Upper Matakitaki settlement (Adamson 1966; Cutten 1987). The complex also contains metasedimentary gneiss with an amphibolite facies garnet-biotite-sillimanite-kyanite mineral assemblage and two-pyroxene granulite facies dioritic orthogneiss (retrogressed to amphibolite facies). The orthogneiss was emplaced into the lower crust in the Early Cretaceous (Tulloch & Challis 2000).

**Brook Street terrane**

**Early Permian volcanic and sedimentary rocks**

The **Brook Street Volcanics Group** (Yb) is the only stratigraphic group mapped within the Brook Street terrane in the Kaikoura map area. It crops out around the northern end of Lake Rotoiti, where it forms the southern end of the Permian sequence of east Nelson (Johnston 1990). Farther southwest the group is concealed by Quaternary deposits except for a fault-bounded sliver at the south end of Lake Rotoroa (Challis & others 1994). The group is bounded in the northwest by the Delaware-Speargrass Fault Zone and to the southeast by the Waimea and Alpine faults. It comprises a southeast-dipping and younging sequence of intermediate to mafic volcanic-derived sedimentary rocks and associated igneous rocks.

The **Kaka Formation** (Ybk), the dominant unit in the group within the map area, comprises green, coarse-grained mafic volcanic flows and shallow intrusives with widespread pyroclastic and clastic rocks derived from the igneous rocks. The volcanic rocks are basaltic andesite to calc-alkaline basalt, with augite and plagioclase the dominant minerals. The sedimentary rocks are dominated by breccia, with clasts of augite-rich igneous rocks up to 0.4 m across. Minor rock types are green siltstone and sandstone, and rare lenses of grey calcareous siltstone and impure limestone, the latter having a foetid smell when freshly broken. The lenses contain atomodesmatinid shell fragments and, at Speargrass Creek, a 3 m thick limestone has abundant impressions of Maitaia obliquata Waterhouse (Johnston & Stevens 1985). Conformably overlying the Kaka Formation is the 1500 m thick **Brough Formation** (Ybb), dominated by dark, fine-grained basalt and dolerite with minor gabbro and tuffaceous sequences. The formation grades upwards into **Groom Creek Formation** (Ybg), which is dominated by poorly bedded grey, greenish grey and whitish grey, tuffaceous siltstone and sandstone (Fig. 16). The Brough and Groom Creek formations are intruded by lensoidal masses, up to 100 m thick, of very altered dolerite and fine-grained gabbro.

The Brook Street Volcanics Group typically has been metamorphosed to prehnite-pumpellyite facies. The Kaka Formation is of Permian age and a late Early Permian age is inferred for the group based on better constrained dating in Southland (Turnbull & Allibone 2003).

**Murihiku terrane**

**Late Middle Triassic and Early to Late Jurassic sedimentary rocks**

The Murihiku terrane encompasses the Murihiku Supergroup which, in the Kaikoura map area, forms two fault-bounded blocks of zeolite facies rocks, 6 km in length, along the Waimea Fault north of Tophouse (Johnston 1990). The eastern block comprises the 1000 m thick **Blue**...
Glen Formation (Trb) of the Richmond Group (Johnston 1990). The formation dips and youngs eastwards and consists of bedded grey sandstone, siltstone and mudstone with numerous tuffaceous beds and local conglomerate. The finer grained rocks are commonly bioturbated, with sparse ammonites, bivalves, palynofloras and marine acritarchs of late Middle Triassic age. The formation was deposited in an outer shelf environment with periodic incursions of submarine fans.

To the west of the Blue Glen Formation, and separated from it by Paleogene rocks, is a >250 m thick fault-bounded sliver of the non-marine Berneyboosal Formation (Jb; Johnston 1990). The formation consists of grey, poorly bedded sandstone and siltstone with interbedded carbonaceous horizons and coarse sandstone and conglomerate. The sandstones contain andesitic debris and the conglomerate clasts include intermediate to mafic volcanics, granitoids and sedimentary rocks. The carbonaceous horizons are dominated by dark mudstone with rare coal seams up to 0.5 m thick. Miospores indicate an Early to Late Jurassic (Ururoan to Puaroan) age.

Dun Mountain-Maitai terrane

The Dun Mountain-Maitai terrane is a distinctive feature of South Island geology. In the Kaikoura map area the terrane crops out between Tophouse and Red Hills Ridge (Figs 14, 17) at the southern end of the east Nelson section (e.g. Rattenbury & others 1998). To the south the terrane has been truncated and displaced by the Alpine Fault (Johnston 1990) and a fault-bounded outlier of the terrane occurs between the Matakitaki and Glenroy valleys, west of the bend in the Alpine Fault (Waterhouse 1964; Adamson 1966; Johnston 1976). The Dun Mountain-Maitai terrane reappears on the southeast side of the Alpine Fault in northwest Otago, northern Southland and south Otago, an apparent displacement of 480 km. In all areas the rocks are very similar although some lithological units have been reduced in thickness, or are missing, due to subsequent faulting.

The terrane contains Early Permian ultramafic and mafic igneous rocks of the Dun Mountain Ophiolite Belt, comprising the Dun Mountain Ultramafics Group and the

Figure 17 The Dun Mountain Ultramafics Group forms the distinctive red-brown, forest-free Red Hills Ridge at the northern edge of the Kaikoura map area. Vegetation growth is inhibited by higher and more toxic levels of extractable nickel and/or magnesium in the soils derived from the ultramafic rocks. The Alpine Fault, extending southwest from the Wairau River (middle left) towards Lake Rotoiti (distant centre), truncates the Dun Mountain Ultramafics Group. The plateau on the southern end of the ridge is an erosion surface capped by Pleistocene Plateau Gravel.

Photo CN7120/1: D.L. Homer.
overlying mafic Livingstone Volcanics Group. The Dun Mountain Ophiolite Belt is unconformably overlain by sedimentary rocks of the Maitai Group. Mélange occurs at the suture between the Dun Mountain-Maitai and Caples terranes. The ophiolite belt produces the Junction Magnetic Anomaly or Eastern Belt of the Stokes Magnetic Anomaly (Hunt 1978).

Early-Middle Permian ultramafic and mafic igneous rocks

The Dun Mountain Ultramafics Group within the Kaikoura map area crops out in the Porters Knob and Red Hills Ridge area where it reaches a maximum width of 10 km (Walcott 1969; Davis & others 1980), and also in the Matakitaki outlier. The rocks weather to a distinctive red-brown (dun) colour and tend to be sparsely vegetated (Fig. 17). In the Red Hills the group is dominated by harzburgite, which in the east is massive to very poorly layered with a protoclastic texture (Ydp, Fig. 18). Westward the protoclastic rocks grade into layered harzburgite with minor dunite, chromite segregations and sparse eucrite, wehlrite, lherzolite and pyroxenite (Ydm). Dikes of dark grey microgabbro and amphibolite, largely striking NNW and up to 10 m thick, are relatively common in the central part of the Red Hills. Along the western margin of the Red Hills is a tectonised zone of serpentinised, layered harzburgite and minor dunite, pyroxenite and gabbro with rodingite dikes (Johnston 1990). The Dun Mountain Ultramafics Group in the Matakitaki outlier is poorly defined but is composed of serpentinised harzburgite and minor dunite up to 500 m wide (Adamson 1966). Elsewhere in the South Island the ultramafics have been dated, using the U-Pb method, at 280–265 Ma (Early-Middle Permian; Kimbrough & others 1992).

The Livingstone Volcanics Group (Yl) is present on the western margin of the Red Hills and in the Matakitaki outlier. In the Matakitaki outlier the group, which is about 1800 m thick, is not differentiated. In the Red Hills the poorly exposed and fault-disrupted Tinline Formation (Ylt) consists of vertical to steeply northwest-dipping, alternating coarse- and fine-grained tholeiitic gabbro, emplaced as a dike complex with individual intrusions up to several metres thick. Cross-cutting the complex are irregular coarser grained dikes, with augite crystals up to 15 mm in length, containing gabbro xenoliths. The dike complex is approximately 400 m thick. Unfaulted parts of the Tinline Formation grade upwards through fine-grained, apparently massive, microgabbro or dolerite, into the poorly exposed Glennie Formation (Ylg). The Glennie Formation is about 800 m thick in the Red Hills and consists of dark green or greenish-grey, spilitic augite basalt with lenses of basaltic breccia in its upper part. The basalt has a subophitic texture and forms sheets several metres thick with locally brecciated margins; pillow basalt is absent (Johnston 1990).

Figure 18 Blocky, dark, massive, partly serpentinised harzburgite of the Dun Mountain Ultramafics Group, locally weathered to a characteristic dun colour, in a creek draining south from the Red Hills Ridge. The streaky white surfaces are shears with fibrous serpentine.
In both formations primary augite crystals are completely or partly replaced by hornblende, and plagioclase is partially replaced by hydrogроссular, prehnite, pumpellylite, chlorite and epidote. In east Nelson the upper basaltic part of the Livingstone Volcanics Group has been metamorphosed to greenschist facies (Davis & others 1980). The group has subsequently been affected by prehnite-pumpellylite metamorphism. Zircon U-Pb dates from outside the map area indicate an Early Permian age (Kimbroagh & others 1992).

Late Permian to Early Triassic sedimentary rocks

The Maitai Group is exposed north of Tophouse in the Roding Syncline (Johnston 1990) and in the Matakitaki outlier as a northwest-younging sequence in which the beds are commonly overturned (Waterhouse 1964; Adamson 1966; Johnston 1976). The basal Upukerora Formation (Ymu) in the Matakitaki outlier is several hundred metres thick and consists of coarse tuffaceous sandstone with lenses of hematitic breccia overlain by grey calcareous siltstone (Adamson 1966). In the Red Hills the formation comprises lenses of conglomerate with tuffaceous horizons. Because of very poor exposure in east Nelson and Matakitaki, the stratigraphic relationship with the underlying Livingstone Volcanics Group is unclear, although north of the Kaikoura map area, an unconformity between them is preserved (Johnston 1981). The Wooded Peak Limestone (Ymw) is up to 750 m thick, dominantly grey, and consists of a basal poorly bedded limestone and an upper well-bedded limestone, separated by well-bedded calcareous sandstone with minor siltstone and conglomerate. In the Matakitaki outlier the limestone is about half the thickness of the east Nelson limestone and the lithological distinctions are less well defined. The limestone has a strong foetid smell when freshly broken. The Wooded Peak Limestone grades upwards into the grey Tramway Sandstone (Ymt). The Tramway Sandstone, up to 800 m thick, contains more quartz than the rest of the Maitai Group (but still less than 10%). In east Nelson it ranges from well-bedded calcareous sandstone and siltstone to poorly bedded fine-grained sandstone and siltstone. Fragmentary atomodesmatinid fossils, including Maitai trechmanni Marwick, are widespread. By contrast, the formation in the Matakitaki outlier is a poorly bedded, calcareous, dark grey to black siltstone or mudstone with green sandstone interbeds. Wellman (1953) reported an Orthoceras from float downslope from Baldy, but atomodesmatinid fossils are less abundant here.

In east Nelson the Tramway Sandstone is conformably overlain by up to 700 m of poorly to locally well-bedded, green volcanogenic Little Ben Sandstone (Tml), but this formation has not been recognised in the Matakitaki outlier. Thin dark grey siltstone beds and rare lenses of conglomerate contain calcareous siltstone and limestone but no fossils. The Little Ben Sandstone grades upwards into the generally thin-bedded or laminated, grey sandstone and mudstone of the c. 1700 m thick Greville Formation (Tmg; Fig. 19a). The upper 200 m in east Nelson consists of poorly bedded green sandstone, with thin, dark grey mudstone and lenses of conglomerate. The conglomerate clasts, up to 0.2 m across, include mafic tuff and breccia. The Waiau Formation (Tmw) differs mainly from the underlying Greville Formation in the reddish-purple hematite in the finer grained beds (Fig. 19b). The formation is >750 m thick in east Nelson where it occupies the core of the Roding Syncline. In the Matakitaki outlier the Waiau Formation has a maximum reported thickness of only 180 m (Adamson 1966).

The Stephens Subgroup (Tms) is over 2000 m thick and conformably overlies the Waiau Formation in the Matakitaki outlier but near Tophouse is separated from the rest of the Matai Group by the Whanganui Fault. It consists predominantly of variably bedded, grey sandstone with dark grey siltstone and mudstone, and beds are generally thicker than those in the Waiau and Greville formations. Thin conglomerate horizons also occur, and in the Matakitaki outlier the subgroup contains a 220 m thick coarse conglomerate composed mainly of sandstone, siltstone and igneous clasts (Adamson 1966).

The lower part of the Maitai Group was deposited on the flanks of a submarine high of Livingstone Volcanics with the Wooded Peak Limestone being largely derived from atomodesmatinid shell banks with influxes of volcanic- derived sand (Johnston 1990). The abundance of complete atomodesmatinid fossils in parts of the Tramway Sandstone suggests relatively shallow water deposition, but the source of the detrital quartz remains unknown. The Little Ben Sandstone was deposited as submarine fan derived from the Livingstone Volcanics, probably at the beginning of the Triassic. The remaining Maitai Group units were deposited in deeper water with widespread submarine fan deposition in the Stephens Subgroup. Following deposition, the group was subjected to burial metamorphism to prehnite-pumpellylite facies, or locally lawsonite albite chlorite facies (Landis 1969), and folded into the Roding Syncline.

Caples terrane

Late Permian to Early Triassic sedimentary rocks

Caples terrane sedimentary rocks and their schistose equivalents were formerly mapped as Pelorus Group but, following stratigraphic nomenclature rationalisation between Nelson/Marlborough and Otago/Southland, are now assigned to the Caples Group (Yc). The rocks crop out extensively to the north of the map area (Rattenbury & others 1998) but in the Kaikoura map area they occupy only about 20 km² in the Wairau valley, north of the Alpine Fault (Walcott 1969; Johnston 1990), and approximately 8 km² in the east of the Matakitaki outlier. The group is separated from the Dun Mountain Ultramafics Group by the Patuki Mélangé (see below). In the east the group becomes increasingly metamorphosed to form part of the Marlborough Schist Zone of the Haast Schist. The less metamorphosed rocks in the Wairau valley comprise an east-dipping, but overturned, succession >4000 m thick. The oldest rocks in the group belong to the
Figure 19 Maitai Group sedimentary rocks.

(a) Laminated fine-grained sandstone and mudstone of the Greville Formation east of Tophouse. The conglomerate boulder is derived from the upper part of the formation.

(b) Finely bedded greenish grey sandstone and purplish red mudstone of the Waiua Formation, from Beebys Knob. Cross-bedding and other sedimentary features show that the beds young upwards (southeast).

Figure 20 Moderately foliated and transposed Caples Group semischist east of Wether Hill in the Wairau valley.
Star Formation (Yes), comprising poorly bedded green sandstone with grey siltstone and mudstone beds, particularly in the upper part. To the west the overlying Wether Formation (Yew) is bedded green sandstone and purplish-red siltstone and mudstone. The youngest rocks in the sequence, the Ward Formation (Yca), are grey to greenish-grey sandstone and siltstone with subordinate thick, grey or green sandstone and grey mudstone. Caples Group sedimentary rocks are predominantly feldspathic with abundant lithic (volcanic) rock fragments and subordinate quartz.

In the Matakitaki outlier, and parts of the eastern Wairau valley, rocks are mapped as undifferentiated Caples Group. In the Wairau valley these rocks have a weak southeast-dipping foliation that becomes more pronounced eastward as the rocks grade into semischist (Fig. 20). The foliated rocks have been mapped in textural zones (t.z. IIA, IIB; see box). In lower Chrome Stream adjacent to the Wairau River, poorly exposed, crushed metavolcanic rock (basalt, gabbro) and phyllonite occur with green sandstone and red mudstone in fault contact with t.z. IIA and IIB semischist to the north. In the Matakitaki outlier the group comprises massive to poorly bedded green and grey sandstone and grey siltstone (Adamson 1966) that is weakly foliated (t.z. IIA). The Caples Group rocks grade from prehnite-pumpellyite facies into pumpellyite-actinolite facies, and possibly into lower greenschist facies in the south adjacent to the Wairau River.

North of the Kaikoura map area the Caples Group contains sparse, poorly preserved radiolarians, atomodesmatinid fragments, palynomorphs and leaves, that indicate a Permian (?Late Permian) to Triassic age (Johnston 1996). Rb-Sr and K-Ar whole rock ages date regional metamorphism at about 200 Ma (Late Triassic to Early Jurassic), and uplift and cooling at about 200–110 Ma (Jurassic to Early Cretaceous), indicating a minimum age for deposition of the Caples Group (Adams & others 1999; Little & others 1999). Caples Group sediments were derived from erosion of an andesite-dacite source area and deposited in submarine fans in a trench slope and trench environment.

