WILLIAM LESLIE LEASK

BASIN ANALYSIS OF TERTIARY STRATA IN GOLDEN BAY, NELSON

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ABSTRACT

Eocene to Miocene strata comprise the Brunner Coal Measures (Ak-Ld), Takaka Limestone (Ld-Po), Tarakohe Mudstone (Pl-Sl) and Waitui Sandstone (Sc-Sl), and form a transgressive-regressive sequence on an essentially stable structural platform. Brunner Coal Measures in the Takaka valley (up to 350m thick) consist of cross-bedded sand and gravel, interlaminated sand and silt, bioturbated muddy sandstone, carbonaceous mudstone and coal. Five facies associations are recognized and interpreted as river/floodbasin, estuarine and shallow marine deposits. In the Aorere and Parapara River catchments, two new members are recognized: the Quartz Wash Member, comprising quartzose sand and conglomerate, and the Washbourn Limonite Member, a sedimentary iron-ore deposit.

The Takaka Limestone (up to 100m thick), consists of bryozoan, bivalve or sandy grainstone or packstone, deposited on a tidal current-swept shallow-middle shelf with minimal terrigenous influx. Diagenesis was controlled by pressure-solution during deep burial, and resulted in a tightly cemented rock with dolomite and neomorphic features.

The Tarakohe Mudstone (up to 900m thick) is dominated in its lower half by massive mudstone of hemipelagic and turbiditic origin, and in its upper half by shallow shelf-estuarine sandstones and mudstones. The Waitui Sandstone (160m thick) comprises shallow marine sandstone.

Deposition of the Brunner Coal Measures took place in localized fault-angle depressions. The Takaka Limestone was deposited during a period of regional subsidence and minimal tectonic activity. The Tarakohe Mudstone and Waitui Sandstone were deposited in synclinal basins which were later modified by rising monoclinal boundaries.

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CHAPTER ONE

INTRODUCTION

The aim of this study is to construct a basin analysis of the Tertiary strata in Golden Bay, by integrating the shape, tectonic setting, lithofacies and current systems into a sedimentary model (cf. Potter & Pettijohn, 1963:248) and defining the evolution of the basin during the thirty million years represented by the stratigraphic record. The Golden Bay area is eminently suitable for this type of study in that:

(1) it comprises a relatively well exposed sequence with a wide variety of terrestrial, shallow marine and deep water facies;

(2) the study area is the southern extremity of the Taranaki Basin and is an onshore equivalent of facies associations located in offshore wells;

(3) it is preceded by several detailed studies of Tertiary strata in west Nelson and therefore paleogeographic conclusions can be placed in a regional perspective.

Location

The study area (with the exception of Gouland Downs) lies within the Golden Bay watershed, north-west Nelson (figs.1,5,6). It is drained by two major river systems, the Takaka and Aorere Rivers, which are separated by mountain ranges up to 1775m high, and is bounded to the east and west by the steep flanks of the Pikikiruna and Wakamarama Ranges. Tertiary rocks are mainly confined to the two valleys and to remnants of an Early Tertiary peneplain preserved on the Gouland Downs, the south-east flank of the Aorere valley and the Mount Arthur Tableland (fig.5a,b). The greatest thickness of strata (at least 900m) is on the coastal plain between the two rivers.

The mountain ranges in the centre of the study area are devoid of Tertiary strata, and one of the major challenges of this study is to construct the paleogeography of this area by inference from adjoining areas.

Past and Present Investigations

The German geologist von Hochstetter visited Golden Bay in 1859

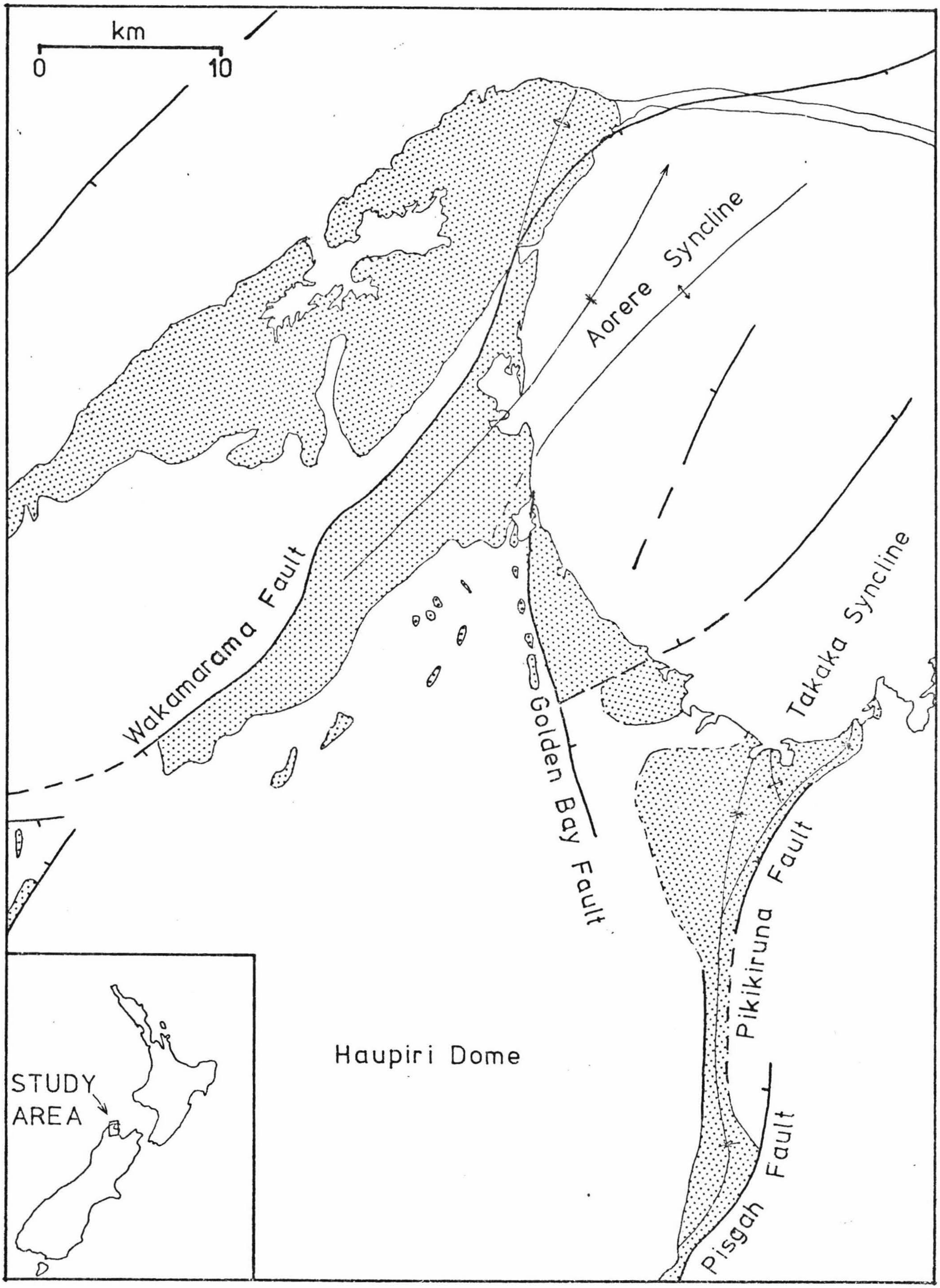

Fig.1: Simplified Tertiary geology of Golden Bay, Nelson (after Grindley,1961). Quaternary sediments omitted. For legend, see fig.4.

in the closing stages of the Aorere goldrush (Fleming, 1959a), and most subsequent investigations of the Tertiary strata during the nineteenth century (summarized by Bell et al., 1907) were concerned with the economic potential of the Brunner Coal Measures in the Aorere Valley. Bell et al. (1907) presented the first thorough investigation of Golden Bay geology. They divided the Tertiary strata into stratigraphic units identical to the present formations and members, in contrast to Henderson et al. (1959) who mapped the Tertiary strata in the southeast part of the study area, without elaboration, as "Oamaruian". Bell et al. also discussed the potential of coal, clay and gold deposits and, in particular, they mapped and interpreted the Washbourn Limonite Member. A more detailed assessment of the iron-ore in the mid 1930s was reported by Jones (1939) and Gage (1940). Wellman (1945, 1950a,b,c) surveyed coal resources in the study area, mapped the Tertiary strata in chronostratigraphic units and synthesized the stratigraphy and structure. His maps were incorporated, largely unaltered, in the 1:250,000 map of Grindley (1961) and his stratigraphic columns were published in Wellman et al. (1973).

In recent years the region has been mapped at 1: 63,360 scale by Bishop (1971, Sheet S1-3) and Grindley (1971, Sheet S8 ; in press, Sheet S13). Large-scale maps of smaller areas have been prepared by Cooper (1962, Upper Takaka) and Bishop (1968, Gouland Downs). These maps have been used in the compilation of two 1: 63,360 maps presented with this thesis which emphasize the Tertiary geology of the study area.

Previous detailed investigations of Tertiary strata in northwest Nelson (fig.2.) include sedimentological studies at Karamea (German, 1976), Heaphy River (Leask, 1977) and Kahurangi Point - Abel Head (Titheridge, 1977). Brief oil company reports on the Golden Bay strata were made by Sprigg (1962), Hicks and Cope (1964) and Harrison and van Oyen (1969). The offshore structure of the Taranaki Basin has been outlined by marine seismic surveys, (Officer, 1959; Tasman Petroleum, 1966; Godechot, 1968; and Pinchon, 1972). The stratigraphy and structure of the Taranaki Basin has been synthesized by Pilaar and Wakefield (1978).

Fieldwork for the present study was carried out mainly during May-June and December 1978. The writer also visited Tertiary sequences at Kahurangi Point - Abel Head, Heaphy River, Karamea, Nelson City and Kaka.

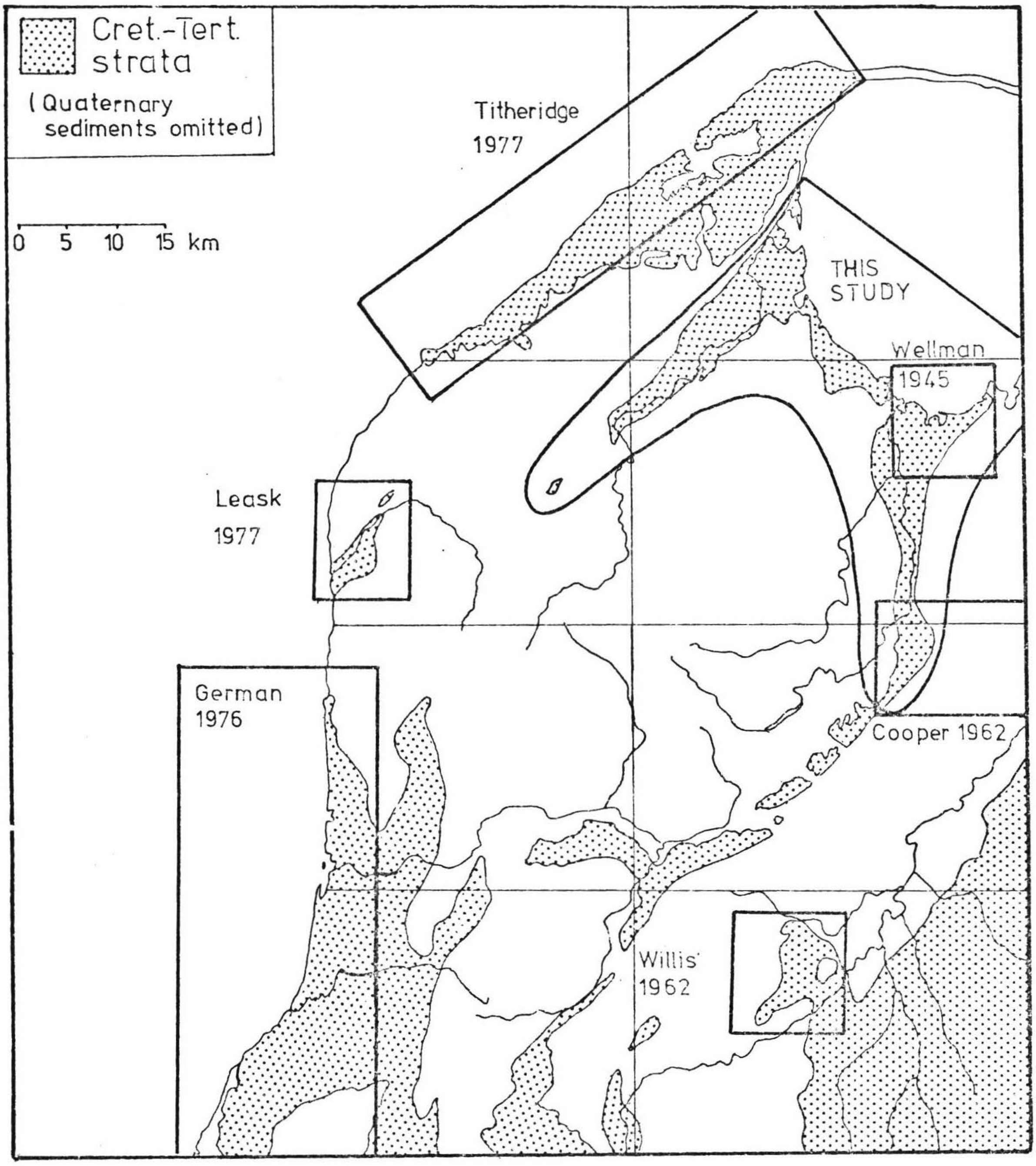

Fig.2: Previous studies of Tertiary strata in west Nelson. NZMS 1 sheet boundaries delineate unpublished bulletin manuscripts by H.W.Wellman in Sheets S1-3, 7, 8, 12 and 17-18.

Helicopter-assisted fieldwork in the Garibaldi Ridge area will be discussed by Andrews, Leask and Titheridge (in prep., Tertiary geology of the Garibaldi Ridge and Karamea Bend area, southwest Nelson).

Methods

Thirty-two stratigraphic sections were measured and are presented in Appendix 1. Measurements were mainly by 1.5m staff and Abney Level or eye levelling.

Thin sections of 115 limestones and cemented sandstones were examined. All carbonate samples were stained in acidic solutions of Alizarin Red-S and potassium ferricyanide (Dickson, 1965: ref.Appendix 3) and sprayed with a protective coat of polyurethane varnish.

Selected limestone samples were dissolved in hydrochloric acid solution not exceeding 10% concentration and the insoluble residues were wet-sieved and dried to determine their $CaCO_3$: terrigenous sand: terrigenous mud ratios. For a small number of samples, the insoluble sand fractions were dry-sieved at 0.5 Ø intervals.

The mineralogy of selected sand samples of Brunner Coal Measures, Tarakohe Mudstone and Waitui Sandstone was determined on unmounted samples under reflected light. Thirteen clay and siltstone samples were examined by X-ray diffraction.

Seven macrofossil samples were identified with the assistance of Prof. Paul Vella and Dr. Alan Beu.

Sandstones are classified according to texture and composition (relative proportions of quartz, feldspar and rock fragments) after Folk et al. (1970). Limestones are classified by depositional texture (Dunham, 1962) but where texture is indeterminable in the field or in hand specimen the terms calcarenite or calcisiltite have been used (cf. Andrews, 1976).

Grid references were determined from NZMS 1 maps of 1:63,360 scale overprinted with metric grid coordinates. The study area lies within NZMS 1 maps S3, S7, S8 and S13 and NZMS 260 maps M25, M26,, N25 and N26.

CHAPTER TWO

REGIONAL SETTING

Pre-Tertiary Geology

Lower Paleozoic rocks are subdivided into Western, Central and Eastern Sedimentary Belts separated by major thrust faults (Cooper, 1979). The Western Sedimentary Belt consists of quartz-rich sandstone, siltstone and black shale. The Central Belt is dominated by volcanics, volcanogenic sediments and limestones, and the Eastern Belt contains limestones, quartz-rich sandstone and shale. These rocks are complexly deformed and metamorphosed. Grindley (1971) suggested that the Central Belt strata were thrust over Eastern and Western Belts as three nappe folds originating from the south and east. Alternatively, the Central Belt could have been the basal part of a continuous Central and Eastern Belt succession and was emplaced by upwards and westwards thrusting (Cooper, 1979). The whole sequence was folded about steep axial planes plunging either north or south during Middle-Late Devonian time, and this deformation was closely followed by intrusion of granites of the Karamea Batholith. A second phase of granite intrusion during the Middle Cretaceous emplaced the Separation Point Batholith (Grindley, 1971) and overprinted many mineral ages within the Karamea Batholith.

Permian conglomerate and sandstone, deposited in fluvial and shallow marine environments, unconformably overlie Lower Paleozoic rocks on Parapara Peak.

Northwest of the study area, the Pakawau Group comprises conglomerates, sandstones and mudstones of Haumurian-Teurian age (Titheridge, 1977). These are interpreted as braided river and flood-basin sediments which accumulated in a fault-angle depression west of the Wakamarama Fault.

Tertiary Stratigraphy

Nomenclature.

The group nomenclature of Nathan (1974) is extended for the first time beyond the Buller-North Westland Region. The writer considers that there are no significant differences between the sequences of the West Coast and the Nelson Regions; in particular the Karamea-Heaphy River sequence (German, 1976; Leask 1977) is very similar to that in Golden Bay.

The Westhaven Group is replaced by the Mawheranui, Nile and Blue Bottom Groups (Table 1; Nathan, 1974). Brunner Coal Measures is considered synonymous with Motupipi Coal Measures and has precedence by age and wider distribution. Two new members are defined below.

The Takaka Limestone is redefined, and is extended into the Buller Region as far south as Karamea. The name therefore has precedence over a number of unpublished stratigraphic names proposed in recent theses (Table 2).

In general, the adoption of formal lithostratigraphic members has been avoided, and a number of informal lithofacies have been defined for each formation.

Mawheranui Group

Brunner Coal Measures (Hector, 1884:xiv)

The Brunner Coal Measures in the Takaka Valley consist of up to 350m of strata, typically composed of alternating sequences of cross-bedded sand, laminated sandstone, carbonaceous mudstone and thin sub-bitumenous coal. Pollen samples date the formation as Bortonian to Duntroonian (fig.3; Couper, 1960; J.I. Raine, 1979). Two new members are proposed:

Quartz Wash Member (new name)

Coarse quartzose conglomerate and sandstone occur in scattered patches up to 20m thick on the southeast flank of the Aorere Valley and at Parapara. Thin muddy sandstone and sheared pyritic coal seams are also present. The name of the member is the old miners' term "quartz wash" (cf. Bell et al., 1907) and the type locality is proposed as the Quartz Ranges,[1] an area of subdued relief near Trig Q in the headwaters of Finney and Little Doctor Creeks (M26/697392[2]-·694391). The age is

1. Not a recognised Geographic Board name, but described by McKay (1896:17)
2. This and subsequent six-figure numbers are grid references based on the NZMS 260 metric grid.

Bell et al. (1907)		Bishop (1971); Grindley (1971; in press)		This Study		
OAMARU SERIES		WESTHAVEN GROUP	WAITUI SANDSTONE	BLUE BOTTOM GROUP	WAITUI SANDSTONE	
	BLUE & YELLOW CLAYS		TARAKOHE MUDSTONE		TARAKOHE MUDSTONE	
	LIMESTONES		TAKAKA LIMESTONE	NILE GROUP	TAKAKA LIMESTONE	
	SANDSTONES, SHALES, COAL SEAMS & CONGLOMERATES		MOTUPIPI COAL MEASURES	MAWHERANUI GROUP	BRUNNER COAL MEASURES	QUARTZ WASH MBR
	QUARTZOSE CONGLOMERATES		LIMONITIC IRON ORE			WASHBOURN LIMONITE MBR
IRON ORE						

Table 1: Stratigraphic nomenclature used in past and present studies of the Tertiary strata in Golden Bay. Bell et al. (1907) summarize earlier classifications, many of which were chronostratigraphic in intent. The Brunner Coal Measures were earlier called Middle Coal Measures (Wellman, 1950c) and Quartzose Coal Measures (Suggate, 1950).