Mesozoic mélange

The Patuki Mélange (Tmp) crops out extensively in the head of Station Creek in the Matakitaki outlier and is up to 1 km wide. The mélange is also present as fault-bounded slivers on the east side of the Red Hills between the Dun Mountain-Maitai and Caples terranes, where it is locally more than 1 km wide but more typically <600 m wide. Another mélange zone about 1 km wide is present on the northwest side of the Red Hills and is inferred to be an infaulted block of Patuki Mélange along the tectonically complex contact between the Dun Mountain Ophiolite Belt and the Maitai Group (Johnston 1990). Blocks within the mélange are dominantly grey siltstone or mudstone, but gabbro, basalt, ultramafic rocks and rare rodingite are also present. Because the blocks are more resistant to erosion than the sheared serpentinitic matrix, a characteristic hummocky topography defines the mélanges on either side of the Red Hills. The siltstone and mudstone blocks have been altered by the introduction of albite and tremolite to form argillite (or pakohe). The emplacement age of the Patuki Mélange is poorly constrained but is no older than Late Triassic.
**Torlesse composite terrane**

The Torlesse composite terrane comprises predominantly quartzofeldspathic indurated sedimentary rocks, commonly called greywacke, which range in age from Carboniferous to Early Cretaceous in the South Island, and Late Triassic to Early Cretaceous in the North Island. In the Kaikoura map area the composite terrane encompasses all of the basement rocks southeast of the Alpine Fault to the eastern coast (Fig. 14). It includes the Rakaia and Pahau terranes (Bradshaw 1989), which can be distinguished from each other on the basis of petrographic, geochemical, isotopic and age differences (Andrews & others 1976; Mackinnon 1983; Roser & Korsch 1999; Adams 2003). The two terranes are separated by the Esk Head belt which consists of deformed elements of both terranes and locally allochthonous lithologies.

**Rakaia terrane**

*Late Triassic sedimentary rocks*

Grey, indurated, quartzofeldspathic sandstone (greywacke) and mudstone (argillite) of the **Rakaia terrane** (*Tt*) occur in the Southern Alps within the Kaikoura map area. Formal lithostratigraphic groups within the terrane have been proposed, for example, Mt Robert and Peanter groups (Johnston 1990) but their geographical extents are not known outside their mapped areas. In keeping with adjacent QMAP sheets no lithostratigraphic groups have been adopted for the Rakaia terrane of the Kaikoura map. Rakaia terrane sandstones are typically poorly to moderately sorted, fine- to medium-grained, and contain abundant lithic clasts of felsic igneous and sedimentary rock. Sedimentary lithotypes (facies) are dominated by thick to very thick, poorly bedded sandstone and thin- to medium-bedded, graded sandstone and mudstone (Fig. 21; Andrews & others 1976). The graded-bedded lithotype is generally dominated by sandstone, commonly well graded with cross bedding, sole markings and ripples. Thick mudstone beds, with or without thin- to medium-bedded sandstone, are less common in the map area. Calcareous lenses up to 0.6 m in length and rare phosphatic nodules occur rarely in the graded-bedded lithotype. Locally within the sandstone are angular, unsorted rip-up fragments of grey mudstone, and comminuted leaf and wood fragments that form carbonaceous laminations. Conglomerate (*Ttc*) occurs sparingly and is more obvious in river boulders than in outcrop. Thicker lenses of conglomerate are present on the Travers, Ella and Mahanga ranges and Emily Peaks (Rose 1986; Johnston 1990). The clasts range from sub-angular to well-rounded and are dominated by pebble- to cobble-sized indurated quartzo-feldspathic sandstone and mudstone, with lesser amounts of felsic igneous and quartz-rich metamorphic rocks.

Distinctively coloured mudstone (*Ttv*) is a minor rock type in the map area. The mudstones are typically dark red to brown or pale green to grey, the difference reflecting the oxidation state of contained iron (Roser & Grapes 1990). The red and green mudstone occurs in bands up to several hundred metres thick (Fig. 22), commonly associated with dark grey mudstone, sandstone, minor basalt, chert and rare limestone. These bands are one of the few distinct marker horizons within the Rakaia terrane that can be used to map regional structural trends. One prominent band, locally offset by strike-slip faults, extends for over 90 km through the map area, and continues for at least another 50 km southwest towards Arthurs Pass (Nathan & others 2002). The basalt, of tholeiitic composition, occurs as red, green or grey bands or lenses, commonly with pillow form. It is generally accompanied by purplish red to red, white or grey chert that may form layers up to several metres thick. The basalt and/or chert are rarely more than a few tens of metres thick or several hundred metres in length.

![Figure 21 Thin- to medium-bedded sandstone and mudstone interlayered with very thick-bedded sandstone of the Rakaia terrane on the St Arnaud Range near Rainbow Skifield. Bedding-parallel shearing has caused the changes in bed thickness.](image)
Fossils are rare in the Rakaia terrane. Although trace fossils are the most common, they are of limited use for dating purposes. Microfossils, including radiolaria and conodonts, occur in relatively rare rock types such as chert and limestone. In the St Arnaud Range, east of Lake Rotoiti, scattered macrofossils occur in poorly sorted siltstone within graded-bedded lithotype rocks (Campbell 1983). Monotis (Inflatomonotis) cf hemispherica Trechmann, Monotis sp. indet. and Hokonui limaeformis Trechmann, of Warepan (Late Triassic) age, have been formally described (Campbell 1983).

The Rakaia terrane contains zones of deformed rocks (Ttm) that have preferentially developed in the graded-bedded lithotype, and which range in width from less than a metre to over a kilometre. The zones are characterised by layer-parallel extension resulting in pinching and swelling of individual beds to form sandstone boudins in a pervasively sheared mudstone. Quartz veining is widespread, particularly where a weak shear fabric has developed (Fig. 23). The zones are commonly referred to as broken formation, or as mélange where “exotic” rock types are present. Although generally poorly exposed, some zones can be traced for many kilometres. Contacts with the surrounding Rakaia rocks typically show a gradational change in the shearing intensity, except where separated by younger faults.

Rakaia terrane rocks are difficult to interpret because of structural complexity, multiple folding events, few marker horizons, poor age control and widespread shearing and faulting. Fold hinges are rarely preserved but widespread macroscopic folding can be inferred from sedimentary younging reversals. Slaty cleavage and fracture cleavage are weakly developed in finer grained lithologies and range from parallel or sub-parallel, to locally oblique to bedding. Burial and deformation have metamorphosed the non-schistose Rakaia rocks to zeolite facies in the east, increasing to prehnite-pumpellyite facies in the northwest. A 206 Ma Rb-Sr isochron from Rakaia terrane rocks at Lewis Pass is interpreted to date Late Triassic burial and regional metamorphism (Adams & Maas 2004) whereas K-Ar data ranging mostly between 133 and 170 Ma reflect progressive uplift and cooling in the Jurassic (Adams 2003).

Two depositional environments for the Rakaia terrane clastic rocks have been inferred. These are large, deep submarine fans fed by channelised turbidity currents (Howell 1980; Johnston 1990) and relatively shallow-water fan-deltas (Andrews 1974). It is possible that both environments may have been operating at different times and/or locations (Andrews & others 1976).
Permian to Late Triassic semischist and schist

The Rakaia terrane rocks are increasingly metamorphosed to semischist and schist of the Alpine Schist (Fig. 24a, b) northwest towards the Alpine Fault. The metamorphosed rocks are subdivided into textural zones (IIA, IIB, III; see text box) after Bishop (1974) and Turnbull & others (2001). The schists grade westwards from quartz-albite-muscovite-chlorite through biotite-albite-oligoclase to garnet zone mineral assemblages within greenschist facies. Bands of greenschist (Ttg; Fig. 24c), rarely thicker than 10 m and generally of limited strike length, occur in places. The greenschist bands are metamorphosed igneous rocks, possibly originally tuffs, dikes, sills or flows. The depositional age of the semischist and schist protolith is assumed to be Late Triassic based on the fossils from less metamorphosed (t.z. 1) rocks in the St Arnaud Range and 30 km west of the Kaikoura map area (Wellman & others 1952).

The Aspiring lithologic association (Ya) is the protolith of a strip of t.z. III schist adjacent to the Alpine Fault that is about 2 km wide in the southwest and is obliquely truncated by the Alpine Fault between the Glenroy and Matakitaki rivers. Although largely derived from quartzofeldspathic sedimentary rocks, it contains more mudstone than other Rakaia terrane rocks, and has numerous bands of greenschist derived from mafic igneous rocks and rare chert. The southeastern contact with the sandstone-dominated Rakaia terrane schist is probably a ductile sheared zone (Nathan & others 2002). The depositional age of the Aspiring lithologic association is poorly constrained in the northern South Island, and the Permian age inferred for the association in northwest Otago (Turnbull 2000) has been adopted for the Kaikoura map area.

Metamorphism of Rakaia terrane rocks to schist occurred about 210 Ma (Late Triassic), followed by uplift and cooling between 200 and 110 Ma (Jurassic to Early Cretaceous; Little & others 1999; Adams 2003). Fission track apatite and zircon data suggest more than 10 km uplift of the schist around Lewis Pass since 5 Ma (Tippett & Kamp 1993; Kamp & others 1989).

Within 1–2 km of the Alpine Fault southwest of Lake Rotoroa, non-schistose Rakaia terrane becomes increasingly tectonised with the development of a pronounced shear foliation and cleavage. The tectonism and foliation result from Late Cenozoic movement of the Alpine Fault (Challis & others 1994).

Figure 24 The Rakaia terrane is increasingly metamorphosed west towards the Alpine Fault. (a) t.z. IIB semischist showing strong intersection lineation between transposed bedding (light and dark bands) and penetrative cleavage (parallel to slope) near Mt Mueller. Photo: P.J. Forsyth.

(b) Folded t.z. III schist showing relict mudstone (dark bands in centre) with injected quartz veins (pale), Nardoo Stream headwaters. Photo: I.M. Turnbull.

(c) Greenschist comprising t.z. III metamorphosed volcanic tuffs, shown here in Branch Creek, is common in the Aspiring lithologic association. Photo: I.M. Turnbull.
**Pahau terrane**

Late Jurassic to Early Cretaceous sedimentary and volcanic rocks

The **Pahau terrane** forms the bulk of the basement rocks in the Kaikoura map area. Formal lithostratigraphic groups within the terrane have been proposed, for example, Waihopai Group (Johnston 1990) and Pahau River Group (Bassett & Orlowski 2004) but the geographical extent of these groups is not yet clear and they have not been adopted in this map. As with the Rakaia terrane, Pahau terrane is dominated by indurated, grey, quartzofeldspathic, thin- to medium-bedded and commonly graded sandstone and mudstone, and poorly bedded, very thick-bedded sandstone lithotypes (Ktp; Andrews & others 1976). These rocks are collectively (and loosely) termed greywacke. Other rock types include conglomerate, green sandstone, purplish red and green mudstone, sparse limestone and, particularly in the northeast, basalt and dolerite. The Pahau sandstones are generally slightly lighter in colour and have a more “sugary” appearance than similar low-grade Rakaia terrane sandstone. Pahau terrane rocks also differ in that they locally contain more carbonaceous matter, conglomerate bands and volcanic rocks.

Within the Pahau terrane the graded bedded lithotype (Fig. 25) is commonly planar and relatively undisrupted over large areas. The poorly bedded to massive, very thick-bedded sandstone lithotype is up to several kilometres thick with the larger beds traceable over tens of kilometres. Conglomerate lenses (Ktc) are present throughout the terrane but are volumetrically significant only locally e.g. in the upper Pahau and Hossack rivers. The conglomerates are generally poorly sorted with sub-rounded to rounded granule to pebble size clasts enclosed in a sandstone matrix. The clasts are dominated by quartzofeldspathic sandstone, mudstone, volcanics, granitoids, quartz and chert and the volcanic clasts include rhyolite, dacite, andesite and basalt (Smale 1978; Johnston 1990; Reay 1993; Bassett & Orlowski 2004; Wandres & others 2004).

Calcareous concretions, up to 0.3 m across, are distributed sparsely throughout the Pahau terrane. The graded sandstone and mudstone lithotype, particularly where mudstone is dominant, contains concretionary lenses, generally less than 10 cm thick, composed of dark grey, very fine-grained limestone. These, and rare phosphatic nodules, contain variably preserved dinoflagellates.

Igneous rocks (Ktv), consisting of basalt and dolerite, are present as flows and sills up to 2 km thick from the head of the Avon valley to the lower Awatere valley, and as less continuous, thinner bands farther south (Fig. 26a). The flow rocks are commonly pillowed and include tuffaceous horizons and thin igneous breccia. They are usually accompanied by green and red tuffaceous mudstone (Fig. 26b), red and white chert (Ktt) and, locally, limestone.

**Figure 25** The Pahau terrane contains large areas of coherent sub-parallel strata comprising two dominant sedimentary facies: thick-bedded sandstone (centre) and thin-bedded graded sandstone and mudstone. Middle Clarence River gorge downstream of Dillon River.

*Photo: C. Mazengarb.*
Zones of intra-Pahau mélange, characterised by relatively abundant boudins of mafic volcanic rock, chert and red and green mudstone (Fig. 26c), occur widely and are in places large enough to map separately (Ktm). A zone of relatively sheared rocks, up to 7 km wide in the Waihopai valley, extends south to the Awatere Fault. Another prominent zone, up to 10 km wide, in the Cheviot-Waiau area separates planar-bedded northeast-striking Pahau rocks in the Lowry Peaks Range from northwest-striking Pahau rocks in the Hawkswood Range. This zone extends into the Kaiwara valley where it has been termed the Random Spur Mélange (Bandel & others 2000). These zones have Late Triassic and Early Jurassic faunas and Early Cretaceous microflora.

Fossils in the Pahau terrane are sparse and poorly preserved (Andrews & others 1976). Plant remains, although widespread, are largely comminuted and indeterminate. In the Leatham valley (N29/f44) plant fragments are better preserved and include Taeniopteris cf daintreei, ?Fraxinopsis sp., a gymnosperm seed, and fern-like pinnules. Basaltic conglomerate in the Leatham valley (N29/f94) is fossiliferous but few species are recognisable (Johnston 1990). Dinoflagellates preserved within some of the thin calcareous mudstone beds indicate that the Pahau rocks are predominantly Early Cretaceous, but may be locally as old as Late Jurassic (G.J. Wilson pers. comm. 2004). Bivalves including Buchia, Anopaea and "Inoceramus" as well as belemnites of the genus Hibolithes occur in the Clarence River (Reay 1993) and indicate an Early Cretaceous age.

Outside the mélange zones there is little variation and no systematic change in sedimentation age across the entire >70 km width of Pahau terrane in the map area. Together with the widespread steep dips, inconsistent younging directions, rarely preserved large fold hinges and relatively uniform metamorphic grade, this suggests that the Pahau terrane consists of imbricated slices and/or recumbent folds of largely Early Cretaceous rock, locally incorporated with mélange containing rocks as old as Late Triassic.

The environment of deposition of the clastic rocks of Pahau terrane, like the Rakaia terrane, has been interpreted as deep water submarine fans (Johnston 1990; Reay 1993) and marginal marine fan-deltas (Bassett & Orlowski 2004). It is also possible that both environments may have been present at different locations and at different stratigraphic levels and times (Andrews & others 1976).

The metamorphic grade of Pahau terrane in the map area varies between zeolite facies (Reay 1993) and prehnite-pumpellyite facies (Bradshaw 1972; Crampton 1988; Johnston 1990). Local hornfelsing of the Pahau terrane rocks (Kth) occurs adjacent to mafic intrusions at Tapuae-o-Uenuku and Blue Mountain.

Figure 26 (a) Basalt, here showing relict pillow structure, occurs sporadically within Pahau terrane, Seaward Kaikoura Range. Photo: M. J. Isaac.

(b) Red mudstone beds with scattered red chert horizons, within a northwest-dipping and -younging succession of finely bedded, sheared grey sandstone-mudstone of the Pahau terrane, southeast face of Barometer, Awatere valley.

(c) Broken formation and mélange occur widely in the Pahau terrane of the Seaward Kaikoura Range.
**Esk Head belt**

**Late Triassic to Early Cretaceous sedimentary and volcanic rocks**

The generally well-bedded Pahau terrane is separated from the Rakaia terrane by a zone of more sheared rocks, the **Esk Head belt** (Te, after Begg & Johnston 2000). The zone has also been named the Central Belt (Johnston 1990) and the Esk Head subterrane (Silberling & others 1988), incorporating the Esk Head Mélange of Bradshaw (1973). Although significant zones of mélange (Tem) with blocks of "exotic" material such as limestone, basalt and chert are present, the belt is composed largely of mixed, weakly to strongly deformed Rakaia and Pahau rocks. The belt is up to 20 km wide in the northern and southern parts of the Kaikoura map area but is narrower in the central part, due to subsequent faulting. The Esk Head belt is also offset by strike-slip movement on numerous faults of the Marlborough Fault System.

Deformation within the Esk Head belt is highly variable due to the degree of tectonism and differences in the competency of the rocks. Well-bedded graded sandstone and mudstone which have had significant layer-parallel shearing are termed broken formation, or where exotic rock types are present, mélange. The sandstone beds and other competent rock types have undergone relatively brittle deformation and form boudins or discontinuous lozenges (Fig. 27). Preferential erosion of the sheared enveloping mudstone matrix has resulted in hill crests with numerous pinnacles. Large areas dominated by poorly bedded sandstone occur between the Hurunui River and the upper Wairau valley and lack the layer-parallel shearing usually associated with the belt elsewhere.

The main rock types within the Esk Head belt are quartzofeldspathic sedimentary rocks, incorporated from the Rakaia and Pahau terranes. Alternating sandstone and mudstone sequences and thick, poorly bedded to massive sandstone are dominant, but minor conglomerate and other lithologies are also present. Chert, with associated greenish-grey sandstone and red mudstone, igneous rocks (Tev) and limestone (Tel) are common within fault zones and generally more abundant within the Esk Head belt than in the less deformed Rakaia and Pahau terrane rocks.