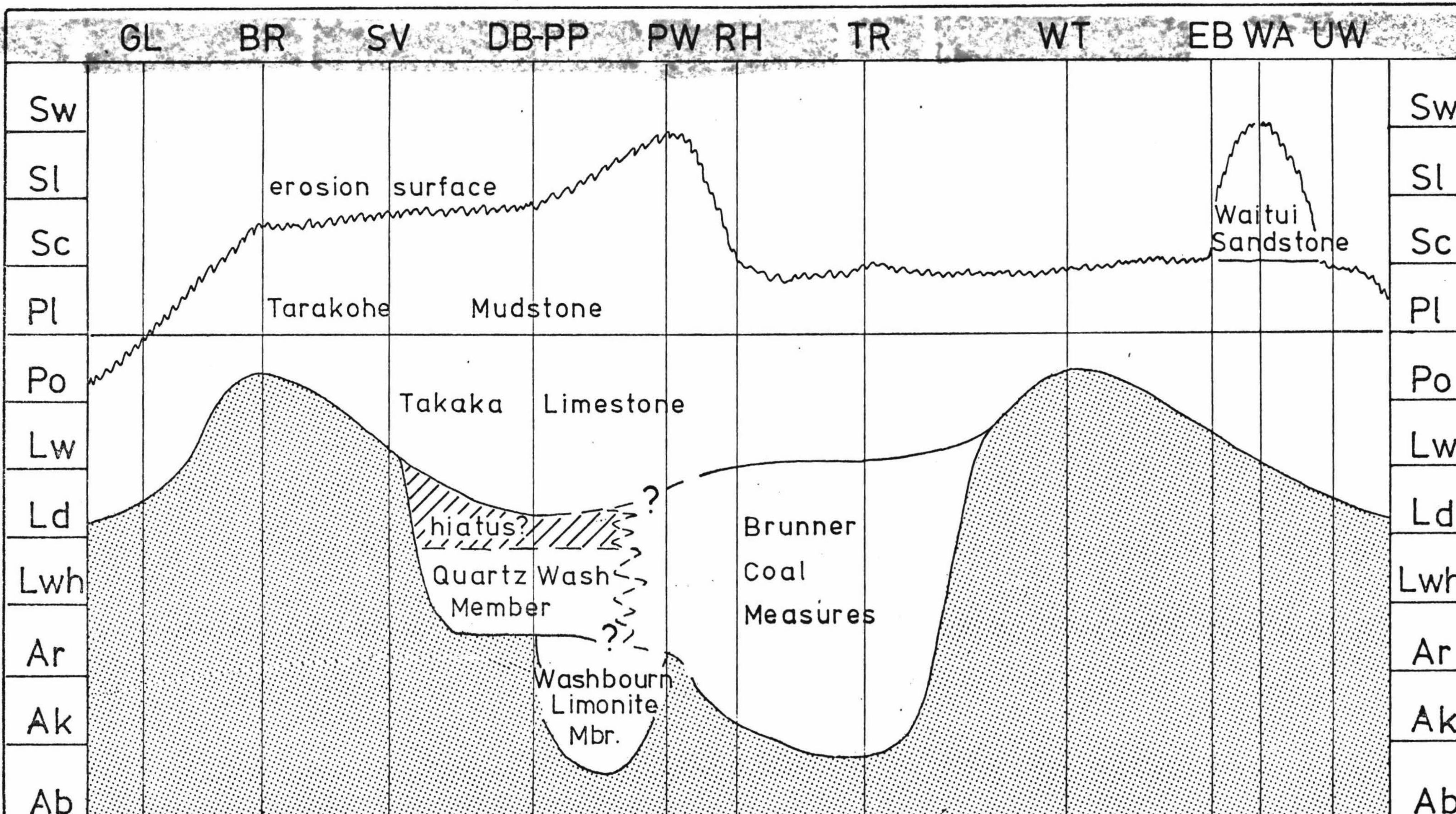

Fig. 3: Representative stratigraphic columns of Golden Bay Tertiary strata, showing age variation of the constituent formations. See Appendix 1 for explanation of column code letters and location of measured sections.

Runangan to Whaingaroan (J.I. Raine, 1979).

Washbourn Limonite Member (new name)

This member consists of blocky iron-ore forming irregular masses up to 30m thick on ridge crests, with abundant talus on adjacent valley flanks. It has been previously mapped as a separate unit by Bell et al (1907) and Bishop (1971), but no previous formal name has been proposed. The name is derived from the type locality, Washbourn Creek (M25/828514), which is the most accessible part of the member and which cuts a gorge through the ore. The member has not been dated, but probable gradation into Quartz Wash Member suggests an Arnold age.

Nile Group

Takaka Limestone (Thomson, 1917; Suggate, in Fleming, 1959b; redefined herein).

Suggate (in Fleming, 1959b) defined the Takaka Limestone as a pure, white, crystalline limestone, sandy in its lower half and becoming a muddy blue limestone at the top. This definition broadly describes the formation at the type locality, the Golden Bay Cement Co. quarry at Tarakohe, but neglects composition and texture and is therefore inadequate as a limestone formation definition.

The formation is redefined as a pure, hard, flaggy limegrainstone or packstone, typically dominated by bryozoa and with common bivalves, echinoderms and brachiopods and minor foraminifera and red algae. Basal limestone is usually rich in terrigenous sand and may grade to calcite-cemented quartzarenite. The rock is usually white or light grey. Massive or faintly bedded green-grey sandy calcarenite, with common horizons of bivalves, echinoderms and brachiopods, is the major facies in the Aorere Valley and on the northwest Nelson coast between Kahurangi Point and Abel Head.

This redefinition specifically excludes fine-grained echinoderm-foraminifera lime packstone southwest of the Mount Arthur Tableland, mapped as Takaka Limestone by Grindley (in press), which is a distinctly different lithology in a thick basinal sequence. The

German (1976) Karamea		Leask (1977) Heaphy River		Titheridge (1977) Abel Head - Kahurangi Point		This Study West Nelson
KARAMEA LIMESTONE	OPARARA MEMBER	HEAPHY FORMATION	MBR C	TAKAKA LIMESTONE	ANATORI MEMBER	TAKAKA LIMESTONE (redefined)
	STONY CREEK LIMESTONE MEMBER		MBR B			
LITTLE WANGANUI FORMATION	KOHAIHAI LIMESTONE MEMBER		MBR A		PATURAU MEMBER	

Table 2: Stratigraphic nomenclature of Nile Group bryozoan-dominated limestone in West Nelson.

formation is extended to include limestone at Heaphy River, Karamea and Cuckoo River.

In Golden Bay the formation is mainly Waitakian-Otaian in age, but basal Duntroonian limestone occurs at Gouland Downs and the lower Aorere valley, and basal Otaian limestone is found in the upper Aorere valley and the central Takaka valley (fig.3). The Takaka Limestone conformably overlies the Brunner Coal Measures in the lower Takaka valley and in a few places in the Aorere valley, in the upper Takaka valley, Aorere valley and on Gouland Downs it rests directly on a generally smooth basement. It is conformably overlain by the Tarakohe Mudstone.

Blue Bottom Group

Tarakohe Mudstone (Henderson, 1929; Suggate, in Fleming, 1959b).

The Tarakohe Mudstone is dominated by massive blue-grey or green-grey siltstone, with basal glauconitic sandstone and minor alternating sandstone and mudstone, cross-bedded and burrowed sandstone. The formation is at least 900m thick in the Onekaka-Patons Rock area, 350m thick at Upper Takaka, where it is overlain by Waitui Sandstone, and c. 400m thick in the Aorere valley. It conformably overlies Takaka Limestone with an age close to the Otaian-Altonian boundary, and ranges as young as Lillburnian (fig.3).

Waitui Sandstone (Grindley, in press).

This formation was informally called Hope Creek* Sandstone by Cooper (1962). It comprises 160m of white-light brown moderately soft medium-fine sandstone with common pebble laminae and trough cross-bedding.

A single microfauna collection is Clifdenian-Tongaporutuan but a Clifdenian-Lillburnian age is considered likely for the whole formation (see Chapter 6).

Pleistocene coverbeds

Pleistocene gravels, formed as aggrading outwash surfaces during major glacial advances (Grindley, 1971), unconformably overlie the

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* Not a recognized Geographic Board name

Tertiary rocks in the Takaka and Aorere valleys. Tertiary strata at Upper Takaka are unconformably overlain by a cemented marble breccia.

Structure

During the Cenozoic Era, northwest Nelson has been a relatively stable tectonic platform (fig.4; Western Platform of Pilaar and Wakefield, 1978) bounded to the east by the Cape Egmont Fault Zone and the Moutere Depression and to the south by a series of north-south elongate basins filled with up to 6000m of Oligocene-Miocene sediment (Fyfe, 1968 ; Andrews et al., in prep.). Although dominated by a gently folded, thin sedimentary sequence, the region is characterized by several large north-northeast trending monoclinal flexures, commonly oversteepened and sheared to become steep reverse faults. The structure of the study area (fig.1) is roughly symmetrical in cross-section, with two asymmetrical synclines bounded by steep monoclinal folds/faults and separated by a broad dome-shaped anticline up to 1775m high defined by accordant summit heights (Wellman, 1939). The Wakamarama Fault to the west is completely faulted throughout its onshore length. It extends offshore to the northeast of Farewell Spit into the Cape Egmont Fault Zone (fig.4), a zone of steep en echelon faults characterized by abrupt changes in throw, scissor-type reversals of throw and low-angle overthrusts (Pilaar & Wakefield, 1978). To the southwest it may continue offshore north of Heaphy River and join the Cape Foulwind Fault Zone (Esso Exploration and Production, 1969), a large monoclinal flexure bordering the west Nelson coast.

The Aorere Syncline is a fault-angle depression steeply folded against the Wakamarama Fault to the northwest and sloping gently off a fossil peneplain remnant to the southeast. Seismic profiles north of Collingwood (Godechot, 1968) suggest that the syncline plunges offshore* and wedges out against the Wakamarama Fault in the Farewell Spit area. The maximum thickness of strata preserved onshore in the syncline is approximately 450m.

* to a maximum of 1700 milliseconds two-way time

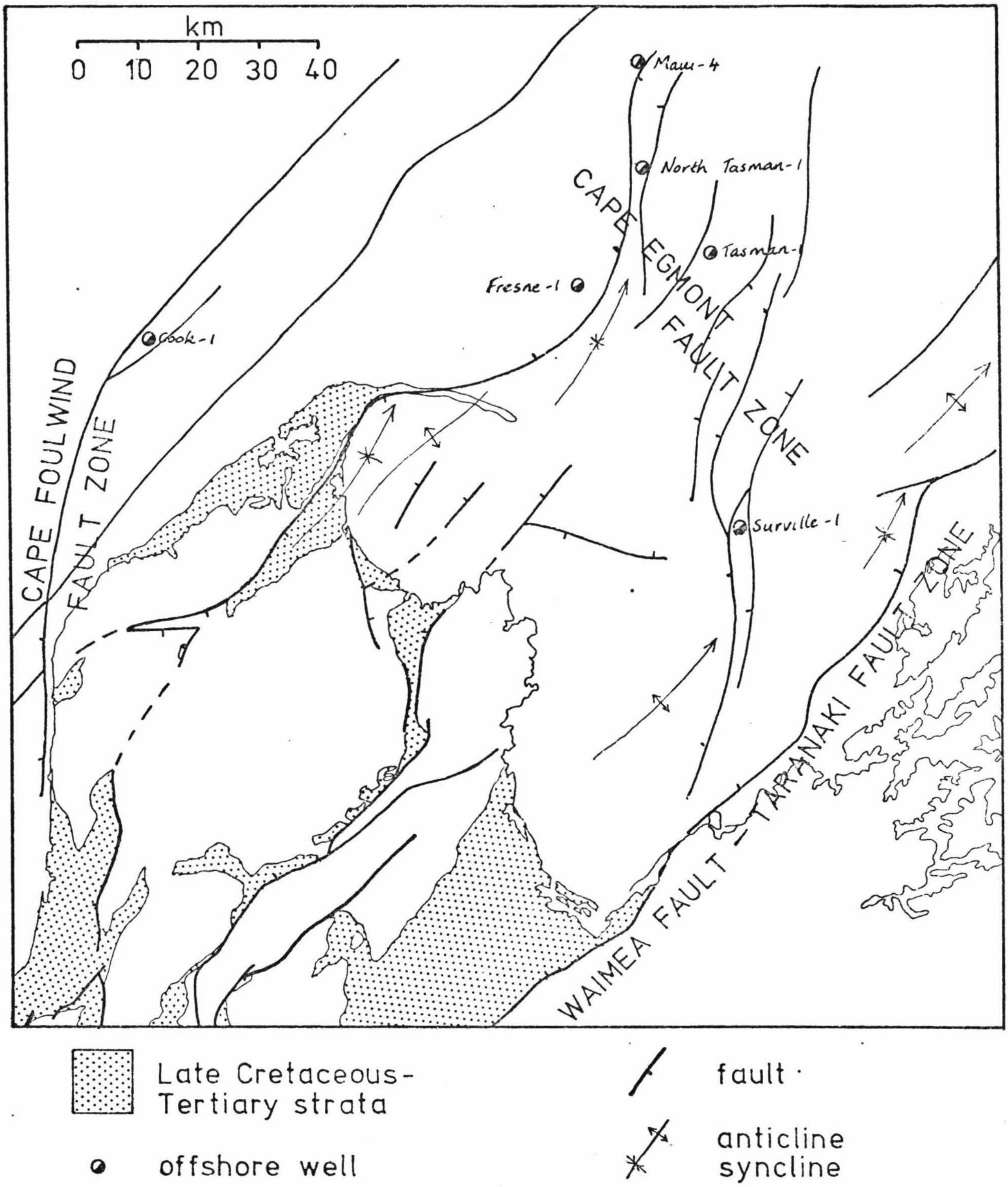


Fig.4: Tertiary structure in north Nelson and southern Taranaki Bight, after Grindley (1961), Esso Exploration and Production (1969) and Pinchon (1972).

Many small areas of Quartz Wash Member and Takaka Limestone dot the peneplain southeast of Aorere River. Hector (1892) suggested that distribution of the Quartz Wash was related to a northeast trending fault-angle depression between the Quartz Ranges and Parapara. In partial support of this theory, there are small areas of very steeply dipping strata at Parapara, upper Appo's Creek and Golden Gully. The present status of this theory will be discussed in Chapter 3. Gouland Downs, a fossil peneplain remnant in the southwest of the study area, is downfaulted to the north by the steep Slate Fault (Bishop, 1968) and folded on the southeast by a monoclinal scarp (Cotton, 1916).

The east side of the study area is bounded by the Pikikiruna Scarp/Fault, a steep monoclinal fold which is reverse faulted south of Ellis Creek. The adjacent Takaka Syncline comprises a series of shallow folds with steep eastern limbs (dipping up to 60°) and shallow western limbs (dipping c.10°). The Syncline narrows to an elongate graben in the middle Takaka valley and widens as an oval basin filled with 550m of strata at Upper Takaka. The basin is faulted against the monocline by the Pisgah Fault, which continues southwest bordering the Mount Arthur Tableland, a fossil peneplain remnant. Patches of Takaka Limestone cover part of the Tableland, but in the headwaters of the Leslie River there is an abrupt change to a thick Oligocene basinal sequence (Andrews et al., in prep.).

Flanking the central Golden Bay coastline is the Golden Bay Fault, another reverse fault of probable monoclinal fold origin. This separates low-lying strata in the Onekaka and Pariwhakaoho River area from steep hill country up to 700m high capped by Washbourn Limonite.

An eastnortheast trending fault at Puramahoi has been proposed by Wellman (1950c) and Grindley (1971) to explain the abrupt disappearance of at least 900m of strata south of Pariwhakaoho River. Despite the considerable vertical displacement, there has been minimal deformation of adjacent strata, and the fault does not continue beyond the Golden Bay Fault. It continues offshore as a northeast trending fault into central Golden Bay (Pinchon, 1972).

Peneplanation

The existence of an Early Tertiary peneplain, albeit modified by marine planation, is a well-established axiom of northwest Nelson geology, first demonstrated by Cotton (1916) in the Aorere valley and Gouland Downs. Wellman (1939) showed that the peneplain surface was a convenient reference from which to measure later deformation. He contoured this surface from:

(1) summit heights where the Tertiary cover is completely removed;
(2) the height of the base of Tertiary residuals;
(3) dips of the overlying strata where the peneplain is deeply buried.

The fossil peneplain surfaces on the Mount Arthur Tableland, Gouland Downs and flank of the Aorere valley (fig.5a,b)obey the following criteria of Thornbury (1969):

(1) accordant interstream levels and summit heights;
(2) topographic unconformities (marked nickpoints of modern valleys dissecting the peneplain);
(3) truncation of rocks of varying resistance;
(4) presence of deeply weathered basement rock.

Formation of the Washbourn Limonite Member probably required minimal erosion and sedimentation (see discussion in Chapter 3). In addition, common limonite gravel on the Aorere peneplain remnant and limonite nodules on the Pikikiruna Range (Cooper, 1962 : 92) suggest an Early Tertiary origin in a well-weathered soil profile. Grindley and Wodzicki (1960) described gossans, subsurface oxidized zones up to 15m deep and secondary enrichment zones at the Johnston's United and Richmond Hill base-metal lodes on the Aorere peneplain. They considered that the gossans formed during Early Tertiary peneplanation and suggested that the extremely high gold content of the gossan indicates little erosion since peneplain formation.

Wellman (1939) contoured the peneplain surface over the top of the Haumurian-Teurian Pakawau Group, and Titheridge (1977) described silcrete, soil formation and kaolinization in the youngest Pakawau sediments. The Group is unconformably overlain by marine sandstone of late Arnold age, indicating a hiatus of 10-15 million years, during which time peneplain formation probably took place over the north-west Nelson region.

FIG. 5 : THE PRESENT DAY GEOGRAPHICAL SETTING OF TERTIARY STRATA IN GOLDEN BAY

a/ Gouland Downs. Heavily-bushed, low hills of Takaka Limestone are scattered across the east side of the Downs on a tussock-covered basement of Paleozoic schist, hornfels and quartzite. Caves, sinkholes and water-worn fluted outcrops are common in the limestone.

b/ Limestone hills near Doctor Creek, on the southeast flank of the Aorere valley. As at Gouland Downs, the bush-clad hills form a sharp contrast to the undulating scrub-covered basement. A thin, irregular cover of Quartz Wash Member sands is exposed in the four-wheel drive track, which gives access to many former gold-mining localities including Golden Gully.

c/ Onekaka, seen from the margins of the Washbourn Limonite Member above Ironstone Creek. The coastal plain is formed by Pleistocene terrace surfaces cut into Tarakohe Mudstone. The Golden Bay Fault runs along the foot of the steep bush- and scrub-covered hills.

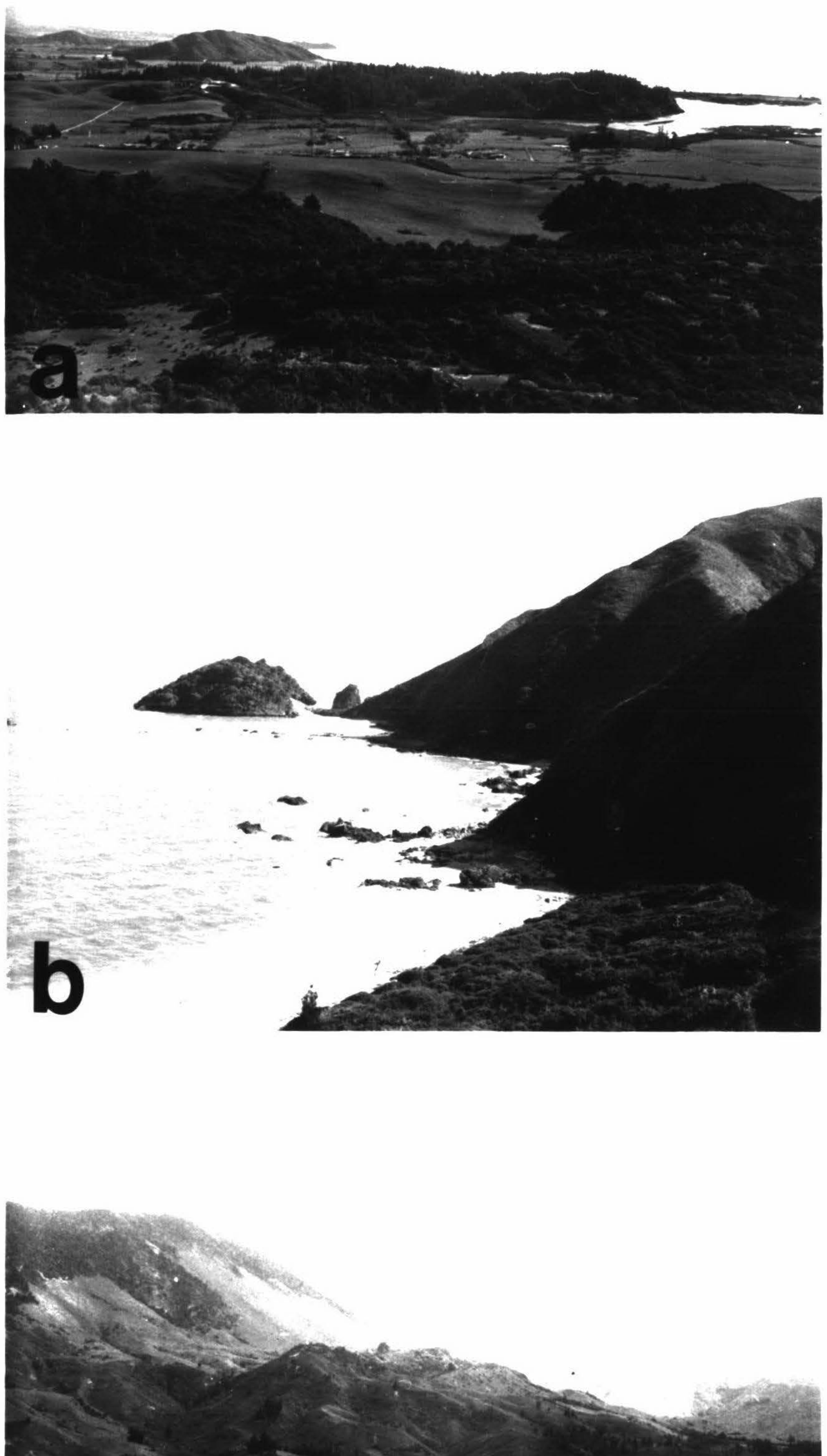

a
b

FIG. 6 : THE PRESENT DAY GEOGRAPHICAL SETTING OF TERTIARY STRATA IN GOLDEN BAY (CONTINUED)

a/ Motupipi, seen from the eastern flank of the Takaka valley. The low hills in the foreground consist of Takaka Limestone. The tree-covered ridge in the middle distance consists of Brunner Coal Measures. Coal mining was carried out at sea level at its northern end from the 1850s until the 1930s. A sandpit is presently operated by Golden Bay Cement Co. at its southern end.

b/ Taupo Point is a small peninsula composed of weathered Takaka Limestone at the eastern extremity of Golden Bay. The steepness of the Pikikiruna monoclinal fold scarp is indicated by the steeply overturned Brunner Coal Measures which comprise the lowlying isthmus. The hills to the left consist of granite of the Separation Point Batholith.

c/ Tertiary strata at Upper Takaka are preserved in an ovoid basin faulted against Paleozoic strata of Takaka Hill and Hailes Knob to the east (left). The hill in the centre of the photograph consists of Waitui Sandstone and is capped by marble breccia, a gravity-nappe from the range to the east (Grindley, in press). The flatter country in the foreground is composed of Tarakohe Mudstone. Takaka Limestone crops out along the faulted eastern margin, and caps a well-preserved peneplain surface to the west (right, distance).


a
b
c

CHAPTER THREE

BRUNNER COAL MEASURES

The Brunner Coal Measures in Golden Bay are preserved in three different areas, each with a distinctive range of facies deposited in a distinct paleogeographic setting:

(1) Brunner Coal Measures in the lower Takaka valley,

(2) Quartz Wash Member on the southeast flank of the Aorere valley

(3) Washbourn Limonite Member on hill country west of Onekaka.

BRUNNER COAL MEASURES IN THE LOWER TAKAKA VALLEY

Distribution

Coal measures up to 350m thick occupy the Takaka valley as far south as Stony Creek (N26/933305). They are mainly obscured by the thick Quaternary cover, but there are many scattered outcrops in stream beds, coastal cliffs, roadcuts and quarries. In general, lateral changes in a section can only be traced over a few metres. The Rangihaeata section is a useful reference section, in which several different facies are well-exposed in coastal cliffs and roadcuts. The coastal cliffs near Trig DD at Motupipi River estuary were nominated by Grindley (1971) as the type section of the Motupipi Coal Measures (herein abolished in favour of Brunner Coal Measures), but at present the cliffs are covered with thick vegetation. A few creeks on the east side of the valley expose steeply dipping strata, the best being Dry River. Roadcuts around Pohara, Tarakohe and Ligar Bay give reasonable exposure whereas stream outcrops are virtually absent. Coal measures are moderately well exposed at Taupo Point, the eastern extremity of Golden Bay.

The gently dipping coal measures on the west side of the Takaka valley are generally covered by Pleistocene gravels, but there are useful outcrops on the Pupu Springs Road, at Payne's Ford and at Anatoki River.

Age

The age of the Brunner Coal Measures has been established by pollen biostratigraphy (Couper, 1960; Raine, 1979). In the lower Takaka valley the base of the formation is Bortonian-Kaiatan at Rangihaeata and Dry River, and Late Kaiatan-Runangan at One Spec Creek (on the west side of the Takaka valley) and probably also at Taupo Point. The upper part of the formation has been dated as Whaingaroan at Tarakohe, Dry River and Rangihaeata; facies mb_4 sands at Tarakohe and Takaka are inferred to be Duntroonian.

Facies Associations

mb_1: Alternating sand, fine sandstone and mudstone
mb_2: Bioturbated muddy sandstone
mb_3: Cross-bedded sand
mb_4: Thick-bedded sand and gravel
mb_5: Alternating sandstone/conglomerate and mudstone

mb_1: Alternating sand, fine sandstone and mudstone

This association consists of fining-upwards sequences of sand and mud(stone), in which lenses of cross-bedded sand up to 3m thick and less than a few tens of metres wide occur sporadically within a mudstone-fine sandstone framework. This is the most important association in the coal measures, and always the oldest, resting unconformably on deeply leached basement. A variety of sequence types (figs.7,8,9,11) are composed of a few distinctive facies:

(1) 50-200mm thick, horizontal-bedded sandy gravel, alternating with muddy medium sand, comprise the lowest outcrop at the Dry River section (fig.11). The gravel consists of moderately sorted, well rounded, rodlike pebbles averaging 60mm length in a muddy sand matrix. Pebble composition is dominated by vein quartz with minor soft dark grey mudstone and soft light grey quartzose sandstone.

(2) Friable, light brownish-grey, moderately to poorly sorted medium-coarse sand; subfeldsarenite-micaceous feldsarenite forms 1-3m thick units with sharp or scoured bases and 50-300mm (rarely 1m) thick trough cross-beds (fig.10a). Paleocurrent data show a strongly unimodal distribution (fig.24). Grain-size and cross-bed set thickness decrease upwards within each unit. Planar cross-beds 100-200mm thick are sometimes present at the top of the unit.

(3) Interlaminated sandstone and siltstone (fig.10b,c) vary from 1-2mm thick horizontal-bedded light grey-yellow fine sandstone and dark brown siltstone, to 10-40mm thick ripple-bedded fine sand with thin mud drapes. Wavy-bedding and lenticular-bedding are common; flat or

thick single sand lenses indicate current origin (Reineck and Singh, 1973).

(4) Dark brown, massive carbonaceous mudstone often contains abundant leaf and stem remains, pyrite nodules and coaly streaks. Rootlets are rare or absent. In the basal part of some sections, the mudstone is white to light grey and varies in texture from sandy silt to an almost pure, plastic clay.

(5) Hard, bright coal of medium sub-bitumenous rank (Wellman 1945:197) forms seams up to 1.5m thick, but commonly 200mm and interbedded with carbonaceous mudstone.

(6) Alternating sand and muddy sand beds 200m thick consist of light brown medium sand with ripple - or horizontal - lamination and lenses of coarse sand, grading up to dark brown carbonaceous muddy sand with lenticular-bedding and abundant 10-20mm thick coal lenses and rootlets. Spherical pyrite nodules 20mm in diameter are common. A single channel 0.5m deep and 14m wide with asymmetrical channel-fill is exposed on Pupu Springs Road (N25/912405).

This facies occurs in units 4-10m thick at Waikoropupu River and Taupo Point; a similar facies, although with white muddy sand beds, occurs in association mb_3.

There are several gradual changes in facies abundance from the base to the top of association mb_1: in particular, a general rarity of coal (5) and interlaminated sandstone/siltstone (3) in the lower part and a higher proportion of cross-bedded sand (2).

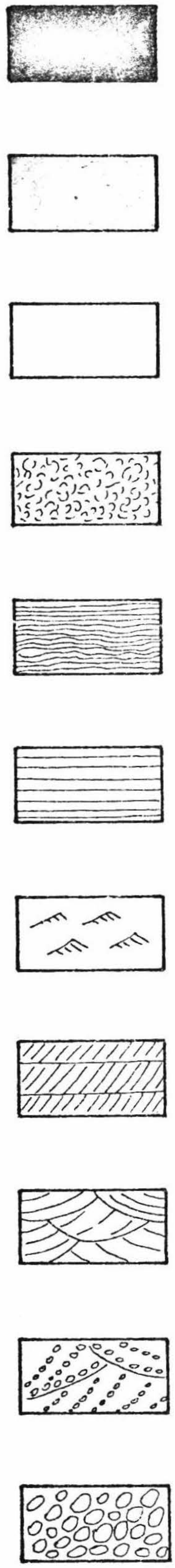
Five types of vertical sequence occur:

(a) Trough cross-bedded sand (2) overlain by ripple-bedded fine sand and/or interlaminated sandstone/siltstone (3) which grade up to carbonaceous mudstone (4) and coal (5) (e.g. figs.7,8,9,11);

(b) Trough cross-bedded sand (2) grading quickly up to massive mudstone (4) (e.g. fig.7)

(c) Interlaminated sandstone/siltstone (3) up to 3m thick alternating with mudstone (4) and coal up to 2m thick (e.g.fig.11);

(d) Massive carbonaceous muddy sandstone-mudstone 0.5-2m thick alternating with 100-200mm thick coal (restricted to One Spec Creek and Anatoki River);



coal

dark brown carbonaceous mudstone

white, leached mudstone

bioturbated muddy sand

interlaminated sand/silt

horizontal-bedded sand(stone)

ripple-bedded sand

planar cross-bedded sand

trough cross-bedded sand

trough cross-bedded gravel/conglomerate

massive conglomerate

Legend for detailed measured sections of Brunner Coal Measures and Tarakohe Mudstone (figs. 7,8,9,11,12,13,42,43). Additional symbols and abbreviations listed in Appendix One.

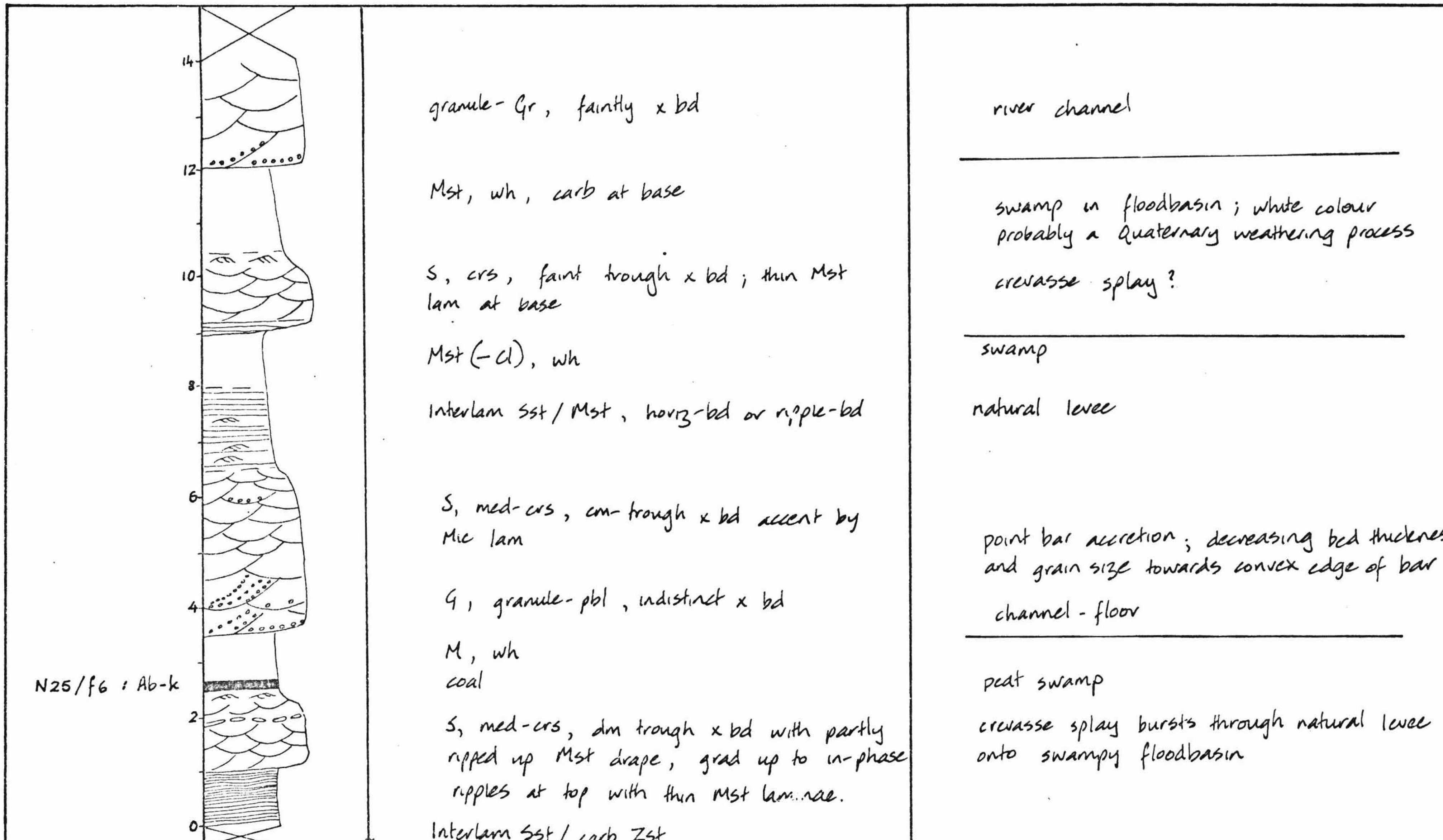


Fig.7: Detailed section of facies association mb_1 at Rangihaeata (N25/920434)

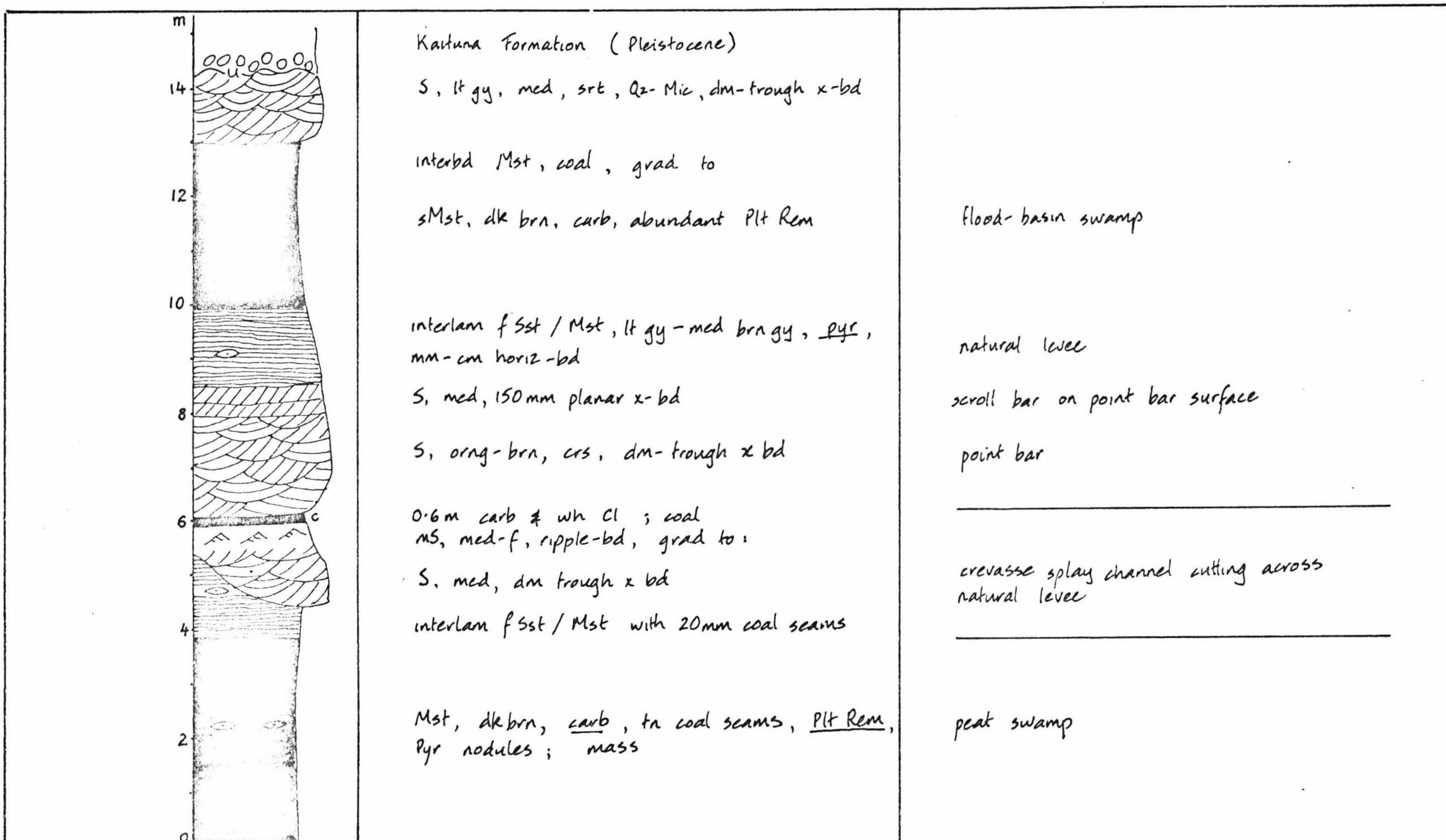
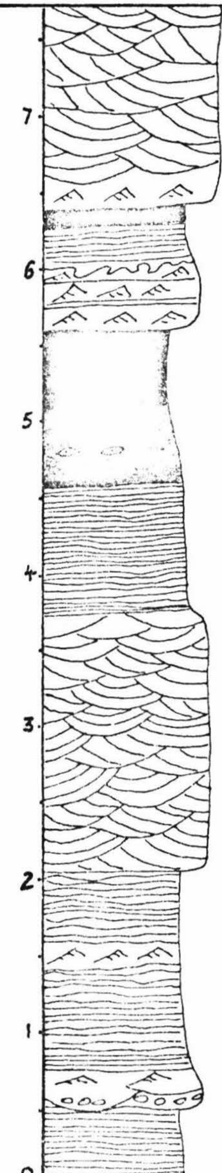