Igneous rocks include gabbro, green dolerite and reddish-purple basalt, some with pillow structures. Along the eastern margin of the Esk Head belt, in the Leatham valley, thin and discontinuous lenses of grey to white, crystalline limestone are present. The limestone is locally fossiliferous and may be part of a dismembered seamount (Johnston 1990). In the north, phyllonitic rocks of the Silverstream Fault Zone separate Rakaia- and Pahau-derived parts of the Esk Head belt (Johnston 1990).

Fossils are sparse in the Esk Head belt but the limestone in the Leatham valley contains a restricted macrofauna indicating a Jurassic or Early Cretaceous age. Limestone in the Okuku River contains fossils including *Monotis*, possible “*Inoceramus*” and a Late Jurassic belemnite (Bradshaw 1973). Other limestones in the map area contain *Monotis*, radiolaria and conodonts of Late Triassic age (Silberling & others 1988). Chert contains radiolaria of Late Triassic to Jurassic age and may represent part of the seafloor basement to the younger quartzofeldspathic rocks of the Pahau terrane (Johnston 1990).

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**Figure 27** Broken formation resulting from deformation of the thin-bedded graded sandstone and mudstone lithotype is common in the Esk Head belt. The lenticular and discontinuous sandstone boudins are enveloped in sheared mudstone, shown here in the lower Leatham River.
Figure 28 Late Early Cretaceous and Cenozoic stratigraphy of the eastern part of the Kaikoura map area highlighting areas of deposition and non-deposition (grey background). In some areas, intervening erosion has probably removed stratigraphic units. A large number of stratigraphic units have been described and formalised within the area but many (shown with asterisks) have not been used in this publication. After Field, Browne & others (1989), Field, Uruski & others (1997).
CRETAceous TO Pliocene

Following amalgamation of the basement terranes and after the mid-Cretaceous cessation of convergent margin tectonics along the Gondwanaland margin, much of the New Zealand area was uplifted and then eroded to a low-lying landscape. This landscape was subject to extension as the Tasman Sea opened and the New Zealand continent separated from Gondwanaland in the late Early Cretaceous. In the west, there was extensive pluton intrusion followed by rifting and the development of sedimentary basins (Bishop & Buchanan 1995; King & Thrasher 1996). Opening of the Tasman Sea ceased in the Paleocene and the New Zealand area entered a period of prolonged tectonic stability coupled with subsidence and, in the east, widespread marine sedimentation. In the Kaikoura map area these conditions persisted until the Miocene, when a compressional tectonic regime was initiated as the boundary between the Australian and Pacific plates propagated through New Zealand. Rapid uplift and consequent erosion provided a vast amount of sediment that filled developing basins adjacent to major strike-slip faults.

With the exception of a small area of Late Cretaceous conglomerate in the Moutere Depression, all of the Late Cretaceous to Middle Eocene rocks in the Kaikoura map area occur southeast of the Alpine Fault. These rocks crop out in two geographically distinct areas, eastern Marlborough and northern Canterbury. Despite many geological similarities, the two areas have acquired two separate systems of stratigraphic nomenclature (Fig. 28) although some rationalisation has been attempted (Field, Browne & others 1989; Field, Uruski & others 1997). Within both areas there are many formalised formations and members that have been defined on key stratigraphic sections but are difficult to map out areally. The following descriptions refer to many of these stratigraphic units but only the bold named units are distinguished on the map. Where formations are thin, in areas that are geologically complex, and offshore, the rocks are mapped as undifferentiated Late Cretaceous (IK), Paleocene-Eocene (PE), Oligocene (O) or Miocene (M).

Cretaceous sedimentary and volcanic rocks

Cretaceous rocks are locally well preserved in Marlborough. In the middle Awatere valley and the northern Clarence valley, a late Early Cretaceous succession is preserved that has elsewhere presumably been eroded or was never deposited.

The earliest confirmed post-Pahau deposition is that of the Champagne Formation (Kc; Ritchie and Bradshaw 1985; Crampton & others 1998) of the Coverham Group (Kc; Lensen 1978). The Champagne Formation is exposed in a narrow, 10 km long band in the middle Clarence valley, from Ouse Stream (Fig. 29) to Dee Stream and in Wharekiri Stream (too small to be shown on the map). It consists of highly deformed sandstone, mudstone and minor conglomerate, typically with boudinage of sandstone beds, faults, asymmetric folds, remobilisation of mud from fold hinges and soft-sediment deformation (Crampton & others 1998). The Champagne Formation unconformably overlies Pahau terrane and its base is late Early Cretaceous (Crampton & others 2004).

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<th>Basement versus cover</th>
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<td>Despite a wealth of previous work, the stratigraphic location of the top of the Torlesse composite terrane in New Zealand is difficult to pinpoint. For example, in the East Cape region, the contact between Early Cretaceous (Korangan) Torlesse Waioeka terrane and overlying Early Cretaceous “cover” rocks is a fault, a high angle unconformity or series of unconformities, an olistostrome breccia, or a channelled contact (Laird &amp; Bradshaw 1996; Mazengarb &amp; Speden 2000). In the Wairarapa region, Early Cretaceous (Motuan) Pahaua Group is placed within the Torlesse composite terrane and the oldest overlying “cover” rocks are also of Motuan age (Lee &amp; Begg 2002). Radiometric dating of zircons from both below and above the unconformity yields ages of c. 100 Ma (Laird &amp; Bradshaw 2004) suggesting derivation from the same or similar-aged source rocks or recycling of the zircons.</td>
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| In Marlborough the contact cannot always be defined on the basis of metamorphic grade, degree of induration or by changes in clastic composition (Montague 1981; Powell 1985). Fossils are rarely preserved in the Pahau terrane and these rocks are comparatively poorly dated. Lensen (1962) included latest Early Cretaceous (Motuan) rocks within the Torlesse composite terrane and Field, Uruski & others (1997) state that a regional unconformity exists between older and younger, more fossiliferous rocks, but that rocks both above and below the unconformity are Motuan in age. This implies that the “regional unconformity” was intra-Motuan and of very short duration in Marlborough, even though bedding discordance across the unconformity can be marked. Crampton & others (2004) show no significant stratigraphic break during the Motuan at Coverham, in the Clarence valley, but they note the presence of older late Early Cretaceous unconformities (intra-Urutawan). |

| A mid-Cretaceous unconformity is widespread throughout New Zealand. The diachronous nature of the unconformity surface (Laird & Bradshaw 2004) in Marlborough probably reflects ongoing deposition in localised, syntectonic basins adjacent to areas of uplift and erosion. However, there are many locations where a clearer stratigraphic break is apparent, i.e. where the Pahau terrane is overlain by significantly younger Cretaceous or Cenozoic rocks. |
The **Split Rock Formation (Kcs)** is preserved in a fault-angle depression on the footwall of the Clarence Fault (Suggate 1958). Except in the northeast where it lies unconformably on Champagne Formation, Split Rock Formation rests on Pahau terrane with sharp angular discordance. The formation includes basal, mass flow conglomerate overlain by mudstone and locally ridge-forming sandstone, and interbedded sandstone and mudstone (Reay 1987, 1993; Crampton & others 1998; Fig. 30). In the northeast Clarence valley, the upper part of the formation consists of poorly bedded to massive, laminated mudstone containing abundant concretions and minor sandstone beds (Crampton & others 1998, 2004). The Split Rock Formation is no older than middle Early Cretaceous (Korangan; Reay 1993) and is as young as earliest Late Cretaceous (Ngaterian; Crampton & others 2004).

In the Awatere valley, Coverham Group rocks are preserved in a fault angle depression to the south of the Awatere Fault. The late Early Cretaceous **Gladstone Formation (Kcg)** (Challis 1966) is exposed east of Mt Lookout between the Awatere and Winterton rivers. The formation comprises poorly fossiliferous, indurated conglomerate, sandstone, siltstone and mudstone and it becomes finer grained up-section. Localised slump-folding is common (Montague 1981) and the formation unconformably overlies Pahau terrane, commonly with minor shearing along the contact.

The overlying **Winterton Formation (Kcw)** (Challis 1966), of latest Early Cretaceous (Motuan) age, is preserved to the south, east and northeast of Mt Lookout with correlative rocks exposed to the northeast in the middle Awatere valley and Penk River (Montague 1981). It consists of laterally discontinuous lenses of moderately indurated, mildly deformed conglomerate and siltstone. The formation onlaps and unconformably overlies Pahau terrane and Gladstone Formation.

The Coverham Group is interpreted to represent parts of a fan-delta complex that filled local, fault-controlled basins. Collectively, the Gladstone and Winterton formations contain three fining upward successions that are typical of fan-delta complexes associated with faults (Laird 1992). The Mt Lookout and Penk River successions formed in separate, unconnected half-grabens (Lewis & Laird 1986). The Coverham Group fills channels and canyons cut into the underlying Pahau terrane and is locally up to 800 m thick (Laird 1981, Montague 1981; Powell 1985; Reay 1993).
The **Wallow Group** (Kw; Reay 1993) includes fluvial, terrestrial and shallow marine deposits that locally interfinger with subaerial basalt flows. The group crops out in the northern half of the Kaikoura map area from the Awatere valley in the west to Monkey Face in the east (Crampton 1988; Reay 1993; Warren 1995) and is well preserved in the middle Clarence valley. The earliest Late Cretaceous **Warder Formation** (Kww; Fig. 31) consists of moderately indurated, non-marine sandstone, siltstone, minor conglomerate lenses, thin coal seams and lake silt deposits (Browne & Reay 1993). The formation unconformably overlies Pahau terrane or Split Rock Formation (Reay 1993; Crampton & others 2004) and was deposited in a fluvial, coastal plain environment.

The earliest Late Cretaceous **Gridiron Formation** (Kwg; Suggate 1958; Reay 1993) encompasses the volcanic part of the Wallow Group in the middle Clarence valley. It includes subaerial basalt flows, pillow basalt and volcanogenic conglomerate, breccias, dikes and sills (Fig. 31). The lavas include alkaline basalt to trachybasalt, with minor olivine basalt (Reay 1993). The lower flows of the Gridiron Formation are locally interbedded with the Warder Formation, and elsewhere the flows lie on the laterally correlative Bluff Sandstone (see below). The lowest lava flows have been K-Ar dated at 93–99 Ma (Reay 1993) and Ar/Ar dated at 96 Ma (Crampton & others 2004).

The **Bluff Sandstone** (Kwb; Reay 1993) is dominated by massive and thick-bedded sandstone but also includes conglomerate and alternating sandstone and mudstone and is locally carbonaceous. The conglomerate clasts are cobble to boulder-size and include Pahau sandstone, chert, vein quartz, jasper, rhylolite, granite and basalt (Reay 1993). The Bluff Sandstone conformably overlies Warder Formation or is locally interstratified with the upper part of the Gridiron Formation; elsewhere it overlies Pahau terrane or Split Rock Formation with angular unconformity. Sparse macrofossils indicate an early Late Cretaceous age (Reay 1993). Crampton (1988) suggested that the base of the Bluff Sandstone may be diachronous, being Ngaterian in the west and as old as late Motuan in the east near Monkey Face. The depositional environment of Bluff Sandstone is interpreted as a marginal to shallow marine fan-delta (Reay 1993) in an asymmetrically subsiding basin (Crampton 1988).

The **Lookout Formation** (Kwl; Challis 1960, 1966; Montague 1981) comprises basal pebble conglomerate and coal measures overlain by extensive volcanic flows (Fig. 32). It crops out extensively around Mt. Lookout and extends discontinuously as fault-bounded slivers for...
The Hapuku Group (Kh; Laird & others 1994) crops out between the Hapuku and Kekerengu rivers and in the northeast Clarence valley. Near Ouse Stream, the Hapuku Group is structurally subdivided by the synsedimentary Ouse Fault. West of the fault the group consists of the Nidd and Willows formations and other unnamed sedimentary rocks. The Willows Formation comprises purplish-brown, epiclastic conglomerate of basaltic composition (Reay 1993). The Nidd Formation (Lensen 1978) is preserved as fault-bounded slivers southeast of the Clarence Fault and comprises richly fossiliferous, weakly bedded, purple-brown siltstone to very fine-grained sandstone, commonly glauconitic and burrowed. West of the Ouse Fault the Hapuku Group rests with erosional contact on the Wallow Group.

East of the Ouse Fault, Hapuku Group consists of the Burnt Creek Formation (Lensen 1978). The formation has basal poorly sorted, clast-supported conglomerates containing clasts of sandstone, mudstone, quartzite, chert, and felsic volcanic and plutonic rocks. These conglomerates grade upwards into pebbly mudstone, sandstone and siltstone (Fig. 33). The Burnt Creek Formation lies with sharp angular unconformity on Pahau terrane and it is inferred to have been fed by numerous basanitic dikes emanating from the Mt Tapuae-o-Uenuku intrusion during the earliest Late Cretaceous.

The Seymour Group occurs in the northern part of the Kaikoura map area between Cape Campbell and Whales Back, north of Waiau. The middle Late Cretaceous (Prippauan) Paton Formation (Kyp; Webb 1971) consists of glauconitic, fine- to medium-grained sandstone and graded sandstone and siltstone. The formation is commonly bioturbated and locally contains abundant inoceramid fossils, as fragments or as whole valves. The Paton Formation unconformably overlies Bluff Sandstone (Reay 1993), is locally scoured into the Hapuku Group (Crampton and Laird 1997), or conformably and gradationally overlies the Burnt Creek Formation (Field, Ursuki & others 1997). The formation is inferred to have formed in an inner to mid-shelf environment, based on sedimentary structures and dinoflagellates (Laird 1992; Schiøler & others 2002).

Undifferentiated rocks of the Seymour Group (Ky) include latest Cretaceous (Haumurian) Herring and Woolshed formations, and to the east of the London Hill Fault, the Butt and Mirza formations (Suggate & others 1978; see below). Collectively, these rocks are time-equivalents of the Whangai Formation of the North Island’s East Coast (Lee & Begg 2002). In the Clarence valley-Kekerengu area, Herring Formation overlies Paton Formation with a sharp contact. It is predominantly a light grey, sulphurous muddy siltstone interbedded with pale, well-sorted fine sandstone. The formation has a characteristic rusty brown appearance when weathered, due to iron staining leaching from joint planes. Jarosite staining and pyrite nodules are common. The formation commonly contains spectacular ovoid concretions, up to 3 m diameter (Reay 1993), and locally abundant sandstone dikes. Microfossils indicate a mid-to outer shelf environment of deposition (Schiøler & others 2002; Crampton & others 2003). The Woolshed Formation (Fig. 34a) is a local facies variant exposed north of Kekerengu and consists of muddy siltstone containing abundant concretions (Suggate & others 1978).

In the Ward coastal area, east of the London Hill Fault, the upper Seymour Group includes conglomerates, slumped horizons and channelled sandstone bodies of the Mirza Formation (Suggate & others 1978), white micritic limestone (Flaxbourne Limestone) and turbidites deposited by sediment gravity flow processes (the Butt Formation (Fig. 34b); Laird & Schiøler 2005; Hollis & others 2005b). The stratigraphy east of the London Hill Fault more closely resembles that of Late Cretaceous rocks of the Wairarapa area, rather than Marlborough (Laird & Schiøler 2005).

From the Clarence valley to the coast, the uppermost Seymour Group includes latest Cretaceous Branch Sandstone, which overlies the Herring Formation with sharp but conformable contact. The formation consists of massive, well-sorted, muddy fine sandstone, typically about 10 m thick, but locally up to 40 m, and is interpreted as an offshore sand bar (Reay 1993).

South of Kaikoura, Late Cretaceous rocks equivalent in age to the Seymour Group are mapped as the lower part of the Eyre Group (IKE; Warren & Speden 1978; Browne & Field 1985; Andrews & others 1987; Warren 1995; Fig. 28). Undifferentiated Eyre Group (K Ke) may also include Cretaceous sedimentary rock, where it is too thin to

Figure 33 The Burnt Creek Formation siltstone and sandstone in Ouse Stream are typical of the upper Hapuku Group.

Photo: J.S. Crampton.
distinguish from the upper part of the group. In the Haumuri Bluffs-Parnassus area, the lower part of the Eyre Group includes quartzose sandstone, thin conglomerate beds, calcareous and carbonaceous beds and granule conglomerate (Okarahia Sandstone and Tarapuhi Grit). These coarse clastic rocks grade up into 240 m of massive, jarositic, grey siltstone to very fine-grained sandstone of the Late Cretaceous Conway Formation (Warren 1995; Fig. 35), in which sub-spherical concretions up to 5 m in diameter are common (Browne 1985). Overlying the Conway Formation, the Claverley Sandstone (Warren & Speden 1978) constitutes up to 40 m of poorly bedded, yellow-grey glauconitic sandstone. Dinoflagellates indicate a mid-Haumurian age near the base and a late Haumurian-early Teurian age near the top (Warren 1995).

Inland, north of Waiau, Late Cretaceous Eyre Group includes conglomerate, comprising well-rounded clasts of Pahau-derived sandstone, quartzite, rhyolite, granite and schist (Stanton Conglomerate; Browne & Field 1985). Sparse plant fossils and pieces of coalified or silicified wood are interspersed with sandstone beds and pebbly sandstone layers. The conglomerate is locally overlain by fine sandy siltstone and interbedded sandstone of the Lagoon Stream Formation or by the Conway Formation. In the southern part of the Kaikoura map area, the lower part of the Eyre Group consists of thin conglomerate beds which grade upwards into fine-grained quartzose sandstone and mudstone, with thin, rare coal seams of the Broken River Formation (Gage 1970; Browne & Field 1985). Grey, slightly calcareous silty fine sandstone of the Conway Formation overlies, and in turn grades upwards into, the jarositic, sandy Loburn Mudstone.