Fig.8: Detailed section of facies association mb_1 at Waikoropupu (N26/908399)



Description	Interpretation
S, lt brn, crs, 50-80 mm trough x bd, common mm-bd dk brn Mst drapes, calc-cmt Conc	Channel aggradation (base of mb_3)
Zst, med gy, grad down to interlam Sst/Zst, mm-horiz bd; bed of loadcasted ripples at base Sst, med-f, ripple-bd 50-100 mm tk alt with interlam Sst/Zst	natural levee
Mst, med brn-blk, grad down to 100 mm coal Zst, med gy, mass, wthd Pyr Nod	Peat accumulation in poorly-drained swamp
Interlam f Sst/Zst, cm-wavy bd; mm-horiz bd f Sst on basal sharp contact	Natural levee
S - Sst, med-crs (srt) subfeldsarenite, 200 mm trough x bd, accent by Mic lam; common calc-cmt Conc	Point bar accretion
Interlam f Sst/Zst, mm-cm wavy-bd and horiz-bd, sparse ripple-bd Sst and Cgl	Natural levee or floodbasin, with periodic crevasse splays of coarser material

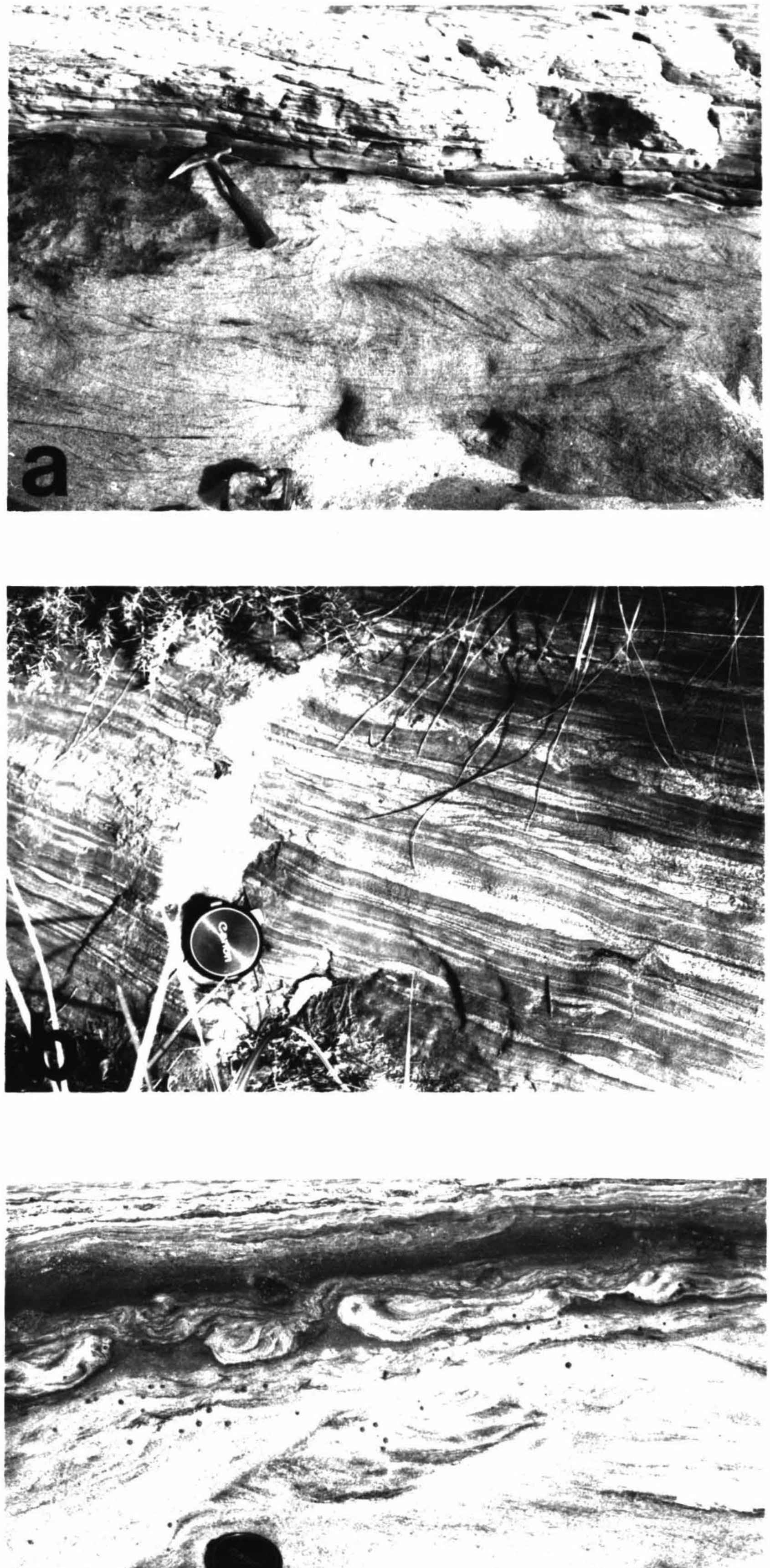
Fig.9: Detailed section of facies association mb_1 at Rangihaeata (N25/924440)

FIG. 10 : FACIES ASSOCIATION mb_1 AT RANGIHAEATA.
(Takaka Rivermouth, N25/924440; see Fig. 9)

a/ Trough cross-bedded medium sand, sharply overlain by horizontal-interlaminated sandstone and siltstone. Hammer 330mm long.

b/ Horizontal lamination, wavy bedding and lenticular bedding in the interlaminated sandstone and siltstone facies.
Lens cap 60mm diameter.

c/ Trough cross-bedded sand, overlain by load-casted and convoluted sand lenses.


a
b
c

(e) Alternating sand and muddy sand of facies (5).

Interpretation: These facies resemble point bar, channel-plug, levee, crevasse - splay and floodbasin deposits within a meandering river system (for examples, Allen, 1970; Reineck and Singh, 1973; Collinson, 1978). Sequence (a) is interpreted as point-bar accretion with successively finer-grained sediments and thinner bedforms representing decreasing flow regime following peak floodwaters. Sharp basal contacts represent the channel floor. Trough cross-bedded sands are attributed to high and falling flood stages, with cross-bed set thickness decreasing towards the convex edge of the point bar. Rare planar cross-bed sets may represent small scroll-bars migrating across the point-bar surface during late flood stages. Ripple-bedded sand with thin mud drapes, or interlaminated sand and silt, was formed by low-water accretion on the point-bar surface or on the adjacent natural levee.

Sequence (b) may represent the initial stages of point-bar accretion followed by neck - or chute - cut off and subsequent channel abandonment, although it could also be interpreted as a crevasse splay flood deposit (Collinson, 1978:54), depending on the lateral extent of the unit.

Sequences (c) and (d) suggest alternation of levee and swamp facies in a poorly-drained floodbasin environment. It is likely that inter-laminated sandstone/siltstone may be formed in a variety of environments characterised by periods of slack and moving water, ranging from natural levees to mixed tidal flats and possibly to lacustrine deposition. The latter origin may be important in sequence (c). A shallow lake in a flood-basin setting may have finely laminated sand and silt deposited in deeper waters, organic-rich mud predominating in stagnant, shallow water and peat deposition in lake-edge swamps.

The regular, thin-bedded nature of the alternating sand and muddy sand facies suggests periodic and rapid deposition of sand sheets followed by gradual settling of suspended sediment. Rootlets and coal lenses indicate stabilization by vegetation. Deposition by a series of crevasse splays into a swampy floodbasin is inferred.

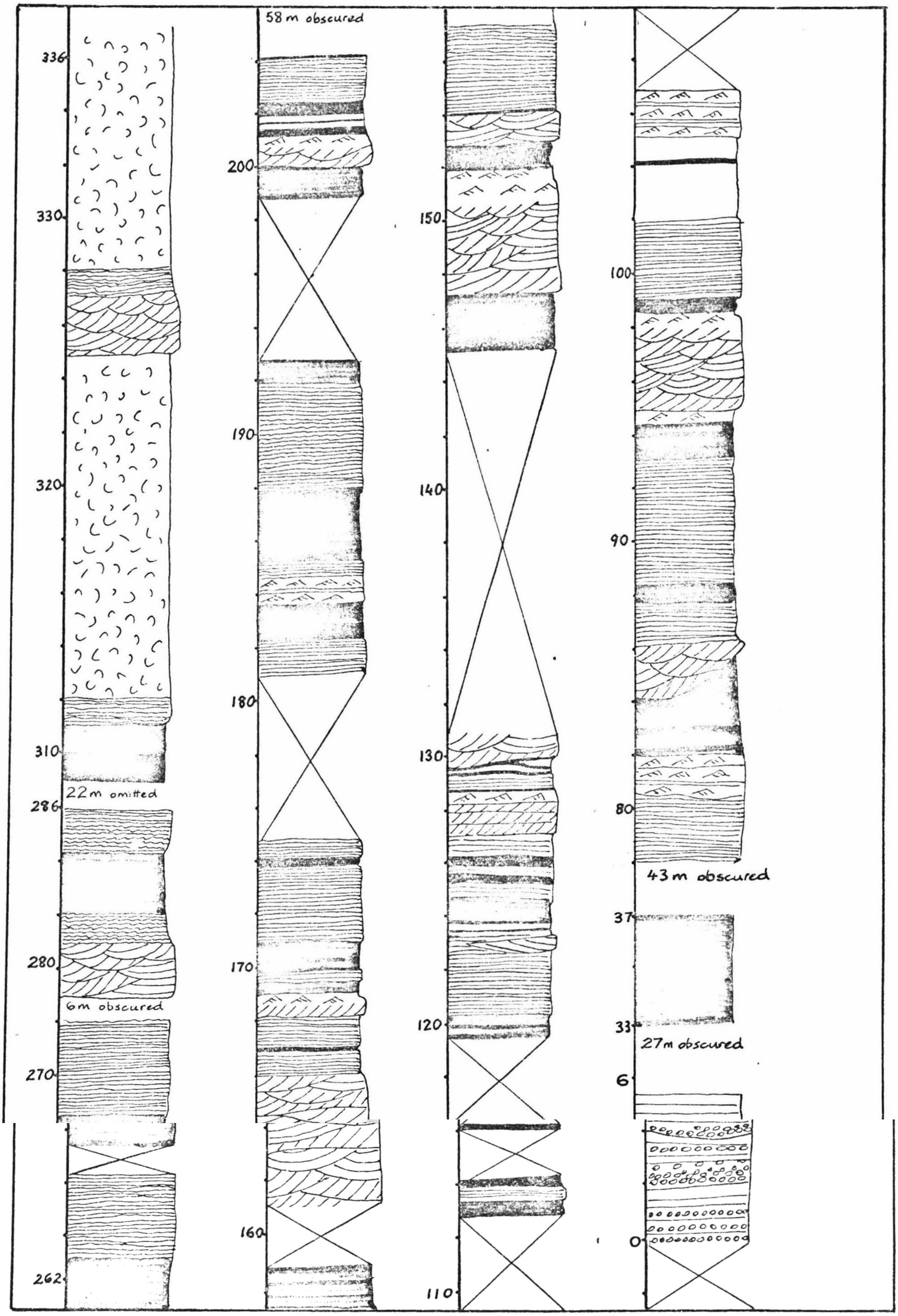


Fig.11: Detailed section of facies associations mb_1 and mb_2 at Dry River (N26/975364 to 971367)

The lower part of association mb_1 in some sections is characterized by the absence or scarcity of carbonaceous material and the presence of white to light grey mud beds. Prominent iron pans at the base of mud beds, liesegang rings in the underlying sand and highly weathered feldspar grains are additional features. These white mudstone beds are generally confined to Pleistocene terrace surfaces on mature relief hillsides, and it is likely that organic matter was leached from them by eluviation during a long period of Quaternary subaerial exposure under a moist and cool climate.

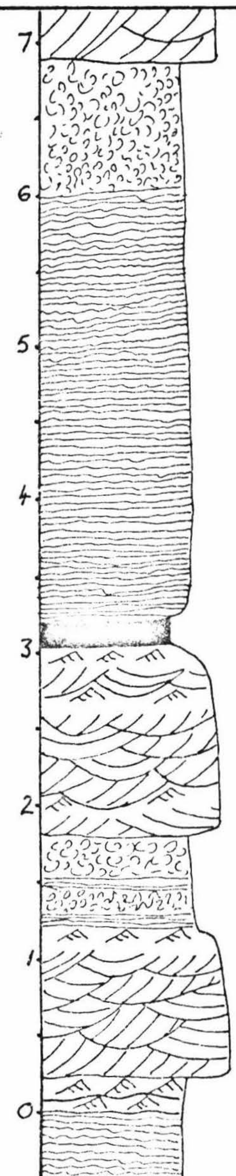
mb_2: Bioturbated muddy sandstone

This is a variant of association mb_1, characterized by a predominance of strongly bioturbated carbonaceous micaceous muddy fine sand(stone). The sandstone is moderately soft, rarely homogeneous but generally mottled. A typical fining-upwards sequence (figs.11,12) consists of 2m of trough cross-bedded medium sand overlain by horizontal or lenticular-bedded fine sandstone/siltstone which grades into up to 12m of dark brown mottled muddy sandstone.

The association is common in the upper part of the Brunner Coal Measures, typically overlain by mb_4 and grading down to mb_1. Microflora collections N25/f12 and f13 contain dinoflagellates, indicating marine influence (Raine, 1979).

Interpretation: A tidal flat origin is indicated by the abundance of strongly bioturbated sediment, the proximity to marine sands and limestone and the presence of dinoflagellates. The sequence described above resembles the sediments of the Jade (North Sea coast of Germany) described by Reineck and Singh (1971, 1973). Trough cross-bedded medium-coarse sand is restricted to tidal channels. Ripple-laminated and flaser-bedded fine sand and interlaminated fine sand and mud are deposited in increasingly marginal channel areas and tidal flat areas. Bioturbation is most pronounced in the finer sediments.

The gradation from association mb_1 to mb_2 may represent the change from a swamp-dominated floodplain with occasional meandering river channels, to a tidal flat complex cut by meandering tidal channels.



Sst, lt gy, crs, x bd	
Sst, dk brn gy, f, mic, strongly bioturb	Strong bioturbation in area far from active deposition
Interlam f Sst / Zst, lt gy - lt yel / dk brn, mm & cm - lenticular - bd or wavy - bd	mixed tidal flat ; alternate sst and zst deposited by alternating moving and slack water ; lack of bioturbation suggests rapid deposition and growth of sequence
200mm coal	Coal possibly formed in fresh-water peat swamp fringing river channel
S, lt gy, med - crs, 100 - 300 mm trough x bd, alt. with cm - ripples ; scoured base	Point bar : meandering creek in a generally estuarine environment ; tidal influence suggested by alternation of ? ebb-flow megaripples with ? flood-tide cm-ripples.
Alt wavy - bd Sst / bioturb Sst, dk brn / lt brn,	Mixed tidal flat ; varying rates of deposition
S, med, 100 mm trough x bd, rare Mst drapes	Point bar of small estuarine channel ; rare Mst drapes suggest slack water during reversal of tide phase ?
S, med-f, cm - ripples with dk brn Mst drapes	
Interlam Sst / Zst, mm-cm lenticular bd	mixed tidal flat

Fig.12: Detailed section of facies association mb_2 at Payne's Ford (N26/941357)

mb_3: Cross-bedded sand

This consists of thick, homogeneous sequences of trough cross-bedded sand with a general absence of fine sediments other than perigenic mud clasts. A subordinate alternating sand and muddy sand facies sometimes overlies this prominent facies. The sand is light grey-yellow, sometimes with limonitic liesegang rings, friable, moderately-poorly sorted medium-granule sand; subfeldsarenite-micaceous feldsarenite.

Crude fining-upwards sequences at Rangihaeata (fig.13) consist of:

(1) a scoured base;

(2) very coarse sandy-pebbly gravel, poorly sorted with abundant white perigenic mud clasts (fig.14a) and trough cross-beds 0.5-1m thick. One such unit at Rangihaeata has been worked in the past for gold, yielding 10-12 colours (fine specks) per pan (C. Vowless, pers.comm.);

(3) medium-coarse sand, with 50-500mm thick trough cross-bedding, accentuated by mica laminae (fig.14b);

(4) medium-coarse sand with planar cross-bedding 250-500mm thick (fig.14c). Interbedded ripple-beds and horizontal-bedded medium sand are common.

Paleocurrent data at Rangihaeata indicate a generally unimodal north-northnorthwest current direction with a minor southeast-heading component (fig.24).

The association at Motupipi Sandpit consists of medium-coarse sand with minor fine pebbly gravel in rather indistinct 0.3-0.5m thick trough and planar cross-bedding. Cross bed sets can be traced up to 30m across the quarry. Perigenic clasts are absent. Paleocurrent data (fig.24) show a strongly unimodal ~~southwes~~ east-southeast-heading distribution.

A subordinate facies occurring at Motupipi and Pohara consists of alternating sand and muddy sand in c.200mm thick units. White, fine to coarse sand in well-sorted thin laminae comprises 50-100mm thick trough cross-beds and scour-fill, and grades up to ripple-bedded or horizontal bedded, light yellow muddy fine sand.