The Eyre Group unconformably overlies Pahau terrane (Fig. 28). At its northernmost extent, at Haumuri Bluffs, it is entirely Late Cretaceous, but towards the south of the Kaikoura map area it includes progressively younger rocks (as young as Eocene; see below). Rocks in the lower part of the Eyre Group were deposited in alluvial, estuarine and shallow marine environments with progressive deepening to a restricted basin (Browne & Field 1985; Field, Browne & others 1989).

In the southeast of the Moutere Depression, the Late Cretaceous Beehys Conglomerate (Kbc; Johnston 1990) rests unconformably on Brook Street terrane rocks. The formation has a preserved thickness of 2400 m and in addition to conglomerate it contains sandstone, siltstone and mudstone beds, and rare seams of medium- to high-

Figure 34 The Seymour Group includes (a) Jarositic siltstone of the Woolshed Formation, shown here in Ben More Stream with deformation typical of that area. (b) Well-bedded Butt Formation sandstone at the mouth of Flaxbourne River.

In the southern part of the Kaikoura map area, the lower part of the Eyre Group consists of thin conglomerate beds which grade upwards into fine-grained quartzose sandstone and mudstone, with thin, rare coal seams of the Broken River Formation (Gage 1970; Browne & Field 1985). Grey, slightly calcareous silty fine sandstone of the Conway Formation overlies, and in turn grades upwards into, the jarositic, sandy Loburn Mudstone.

Figure 35 The Conway Formation near Haumuri Bluffs comprises sandstone and siltstone with horizons of calcareous concretions.

Photo: G. H. Browne.
volatile bituminous coal. The conglomerate clasts, up to 0.4 m across, include felsic igneous intrusives, intermediate to mafic volcanic and igneous rocks, and indurated sedimentary rocks. Plant fossils are locally present and microfloras indicate an early Late Cretaceous (Raukumara Series) age. The formation has been weakly metamorphosed to zeolite facies. It is interpreted as part of an extensive braided and locally meandering river deposit that accumulated in a fault-angle depression or half-graben under a warm oxidising climate (Johnston 1990).

Cretaceous igneous rocks

A northeast-southwest aligned belt of isolated igneous bodies extends for over 150 km through Marlborough and northern Canterbury (the Central Marlborough igneous province of Nicol 1977). Undifferentiated Cretaceous igneous rocks (Ki) include an alkaline ultramafic gabbro ring complex and associated hornfels zone preserved at the summit of Blue Mountain (Grapes 1975), and basalt flows and breccia preserved at Hungry Hill north of the Waima River. Neither of these occurrences has been dated directly, but Hungry Hill basalt rests unconformably upon Cretaceous Pahau terrane and is overlain by Late Cretaceous (Piripauan) Paton Formation (Waters 1988).

The Tapuaenuku Igneous Complex (Kit; Nicol 1977) crops out as a sub-circular intrusion, 7 km in diameter. Approximately 600 m of vertical section is exposed on Mt. Tapuae-o-Uenuku. The complex is composed of layered pyroxenite, peridotite, anorthosite, gabbro and minor carbonatite (Fig. 36a). The upper part is intruded by syenite sills and dikes (Baker & others 1994). Magnetite and ilmenite, largely within the anorthosite, are responsible for a major magnetic anomaly centred on the Inland Kaikoura Range (Reilly 1970). The intrusion is surrounded by a contact-metamorphosed hornfels zone (Kth) up to 400 m wide in the surrounding Pahau terrane rocks (Baker & others 1994). A radial suite of basanitic dikes (Fig 36b,c) extends outwards from the main body for a distance of more than 10 km, and the top of the intrusion was probably emplaced at a depth of 3–4 km. A 96 Ma intrusion age for the Tapuaenuku Igneous Complex, based on U-Pb dating (Baker & Seward 1996), is supported by K-Ar ages of cogenetic dike intrusion between 100 and 60 Ma (Grapes & others 1992). The complex is genetically related to the 96 Ma Gridiron Formation (Crampton & others 2004) and the Lookout Formation (Challis 1966; Nicol 1977; Reay 1993), but has a greater age range.

The Mandamus Igneous Complex (Kim) is exposed in the hills at the northwestern edge of the Culverden Basin. The complex is generally erosion-resistant compared with its Pahau host-rock and is the southernmost of the alkaline gabbro intrusives in the map area. It is composed principally
of feldspar-clinopyroxene-biotite-amphibole syenite and clinopyroxene-labradorite-olivine-biotite gabbro. Volcanic flow rocks are predominantly trachytic with minor basalt, including possible vent-lavas/breccias around Hurunui Peak. The Mandamus Igneous Complex has been Rb-Sr dated at 97 Ma (Weaver & Pankhurst 1991).

**Paleocene to Eocene sedimentary rocks**

In the south of the Kaikoura map area, deposition of the Eyre Group including Conway Formation and Loburn Mudstone (see above) continued through into the Paleocene. The upper part of the Eyre Group is commonly too thin to differentiate from lower parts and is mapped as undifferentiated (KEe; Fig. 28). Paleogene **Eyre Group (PEe)** includes the Paleocene to Early Eocene Waipara Greensand, consisting of fine- to medium-grained, glauconitic sandstone that becomes increasingly muddy up section (Browne & Field 1985). The overlying Early to Middle Eocene Ashley Mudstone consists of glauconitic, calcareous sandy mudstone, siltstone and sandstone. In general the Ashley Formation rests disconformably on Waipara Greensand (commonly with a burrowed, phosphatised contact) but, locally, around the lower Hurunui River-Culverden area, it is unconformable on Pahau terrane (Fig. 28). In the far south of the Kaikoura map area, the Middle to Late Eocene Homebush Sandstone overlies the Ashley Mudstone. It is a massive, glauconitic, unfossiliferous, well-sorted, quartzose sandstone, that may have become remobilised or intruded into underlying and overlying units since deposition (Browne & Field 1985). The environment of deposition of upper Eyre Group rocks includes shallow marine, low energy outer shelf (bathyal), and relatively high-energy near-shore beach settings.

The **Muzzle Group** (Reay 1993) consists of mainly strongly indurated micritic limestone and calcareous mudstone, chert, and minor greensand and volcanic rocks. The group contains two formations, the Mead Hill Formation and the Amuri Limestone, and in areas where both formations are thin the Muzzle Group is undifferentiated (KPz) on the map. The **Mead Hill Formation (Kzm; Webb 1971)** is typically a greenish-grey, chert-rich, micritic limestone, weathering to white and black (Fig. 37), with calcareous mudstone and nodular chert. The formation is limited to the northeastern part of the map area and varies greatly in thickness. In Branch Stream it is about 120 m thick but it pinches out in the middle Clarence valley and is absent in Seymour Stream (Reay 1993); it reaches its greatest thickness in Mead Stream, where it is over 250 m thick (Strong & others 1995). In the northern Clarence valley and in coastal eastern Marlborough, the formation contains the Cretaceous-Paleogene boundary, which is particularly well exposed in Mead Stream (Fig. 38) and is marked by major changes in microfossil assemblages (see text box). At Mead Stream the top of the formation is as young as Late Paleocene (Strong & others 1995; Hollis & others 2005a).

**Figure 37** The Mead Hill Formation, Muzzle Group, is a well-bedded siliceous limestone, shown here in Mead Stream.

**Figure 38** The Cretaceous-Paleogene boundary occurs within the Mead Hill Formation in Mead Stream. The hammer handle rests on the thin bed marking the boundary.
The Cretaceous - Paleogene Boundary

The Cretaceous-Paleogene boundary marks a global mass extinction event and associated paleoenvironmental changes brought about by a meteorite impact in Central America (Alvarez & others 1980). Complete or near-complete boundary sections are preserved at many locations throughout Marlborough and northern Canterbury (e.g. Strong & others 1987; Hollis 2003). A near-complete record is preserved within the bathyal siliceous limestone at Flaxbourne River (Strong & others 1987; Strong 2000; Hollis 2003) and on the southern edge of the Kaikoura map area, in the shallow marine Conway Formation. Elsewhere the boundary is a significant erosion surface and latest Cretaceous and/or earliest Paleocene rocks are not always preserved, e.g. south of Branch Stream in the Clarence valley (Reay 1993) and at Monkey Face southwest of Kaikoura (Crampton 1988).

Paleoenvironmental changes across the boundary include a major decrease in calcareous plankton, matched in some sections by an increase in biosiliceous productivity (Hollis 2003). Biosiliceous rocks are initially diatom-rich then radiolarian-rich, indicating a pronounced cooling at this time. In the Mead Stream section, the sedimentation rate drops from 16 to < 2.5 mm/ka, largely due to the extinction of calcareous plankton. The proportion of terrigenous sediment and total organic carbon increases across the boundary, possibly due to soot/charcoal from forest fires that would have accompanied meteorite impact (Hollis & others 2003). Pollen records from the Paleocene Waipara Greensand indicate an abrupt disappearance of mixed-forest vegetation and a rapid expansion of opportunistic fern species (Hollis 2003; Vajda & Raine 2003).

The Cretaceous-Paleogene boundary in the Kaikoura map area is commonly marked by geochemical changes, including elevated levels of iridium, inferred to be of extraterrestrial origin, and enrichment of nickel and chromium (Brooks & others 1986; Hollis 2003).

Figure 39 Geological map of the Kaikoura Peninsula with the considerable shore platform geology shown. The area has been uplifted and gently folded. NZMS 260 series 1 km grid is shown for reference. After Campbell (1975); Fyfe (1936); Ota & others (1996).
The **Amuri Limestone** (Pza, Eza) is widely preserved in the eastern part of the Kaikoura map area (Figs 39, 40). In the north it is included within the Muzzle Group (Reay 1993; Field, Uruski & others 1997), but south of Kaikoura it has not previously been assigned to any group (e.g. Browne & Field 1985; Field, Browne & others 1989). The southern occurrences of the Amuri Limestone are now included within the Eyre Group on the Kaikoura map following stratigraphic rationalisation (e.g. Forsyth 2001). The formation consists predominantly of white, hard, siliceous, micritic limestone or interbedded limestone and marl (Fig. 40), composed of coccolith and foraminifera tests and clay. Other lithologies, not differentiated on the map, include dark siliceous mudstone (equivalent of the Waipawa Formation in the North Island; Lee & Begg 2002), yellow-grey sandy limestone (Teredo limestone member), bedded greensand (Fells Greensand member) and graded sandstone and siltstone couplets (Woodside “formation”).

At Mead Stream the Amuri Limestone rests with apparent conformity on Mead Hill Formation (Hollis & others 2005a), but south of the middle Clarence valley, Mead Hill Formation pinches out and the Amuri Limestone rests unconformably on the Seymour Group (Reay 1993). In the Clarence valley, the limestone reaches 400 m thick; in the south of the map area it varies considerably in thickness, but rarely exceeds 50 m, and it rests conformably (locally unconformably) on older Eyre Group (Browne & Field 1985).

Both the base and top of the Amuri Limestone are highly time-transgressive (Fig. 28). In the Clarence valley the age range of the formation is Paleocene to latest Eocene (Reay 1993; Strong & others 1995; Hollis & others 2005b). At Kaikoura Peninsula, earliest Eocene Amuri Limestone rests disconformably on Late Cretaceous Mead Hill Formation (Hollis & others 2005b). From Kaikoura southwards, the Amuri Limestone youngs progressively: at Haumuri Bluffs, the age range is Early to Late Eocene; at Hurunui River it is entirely Late Eocene; at Napenape it is Late Eocene to Early Oligocene; and at Waipara River, on the southern edge of the Kaikoura map area, the formation is entirely Oligocene (Field, Browne & others 1989).

The bulk of the Amuri Limestone was deposited under pelagic to hemipelagic conditions (Strong & others 1995; Hollis & others 2005a) and bentonitic parts of the Amuri Limestone indicate increased influx of terrigenous mud (Reay 1993), most likely during globally warm periods (e.g. Hollis & others 2005a,b). Microfossils indicate an upper to lower bathyal setting (Field, Uruski & others 1997).

![Figure 40](image)

**Figure 40** The Amuri Limestone, consisting of interbedded siliceous limestone and bentonitic marl, at Haumuri Bluffs.

*Photo: D.L. Homer CN30428.*
The *Grasseed Volcanics* member (*E哲*: Reay 1993) occurs within the Amuri Limestone as isolated bodies in the middle Clarence valley and in the Waima River-Kekerengu area. The member comprises both intrusive and extrusive igneous rocks, including dikes, flows, sills, pillow lavas (Fig. 41) and agglomerate of peridotite, gabbro, dolerite and basalt. Gabbro sills up to several tens of metres thick locally intrude the limestone. The dikes intrude the Seymour Group and the Mead Hill and Amuri formations, becoming extrusive in the upper parts of the Amuri Limestone. The extrusive parts of the Grasseed Volcanics are within-plate alkali basalts and K-Ar dating of phlogopite from the Clarence valley yielded ages of 43–53 Ma (Early to Middle Eocene). Microfossils in the overlying limestone constrain the minimum age to Late Eocene (Reay 1993).

**Late Eocene to Pliocene sedimentary and volcanic rocks**

During the Late Eocene, the New Zealand continent area was partly emergent but remained low-lying. Late Eocene terrestrial coal measures were widely deposited, followed by a variety of marine rocks. Within the Kaikoura map area the rate of sedimentation was highly variable. Thick deposits accumulated in the rapidly subsiding Murchison Basin (see below), but on the east coast, no latest Eocene or Oligocene rocks are preserved north of the Waima River to the Kaikoura map boundary (Townsend 2001). Elsewhere in the map area, Late Eocene to Middle Miocene rocks are preserved locally along the Waimea Fault in the northwest and more extensively in northern Canterbury. Subsequently carbonate rocks were deposited above extensive erosion surfaces that developed during the Oligocene (including the Marshall Paraconformity; Carter & Landis 1972; Carter 1985; Fig. 42). Early to Middle Miocene clastic deposition in the Kaikoura-Kekerengu area was in response to an increasing component of convergence on the plate margin and consequent uplift. Rapid clastic deposition in the northeast (Awatere Sub-basin) during the Late Miocene and Early Pliocene resulted from the formation of localised, tectonically controlled sub-basins (Browne 1995).

**Southeast of the Alpine Fault**

The *Cookson Volcanics Group* (*O哲*: Browne & Field 1985) crops out extensively in the middle Clarence valley and from Whales Back southwards along the edges of the Culverden Basin. The group comprises basaltic plugs, flows, pillow lavas, dikes, and sills (Fig. 43), with breccia, conglomerate and volcanioclastic sandstone, interbedded with calcareous rocks. The group is up to 50 m thick in the Clarence valley (Reay 1993) and up to 1200 m thick in a syncline north of Waiau township (Field, Browne & others 1989). It unconformably overlies the Amuri Limestone and forms laterally discontinuous lenses. In the Clarence valley, the sandstone contains Early Oligocene foraminifera and the basalt plug at Limestone Hill has been K-Ar dated at 27.6 Ma (Reay 1993).

The *Motunau Group* occurs widely through the eastern Kaikoura map area and in most cases unconformably
overlies older rocks (Carter & Landis 1972; Findlay 1980; Field 1985). Many of the formations within the group are too thin to be shown on the Kaikoura map, and these are mapped as undifferentiated (Mn).

Widespread, undifferentiated Late Oligocene basal greensands, limestones and calcareous mudstones (Onl) are included within the lower Motunau Group. The limestone commonly forms prominent bluffs and distinctive landforms with local stratigraphic names including Omihi and Spy Glass formations, Tekoa, Flaxdown, Isolated Hill, Weka Pass and Whales Back limestones, and Hanmer Marble (Fig. 44a,b). Collectively, however, these undifferentiated rocks are shallow to deep-water sedimentary facies variants of a semi-continuous blanket of Late Oligocene carbonate deposition that only locally exceeded 50 m in thickness. These rocks conformably overlie or are locally interbedded with the Cookson Volcanics Group but are generally unconformable on older rocks such as the Amuri Limestone.

The Early to Middle Miocene Waima Formation (Mnw) is widespread throughout the northern and eastern parts of the Kaikoura map area (Browne & Field 1985; Field, Uruski & others 1997). It comprises more than 360 m of generally massive to poorly bedded, greenish to bluish-grey calcareous silty mudstone (Fig. 45a). The Waima Formation is generally conformable on Oligocene limestone with a gradational, usually interbedded, contact. Locally the formation is disconformable on Amuri Limestone (e.g. between Bluff and Dart streams in the Clarence valley; Reay 1993). Microfossil evidence suggests that the age ranges from early Late Oligocene to late Early Miocene; deposition may have locally continued into the Middle
Figure 45 The upper Motunau Group contains many different rock types.

(a) Gently-dipping, well-bedded Waima Formation siltstone forms the Haumuri Bluffs. The horizontal surface is an elevated marine terrace.

Photo CN30458/23: D.L. Homer.

(b) The Great Marlborough Conglomerate facies within the Waima Formation contains clasts from most of the Cretaceous and Paleogene rocks of the eastern Kaikoura map area.

Photo: G.H. Browne.

(c) The interbedded sandstone and conglomerate of the Greta Formation at Gore Bay exhibits "badlands"-type, vertical erosive fluting.

Photo CN30528/16: D.L. Homer.

Miocene (e.g., at Haumuri Bluffs; Browne 1995; Warren 1995). In the north the Waima Formation includes the Early Miocene Great Marlborough Conglomerate (not mapped), an extremely poorly sorted pebble to boulder conglomerate (Fig. 45b). Clasts are derived from Pahau terrane, Late Cretaceous igneous rocks, Seymour Group, Mead Hill and Amuri formations, with large rafts of Oligocene limestone and rip-up clasts of Waima Formation siltstone. The conglomerate generally forms lenses within the Waima Formation, or is locally unconformable on Pahau terrane or on Oligocene limestone. The conglomerate was deposited by a number of debris flow mechanisms and accumulated in broad, shallow feeder channels (Lewis & others 1980) or locally filled canyons that were incised into the Miocene continental shelf (Townsend 2001). In the Clarence valley the Great Marlborough Conglomerate reaches almost 300 m in thickness (Reay 1993).

The Early Miocene Waikari Formation (Mnk) (Andrews 1963) is widespread in the south of the Kaikoura map area. The formation includes basal calcareous glauconitic siltstone; massive blue-grey siltstone; and bedded, yellow-brown sandstone. The Waikari Formation unconformably overlies Oligocene limestone (Andrews 1963), except where it conformably overlies Waima Formation (Warren 1995).

In the south of the map area, the Early to Middle Miocene Mt Brown Formation (Mnb) consists of siltstone, sandstone and bioclastic limestone with interbedded debris flow conglomerate that conformably overlies the finer grained Waikari Formation. It is locally up to 830 m thick and was deposited in mid- to outer shelf environments in a rapidly subsiding basin (Browne & Field 1985).

The conformably overlying Middle Miocene to Early Pleistocene Greta Formation (\textsuperscript{Fn}g; Fig. 45c) is dominated by fine-grained siltstone (Browne & Field 1985; Warren 1995). Other facies are only locally developed and include poorly bedded marine, deltaic and fluvial mudstone, limestone and debris flow conglomerate, and a small proportion of sandstone. Up to 800 m of siltstone is recorded near Waiau (Browne & Field 1985), but the thickness of the formation varies greatly (e.g. Warren 1995).
Late Miocene to earliest Late Pliocene rocks of the **Awatere Group** crop out in the northeast of the Kaikoura map area. The group is divided into three formations (Roberts & Wilson 1992). The oldest rocks of the middle Late Miocene **Medway Formation (Mam)** crop out extensively in the Medway valley and thin eastwards into the Awatere valley. The formation consists of a basal conglomerate, 50–100 m thick, which grades upwards into 200 m of sandstone with conglomerate lenses, in turn overlain by mudstone and siltstone (Browne 1995). Isolated Miocene fossiliferous conglomeratic sandstone on the west limb of the Ward Syncline, and a single occurrence of fine sandstone with poorly preserved macrofossils in the Waihopai valley, indicate that the Medway Formation originally extended well to the north and east of the Medway and upper Flaxbourne valleys. The formation is interpreted as a syntectonic, inner to mid-shelf deposit (Melhuish 1988), formed near an actively rising Pahau terrane at sedimentation rates of up to 870 m/Ma (Browne 1995).

Unconformably overlying the Medway Formation or, locally, Pahau terrane, is the Late Miocene **Upton Formation (Mau)**. It consists of basal sandstone or conglomerate that grades upward into siltstone-dominated rocks, with scattered macrofossils and shellbeds. The lower part of the Upton Formation was deposited near actively rising ranges, while the finer grained parts were deposited in a bathyal setting (Browne 1995). The upper part of the formation coarsens upwards into sandstone in the northwest. The overlying latest Miocene to Late Pliocene **Starborough Formation (Pas)** is generally poorly exposed and consists of poorly bedded brownish-grey fossiliferous sandstone and sandy siltstone (Fig. 46).

The lower part of the Awatere Group comprises a transgressive sequence resulting from the incursion of the sea over a low-lying landscape cut in Pahau terrane. The upper part represents a regressive phase with shallowing of the sea (Roberts & Wilson 1992; Browne 1995).

Undifferentiated Early Pliocene blue-grey calcareous siltstone and sandstone, with Pahau-derived debris-flow conglomerate (Whanganui Siltstone; **Pu**), occurs north of the Clarence River mouth (Browne 1995).

The Pliocene **Kowai Formation (Pk)** crops out in the southern part of the Kaikoura map area where it unconformably overlies Mt Brown and Greta formations. It consists of up to 650 m of Pahau-derived fluvial and shallow marine conglomerate (Fig. 47) with interbedded sandstone and mudstone (Browne & Field 1985). Like the conglomerates of the Awatere Group, Kowai Formation resulted from the accumulation of debris shed from actively rising mountain ranges.

**Northwest of the Alpine Fault**

Late Eocene to Early Pleistocene rocks crop out extensively in the northwest of the map area and are up to 9 km thick in the Murchison Basin. The basin has been shortened by up to 60% since the Late Miocene resulting in steeply dipping fold limbs and faulted-out anticlinal axes (Suggate 1984; Lihou 1993).

Slivers of Late Eocene to middle Oligocene **Brunner Coal Measures (Eb)** and massive mudstone are preserved along the Waimea Fault in the southeast of the Moutere Depression. The coal measures, up to 300 m thick, have close similarities to the Eocene rocks of the Jenkins Group in Nelson (Johnston 1990; Rattenbury & others 1998).

In the northeast of the Murchison Basin, latest Eocene to earliest Oligocene **Maruia Formation (Em)** (Fyfe 1968) is composed of 50 to 500 m of coarse, quartzofeldspathic sandstone with minor conglomerate, carbonaceous mudstone and thin seams of bituminous coal. These rocks are overlain by up to 500 m of largely massive, dark brown, micaceous mudstone or siltstone with minor bands of feldspathic sandstone, becoming more calcareous towards the top. The Maruia Formation was deposited unconformably on basement rocks, initially in a terrestrial environment. The mudstone represents deposition in an estuarine to partly enclosed inner shelf environment with periodic incursion of submarine fans derived from a rising area of Separation Point Batholith granite, probably to the east (Suggate 1984).
The youngest formation in the Murchison Basin is the late Early to Middle Miocene **Longford Formation** (Ml; Fyfe 1968), in the core of the Longford Syncline (Fig. 48). It comprises thick beds of conglomerate, sandstone, mudstone with thin coal seams, and interbedded fine sandstone and mudstone. In the south, the lower part of the formation contains proportionately less conglomerate and more sandstone and mudstone. Clast provenance was mostly from the Separation Point Suite granite, with a significant component derived from the Dun Mountain-Maitai and, in its upper part, Caples terranes (Suggate 1984). The formation accumulated in an estuarine environment in the south with extensive deposition farther north by meandering rivers in an alluvial plain setting.

Farther south, at an equivalent stratigraphic level to the Longford Formation, is the poorly dated terrestrial **Rappahannock Group** (Cutten 1979). The lower Rappahannock Group (eMr) consists of conglomerate interbedded with sandstone and, more commonly at the base, carbonaceous mudstone with thin coal seams. Near the base, the conglomerate is dominated by clasts of Caples Group sandstone, but Rakaia terrane Alpine Schist clasts become more common higher in the succession. The upper part of the Rappahannock Group (mMr) is also dominated by conglomerate with clasts of chlorite and biotite schist derived from Rakaia terrane (Cutten 1979).

In the southwest of the Moutere Depression, weakly consolidated sandstone and mudstone with conglomerate and minor lignite seams comprise the **Glenhope Formation** (^tg) at the base of the **Tadmor Group**. Clasts in the formation are dominated by Separation Point granite with minor amounts of Rotoroa Complex and, towards the top, an increasing percentage of Torlesse-derived sandstone. The formation is Late Miocene to Early Pliocene (Mildenhall & Suggate 1981). The overlying **Moutere Gravel** (^tm) is of early Late Pliocene (Waipipian to Mangapanian) age, and in the Kaikoura map area is up to 500 m thick where it is down-faulted along the Waimea-Flaxmore Fault System (Lihou 1992). In the west it conformably (locally disconformably) overlies the Glenhope Formation. The Moutere Gravel is characterised by rounded, slightly to deeply weathered, Rakaia-derived sandstone clasts, up to 0.6 m across but mostly less than 0.2 m, in a yellow brown muddy matrix (Fig. 49). Palynofloras are dominated by cool temperate species (Mildenhall & Suggate 1981; Johnston 1990).

Unconformably resting on the Moutere Gravel in the south of the Moutere Depression are Torlesse-derived till, lake beds and moderately well-sorted outwash gravel of the **Porika Formation** (eQp). The formation is up to 150 m thick and records a Late Pliocene to Early Pleistocene piedmont glacial advance that extended from the Spencer Mountains into the developing Moutere Depression (Suggate 1965; Johnston 1990; Challis & others 1994).
The tectonic regime initiated in the Early Miocene continued into the Quaternary, with uplift of the Southern Alps, and other Marlborough, Nelson and northern Canterbury ranges. The widespread Late Quaternary deposits in the map area formed in response to both rising ranges and alternating glacial and interglacial climatic fluctuations. However, in many localities the deposits are thin (less than 5 m) and/or of restricted distribution and have been omitted from the map.

Alluvial terrace and floodplain deposits

The gravel deposits forming terraces and floodplains (Q1a, Q2a, Q3a, Q4a, Q6a, Q8a, Q10a, eQa, uQa) are dominated by poorly to well-sorted gravel with sand and silt (Fig. 50a,b). Many gravel units originated as outwash from glaciation episodes. Within the gravel deposits, clasts are up to a metre across but most are less than 0.3 m. In general the average clast size decreases, and degree of sorting increases, in direct proportion to the distance from the source of the gravel. Torlesse-derived sandstone is the

Figure 50

(a) The alluvial delta at the Clarence River mouth showing a muddy sediment plume being dispersed northwards by the longshore current. Flanking the present day flood plain are remnants of older, uplifted late Pleistocene gravels.

Photo CN23903/6: D.L. Homer.

(b) Over 160 m of alluvial outwash gravel, sand and silt underlie an extensively developed last glaciation terrace surface on the south bank of the lower Hope River.
predominant rock type but in the northwest, granite and ultramafic clasts are locally present. Lenses of silt and sand are also present throughout the gravel deposits but are rarely significant.

Except on present-day floodplains, the alluvial deposits form flights of aggradational terraces, with the older terraces preserved at progressively higher levels above the valley floors. Although stratigraphic or glacial episode names have been applied in local settings (Suggate 1965; Eden 1989; Townsend 2001), the deposits are differentiated here by age based on oxygen isotope stages (OIS). Most deposits are poorly dated and their ages are generally based on the height of the capping terrace surface relative to others in the valley. The extent of terrace dissection, degree of clast weathering and the number and thickness of loess units (see below) have also helped to constrain terrace deposit ages.

The Plateau Gravel (eQl) occurs as isolated remnants that overlie the Dun Mountain Ultramafics Group on the crest of Red Hills Ridge (Fig. 17). The formation is up to 25 m thick and comprises poorly sorted and weakly stratified ultramafic clasts, commonly less than 0.5 m across but with large angular blocks near the base and sparse, well-rounded pebbles of Torlesse sandstone. The formation owes its preservation to the sandy matrix being cemented by magnesium compounds released from weathering of the ultramafic rocks. The age of the gravel is uncertain but is inferred to be no older than Middle Pleistocene (Johnston 1990).

Unmapped surficial deposits

Loess deposits are not differentiated on the Kaikoura map, but they sometimes form significant sheets up to several metres thick on older terraces (Q4 to Q10) adjacent to major rivers or in gullies in the lee of the prevailing westerly winds. Identification of one or more loess-soil horizons (Fig. 51) may help to broadly distinguish the ages of aggradation terraces. In the northeast of the map area, the 26.5 ka Kawakawa tephra (Oruanui fall deposit; Wilson 2001), sourced from the central North Island, commonly occurs as a layer in loess deposits on terraces older than OIS 2 and locally in fan gravel deposits (Campbell 1986; Eden 1989; Benson & others 2001; Townsend 2001). The c. 340 ka Rangitawa tephra (Kohn & others 1992; Berger & others 1994), also from the central North Island, occurs rarely in loess older than OIS 10 in the northeast of the map area.

Fill, of varying levels of compaction, is common under roads and railways, particularly in gullies and approaches to bridges. Small areas of uncompacted fill, the result of the dumping of domestic rubbish, are present adjacent to many of the townships in the map area. All of these deposits are too small to show on the geological map.

Alluvial fan and scree deposits

Alluvial fan deposits (Q1a, Q2a, Q3a, Q4a, Q6a, Q8a, Q10a, eQa, uQa) are widespread throughout the map area and many merge into the aggradation surfaces in the main valleys (Fig. 52). Many of the fans are too small to be shown on the map and are either omitted or incorporated into the corresponding alluvial terrace. Mappable scree deposits (Q1s) occur in the higher mountains and consist of locally derived, slightly weathered, angular clasts of pebble to boulder size. Scree commonly merge with more gently sloping, water-borne alluvial fans towards the valley floors. Rock glacier deposits (Q1r) consisting of poorly sorted gravels up to boulder size occur on the Inland Kaikoura Range (Fig. 53). Eight rock glaciers up to 1.2 km length and 500 m wide occur at elevations exceeding 2100 m (Bacon & others 2001). These are probably actively expanding and moving, and result from permafrost conditions in an arid climate where there is a high ratio of rock debris to snow supply.

Figure 51 Loess on the south bank of the Clarence River near SH 1 showing typical vertical fluting. The faint darker banding part way up the loess may be a paleosol, or buried soil. The thickness of the loess and the presence of the paleosol suggest that the age of the underlying gravel deposit is at least OIS 4 (Q4a).
Figure 52 Scree on the southern flanks of Dillon Cone merge into alluvial fans near a prominent gradient change mid-slope towards the Clarence River valley. The Elliott Fault crosses the range close to the change in slope. Q1a and remnant Q2a alluvial terraces occur close to the river.

Photo CN8171/25: D.L. Homer.

Figure 53 Rock glaciers (left, lower right) and scree mantling the southern slopes of Mt Alarm on the Inland Kaikoura Range.

Photo CN25751/11: D.L. Homer.
Till deposits

The aggradational terrace surfaces capping the alluvial gravels (see above) can commonly be traced up the valleys to terminal moraines and associated till deposits (Q1t, Q2t, Q4t, Q6t, Q8t, Q10t, eQt, uQt) in the mountains. The tills consist of subrounded to subangular clasts up to boulder size in a tight clayey matrix, and older tills are generally more weathered than younger.

Landslide deposits

Mass movement deposits (Q1l, uQl) are widespread, although large deep-seated landslides are relatively rare. Small superficial failures, rock falls and slope creep are common, but only deposits >1 km² in area are shown on the map. The large landslide deposits (Fig. 54) range from masses of shattered, but relatively coherent rock, to silt clay containing unsorted angular rock fragments. Large landslide deposits, many triggered by severe earthquake ground shaking, dam several lakes such as lakes Matiri, Constance, Alexander and McRae. Moderately large landslides, commonly with ill-defined margins, have occurred in areas of Pahau terrane in the Flaxbourne River, and in mélangé zones in the lower Waiau valley and near Cheviot. Extensive failures, mostly along bedding planes, are common in the Late Cretaceous to Cenozoic rocks and have resulted in chaotically mixed landslide deposits. Late Cretaceous and Eocene rocks containing montmorillonite-rich clays (smectite) are particularly prone to instability.

Swamp and lake deposits

Holocene swamp deposits (Q1a) are common in many valleys but are generally small in area. Adjacent to the coast, swamps have developed where drainage has been impeded by dunes and marine sand and gravel. Lake deposits of Late Pleistocene age are present in many valleys, either upstream of terminal moraine dams, or in side valleys dammed by lateral moraines or aggrading fans. The lake deposits range from silt to gravel, the latter locally displaying foreset bedding. Most deposits are intermingled with or overtopped by alluvial gravel. Late Holocene lake sediments are present behind landslide dams, many of which were produced by earthquake ground shaking. Near Murchison township the Murchison Lake Beds (Q7k), of middle Quaternary age, consist of consolidated banded silt, gravel and sand. As the upper and lower contacts of the beds have not been seen, the processes that led to lake formation are not known (Suggate 1984).

A swamp deposit at Pyramid Valley (too small to be shown on the map) contains numerous well-preserved fossil vertebrates including at least 46 species of birds (waterfowl, moa, kiwi, weka, parrots amongst others), as well as tuatara, bats and geckos (Scarlett 1951; Holdaway & Worthy 1997). Other swamp sites and some alluvial and colluvial deposits around Waikari and limestone cave sites around Mt Cookson contain more examples of these and other species (Worthy & Holdaway 1995, 1996). The deposits have accumulated over the last 40 000 years.