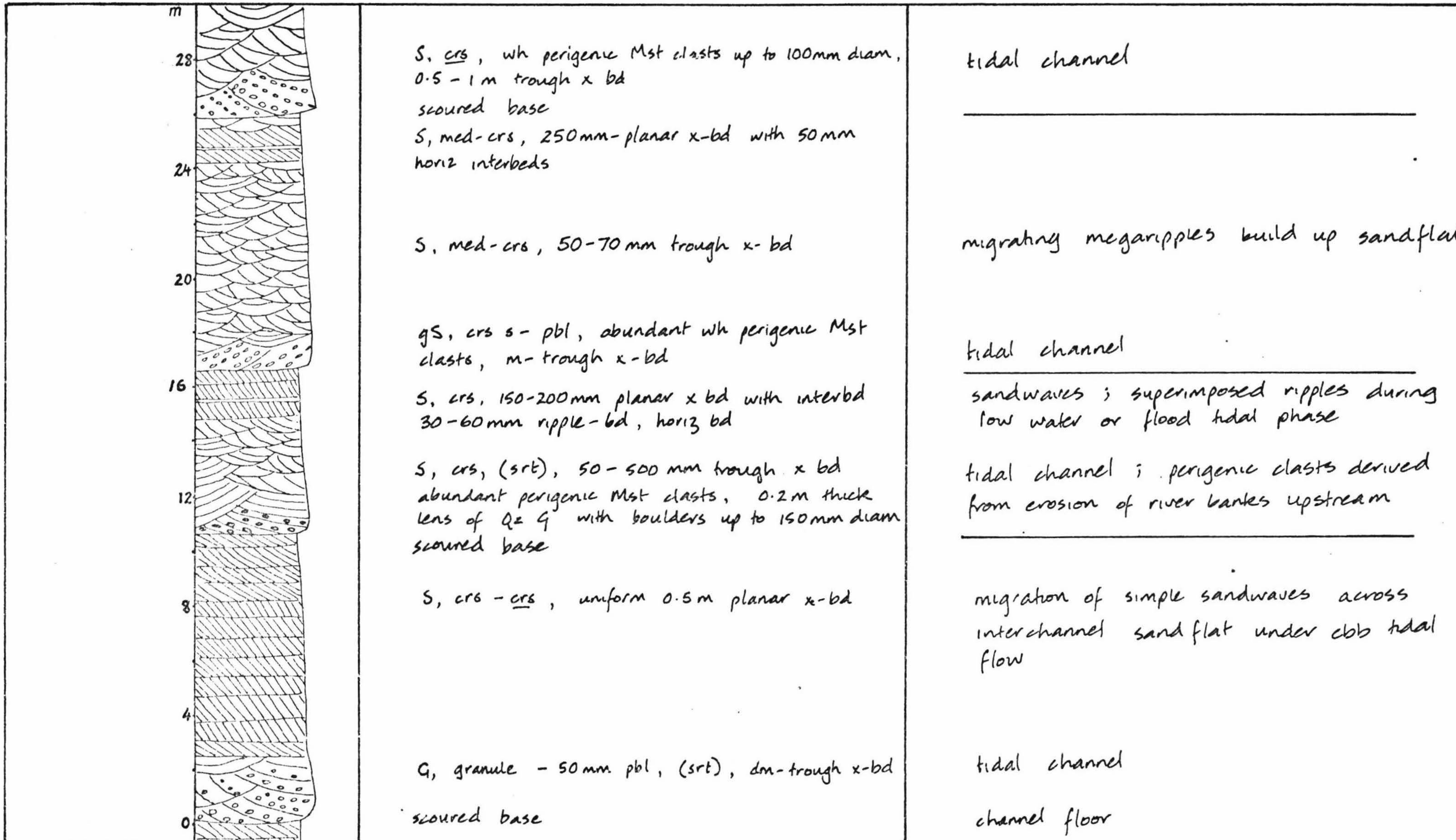


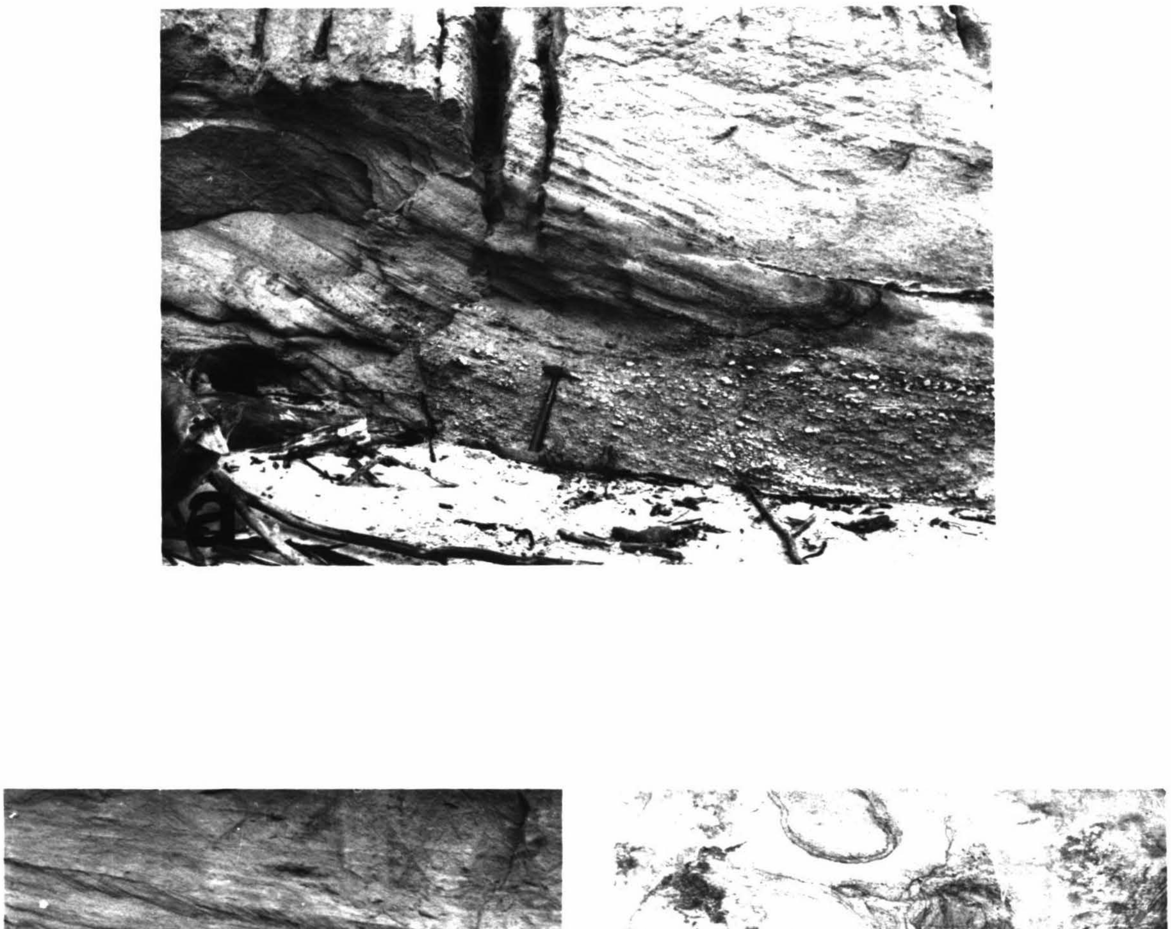
Fig.13: Detailed section of facies association mb_3 at Rangihaeata (N25/922444)

FIG. 14 : FACIES ASSOCIATION mb_3 AT RANGIHAEATA
(Rangihaeata Beach, N25/922444; see fig. 13)

a/ Basal channel-fill: pebbly coarse sand with abundant perigenic mud clasts, grading up to alternate sand and granule laminae, which grades in turn to:

b/ Medium-coarse sand, with 50-100mm thick trough cross-bedding, accentuated by micaceous laminae.

c/ Planar cross-bedded coarse sand with interbedded ripple- and horizontal-bedded horizons.


a
b
c

Interpretation: The range of bedforms and the absence of muddy sediments indicate a broad, shallow braided channel system, characterized by sandwave and megaripple migration. Unimodal paleocurrent distributions at Rangihaeata and Motupipi head in opposite directions, while paleocurrents at Pohara are strongly bimodal. These factors suggest deposition in a tidal current-dominated river estuary, analogous to the lower Ord River in northwest Australia (Wright et al., 1973) and the North Sea coast of Germany (Reineck and Singh, 1973).

A braided river origin (cf. the Platte-type river of Miall, 1977) is discounted, mainly because of the bimodal paleocurrents, and also because of the proximity to overlying and laterally-equivalent marine and/or tidal flat facies (associations mb_2, mb_4; Takaka Limestone). The absence of macro - or microfauna is attributed to dissolution by $CaCO_3$ - undersaturated porewaters and the likelihood that the environment was unfavourable for large colonies of molluscs. The absence of tracefossils is consistent with the probable absence of infauna in such an unstable, moving substrate.

Large-scale trough cross-bedded sand overlying a scoured surface indicates megaripple migration across the floor of a high-energy tidal channel. Smaller planar cross-bedding indicates long-crested megaripple or sandwave migration, perhaps across an inter-channel sandbar. Small-scale ripples were frequently superimposed on sandbar surfaces.

The opposing paleocurrent distributions at Rangihaeata and Motupipi suggest mutually-exclusive flood and ebb tidal channels (cf. Wright et al., 1972; Klein, 1970). The northwards-heading paleocurrent distribution at Rangihaeata is inferred to be the ebb tidal flow direction as it matches paleocurrent data from facies associations mb_1 and mb_5 (fig.24). The abundance of perigenic clasts at this locality also indicates an ebb flow direction. The bedforms at Motupipi Sandpit were probably deposited in a flood tide-dominated channel area, while the bimodal paleocurrent distribution at Pohara indicates both ebb- and flood-tidal currents. Klein (1970) showed that in ebb-dominated areas of the Minas basin, Nova Scotia, bedforms are orientated in the ebb direction and migrate only in that direction; flood tides smooth the slipfaces and crests of the bedforms and subdue the bedform profile.

During the next ebb tidal phase, bedforms build on reactivation surfaces and develop a superimposed set of foresets. A similar process may have operated during the deposition of association mb_3.

The alternating sand and muddy sand facies may represent stranded sand bars periodically inundated by only the highest floods or tides.

Association mb_3 forms the greater part of the Brunner Coal Measures at Heaphy River, west of the study area. Leask (1977) interpreted the association (his units 4,6 and 7) as pointbar deposits of a meandering river system, but re-examination of his data showed several clues to an estuarine environment. The association consists of large- and small-scale trough cross-bedded sands with no apparent fining-upwards sequences; thick trough cross-bedded sands are commonly overlain by mud drapes or ripple-laminated sands. Paleocurrent data show a strongly bimodal distribution of the small-scale cross-bedding (thickness 50mm or less). The upper contact of the association is commonly an erosion surface with extensive Ophiomorpha networks overlain by glauconitic sandstone of the Takaka Limestone.

mb_4: Thick-bedded sand and gravel

Directly underlying the Takaka Limestone, and commonly overlying association mb_2, are 1-3m thick units composed of low-angle cross-bedded medium-pebbly sand and gravel (fig.15a,b; see Tarakohe Section, Appendix 1). The sand is moderately - poorly sorted (e.g. sample 14643 grain-size standard deviation = 1.4). The gravel is moderately consolidated and is largely composed of 10-20mm diameter well-rounded quartz pebbles.

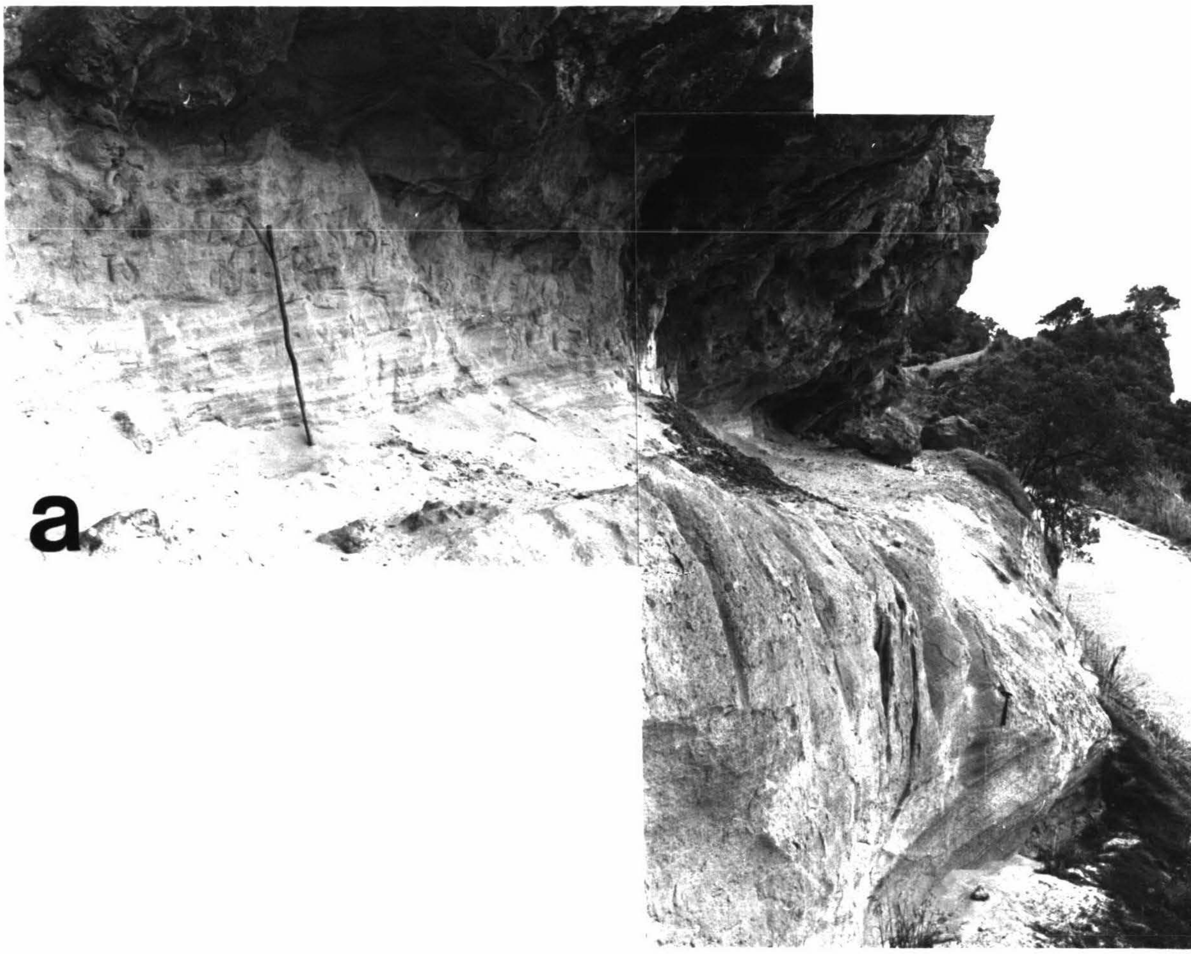
In addition to the large-scale cross-bedding, a small exposure of hummocky cross-bedded medium sand occurs at Tarakohe (fig.15b); this sand is poorly sorted, 5-10mm laminated and varying from light grey to medium brown. Intensely weathered granite pebbles 20-30mm in diameter are common.

FIG. 15 : FACIES ASSOCIATION mb_4 AT TARAKOHE

(South end of Ligar Bay, N25/018427)

a/ Low-angle cross-bedded coarse sand and pebbly sand underlie calcareous sandstone and lime packstone of the Takaka Limestone.
Staff 1.50m long.

b/ Immediately below the limestone is a horizon of brownish, low-angle (hummocky?) cross-bedded sand, with common highly weathered granite pebbles.
Hammer 330mm long.



a

b

Fining-upwards sequences in the Takaka Section (see Appendix 1) consist of sandy gravel overlying a scoured surface and overlain by pebbly coarse sand with cm-horizontal bedding.

In sections where this facies is only thinly developed, and usually poorly exposed, well-sorted and well-rounded medium-coarse sands (quartzarenites) are exposed beneath the Takaka Limestone. No marine fossils have been reported other than a single shark's tooth at Tarakohe (P. Vella, pers.comm. 1979).

Interpretation: The large-scale and low-angle lamination of the bedforms suggest that these sediments were deposited as sandwaves in a tidal-current influenced shallow sea, possibly as tidal shoals offshore from the estuary environment represented by associations mb_2 and mb_3. The poor sorting of the sands may have been caused by burrowing organisms disrupting laminae of varying grain size, although it is unlikely that a coarse-grained, unstable sediment would be colonized by a large infauna.

The sands underlying the Takaka Limestone have been well-sorted and well-rounded by wave or current activity, but limited exposure prevents further interpretation.

mb_5: Alternating sandstone/conglomerate and mudstone

This facies association is restricted to Rangihaeata Head and consists of sandstone and conglomerate units 0.5-2m thick and over 50m wide, with thin interbedded carbonaceous mudstone and muddy sandstone (fig.16). The sandstone is moderately hard, white subfeldsarenite-quartzarenite, rarely silica-cemented. Well sorted laminae of fine sand and rounded pebbles up to 25mm diameter form trough cross-bedding 200-500mm thick or large-scale low-angle scour-fill bedding (fig.16a,b). Paleocurrent data indicate an unimodal distribution northwest through northnortheastwards (fig.24). Rootlets and coal lenses are common at the top and base of the sandstone units respectively. The thin interbedded carbonaceous mudstone and muddy fine sandstone are moderately hard, with irregular lenses of white sandstone and abundant coal stringers and rootlets (fig.16c). Some units consist of convoluted lenses of sandstone within a mudstone matrix (fig.16d).

FIG. 16 : FACIES ASSOCIATION mb_5 AT RANGIHAEATA

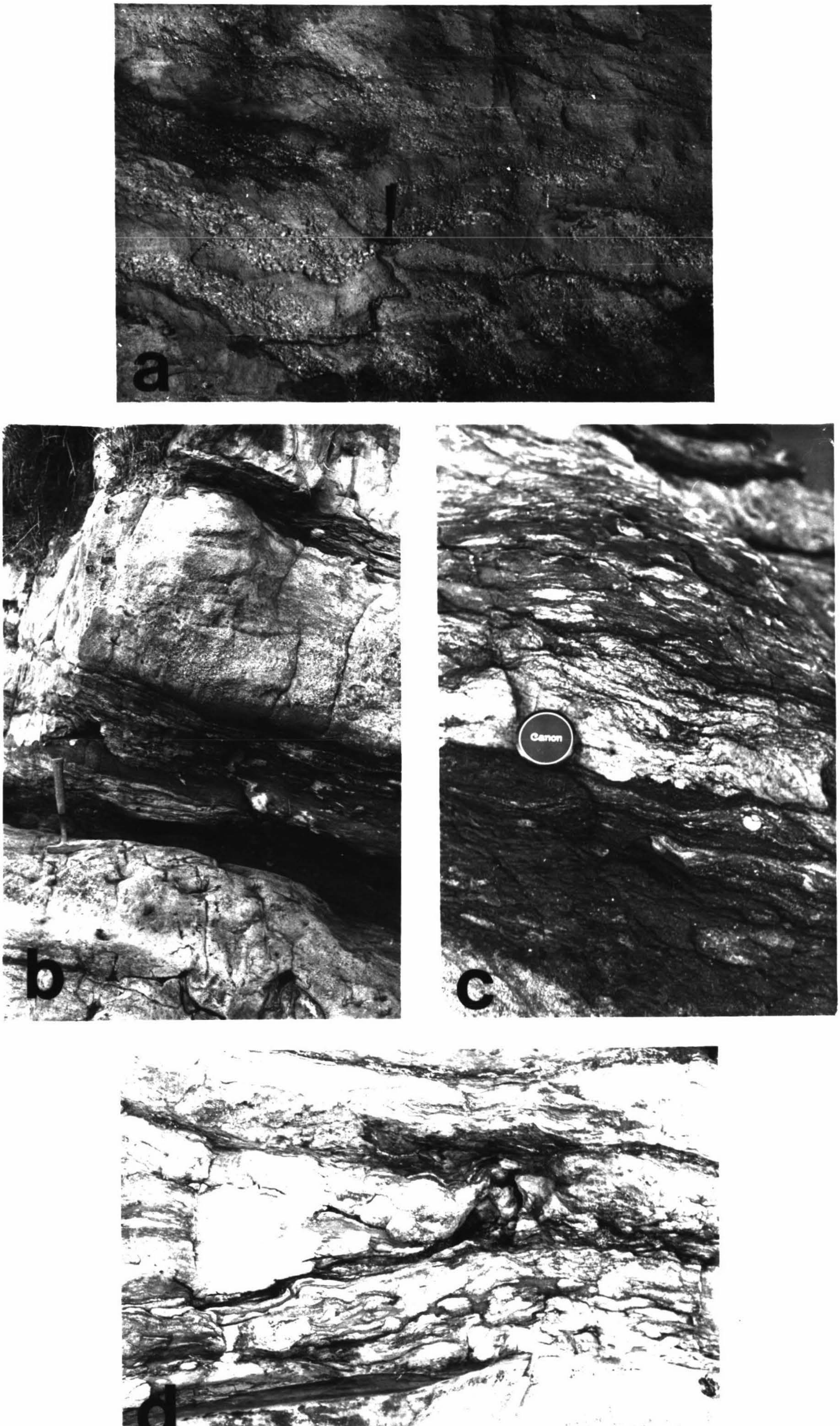
(Rangihaeata Head, N25/924448)

a/ Interbedded sandstone and pebble-conglomerate form lenticular scour-fill deposits.
Hammer 330mm long.

b/ Alternating medium-granule sandstone and lenticular-bedded sandstone, carbonaceous mudstone and muddy sandstone. Note the sharp bases of the carbonaceous beds. Coalified rootlets are abundant in the lowest sandstone bed.

c/ Lenticular-bedded sandstone and carbonaceous muddy sandstone.
Lens cap 60mm diameter.

d/ Convoluted and lenticular sandstone and mudstone, probably formed by disruption of sand sheets deposited on an unstable substrate.


a
b
Canon
c
d

Interpretation: The absence of well-developed fining-upwards cycles and thick overbank deposits argue against a meandering river origin, despite the regular alternation of sandstone and mudstone. A braided, perhaps mixed braided-meandering river or delta system is envisaged, similar to the Donjek-type river of Miall (1977).