Figure 54 The large landslide deposit in Gore Basin, near the crest of the Seaward Kaikoura Range, has originated from Pahau terrane rocks forming the ridge on the right.
Marine deposits

Marine sand and gravel deposits (Q7b, Q9b, uQb) crop out as poorly exposed remnants up to 280 m above sea level, particularly on eastern slopes of the Hawkswood Range. The older deposits are partly dissected and tilted, and their altitude largely reflects tectonic uplift rather than the height of the interglacial sea levels (Ota & others 1984; Warren 1995). Younger marine deposits (Q4b, Q5b) are more extensively preserved along the coast (e.g. Ota & others 1995, 1996; Figs 39, 45a). All the deposits generally consist of boulders, rounded gravel and moderately sorted coarse sand. They are generally poorly fossiliferous, but locally contain remarkably well-preserved trace fossil assemblages (Ekdale & Lewis 1991). Holocene marine sand and gravel (Q1b) crop out in a narrow strip along much of the coast.

Sand deposits

Sand deposits (Q1d) occur locally along the coast and comprise wind-blown sand forming dunes that may extend up-slope onto the fringing hills (Fig. 11). The Kaikoura map area characteristically has coarser beach sand and gravel than many other parts of the country and dunes are comparatively poorly developed.

OFFSHORE GEOLOGY

Offshore, from the Clarence River mouth north towards Cook Strait, the continental shelf is underlain by a sedimentary basin identified from abundant seismic data. This Flaxbourne (Clarence) Basin contains up to 4.5 km of probable Late Cretaceous to Recent strata (Uruski 1992; Field, Uruski & others 1997; Barnes & Audru 1999b). Basal sequences in the basin thicken to the southeast and onlap older units towards the northwest, indicating a rifted half-graben. Growth strata of probable Miocene age resulted from subsequent compressional tectonics (Uruski 1992). A blanket of Holocene mud up to 45 m thick covers the central part of the basin, but around the edges Miocene (Motunau and Awatere groups) to Pleistocene rocks are exposed at the sea floor (Barnes & Audru 1999b). Up to seven Pleistocene unconformities are present within the basin.

The basin is being deformed by active, dextral strike-slip and oblique-slip faults that offset and fold Late Quaternary sediments (Barnes & Audru 1999a,b). These faults include reactivated NNE- to northeast-striking Miocene structures and younger (<1 Ma?) faults striking ENE that have formed approximately parallel to the current plate motion vector. The northeast trend of the basin probably also results from inheritance of a Miocene structural fabric (Barnes & Audru 1999b).

South of the Kaikoura Peninsula, the Kaikoura Canyon is deeply incised into the continental shelf. Although no large rivers feed into the canyon, it is a major sink for north-drifting sand and mud, most of which bypasses the continental shelf sediment prism and is transported further offshore along the Hikurangi Channel and into the Hikurangi Trough (Lewis & Barnes 1999). Gravel and coarse sand turbidites, interbedded with pelagic mud that reflects background sedimentation conditions, are common in the lower part of the canyon. A seismically non-reflective layer in the central part of the canyon, overlain by bedded turbidites, is probably a slump that may have been generated by (c.1833) earthquake shaking.

The northern slope of the Chatham Rise has been subjected to strong, north-flowing ocean-bottom currents since at least the mid-Pliocene (Barnes 1994a). Sea-floor scour channels are evident in the bathymetry and in the underlying geology, suggesting episodic erosion and sediment blanketing events. Lenticular, Late Quaternary sediment drifts have accumulated at the mouths of the channels where they open out onto the toe of the Chatham Rise, reflecting the localised nature of erosion and deposition in this area.
Early to mid-Paleozoic

Greenland Group rocks of the Buller terrane were deposited on the Australo-Antarctic margin of Gondwanaland in the Early Ordovician (Cooper & Tulloch 1992). In the Silurian the group was tightly folded and metamorphosed to lower greenschist facies (Adams & others 1975). The Haupiri Group of the Takaka terrane formed in a volcanic island arc and back-arc setting at a convergent plate boundary (Münker & Cooper 1999). The carbonate-rich Mt Arthur Group rocks were deposited on a passive continental margin, east of the volcanic arc, after cessation of subduction; they were subsequently thrust over the volcanic rocks of the Haupiri Group and folded (Cooper & Tulloch 1992). Accretion of the Takaka terrane onto the Buller terrane occurred in the mid-Devonian, in part by movement along the Anatoki Fault. The tectonic suturing was followed shortly afterwards by the intrusion of voluminous granitic rocks of the Karamea Batholith between 370 and 328 Ma (Cooper & Tulloch 1992).

Late Paleozoic to Early Cretaceous

The emplacement of the Median Batholith, dominated in the Kaikoura map area by Triassic to Early Cretaceous intrusions, occurred along the margin of Gondwanaland and sutured the Western Province to the western part of the Eastern Province (Bradshaw 1993; Mortimer & others 1999). Subsequently much of the eastern part of the batholith has been excised by the Delaware-Speargrass Fault Zone (Johnston & others 1987; Johnston 1990). The Eastern Province contains six terranes within the map area and all record convergent margin tectonism and volcanosedimentary processes (Coombs & others 1976; Bradshaw 1989; Mortimer 2004). The westernmost is the volcanogenic Brook Street terrane, consisting of a tectonically dismembered remnant of a calc-alkaline island arc. An intrusive contact between the Brook Street terrane and the Median Batholith in Southland constrains accretion of the terrane to Gondwanaland to between 230 and 245 Ma (Middle to Late Triassic; Mortimer & others 1999). In east Nelson the contact between the Brook Street and Murihiku terranes is faulted. However the Brook Street terrane may have originally been overlain by the volcaniclastic Murihiku terrane in a Triassic-Jurassic back-arc basin.

Farther east, a “slab” of Permian oceanic ridge or back-arc basin crust, the Dun Mountain Ophiolite Belt, was obducted onto Murihiku and Brook Street terranes during Early to mid-Permian subduction (Coombs & others 1976; Sano & others 1997). Overlying Late Permian to Triassic Maitai Group accumulated in a trench forearc setting adjacent to a convergent margin. Although faulted, and folded into the Roding Syncline, the group has largely retained internal stratigraphic coherence.

The Patuki Mélange separates the Dun Mountain-Maitai terrane rocks from the Caples terrane; the latter accumulated as an accretionary wedge in a Late Permian to Triassic trench or trench slope. The original suture between the Caples and Rakaia terranes (not seen in the Kaikoura map area) is within a zone of greenschist to amphibolite facies schist with multiple generations of recumbent folds and penetrative foliations (Mortimer 1993a,b; Johnston 1994; Begg & Johnston 2000). In the Kaikoura map area the Caples-derived schist was later juxtaposed by Cenozoic movement of the Alpine Fault against non-schistose Rakaia terrane rocks. Greenschist facies (garnet zone) schist is present in the western part of the Rakaia terrane (Turnbull & Forsyth 1986), including the Aspiring lithological association, but farther east weakly metamorphosed, lithologically monotonous, quartzofeldspathic sedimentary rocks predominate. These rocks accumulated in a Late Triassic to Early Jurassic subduction setting and were progressively imbricated and deformed in an accretionary wedge (MacKinnon 1983; Bradshaw 1989). The Esk Head belt, comprising mélange and generally more deformed rock, including the Silverstream Fault Zone in Branch River, is the tectonic suture between the Rakaia terrane and the Pahau terrane to the east. Rocks of the Pahau terrane were deposited in a subduction setting and deformed in an accretionary wedge in the Late Jurassic to Early Cretaceous. The Caples, Rakaia and Pahau terranes were amalgamated during convergent tectonism along the Gondwanaland margin between the Middle Jurassic and the late Early Cretaceous, when subduction ceased (Coombs & others 1976; Bradshaw 1989). Major igneous intrusion occurred in and beyond the west of the Kaikoura map area in the Early Cretaceous with the emplacement of the Separation Point suite and other granitoids (Tulloch 1983).

Mid- to Late Cretaceous and Paleogene

Following cessation of subduction and amalgamation of the Eastern Province terranes, a prolonged period of extensional tectonics resulted in the opening of the Tasman Sea and, within the Kaikoura map area, widespread erosion and deposition into numerous mid-Cretaceous basins (Crampton & others 2003). Intrusion of the Tapuaenuku Igneous Complex and associated dikes was accompanied by extrusive basalt flows, which interfingered with terrestrial and shallow marine sedimentary rocks.

In the Late Cretaceous, subsidence become more regional in extent (Crampton & Laird 1997) as the tempo of extensional tectonics waned and a passive margin developed. Relative quiescence from the end of the Cretaceous resulted in regional subsidence and marine transgression, followed by the slow accumulation of widespread, fine-grained clastic and carbonate rocks (Field, Browne & others 1989). This was punctuated by sporadic intraplate volcanism, particularly in the Canterbury Basin (Browne & Field 1985). In the northeast of the map area this passive, basinal regime continued through into at least the Middle Eocene (Strong & others 1995; Crampton & others 2003). In northern Canterbury, deposition on a broad, relatively sheltered shallow shelf led to accumulation of fine-grained clastic rocks and glauconitic sands. The northern basins extended southwards during the Eocene and Oligocene, resulting in the deposition of a blanket of carbonate rocks. The Early Oligocene period of erosion
and/or non-deposition (including the Marshall Paraconformity), was accompanied by mild deformation associated with the initiation of the modern plate boundary (Lewis 1992; Nicoll 1992). Apart from localised basaltic volcanism the remainder of the Oligocene was characterised by tectonically subdued, regional deposition of carbonate rocks into several distinct depocentres (Browne 1995).

Neogene

The early Neogene is marked by a major influx of coarser clastic sediment eroded from rising mountains in the west. Uplift of mountain ranges was in response to increasingly convergent tectonics across the developing Australian-Pacific plate boundary through the New Zealand continent (Walcott 1978). Convergence associated with the plate boundary in Marlborough is recorded by Early Miocene thrust faults preserved north of Kaikoura (e.g. Rait & others 1991; Townsend 2001). Erosion of the rapidly rising Kaikoura ranges, Spenser Mountains and Southern Alps resulted in deposition of the Early Miocene Great Marlborough Conglomerate (Reay 1993) and western conglomerate units such as the Rappahannock (Cutten 1979) and Tadmor (Johnston 1990) groups. Uplift and cooling of the Tapuaenuku Igneous Complex at 22 Ma (Baker & Seward 1996) indicates significant convergence on the Clarence Fault by the earliest Miocene (e.g. Browne 1992).

Paleomagnetic and sea floor spreading data suggest that the entire coastal part of northeastern Marlborough rotated clockwise about a vertical axis by as much as 100° in the Middle Miocene (Sutherland 1995; Vickery & Lamb 1995; Townsend 2001; Hall & others 2004). The dominant northeast strike of the steeply dipping Torlesse rocks in Marlborough is inferred to have been folded from an original northwest strike at this time (Little & Roberts 1997). The rotation was probably due to locking of the subduction interface beneath Marlborough, possibly triggered by thickened oceanic lithosphere of the Hikurangi plate entering the trench system, and also because the relatively buoyant continental crust of the Chatham Rise was pinned against the Australian plate to the west (Lamb & Bibby 1989; Eberhart-Phillips & Reynolds 1997; Little & Roberts 1997; Reynolds 1998).

In the Late Miocene, strike-slip faulting dominated in Marlborough and associated local, fault-bounded grabens, half-grabens, and folded sedimentary basins are characteristic of this period (Figs 39, 55). In the Pliocene the component of convergence across the plate boundary increased (Walcott 1998), as did transpression on the Alpine Fault and other strike-slip faults (Little & Roberts 1997), resulting in the uplift of the Southern Alps and other mountains in the west. North of the fault, the Moutere Depression developed between the rising mountains of east and west Nelson. Early Miocene uplift of the Inland Kaikoura Range was followed by Late Pliocene uplift of the Seaward Kaikoura Range (Kao 2002). Rotation of the Hikurangi margin continued, but on a more localised scale, in the lower Awatere valley (Roberts 1992).

As the Chatham Rise continued to impinge onto the Australian plate, new faults developed at the edge of the Pacific plate, widening the plate boundary zone and resulting in the redistribution of fault slip towards the south (Knuepfer 1992; Holt & Haines 1995; Little & Roberts 1997; Little & Jones 1998; Barnes & Audru 1999b). The Hope Fault is currently the most active structure of the Marlborough Fault System with a right-lateral slip rate of 20–40 mm/yr (Cowan 1990; Van Dissen & Yeats 1991). The northern Canterbury basin and range topography is a consequence of spreading deformation associated with the Australian-Pacific plate boundary. Some of the ranges are bounded by northeast-striking reverse faults or thrusts and associated folding (Nicol & others 1995; Pettinga & others 2001; Litchfield & others 2003).

Figure 55 The south-plunging Puhipuhi Syncline north of Kaikoura is a spectacular example of folds developed along the eastern coast. The Miocene core of the syncline lies in the valley (centre) and the fold limbs are dominated by Paleogene limestones underlain by mid- to Late Cretaceous sandstones. Folding, together with mountain uplift, occurred in response to increasing convergence across the Australia-Pacific plate boundary in the Neogene.

Photo CN11019/4: D.L. Homer.
The mineral resources of the Kaikoura map area are relatively limited, both volumetrically and economically, and have been described in detail by Doole & others (1987) and Eggers & Sewell (1990). The following account is summarised from these publications with some updating. The most significant resources in the map area are aggregate, limestone and salt.

**Metallic minerals**

**Chromium**, occurring as grains and up to 15 cm thick lenses of chromite, is widespread in dunite and harzburgite of the Dun Mountain Ultramafics Group in the Red Hills. Two analyses gave relatively low Cr<sub>2</sub>O<sub>3</sub> percentages of 38.01 and 39.51. No economic deposits are known or are likely to be found.

**Cobalt** in the form of the cobalt-iron mineral wairauite has been reported from the Dun Mountain Ultramafics Group, in the Wairau valley, but is of academic interest only (Challis & Long 1964).

**Copper**, commonly present as sparse malachite staining, is found on surfaces or fractures of igneous rocks of the Dun Mountain Ultramafics and Livingstone Volcanics groups, and in igneous rocks of the Pahau and Rakaia terranes. The richest known deposit is near Mt Baldy, in gabbro of the Tineline Formation of the Livingstone Volcanics Group. The deposit comprises chalcopyrite within a quartz vein stockwork, up to 1 m thick and possibly continuous over a distance of 3 km, from which a series of samples gave between 0.58 and 7.7% Cu (Johnston 1976). In the northeast of the map area, at Tapuae-o-Uenuku and Blue Mountain in the Inland Kaikoura Range, mafic-ultramafic complexes of Cretaceous age contain sub-economic, disseminated copper-nickel and magnetite-ilmenite mineralisation (Pirajno 1979; Brathwaite & Pirajno 1993). The Tapuaenuku Igneous Complex consists of a layered intrusion with widespread but irregular disseminated pyrite, pyrrhotite and chalcopyrite at or near the contact between pyroxenite and gabbro layers. Chip samples contain up to 1% Cu and 0.3% Ni. At Blue Mountain, disseminated pyrrhotite and chalcopyrite mineralisation forms irregular zones within a marginal ring dike of titanugite-ilmenite gabbro, and at the contact between the ring dike and olivine-pyroxenite. The highest rock geochemical values are 1.6% Cu and 1.3% Ni (Pirajno 1979). The Late Jurassic layered Rotoroa Complex in southeast Nelson contains minor quartz-pyrite-chalcopyrite veins and disseminations adjacent to diorite, on the margins of intrusions of Separation Point granite. Copper values of up to 0.25% have been reported (Challis & others 1994).

**Gold** occurs widely as placer deposits in and adjacent to the rivers draining west from the Main Divide. Gold was first discovered in the late 1850s with the last significant find being in 1915 in the Howard valley, between lakes Rotoiti and Rotoroa. Most gold production occurred during the 1860s in the Mangles, Matakitaki and Glenroy valleys from river beds or from ground sluicing of small alluvial claims on adjacent terraces (Fyfe 1968). Larger claims were developed in the Matakitaki valley downstream from terminal moraines. The gold is largely derived from quartz reefs in Rakaia terrane semischists and schists, and was carried westwards by Quaternary glaciers to accumulate in moraines and outwash gravels. Further erosion and reworking of the deposits has concentrated the gold in flood plains and riverbeds. Minor amounts of gold have also been eroded from the basement rocks west of the Alpine Fault, such as in the Owen valley, and from reworking of the basal Tertiary sequences of the Murchison Basin. No economic quartz reefs have been found in the mapped area.

**Iron** in the form of magnetite (up to 50%) is associated with ilmenite and forms layers up to several metres thick in leucogabbro and anorthosite in parts of the Tapuaenuku Igneous Complex (Brathwaite & Pirajno 1993).

**Nickel** is widespread throughout the Dun Mountain Ultramafics Group, with up to 0.5% Ni present within the lattice of olivine crystals, or as the iron-nickel alloy awaruite (Challis & Long 1964), but economic deposits are unlikely to be present. Copper-nickel sulphide mineralisation forms sub-economic disseminations within the Tapuaenuku Igneous Complex and at Blue Mountain (see above).

**Platinum** group minerals (PGMs) are present in some of the gravels in the northwest of the map area and have been noted during alluvial gold mining (Morgan 1927). The greatest concentrations are in the tributaries of the Howard River, between lakes Rotoiti and Rotoroa, and river-flattened nuggets up to 4 mm across have been reported. The minerals consist of platinum and Cu-rich isoferroplatinum probably derived from the nearby layered Rotoroa Complex (Challis 1989; Challis & others 1994). Platinum group metals have been found in creeks draining the Dun Mountain Ultramafics Group in the Red Hills and in the Matakitaki valley. There is restricted outcrop of likely source rocks, and the amount of PGMs in deposits derived from them is likely to be insignificant.

**Titanium** in ilmenite is present in the Tapuaenuku and Blue Mountain layered intrusions (see above). Ilmenite is a very minor component of black sand in tributaries of the Buller River which drain the garnet zone of the Haast Schist.

**Non-metallic minerals**

**Clay** deposits are widespread throughout the map area although there are no large deposits of uniform quality. Most of the clay deposits are residual, being derived from the weathering of bedrock units. In the northwest, clay minerals are widespread in the Moutere Gravel and Porika Formation but mostly as matrix to greywacke-derived gravel. Porika Formation lake beds contain large volumes of clay to sandy clay, with chlorite and a minor component of vermiculite or interlayered chlorite-vermiculite (Johnston 1990). Southeast of the Alpine Fault, illite and interlayered
hydrous mica clay are widespread as the result of weathering of Torlesse-derived loess. Bentonitic clay, consisting largely of montmorillonite and derived from the weathering of volcanic ash, is associated with Late Cretaceous and Early Eocene volcanic rocks in the southeast of the Kaikoura map area. Early Eocene bentonite of marine origin is more extensive and thicker, but relatively low grade (Ritchie & others 1969).

Glauconite, a possible source of potassic fertiliser, occurs widely within the Late Cretaceous and Tertiary rocks in the east of the map area, but no economic deposits are likely to exist.

Salt is produced from the evaporation of seawater in Lake Grassmere (Fig. 56) in the northeast of the map area. The seawater flows into shallow holding ponds or paddocks and evaporation is aided by a low rainfall, high sunshine hours and frequently strong, warm, northwesterly wind. Between 60 000 and 70 000 tonnes of salt is produced annually, mostly for national and international industrial uses (http://www.domsalt.co.nz/profile.html).

Serpentinite, or partly serpentinised harzburgite and dunite, is widespread within the Dun Mountain Ophiolite Belt, but most of it is inaccessible. North of the Kaikoura map area near Nelson serpentinite has been quarried from these ultramafic rocks and used as a source of magnesium fertiliser (Roser & others 1994).

Figure 56 Lake Grassmere is a modified estuarine lagoon where salt is mined from evaporated sea water.

Photo CN46332/25: D.L. Homer.
Rip-rap is readily obtainable. Potential sources include igneous rocks northwest of the Alpine Fault, and sandstone-dominated parts of the Torlesse composite terrane and Paleogene limestones southeast of the fault. Rip-rap is used for river bank or coastal protection and is largely obtained from hard rock quarries. Talus deposits, such as ultramafic-derived boulders on the southwest of the Red Hills, have been used locally because of their proximity to the area of demand.

Argillite blocks within the serpentinitic Patuki Mélange of east Nelson have been altered by the introduction of minerals such as albite and tremolite. River boulders of altered argillite (pakohe) are tough with a characteristic conchoidal fracture. They were worked by Maori into adzes and other implements.

Dimension and ornamental stone of varying rock type are readily available, but the quantities obtained to date have been small. Basement rocks are commonly jointed and fractured, and generally difficult to access. A black gabbro-norite in the Rotoroa Complex in the Howard valley near Lake Rotoroa has been investigated as a source of dimension stone. Although it is readily accessible, closely spaced jointing would limit the size of blocks to <1 m (Challis & others 1994).

Oligocene pink limestone from the middle Waiau River (Hanmer Marble) and Mead Hill Formation have been used locally as a building stone (Fig. 57). Several rock types would be suitable for ornamental chips, either loose or in decorative paving and precast panels. Rocks suitable for this purpose include calcareous and siliceous components of the Mead Hill Formation and Amuri Limestone, and red argillite and chert in the Torlesse composite terrane.

Limestones occur widely in the Kaikoura map area. In Mesozoic basement rocks, however, limestone deposits are sparse and largely restricted to the Esk Head belt in the Leatham valley of Marlborough. This grey to white limestone is fine-grained and crystalline with a CaCO₃ content of 97–99% (Kitt 1962). In Enchanted Stream in the Leatham valley a 20 m thick limestone lens has been intermittently quarried with the greatest annual production not exceeding 6000 tonnes. On the western flank of the Red Hills, the steeply dipping and faulted Permian Wooded Peak Limestone is largely inaccessible. Some of the more accessible Wooded Peak Limestone in the Matakitaki valley has been sporadically quarried. Near Lake Daniells the Ordovician Sluice Box Limestone consists of crystalline limestone with between 50 and 98% CaCO₃ (Willett in Williams 1974), but it is not easily accessible.

Limestones of Paleogene age northwest of the Alpine Fault are generally inaccessible and of poor quality. Along the eastern part of the map area immense reserves of Mead Hill Formation and Amuri Limestone crop out but much of the limestone is too isolated to be used and the quality is also variable, ranging from a soft marly limestone to a hard, highly siliceous rock. Quarries in the softer limestone exist near Cape Campbell and Ward, where the limestone has been crushed by faulting or landsliding.

In northern Canterbury a number of Oligocene limestone units are quarried. While CaCO₃ content is generally high (Eggers & Sewell 1990), thickness is highly variable. South of Waiau, at Isolated Hill, well-bedded Oligocene limestone is broken up by landsliding, which assists quarrying. South of the Hanmer Plain on SH 7, limestone (Hanmer Marble) forms an easily quarried dip slope.
Dunite boulders are sporadically collected from streams draining from the Red Hills into the Wairau River for use in saunas and hangi because they withstand rapid cooling without explosively disintegrating.

Coal

Coal occurs locally in rocks of Late Cretaceous age and commonly near the base of Paleogene sequences. However, the only coal of economic significance in the map area is in the Murchison Basin (Suggate 1984). Up to five seams have been recorded from the basal Maruia Formation near the lower Matiri valley. Although the coal is strongly swelling and of high-volatile bituminous rank, the seams have a maximum thickness of only 1.2 m, the structure is unfavourable for mining and the coal has a medium to high sulphur content. The Longford Formation in the lower Matakitaki and Owen valleys contains several seams of low-swelling, low-moisture, high-volatile bituminous coal with low (c. 1%) sulphur. The seams pinch and swell, reaching a maximum thickness of 3 m, and the coal is commonly crushed. The easily accessible coal has been worked out and, because of the irregularity of the seams and structure, the prospects for renewed mining are poor. Total production was probably in the order of 150 000 tonnes (Suggate 1984).

Water

Groundwater availability is generally restricted east of the Main Divide where rainfall is lower and aquifers have limited extent. The best yields occur in Late Quaternary alluvial gravel, particularly adjacent to the major rivers draining the hard basement rocks or from the fan gravel aprons on the flanks of the major ranges (Brown in Eggers & Sewell 1990). In the lower Awatere valley, the gravels are thin and overlie Pliocene siltstone of low permeability that restricts river recharge. In the minor rivers and streams, including those draining soft and/or weathered rock, an increase in fine-grained material in the gravel deposits tends to reduce permeability. Along the coast, Holocene beach sands and dunes have a high permeability and porosity but recharge in many areas is dependent on frequent rainfall, and over-extraction can result in saline intrusion (Doole & others 1987; Brown in Eggers & Sewell 1990). The Neogene to Pleistocene gravel and sand deposits have generally low, but usually reliable yields.

The pre-Quaternary Cenozoic rocks in the mapped area generally have few open joints, and except along fault planes and in limestones, groundwater yields are low. The basement rocks have numerous joints, particularly along fault zones, which provide sufficient permeability to yield small quantities of groundwater. In some basement rocks, such as schist, igneous and early Paleozoic rocks, the presence of sulphide minerals tends to reduce water quality. However, where this occurs surface water supplies are abundant.

Thermal and mineralised hot springs are widespread, although not common, throughout the Southern Alps and the ranges of northern Canterbury (Mongillo & Clelland 1984). These springs are the result of groundwater percolating to considerable depth along fault zones before discharging on valley floors (Barnes & others 1978; Allis & others 1979). Measured temperatures range from 27.5°C to 60°C and are commonly accompanied by a sulphurous discharge (Mongillo & Clelland 1984). Commercial thermal resorts have been developed at Hanmer Springs and Maruia Springs along the Hope and Fowlers faults respectively.

Oil and gas

Oil and gas shows are present in a number of places within the Murchison Basin. The basin contains approximately 9000 m of Late Eocene to Miocene sedimentary rocks in its centre and up to a further 3000 m may have been removed by erosion (Nathan & others 1986). The basin was drilled in the late 1920s and in 1968, 1970 and 1985 although only the last hole, Matiri-1, reached bedrock (at 1467 m; Dunn & others 1986). The rocks in the basin are generally steeply dipping, having been folded into a series of synclines separated by faulted anticlines. No closed structural traps are known and there are few potential reservoir rocks with sufficient permeability or porosity, and consequently the hydrocarbon prospects are assessed as low (Nathan & others 1986).

In Marlborough, oil seeps are known from Pahau terrane rocks at London Hill and the Amuri Limestone in Isolation Creek, south of the Waima River. Both seeps occur in close proximity to major faults. The oil is likely to have been sourced from the Late Cretaceous Seymour Group and have migrated up the fault zones to the surface (Field, Uruski & others 1997). While both source rocks and potential reservoir rocks are favourable, deformation has limited the possibility of any significant hydrocarbon traps. Mudstone at the base of the Amuri Limestone in Mead Stream has been correlated with the Waipawa Formation, a hydrocarbon source rock in the eastern North Island (Field, Uruski & others 1997). However, in Marlborough, the mudstone is only a few metres thick, and significant hydrocarbon potential from this rock is unlikely.

In northern Canterbury hydrocarbons have been reported from a number of locations, principally in the Cheviot area (Field, Browne & others 1989). Several seeps occur in the Torlesse rocks although the hydrocarbons are most likely to have originated in adjacent Late Cretaceous-Paleogene rocks (e.g., the Eyre Group), which include potential source and reservoir rocks as well as other seeps. Significant structural traps have not yet been identified, and there is the potential for stratigraphic traps. Gas containing a very high ethane content escapes from the Hanmer thermal springs (Field, Browne and others 1989).

The offshore area of the Kaikoura map has had limited petroleum exploration but seismic data of varying quality has identified several deep sedimentary basins (Uruski 1992; Field, Uruski & others 1997). The basins may contain potential source rocks that have been buried sufficiently to generate hydrocarbons.
It is beyond the scope of this summary text to discuss engineering geological parameters of Kaikoura map area rocks except in very general terms. Site specific investigations should always be undertaken with exploratory trenching and/or drilling, and other testing as appropriate under geotechnical supervision.

**Basement rocks**

The majority of the basement rocks, of Cambrian to Early Cretaceous age, are generally hard and strong. Rock strength may be diminished or influenced by grain size, degree of weathering, joint spacing, cleavage, shearing and bedding. Examples of weaker rocks are the higher grade schists that have a well-developed foliation and minerals such as micas, which decrease rock strength. Mélange and other zones of deformed rocks commonly have a fractured, sheared fine-grained matrix and are consequently less competent than less-deformed basement rocks such as greywacke. Slope failure is common in these zones.

**Late Cretaceous-Pliocene rocks**

The Late Cretaceous to Pliocene rocks vary considerably in lithology and although some of the older sandstones have characteristics similar to Torlesse greywackes, most are less indurated or are only weakly cemented. As a consequence their engineering properties are diverse. While most sandstones and conglomerates are relatively hard, fine-grained lithologies such as siltstone and mudstone are soft. Finer grained lithologies tend to weather more rapidly on exposure, forming clay-rich material with a further reduction in rock strength and an increased potential to fail, particularly where water saturated and/or sheared. Where constituent clay minerals have high plasticity or have swelling properties, such as smectite, the risk of failure on slopes or in excavations is extreme (Fig. 58). Limestones and most igneous rocks are usually competent, with the exception of uncemented or weathered tuff. Rocks with only a slightly elevated carbonate content tend to be more competent than those lacking CaCO₃.

**Quaternary sediments**

Quaternary sediments are characteristically weak, particularly where weathered. Deposits dominated by serpentinite or Cenozoic mudstone clasts are particularly prone to a loss in strength on weathering. However, many deposits have a silty or sandy clay matrix making them less prone to failure on slopes, even where weathered. An example is weathered Moutere Gravel which is usually stable in steep natural or artificial cuts. Loess is widespread in the east of the map area and, on older terraces and in gullies, may form deposits up to several metres thick. Loess has a relatively high internal strength but on hillsides it is prone to tunnel gully erosion. Landslide deposits are generally composed of incompetent materials, contain numerous failure planes and are extremely weak. Many are currently active or are only marginally stable (see below).

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*Figure 58* Bentonitic mudstone within the relatively weak Waima Formation is prone to slipping, and movement of this landslide north of Kekerengu (known as Blue Slip) periodically closes State Highway 1 and the Main Trunk Railway. The active trace of the Kekerengu Fault lies at the base of the steeper slopes behind.

*Photo CN8369/2: D.L. Homer.*
GEOLOGICAL HAZARDS

Parts of the Kaikoura map area are subject to geological hazards including landslides, earthquakes, tsunami, and coastal erosion. The main hazards are discussed here in general terms, but the information presented in this map and text should not be used for detailed natural hazard zonation or assessment of specific sites without additional geotechnical advice. Recording of site-specific natural hazard information is the responsibility of local authorities, and an awareness of the presence of major hazards, and their potential for recurrence, is essential for regional and district planning purposes.

Landslides

Slope instability is widespread in the map area in all rock units underlying sloping ground. Some failures are the result of weak, water-saturated ground, but many are earthquake-induced, as demonstrated during the 1888 Hope and 1929 Buller (Murchison) earthquakes. Excluding failures triggered by earthquakes, extensive failures are rare in the Cambrian-Early Cretaceous rocks northwest of the Alpine Fault. Large, isolated failures occur in Rakaia and Pahau rocks southeast of the fault. Prominent, probably earthquake-induced, failures have dammed lakes Constance, Alexander and McRae as well as Lake Matiri northwest of the Alpine Fault. The Hope Fault scarp between Hanmer and Kaikoura has numerous landslides attributed to fault movement and earthquake shaking (Eusden & others 2000). Landsliding is widespread in weak mélangé rocks and in Cretaceous and Cenozoic rocks, where bedding dips parallel to the slope, or where weak rocks are undercut by the sea or rivers. Examples are the large landslides that dammed the Matakitaki (Fig. 59) and other rivers during the 1929 Murchison earthquake. There are many failures involving Cenozoic rocks in the Waima River area. Late Cretaceous to Early Eocene rocks containing bentonitic clays also tend to be unstable (Fig. 58). In mountainous terrain, rock falls are relatively widespread and superficial failures involving soil regolith are common on most steep slopes in the map area.

Coastal erosion

Hard basement rocks form about half of the coastline in the Kaikoura map area and coastal erosion is only locally a significant hazard. North and south of Kaikoura township, SH 1 is cut into coastal cliffs or built out into the heads of small bays and rip-rap is placed as necessary to mitigate local marine erosion. Even where more extensive coastal plains (composed of softer terrestrial, aeolian or marine sediments) are present, adjacent headlands of hard rock tend to stabilise the coast. Between 1942 and 1974, along a 30 km stretch of coastline from Oaro to Mangamaunu there has been overall net coastal accretion (up to 40 m in places).

Figure 59 The 1929 Buller (Murchison) earthquake triggered widespread landsliding, causing considerable damage and some loss of life. This example originated from east-dipping Mangles Formation on the west bank of the Matakitaki valley, and slid over 1 km to demolish an occupied farmhouse and temporarily dam and divert the river.

Photo CN46447/21: D.L. Homer.
but locally up to 15 m of land lost because of coastal erosion (Gibb 1978). The effects of coastal erosion, and short-term phenomena such as storm and tsunami surges, can be mitigated by ensuring new housing and other structures are set back a prudent distance from the coast. Provision should be made for a potential rise in sea level in response to global warming. A rise in sea level is likely to initiate increased coastal erosion and increase the risk of marine flooding of very low-lying areas inland of beach ridges or dunes.

**Earthquake hazards**

The Kaikoura map area is situated within a region of high seismicity (earthquake activity) as historical records indicate (Figs 3, 60). Large shallow earthquakes, in particular, commonly result in surface rupture and the numerous active faults in the Kaikoura map area are testament to the relatively high frequency of large and shallow earthquakes in the region (Table 1).

Offshore faults include the Needles, Campbell Bank and Boo Boo faults and the Chancet and North Mernoo fault zones. Many more unnamed faults have been mapped onshore and offshore. Active faults by definition have had demonstrable displacement in the last 125 000 years, or two or more movements in the last 500 000 years. Activity is generally determined where faults displace Late Quaternary surfaces and deposits, particularly those of alluvial terraces and fans (Q1a, Q2a). Activity may only be evident at a single locality along a fault but for mapping purposes the fault activity has been extrapolated (or interpolated where there are multiple localities) along strike. An active fold has been mapped near Ward where Late Quaternary surfaces are measurably tilted. The basin and range topography in northern Canterbury is in part due to ongoing active folding (Litchfield & others 2003).