The sandstones were deposited on a floodplain of low relief, characterized by frequent channel abandonment. Channel-aggradation occurred by scour-fill and megaripple migration. Rapid channel avulsion is suggested by the abundance of coalified plant remains in the lower part of sandstone units, and by deformed sandstone lenses (fig.16d); the latter were formed by flood-deposition of a thin sand sheet across a swamp area, causing fluidization of the underlying sediments and disruption of the sand bed into load-casted lenses.

Composition

The sands are friable, light grey - light yellow and sometimes limonite-stained. In any section within the Takaka valley there is an upwards decrease in feldspar content. Basal sands are feldsarenites with a high proportion of weathered feldspar and a trace of granite rock fragments, while sands higher in the sequence are commonly micaceous subfeldsarenites or feldsarenites. Marine sands at the top of the formation are usually quartzarenites. A dominantly granitic provenance is inferred, and the decreasing feldspar content is considered primarily due to increasing maturity. A heavy mineral assemblage, N25/S2, from c.90m in the Rangihaeata Section, contains abundant white and non-magnetic opaques, sparse zircon and rare epidote, suggesting granite provenance (D. Smale, pers.comm).

There are no apparent compositional trends across the basin, except in facies association mb_5 which consists of quartzarenites and subfeldsarenites with low feldspar and mica contents. A heavy mineral assemblage (N25/S3) from this association contains abundant non-magnetic opaques and garnet, common staurolite and sparse muscovite, tourmaline and kyanite. A metamorphic provenance is inferred, probably from the Onekaka Schist.

Cementation is generally absent from the sands of the Brunner Coal Measures. Two instances of cemented sandstone both occur in the Rangihaeata section and both are of probable Quaternary origin:

(1) Calcite-cemented subfeldsarenite.

At the Takaka Rivermouth (N25/924440), several hard oblate concretions up to lm thick outcrop at high tide level, roughly aligned along the bedding plane. In thin section (fig.17), the sand is shown to be cemented by large poikilotopic crystals of ferroan calcite. Cementation has caused local volume expansion of the former grain-supported framework and within mica and feldspar grains, causing rupture of the grains along cracks, cleavages and twins. Silicate grains are also replaced by calcite along rims and cleavages.

The large crystal size and silicate replacement indicate a slow rate of precipitation from dilute solution (Dapples, 1971). The high iron content of the calcite suggests reducing conditions during precipitation, probably in a phreatic environment. Crystal morphology indicates that the calcite is low-magnesian. Although the sandstones are presently in an environment subject to alternate saline and fresh porewaters, it is difficult to envisage a modern beach-rock process as cementation by seawater typically results in aragonite or high-magnesian calcite cement (Friedman, 1964).

Instead the features described above indicate that cementation occurred in a freshwater phreatic environment, probably within the last few thousand years. The porous sands of the coal measures were saturated with water from the Takaka River. This flows for part of its length through an aquifer system in Arthur Marble and probably contains a small proportion of dissolved calcium carbonate. Calcite precipitation could have been caused by changes in Eh or pH, for example in freshwater lenses trapped by an advancing seawater front. The sandstones are presently exposed at high tide level and this may be due to exposure after a fall in river base level.

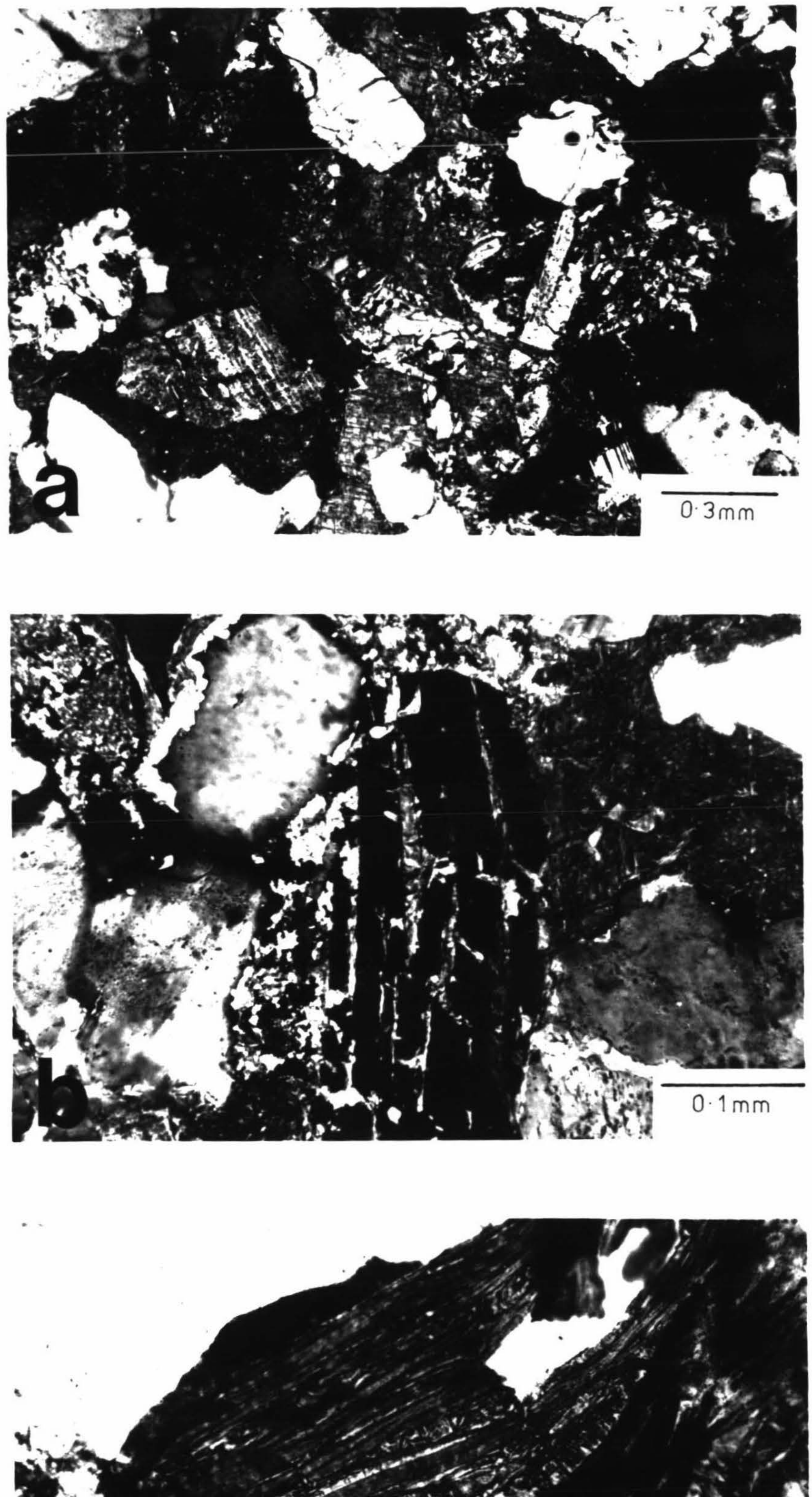
Similarly cemented conglomerate of the Pleistocene Kaituna Gravels outcrops at Patons Rock and cementation may have been related

FIG. 17 : CALCITE-CEMENTED SANDSTONE AT RANGIHAEATA
(Takaka Rivermouth, N25/924440)

a/ Moderately sorted, medium-coarse sandstone; calcite-cemented subfeldsarenite. Cementation of poikilotopic ferroan calcite (stained dark blue) caused expansion of the grain framework and rupture along grain cleavages. Rangihaeata sample 14607; Cross polars.

b/ Plagioclase grain split along twinning planes by force of calcite crystallization.
Sample 14607; Cross polars.

c/ Biotite flake ruptured along cleavages by cementation.
Sample 14607.


a
0·3mm
b
0·1mm
c
0·1mm

to flushing by the Onahau River, but this occurrence was not closely studied during the present study.

(2) Silica-cemented quartzarenite.

Silica cementation in the Brunner Coal Measures is restricted to the Pleistocene Kaituna terrace surface near Rangihaeata Head. Low hummocks of quartzarenite (facies association mb_5) rise a few metres above a swampy, poorly-drained valley, 10-20m above sea level. One such hummock (N25/915446) is capped by angular blocks of well-cemented sandstone, and a recently-cut bench exposes zones of cemented sandstone in areas of ground-water seepage. Prominent, hard liesegang rings occur within the friable sand. Thin sections of the sandstone (samples 14611, 14612) show that a quartz cement has precipitated in crystallographic continuity with the original quartz grains.

These sandstones are interpreted as quartzitic silcrete (Smale, 1973), petrographically identical to sedimentary quartzarenite but cemented under subaerial conditions. Smale notes that all quartzitic silcretes observed have been on raised ground and suggests that cementation takes place merely by prolonged or frequent presence of siliceous solutions.

The hummocks on which the silcretes occur are probably well-drained, but the presence of iron pans and the stunted scrubby vegetation suggest a leached, probably podzolic, soil. Thus, solutions of relatively low pH descending from the organic horizon and interacting with more alkaline, siliceous solutions could be important factors in cementation. Smale (1973) suggests that high salinity of percolating waters may be important for silcrete formation, in which case wind-blown sea spray from Golden Bay could be an additional factor.

The time of silcrete formation is almost certainly Quaternary. Conditions for cementation may exist at present, but could have been more favourable when the areas of quartzarenite formed part of a continuous terrace surface which was weathered during the late Pleistocene.

Mudstone composition has been determined by X-ray diffraction of six white mud(stone)s from widely spaced locations within the Takaka

Valley (Ligar Bay, Pohara, Gibson Ck., Waikoropupu, Rangihaeata and Little Onahau). All samples consist of kaolinite, quartz and muscovite, and there is no variation across the study area.

QUARTZ WASH MEMBER

Distribution

The Quartz Wash Member occurs as patches of conglomerate and sand(stone) up to 20m thick, high on the southeast flank of the Aorere valley and in the lower Parapara River. Many cliff sections were formed by hydraulic sluicing during the 1890s and 1900s and remain well-exposed (e.g.fig.19a). The most extensive of these are at the Quartz Ranges, the head of Blue Creek, Golden Gully, Lightband Gully and Parapara. These and other outcrops have been previously described by Hector (1892), McKay (1896) and Bell et al. (1907).

The majority of outcrops visited during the present study are flat-lying or gently dipping, although often associated with marked changes in basement relief. For example,

(1) Conglomerates in the Quartz Ranges, now substantially removed by sluicing, abut against cliffs along the southern edge of the goldmining area below Trig Q (M26/690389 - 698390: Bell et al., 1907, Plate XX);

(2) At Appo's Flat, a depression in the peneplain surface filled by gravel and conglomerate, more than 42m thick (McKay, 1896) is bounded by steep hills of Bay Schist. Bell et al. (1907) and Gage (1940) considered that the deposit accumulated by slumping into solution cavities in marble basement. Although Bishop (1971) mapped the underlying basement as Bay Schist, there is at present insufficient field exposure to contradict that theory.

(3) On the east side of the Parapara valley, east of Washbourn Creek (M25/520835), gravels abut against a hillside formed of Onekaka Schist;

(4) On the Aorere peneplain surface, there are numerous examples of Quartz Wash sand and gravel abutting against banks 1-2m high.

Hector (1892) and McKay (1896) showed that a line of steeply dipping strata extended from Parapara through Glen Mutchkin, Glen Gyle Creek and the head of Appo's Creek to Golden Gully. A shaft was sunk here in vertical strata to a depth of 39m without reaching basement, although basement was within 4.5m on either side of the shaft (McKay 1896:17). Much of the vertical strata in the Parapara area was considered by Gage (1940:311) to be due to slumping into solution cavities in underlying Arthur marble.

During the present study a vertical fault-wedge of coal, sandstone and conglomerate was mapped immediately west of the lower Parapara River (fig.19c; M25/823530), overlain by near-horizontal Takaka Limestone. The implied unconformity is obscured by vegetation, but if present, would indicate faulting during Whaingaroan-Waitakian time.

Hector (1892) used the evidence of a line of vertically dipping strata to infer a major fault, the "Main Slide Lead". This concept has not been supported by recent mapping (Bishop, 1971; Grindley, 1971) which has instead shown the Quartz Wash in the Quartz Ranges area as being cut by a number of local faults and lineaments of widely varying strike and throw. The Quartz Wash Member in the Golden Gully area is bounded to the west by a north trending fault.

However there are a number of lines of evidence for a northeast-southwest trending fault-zone:

(1) The peneplain surface is bounded by a line of valleys aligned southwest-northeast, to the southeast of which the terrain is moderately dissected and on which the peneplain surface can only be traced by accordant summit heights. This line of valleys includes the upper part of Salisbury Creek, the lower Rocky River and much of the Parapara River;

(2) The thickest areas of Quartz Wash (Fig.25) are concentrated on the southeast boundary of the peneplain surface;

(3) A number of parallel southwest-northeast lineaments can be traced on air photographs across the Boulder River-Rocky River area (see 1:63360 maps M25 and M26), and match similarly-trending faults in the Slate River - Parapara River area (Grindley, 1971; Bishop, 1971).

Age

Pollen samples from Parapara River, Appo's Creek and the Quartz Ranges indicate a Runangan-Whaingaroan age for the Quartz Wash Member (Raine, 1979).

Content

The Quartz Wash Member typically consists of white, crudely bedded or massive pebble-cobble conglomerate, sometimes interbedded with pebbly sandstone or scour-fill sandstone. Subordinate facies include cross-bedded coarse sand, massive muddy sandstone and lenses of carbonaceous mudstone. Six facies can be distinguished (figs.20,21).

(1) Massive boulder conglomerate (-breccia) (fig.18c,d) composed of well-rounded 0.3-1.0m diameter boulders of vein quartz and quartzite and 0.2m long imbricate slivers of phyllite, clast-supported with a sand and pebble matrix. This forms the basal 2-5m at the Quartz Ranges; McKay (1896:16) reports similar "slaty breccias" from the west side of Golden Gully and from Sailors' Gully.

(2) Conglomerate/gravel (fig.18b) with bimodal 100-150mm diameter well rounded cobbles and 10-50mm pebbles of vein quartz and quartzite, sometimes phyllite, crudely orientated or imbricated in a poorly sorted sand matrix. Lenses of coarse sandstone contain inclined pebble laminae.

This facies grades into pebbly sandstone, composed of moderately hard coarse-granule sandstone with pebble laminae in low-angle crossbeds.

(3) Medium-coarse sand with scattered pebbles up to 20mm diameter in cm-dm scale trough cross-bedding (fig.19a,b). The sand is moderately sorted, friable quartzarenite with minor mica and feldspar.

(4) Medium-dark grey muddy fine sandstone, faintly laminated or massive, rarely containing scattered pebbles.

(5) Dark brown, massive carbonaceous mudstone with thin coal stringers, rootlets and sometimes pebble lenses. This facies may occur at

the base of the Quartz Wash in the Parapara area, and consist of highly deformed, slickensided black pyritic and carbonaceous mudstone and coal with lenses of sandstone and conglomerate (fig.19c).

(6) White, well sorted medium or fine quartzarenite sand, with no apparent sedimentary structures, occurs in thin drifts across the peneplain surface. Sand grains are commonly well rounded.

Interpretation

This succession of facies, presented in a generalized order of superposition, suggests deposition of an alluvial fan system, with facies 1-5 corresponding to proximal-distal environments.

The massive boulder conglomerates accumulated as "diffuse gravel sheets" (Hein and Walker, 1977) on an upper fan surface - a gravel lag only one or two clast diameters thick which migrated only during peak flood stages. Sand and silt trapped between boulders gave rise to a clast-supported texture.

Pebble-cobble conglomerates were deposited in longitudinal bars (Hein and Walker, 1977; Miall, 1977) on mid-fan surfaces. Under high flood conditions, the coarsest material was carried in the centre of the channel, and as the flood waned, this material was deposited as a crudely bedded sheet, while the flow separated into channels on either side (Miall, 1977). Pebbly sand lenses indicate foreset - infill of minor channels and scour hollows on the bar surface during low water.

Crude foreset bedding, commonly associated with pebbly sandstones (e.g. Fig.20c, 2-4.5m) indicates transverse bar formation under lower-energy flood conditions (Hein and Walker, 1977).

The trough cross-bedded sand, commonly associated with low-angle foreset-bedded gravel, represents migrating megaripples in sandy braided river channels (cf fig.21a) on the outer margins of an alluvial fan.

Finer-grained facies, the muddy fine sandstone and carbonaceous mudstone, were formed in lakes and abandoned channel areas adjacent to

FIG. 18 : QUARTZ WASH MEMBER AT THE QUARTZ RANGES
(Quartz Ranges, M26/697391; see fig. 20)

a/ The western part of the proposed type section of the Quartz Wash Member, where up to 12m of quartzose conglomerate rests on phyllite of the Bay Schist Formation. The cliffs were formed by hydraulic sluicing during the 1890s.

b/ Crudely bedded pebble-conglomerate with occasional pebbly sandstone lenses.
Staff 1.50m long.

c/ Boulder-conglomerate near the base of the section. The haphazard orientation of the boulders is emphasized by elongate phyllite slabs. Note the roundness of the quartz/quartzite boulders.
Hammer 330mm long.

d/ Cobble and boulder conglomerate with well-developed horizontal stratification in the upper half of the picture, overlying massive, unsorted material.

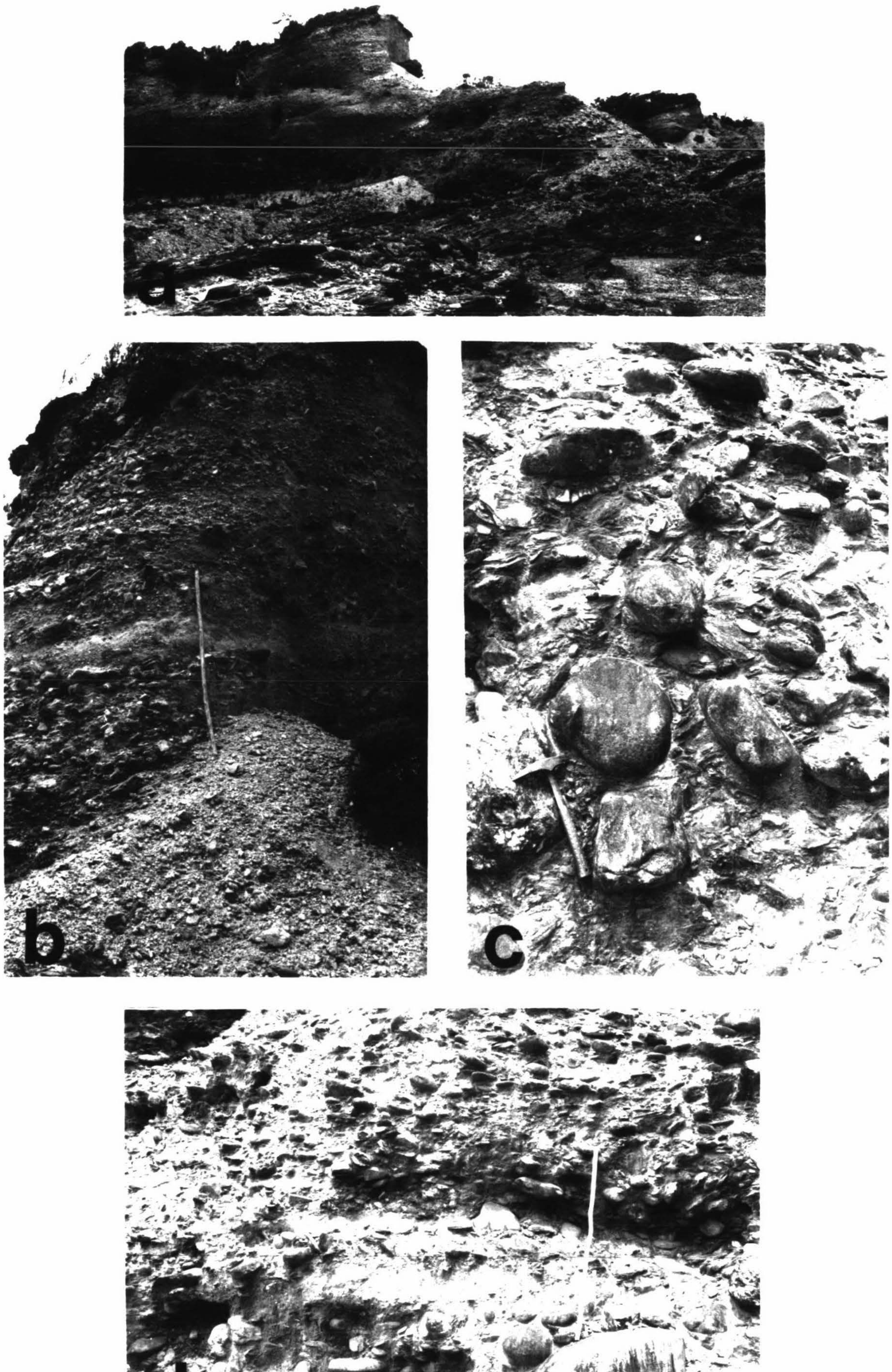

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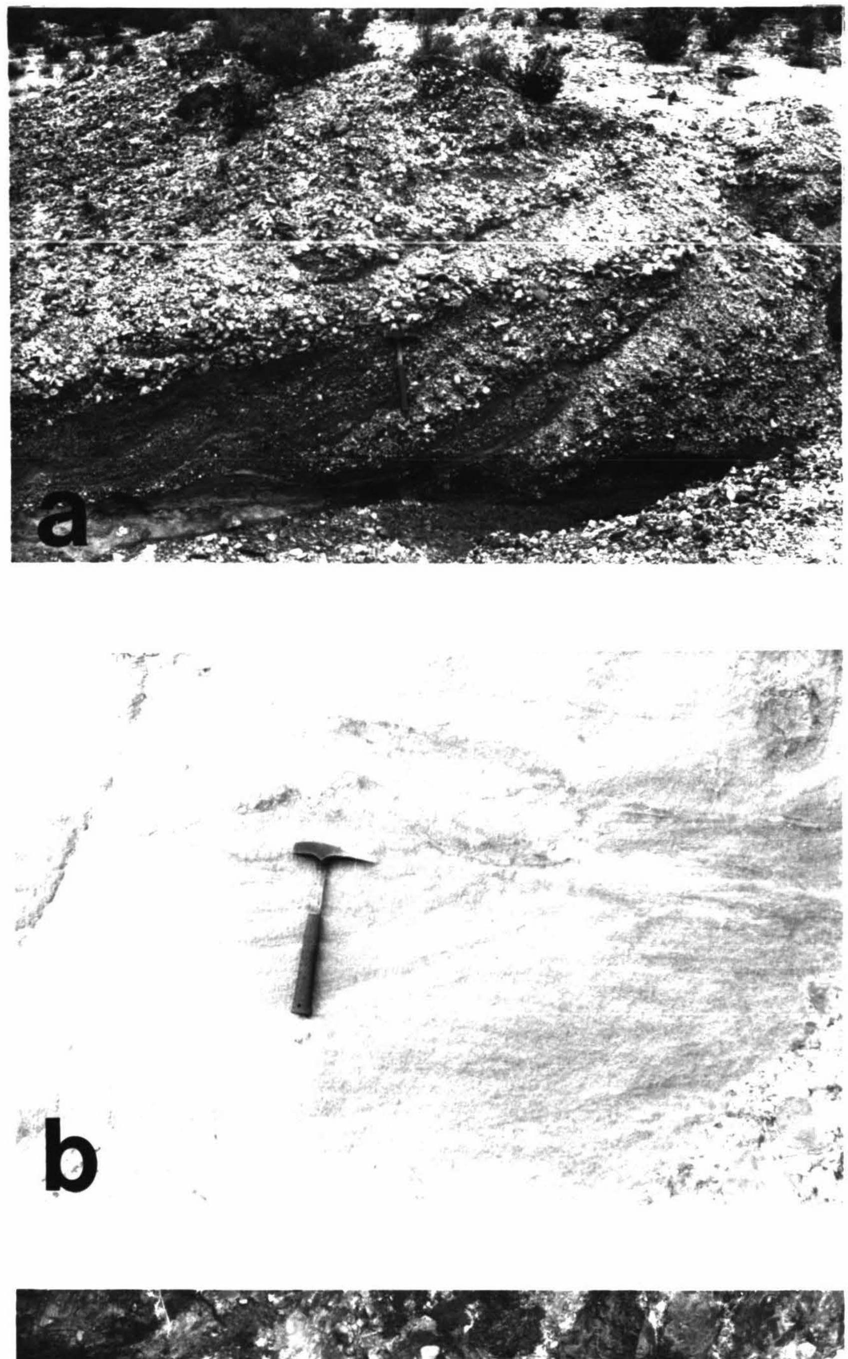
FIG. 19 : QUARTZ WASH MEMBER AT THE QUARTZ RANGES, GOLDEN GULLY AND PARAPARA

a/ Trough cross-bedded sandstone and conglomerate, consisting of quartz pebbles and finely abraded angular phyllite chips. Quartz Ranges, M26/699398.
Hammer 330mm long.

b/ Well-sorted, medium-fine sand in 1m thick trough cross-beds. Golden Gully, M25/c.800470; see fig.21.

c/ Vertically-dipping pyritous mudstone and muddy conglomerate (younging to the left), sheared against a small northwest-trending fault. Location of pollen sample M25/f34 (Runangan age). Parapara River, M25/823350.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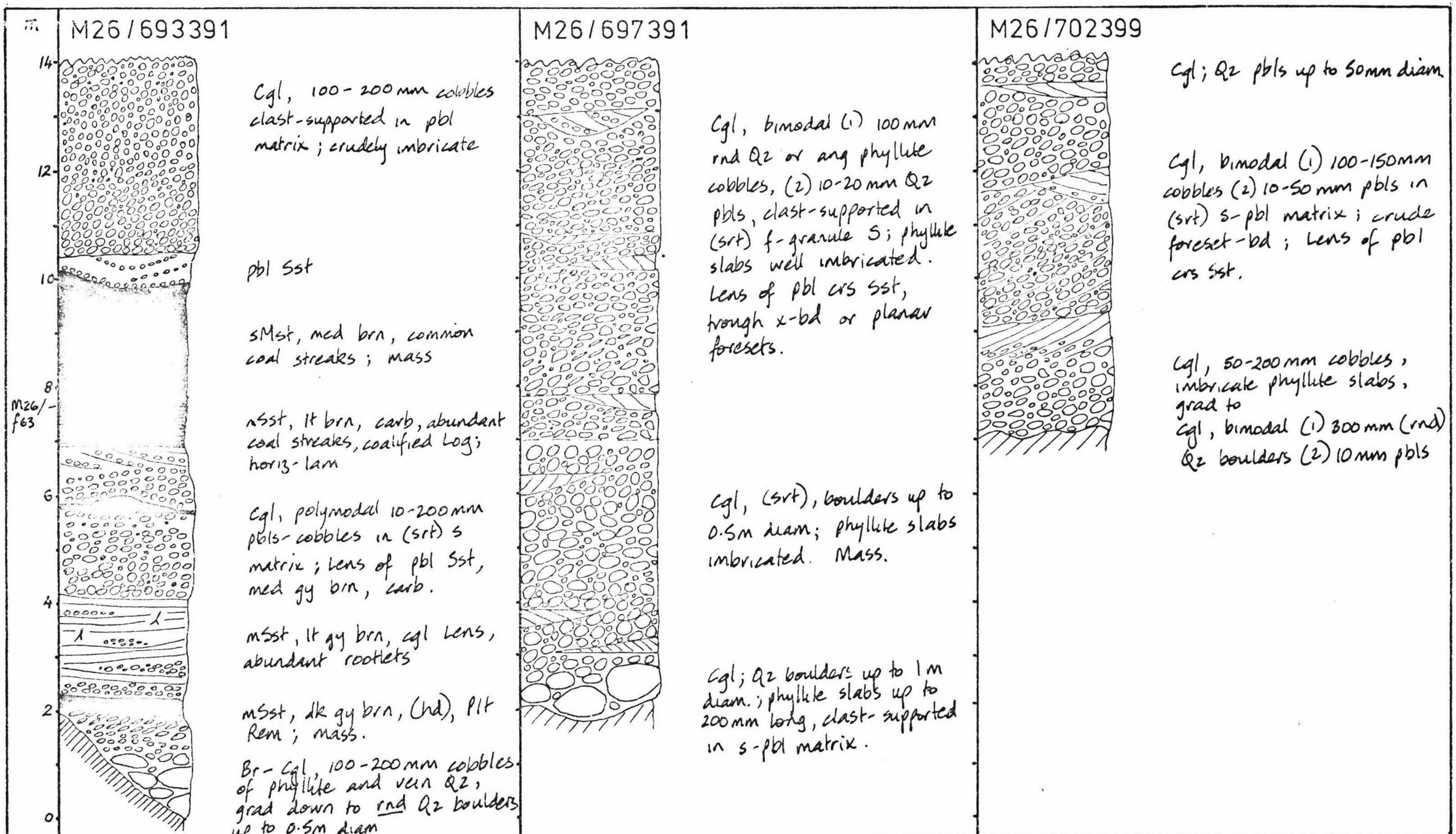


Fig.20: Detailed sections of Quartz Wash Member at the Quartz Ranges

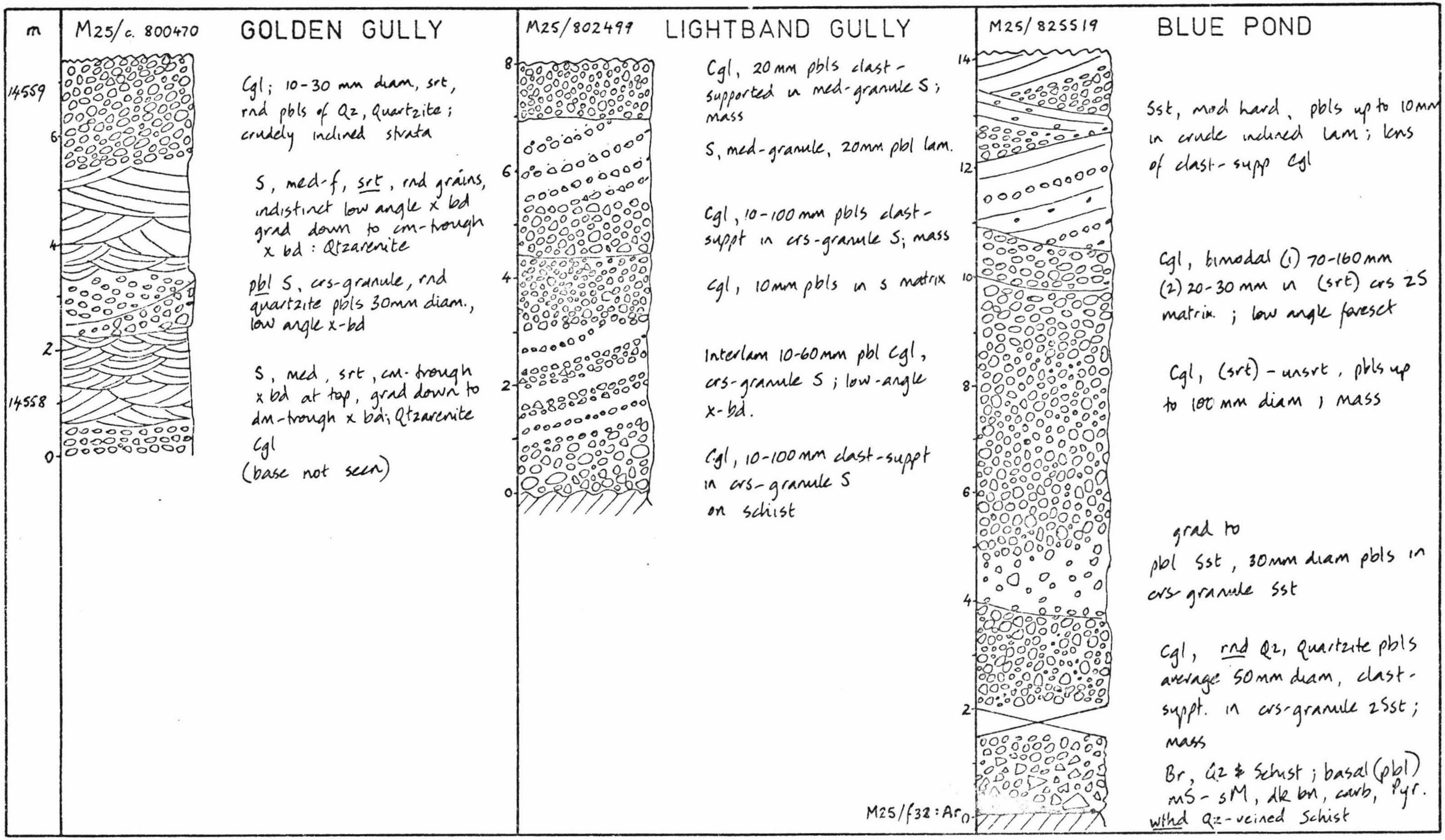


Fig.21: Detailed sections of Quartz Wash Member at Golden Gully, Lightband Gully and Blue Pond (Parapara)

the active fan systems. However the coal and mudstones found at the base of sequences at Parapara and elsewhere probably pre-date alluvial fan formation and were formed in swamps, perhaps in incipient fault-angle depressions (see Chapter 7).

The well-sorted sand drifts occurring across the peneplain surface may represent fluvial sands winnowed and sorted during marine transgression by wave and tidal currents.

The Quartz Wash conglomerates were interpreted by McKay (1896) as shallow marine deposits. He argued that "a rapid stream, having many tributaries from the mountains on each side of the watershed, (could not), owing to the continued influx of fresh material, produce gravels of one kind of rock only - and much less a purely quartz-gravel - in a country where there is a considerable variety of rocks. But these difficulties to a great extent disappear if we suppose the sea to be the agent concerned in the production of the quartz-drifts of the Aorere Valley, and assume the existence of a gradually-sinking land, giving opportunity for the pounding and reduction of the softer rocks, and the conversion of the harder material of these into water-worn material . . ." (p.21).

A marine origin is contradicted by the poor sorting of the conglomerates, the scour-fill sand lenses, the presence of carbonaceous mudstone and coal, and the general association of lithologies and sedimentary structures. Although the inferred proximal fan deposits are composed of both quartz and phyllite or schist, the general predominance of quartz does appear incompatible with an alluvial fan origin. An explanation is suggested by Park (1890) in a description of the Red Hill area (M25/c.805499). The basement rock "is a compact blue gneissic schist . . . (which) decomposes to a great depth from the surface into a tough ferruginous sandy clay, . . . Throughout its whole mass it is interbedded at irregular and distant intervals with lenticular-shaped bodies of white quartz - of which hundreds of tons, as large angular fragments, lie strewn over the surface of the lease, having been left there as the softer decomposed rock became removed by denudation" (p.46).

It is suggested that as the Quartz Wash Member was deposited following a long period of peneplanation the deeply weathered schist or phyllite rock was removed in suspension while the more-resistant quartz formed the bed-load of the alluvial system.

WASHBOURN LIMONITE MEMBER

Distribution

The Washbourn Limonite Member has an elongate north-south trend, capping steep ridges up to 700m altitude between Parapara Inlet and Pariwhakaoho River. Its distribution is described in detail by Bell et al.(1907). The most accessible outcrops are in Washbourn Creek and an adjacent iron-ore quarry. An unmarked foot-track can be followed from Onekaka River to the former Onekaka Iron and Steel Co. quarry.

Ore-bodies are highly irregular in shape and size but are rarely thicker than 30m (Jones, 1939:29). They are restricted to Arthur Marble basement between the Onekaka and Golden Bay Faults. Talus from the ore-bodies covers adjacent valley flanks and floors. Small blocks and boulders of limonite are commonly scattered across the peneplain surface southeast of Aorere River.

Content

The ore consists mainly of limonite with minor goethite and turgite, and quartz and mica impurities (Bell et al.,1907). A medium-grade ore from the Onekaka Block (Bell et al.,1907:86) consisted of 63.84% Fe_2O_3, 0.75% MnO, 0.72% TiO_2, 3.86% Al_2O_3, 19.20% SiO_2 etc.

In texture the ore varies from soft earthy rubble to hard cavernous botryoidal rock, ranging from purple to dark brown and weathering to shades of brown, yellow and red (fig.22b). Botryoidal vugs are commonly lined with silver-black pyrolusite (MnO_2). Blocks of iron-ore with scattered rounded quartz pebbles and quartzose conglomerate cemented with limonite are abundant in Washbourn Creek (fig.22c); Gage (1940) noted that "pebble-containing ore may grade or pass abruptly into dark pyritous and carbonaceous conglomerate, or into quartz conglomerate presenting a bleached whitened appearance" (p.307).

Origin

Gage (1940) showed that the only important sources of iron in the central Golden Bay region are the mineralized fault-zones and veins in Paleozoic schist, probably formed during emplacement of the Richmond Hill Porphyry in the Upper Triassic-Early Cretaceous (Grindley, 1971). Gage also considered that pyrite from the Quartz Wash Member contributed to formation of the iron-ore. The Arthur Marble which underlies the ore deposit is low in iron and is an unlikely source-rock.

Gage (1940) and Bell et al.(1907) considered that iron was leached from gossans formed on the mineralized zones and was transported in solution as sulphuric acid and ferrous sulphate ($FeSO_4$). Contact with the adjacent Arthur Marble led to interaction of the $FeSO_4$ and $CaCO_3$ to form ferrous carbonate ($FeCO_3$) and ultimately hydrated ferrous oxide. Reaction of both the sulphuric acid and the $FeSO_4$ with the marble should have produced large quantities of gypsum ($CaSO_4$), a relatively insoluble mineral, but Gage admits that gypsum is a rare component of the ore. The elongate distribution of the Washbourn Limonite was attributed to accumulation in a fault-angle depression formed by movement of the Onekaka Fault.