Since written records of earthquakes have been kept in New Zealand (from about 1840), eight shallow magnitude 6.0 or greater earthquakes have originated within the Kaikoura map area. Two of these earthquakes, the 1848 Marlborough and 1888 North Canterbury earthquakes, had magnitudes over 7.0. They both caused moderate to strong shaking over a large part of the Kaikoura map and were associated with significant, clearly identifiable surface fault ruptures. Historical documents record that in the 1848 M7.5 Marlborough earthquake, rupture occurred along more than 105 km of the Awatere Fault, from the coast to at least as far as Barefell Pass (Grapes & others 1998). Shaking intensities of MM9, possibly MM10, were experienced in the Wairau and Awatere valleys where most buildings (predominantly cob structures) were extensively damaged or destroyed. There were many instances of ground

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**Figure 60** Major historic earthquakes within and adjacent to the Kaikoura map area.
Table 1. Rupture event displacement, slip rate, last rupture, recurrence interval and likely magnitude of significant active faults and associated earthquakes in the Kaikoura map area (after Pettinga & others 2001; Yetton 2002; Fraser & others 2006).

<table>
<thead>
<tr>
<th>Fault name (segment)</th>
<th>Average displacement per rupture (m)</th>
<th>Slip rate(s) mm/yr</th>
<th>Last rupture (years before present)</th>
<th>Recurrence interval (years)</th>
<th>Magnitude (Mw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waimea Fault</td>
<td>-</td>
<td>0.2</td>
<td>-</td>
<td>-</td>
<td>7.1 – 7.5</td>
</tr>
<tr>
<td>Alpine (Wairau) Fault</td>
<td>7</td>
<td>4 - 5</td>
<td>&gt;1000</td>
<td>1000 - 2300</td>
<td>7.3 – 7.7</td>
</tr>
<tr>
<td>Alpine Fault (Haupiri-Tophouse)</td>
<td>3</td>
<td>2.4 - 12</td>
<td>1600 - 1670</td>
<td>500</td>
<td>7.1 – 7.5</td>
</tr>
<tr>
<td>Awatere Fault (northern)</td>
<td>5.5 - 7.5</td>
<td>7.7</td>
<td>158</td>
<td>690 - 1500</td>
<td>7.5</td>
</tr>
<tr>
<td>Awatere Fault (southern)</td>
<td>-</td>
<td>8</td>
<td>522 - 597</td>
<td>1900 - 4000</td>
<td>7.5</td>
</tr>
<tr>
<td>Clarence Fault (northern)</td>
<td>~7</td>
<td>4 - 7</td>
<td>-</td>
<td>1500</td>
<td>7.7</td>
</tr>
<tr>
<td>Clarence Fault (southern)</td>
<td>7</td>
<td>4 - 8</td>
<td>-</td>
<td>1080</td>
<td>-</td>
</tr>
<tr>
<td>Kekerengu Fault</td>
<td>5.5</td>
<td>5 - 10</td>
<td>-</td>
<td>730</td>
<td>7.2</td>
</tr>
<tr>
<td>Jordan Thrust</td>
<td>2 - 4</td>
<td>1.3 - 2.5 (vertical), 0 - 3.4 (horizontal)</td>
<td>-</td>
<td>1200</td>
<td>7.1</td>
</tr>
<tr>
<td>Hope Fault (Conway-offshore)</td>
<td>-</td>
<td>11 - 35</td>
<td>168</td>
<td>120 - 300</td>
<td>7.6</td>
</tr>
<tr>
<td>Hope Fault (1888 rupture)</td>
<td>1.5 - 2.6</td>
<td>14 ± 3</td>
<td>100</td>
<td>120</td>
<td>7.2</td>
</tr>
<tr>
<td>Hanmer Fault</td>
<td>1 - 3</td>
<td>1 - 2</td>
<td>&lt;10000</td>
<td>1000</td>
<td>6.9</td>
</tr>
<tr>
<td>Kapako Fault</td>
<td>-</td>
<td>4.4 - 8.4</td>
<td>&lt;10000</td>
<td>500</td>
<td>7.3</td>
</tr>
<tr>
<td>Esk Fault</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5000 - 10000</td>
<td>7.0</td>
</tr>
<tr>
<td>Hundalee Fault</td>
<td>1 - 2</td>
<td>0.4 - 1.5</td>
<td>&lt;10000</td>
<td>800 - 5000</td>
<td>7.0</td>
</tr>
<tr>
<td>Kaiwara Fault</td>
<td>-</td>
<td>0.5</td>
<td>&lt;10000</td>
<td>2000 - 5000</td>
<td>7.1</td>
</tr>
<tr>
<td>Omihi Fault</td>
<td>-</td>
<td>1</td>
<td>&lt;10000</td>
<td>-</td>
<td>6.7</td>
</tr>
<tr>
<td>Balmoral Fault</td>
<td>2 - 6</td>
<td>1 - 2</td>
<td>1495 - 1925</td>
<td>5000 - 10000</td>
<td>-</td>
</tr>
</tbody>
</table>

The Modified Mercalli Intensity scale (MM) (in part; summarised from Downes 1995)

**MM 2**: Felt by persons at rest, on upper floors or favourably placed.

**MM 3**: Felt indoors; hanging objects may swing, vibration similar to passing of light trucks.

**MM 4**: Generally noticed indoors but not outside. Light sleepers may be awakened. Vibration may be likened to passing of heavy traffic. Doors and windows rattle. Walls and frames of buildings may be heard to creak.

**MM 5**: Generally felt outside, and by almost everyone indoors. Most sleepers awakened. Some glassware and crockery may be broken. Open doors may swing.

**MM 6**: Felt by all. People and animals alarmed. Many run outside. Objects fall from shelves. Glassware and crockery broken. Unstable furniture overturned. Slight damage to some types of buildings. A few cases of chimney damage. Loose material may be dislodged from sloping ground.

**MM 7**: General alarm. Furniture moves on smooth floors. Unreinforced stone and brick walls crack. Some pre-earthquake code buildings damaged. Roof tiles may be dislodged. Many domestic chimneys broken. Small slides such as falls of sand and gravel banks. Some fine cracks appear in sloping ground. A few instances of liquefaction.

**MM 8**: Alarm may approach panic. Steering of cars greatly affected. Some serious damage to pre-earthquake code masonry buildings. Most unreinforced domestic chimneys damaged, many brought down. Monuments and elevated tanks twisted or brought down. Some post-1980 brick veneer dwellings damaged. Houses not secured to foundations may move. Cracks appear on steep slopes and in wet ground. Slides in roadside cuttings and unsupported excavations. Small earthquake fountains and other instances of liquefaction.


Figure 61

(a) The Hope Fault at Glynn Wye ruptured in 1888 and evidence from offset moraines indicates that lateral movements of 1.5 to 2.6 m have occurred approximately every 120 years on average. The Hope Fault here (centre) tracks towards Hanmer Basin (top centre). 

*Photo CN3602/26: D.L. Homer.*

(b) Geologist Alexander McKay visited the Hope Fault at Glynn Wye soon after it ruptured, noting the dextral displacement marked by the 2.4 m offset of this fence. His inference that faults could have significant and repeated lateral movement was an idea that was not supported by the wider geological community until many decades later.

*Photo: A. McKay.*

damage including landslides, ground cracking, liquefaction and differential settlement (Eiby 1980; Grapes & others 1998). Ground damage may have occurred as far south as northern Canterbury. The 1848 earthquake also caused considerable damage in the then lightly populated town of Wellington.

Forty years later, the Kaikoura map area was strongly shaken by the 1888 M7.0–7.3 North Canterbury earthquake, which ruptured a 30 ± 5 km segment of the Hope Fault west of Hanmer Springs. Up to 2.6 m horizontal displacement on the fault was recorded at the time (Fig 61a,b). Many cob and stone buildings were badly damaged or destroyed (MM9) in the Hope valley and on the Hanmer Plain in a relatively narrow zone parallel to the fault (Cowan 1991). Damage to household contents (MM6) extended as far as Kaikoura and the West Coast. Landslides and ground damage occurred in the highest intensity areas. Other damaging earthquakes centred in the Kaikoura map area include the 1901 M6.9 Cheviot earthquake which caused considerable damage to buildings in the Cheviot area, with intensities of MM8–9 occurring along a 30–40 km strip from Domett to Conway Flat (D.J. Dowrick, unpublished data). The 1922 M6.4 Waiau earthquake caused minor structural damage, principally in and between the settlements of Hanmer and Waiau (Downes 1995).

Parts of the Kaikoura map area have also been subjected to strong shaking from large earthquakes whose epicentres lie outside the area. The 1855 M8.1 Wairarapa earthquake that ruptured the Wairarapa Fault in the southern North Island (Grapes & Downes 1997) caused subsidence in the lower Wairau valley. Intensities of MM5 and above were experienced over a large part of the Kaikoura map area and the maximum intensity of MM8, possibly MM9, occurred from the lower Awatere valley to Kekerengu and Cape Campbell.

The 1929 M7.0 Arthur’s Pass and 1929 M7.7 Buller earthquakes ruptured the Poulter Fault (Berryman & Villamor 2004) and the White Creek Fault (Fyfe 1929) respectively. Both these earthquakes occurred in sparsely populated areas outside the Kaikoura map area. Nevertheless, the Buller earthquake was responsible for 15 deaths, the majority of which were caused by landslides (Henderson 1937). A large part of the Kaikoura map area was shaken with intensities of MM6 or more. Northwestern parts of the area experienced intensities of MM8, resulting in considerable structural and environmental damage and.
extensive landsliding (Hancox & others 2002). The 1968 M7.1 Inangahua earthquake was less extensive in its strong ground shaking effects, and the maximum intensity in the Kaikoura map area was probably MM7 (Downes 1995).

A re-evaluation of seismic hazard in New Zealand by Stirling & others (2001, 2002) uses models of the likely ground acceleration at any one place, based on historical earthquakes and the Late Quaternary geological and active faulting record. The highest levels of Peak Ground Acceleration (PGA) in the map area, corresponding to the most severe shaking and damage, are predicted along the western Hope Fault. The mean return periods for specific intensity levels of earthquake-induced ground shaking vary significantly across the area, the return period decreasing (i.e. earthquakes occurring more frequently) towards the Hope Fault (Table 2).

The consequences of a large, shallow earthquake in or adjacent to the Kaikoura map area will be strong ground shaking, multiple aftershocks, shaking-induced slope instability, and possible surface fault rupture. Fault rupture is known to have occurred within the last 500 years on the Hope and Awatere faults (Table 1; Fig 61). The recurrence interval on individual faults in the Kaikoura map area is between 120 and many tens of thousands of years.

During an earthquake the felt ground shaking intensities will vary considerably depending on ground surface conditions and on distance from the focus of the earthquake. Unconsolidated water-saturated sediments, such as swamp deposits, estuarine mud, marine sand and gravel, and landfill, will amplify shaking compared with hard competent basement rocks nearby. The towns of Murchison, Hanmer Springs and Culverden are built on young Quaternary deposits, and it is likely that parts of these urban areas will show some shaking amplification, as Murchison did in the 1929 earthquake (Suggate & Wood 1979). Surface rupture along a fault could result in ground displacements of several metres both horizontally and vertically. Such offsets would disrupt all services, such as roads, railways, water, and power and telephone cables.

Table 2. Mean return periods for earthquake shaking intensity for the towns of Murchison, Hanmer Springs, Culverden and Kaikoura, derived from unpublished data of W.D. Smith using the seismicity model of Stirling & others (2002).

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Murchison</th>
<th>Hanmer Springs</th>
<th>Culverden</th>
<th>Kaikoura</th>
</tr>
</thead>
<tbody>
<tr>
<td>MM6 or greater</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>MM7 or greater</td>
<td>34</td>
<td>21</td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td>MM8 or greater</td>
<td>230</td>
<td>53</td>
<td>100</td>
<td>120</td>
</tr>
<tr>
<td>MM9 or greater</td>
<td>2400</td>
<td>170</td>
<td>1000</td>
<td>410</td>
</tr>
</tbody>
</table>

Tsunami

Coastal flooding and damage caused by tsunami are possible along the entire coastline of the map area as well as the lower reaches of rivers. The coastal town of Kaikoura and adjacent coastal communities are at risk. Large tsunami of more than 4 m are life-threatening, and can be very damaging to structures. Even small tsunami can cause erosion and create problems - for example, the strong currents generated affect boats at anchor. The impact of a tsunami depends on the size of the energy source and its distance from the coastline, the propagation path of the tsunami and the morphology of the coast and the adjoining seabed. It is difficult to predict the impact accurately.

In historical times the coastline has not been strongly affected by tsunami generated by earthquakes at distant locations, such as South America. Locally generated tsunami, potentially caused by near-shore fault rupture or submarine landsliding, pose a greater threat. The tsunami caused by the 1855 M8.1 Wairarapa earthquake is the largest known local source tsunami to have occurred historically in the Kaikoura map area. The tsunami was observed throughout Cook Strait area and along the Kapiti and northeastern Marlborough coasts (Grapes & Downes 1997). Near the Clarence River mouth, the tsunami inundated parts of the coastline to several tens of metres inland and deposited boats above high-tide mark. Submarine slumping, particularly into the Kaikoura Canyon, has the potential to generate a large tsunami that would arrive onshore with minimal or no warning.

Locally generated tsunami are a cause for concern as wave heights may be large enough to be damaging and life-threatening, possibly catastrophic, and travel times are generally too short for Civil Defence warnings. The public should treat strong earthquake shaking as a signal to leave coastal locations and move inland. Similarly unusual changes in sea behaviour (sudden rise or withdrawal), possibly accompanied by roaring from the sea, could also signal the imminent arrival of a tsunami and the coastal area should be evacuated.
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Aerial photograph interpretation of landslides by T.P Coote, GD. Dellow and S.A.L. Read was compiled from the Landslide Map of New Zealand project. The offshore geology has been compiled from Field, Browne & others (1989), Field, Uruski & others (1997) and unpublished and some published data of P.M. Barnes and co-authors listed in the references. We thank the National Institute of Water and Atmospheric Research for permission to reproduce offshore bathymetry, faults and folds from their digital records.


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The text was written by M.S. Rattenbury, D.B. Townsend and M.R. Johnston with considerable input to the geological hazards section from G.L. Downes. The diagrams were prepared by P. Carthew, M.S. Rattenbury and D.B. Townsend. Parts or all of the map and text were reviewed by G.H. Browne, J.S. Crampton, S.W. Edbrooke, B.D. Field, P.J. Forsyth, C.J. Hollis, M.G. Laird, N.J. Litchfield, T.A. Little, and I.M. Turnbull. The map and text were edited by P.J. Forsyth and D.W. Heron. Text layout was by P.L. Murray. M.J. Isaac checked proofs of the map and text.

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AVAILABILITY OF QMAP DATA

The geological map accompanying this book is derived from information stored in the QMAP geographic information system (GIS) database maintained by GNS Science and from other GIS-compatible digital databases. The data shown on the map are a subset of the available information. Customised single-factor and multifactor maps can be generated from the GIS and integrated with other data sets to produce, for example, maps showing fossil or mineral localities in relation to specific rock types, or maps showing rock types in relation to the road network. Data can be presented for user-defined specific areas, for irregular areas such as local authority territories, or in the form of strip maps showing information within a specified distance of linear features such as roads or the coastline. The information can be made available at any required scale, bearing in mind the scale of data capture and the generalisation involved in digitising. Maps produced at a scale greater than 1:50 000 will generally not show accurate, detailed geological information. The QMAP series maps are available in GIS vector and raster digital form using standard data interchange formats.

For new or additional information, for prints of this map at other scales, for selected data or combinations of data sets or for derivative or single-factor maps based on QMAP data, please contact:

QMAP Leader
GNS Science
P.O. Box 30 368
Lower Hutt
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This map and text illustrate the geology of the Kaikoura area, extending east from Murchison to southern Marlborough, and south to Waikari in north Canterbury. Onshore geology is mapped at a scale of 1:250 000 while offshore the bathymetry, thick Quaternary sedimentary deposits and major structural elements are shown. Geological information has been obtained from published and unpublished mapping and research by GNS Science geologists, from work by staff and students of the University of Canterbury, Victoria University of Wellington and the University of Otago, from offshore mapping by the National Institute of Water and Atmosphere, and from mineral exploration reports. All data are held in a geographic information system and are available in digital format on request. The accompanying text summarises the geology and tectonic development, as well as the geological hazards and the economic and engineering geology of the map area. The map is part of a series initiated in 1996 which will cover the whole of New Zealand.

The map area is mostly underlain by Mesozoic greywacke rocks of the Torlesse terrane, except in the northwest where narrow fault-bounded remnants of the Buller, Takaka, Brook Street, Murihiku, Dun Mountain-Maitai and Caples terranes occur, as well as the Median Batholith and other granitic rocks. Discontinuously preserved late Early Cretaceous to Pliocene, predominantly marine sedimentary and volcanogenic rocks occur in the northwest, the east and the south of the map area. Quaternary terrestrial sediments are widespread on land, including till, loess, scree, landslide, alluvial fan and alluvial terrace deposits. Numerous active faults of the Marlborough Fault System transect the map area, marking the plate boundary zone between the Pacific and Australian tectonic plates. Several of these faults have moved in historic times contributing to the region’s relatively high seismic hazard.

The highest point of the Inland Kaikoura Range is Mt Tapuae-o-Uenuku (2885 m) where the summit region is composed of erosion-resistant Cretaceous mafic igneous intrusive rocks and associated hornfelsed Pahau terrane greywacke. The active Clarence Fault separates the Inland Kaikoura Range from the distinctive Chalk Range in the middle distance, and the white scree there and in the foreground emanate from Paleogene carbonate rocks.

Photo: D.B. Townsend

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