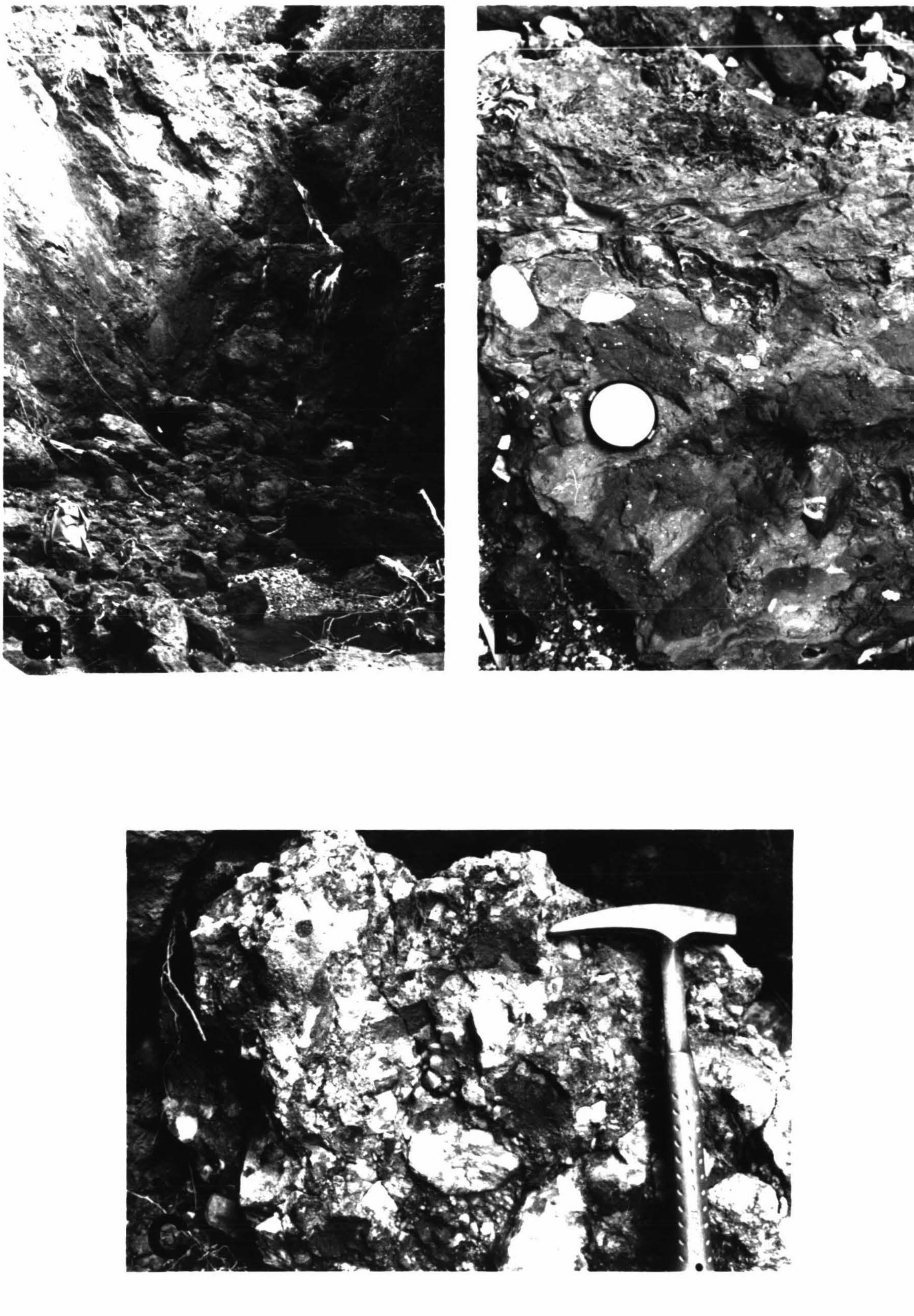
An alternative theory developed during the present study considers the Washbourn Limonite to be a bog iron ore deposit (see Stanton, 1972). Iron leached from pyritic gossans was transported in solution into swamps and marshes common on the peneplain surface. In the marsh waters, decaying vegetation caused reducing conditions and the formation of carbon dioxide; thus iron entering the marsh was reduced to ferrous bicarbonate ($Fe(HCO_3)_2$). In swamps developed on non-calcareous basement, the $Fe(HCO_3)_2$ was converted to pyrite by sulphate-reducing bacteria and remains as such in the pyritic carbonaceous sediments of the Quartz Wash. However, the Washbourn Limonite is restricted to a basement of Arthur Marble. It is likely that then, as at present, the marble contained an extensive system of solution cavities filled with comparatively fast-moving well-oxygenated water, probably under moderate hydrostatic pressure. Interaction of the

FIG. 22 : WASHBOURN LIMONITE MEMBER IN
WASHBOURN CREEK
(Washbourn Creek, M25/828511)

a/ Typical creek exposure of iron-ore, a mixture of hard blocks and soft earthy rubble.
Rucksack and hammer at bottom left give scale.

b/ Hard iron-ore with both smooth and vesicular texture and scattered rounded quartzite pebbles.
Lens cap 60mm diameter.

c/ Quartz breccia cemented by dark red quartz-rich limonite.
Hammer 330mm long.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reduced $Fe(HCO_3)_2$ - charged marsh waters with the oxygenated artesian waters caused oxidation of the iron and precipitation of limonite on the interface. The irregular distribution of the limonite is thus explained by irregularities in original topography and in the marble karst system. Accumulation of up to 30m of iron-ore was effected by steady continuous deposition, fluctuations in the artesian system and probably slumping of the limonite into solution cavities.

This theory is preferred to that of Gage (1940) because it does not involve production of calcium sulphate, and because it can be directly compared with modern bog-iron deposits in northern Europe and North America (Stanton, 1972). Accumulation in a fault-angle depression is not necessary. Contrary to Bell et al. and Gage, this theory excludes the Quartz Wash as a source of iron for the Washbourn Limonite, and indeed the bulk of the Quartz Wash is probably younger than the iron-ore. The significant proportion of quartz sand and breccia in the Washbourn Limonite is not inconsistent with a swamp origin.

FACIES, PALEOCURRENT AND THICKNESS VARIATION WITHIN THE BRUNNER COAL MEASURES, GOLDEN BAY

Facies Interrelationships

A fence diagram of the coal measures in the lower Takaka valley (fig.23) indicates three broad divisions within the formation:

(1) facies association mb_1, of Bortonian-Kaiatan age dominates the thicker sections (Dry River, Gibson Creek). Thick coal seams are common in the middle-upper part of these sections;

(2) laterally interfingering associations mb_1, mb_2 and mb_3, overlain by mb_4, of Runangan-Whaingaroan age, are thickest in the northern sections (Rangihaeata, Motupipi, Tarakohe etc.);

(3) facies association mb_5, of Runangan-Whaingaroan age, is probably derived from metasedimentary rocks on the west side of the Takaka valley. In age and provenance, it resembles the sediments of the Quartz Wash Member.

Within the Quartz Wash Member, three associations are present:

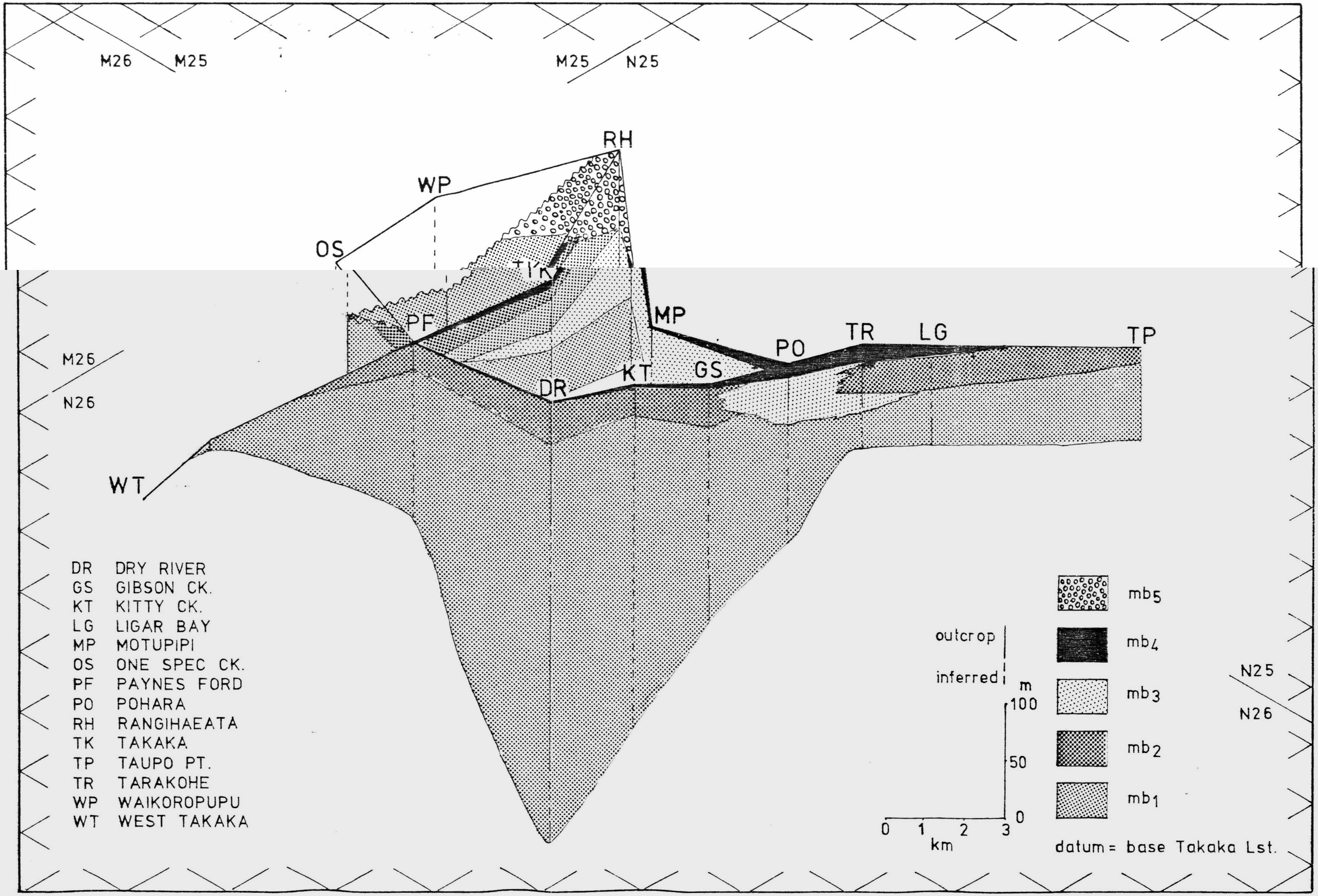


FIG. 23 DISTRIBUTION OF FACIES ASSOCIATIONS OF BRUNNER COAL MEASURES IN TAKAKA VALLEY

the sheared carbonaceous mudstone and sandstone at the base of sections in the Parapara area, the more widespread conglomerates and sandstones, and the well sorted overlying sands of probable marine origin.

The basal carbonaceous material formed in swampy depressions adjacent to incipient fault-scarps. During the main period of faulting these mudstones and sandstones were smeared against the fault, while the conglomerates were deposited in fans gently dipping away from the faults. Following this burst of tectonic activity, the uppermost sands of the Quartz Wash were reworked by the advancing sea.

The age of the Washbourn Limonite Member is unknown, but gradation into the Quartz Wash suggests that at least part of it is Runangan-Whaingaroan. Its inferred origin as a swamp suggests an absence of significant tectonic activity.

Paleocurrents

Paleocurrent measurements were collected only within the Takaka valley. Most measurements are derived from apparent dips measured in cliff exposures and plotted on a sterecnet; horizontal exposures of cross-bedding are confined to three horizons in the Rangihaeata section. Paleocurrent measurements are recalculated to allow for orientation of bedding where the latter exceeds 10^{o} dip.

The resultant rose diagrams (fig.24) indicate a general northwards flow direction. The unimodal distributions of facies associations mb_1 and mb_5 fit the interpretation of a fluvial origin, while the bimodal distributions in association mb_3 are consistent with the inferred ebb and flood tidal channels in a braided estuary.

Within the Quartz Wash Member, imbrication of phyllite slabs at the Quartz Ranges suggests a northwards flow direction.

Isopach Variation

The isopach distribution (fig.25) is largely interpretative, because of the small number of complete or near-complete stratigraphic columns, and relies heavily on structural, paleocurrent and provenance data.

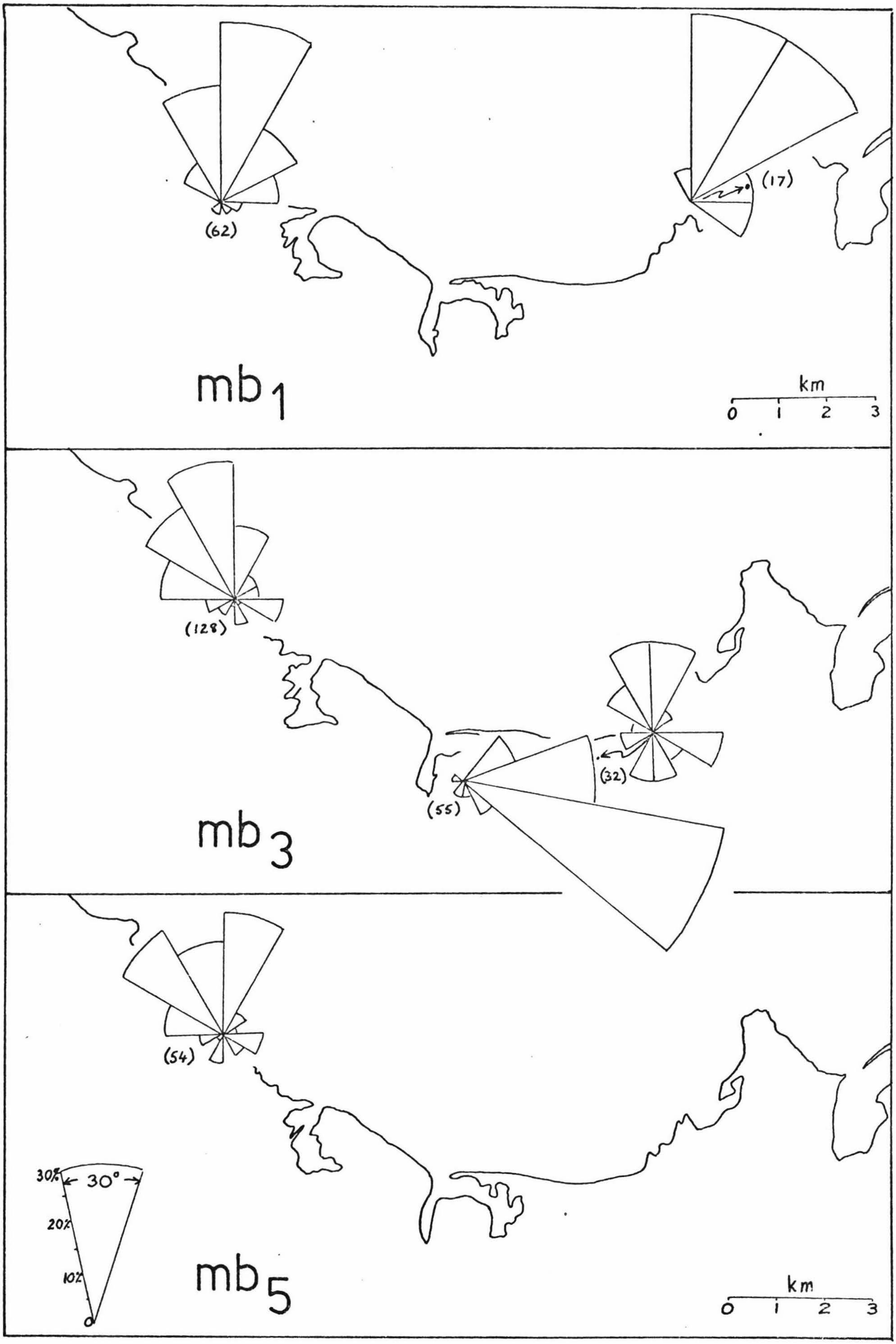


Fig.24: Paleocurrent distributions of facies associations mb_1, mb_3 and mb_5. Data at each locality are grouped in 30^o classes and plotted as percentages. Numbers within brackets are the total number of data at each locality

In the Takaka area, normal faulting is inferred on the unnamed fault bounding the Wainui Shear Zone (Grindley, 1971) to account for the dominantly granite provenance of the sands. However, the fossil peneplain surface does not appear to be displaced across this fault, and therefore no great subsidence can have occurred along it. It is probable that over 300m of continual subsidence took place on a normal "proto-Pikikiruna Fault" concurrently with coal measures deposition. Normal faulting on a "proto-Golden Bay Fault" is postulated to provide the tongue of metasediment-derived facies association mb_5.

Thickness variation and the alluvial fan interpretation suggest that the Quartz Wash Member was derived from a fault or fault-zone on the southeast boundary of the Aorere valley peneplain. This fault has not been recognized by recent regional mapping (Bishop, 1971; Grindley, 1971) but as a large displacement is not required to provide the observed thickness of Quartz Wash, the fault may not have significantly juxtaposed the basement formations.

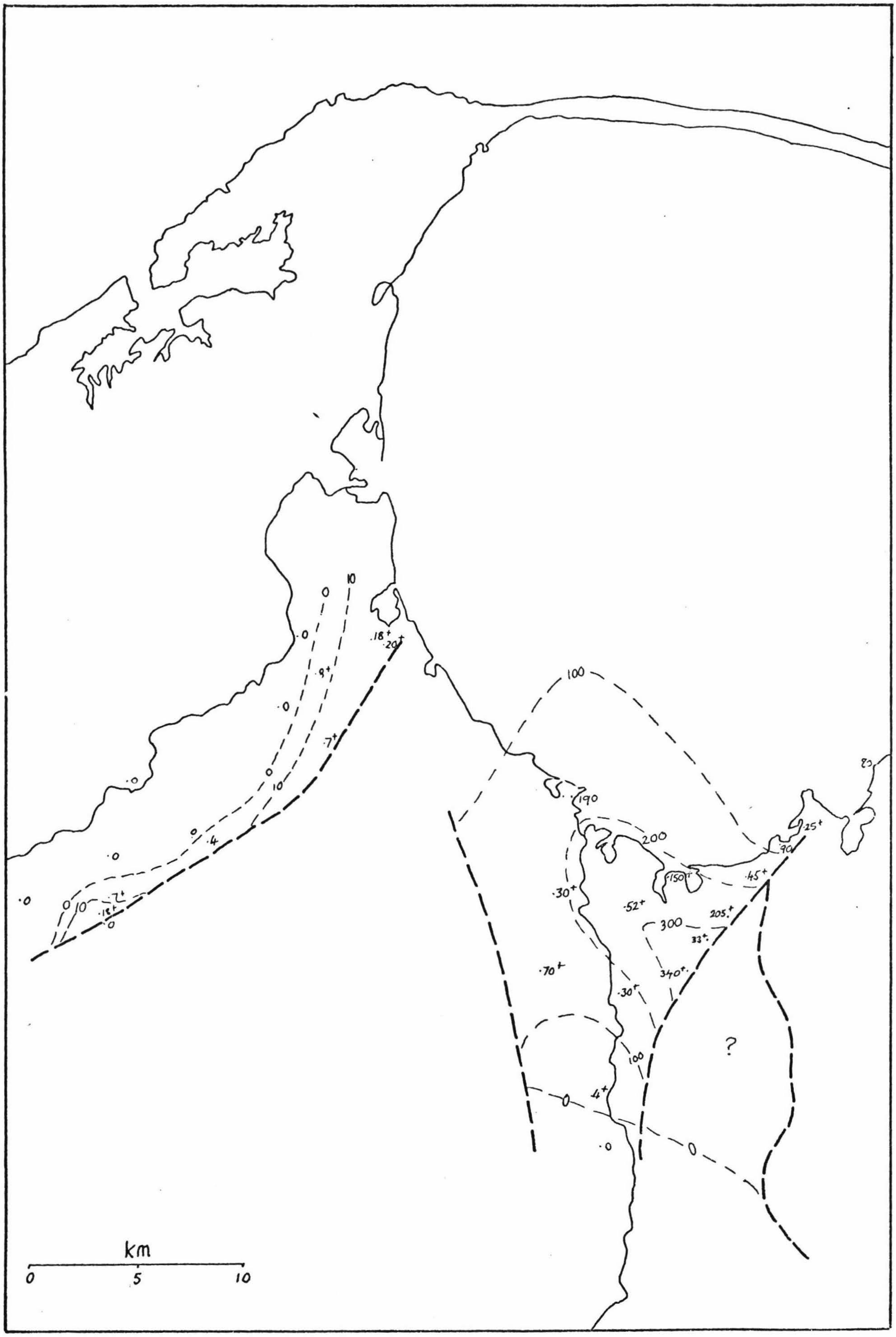


Fig.25: Isopach distribution of the Brunner Coal Measures in Golden Bay. Thickness data are in metres; data with "+" are minimum thicknesses, where an upper or lower contact is not exposed.

ECONOMIC GEOLOGY

Clay

Soft, sandy siltstone, rich in kaolinite and quartz, is presently quarried near Little Onahau River for use as pottery clay; this material is highly refractory and must be blended (I. MacPherson, pers.comm. 1978). Most mudstones in the coal measures have high organic content, and those most suitable for use in the pottery industry are probably the white-light grey mudstones which have been strongly leached. Bell et al.(1907) list four major oxide analyses which indicate 47-50% SiO_2, 32-35% Al_2O_3, 1-2% Fe_2O_3, 0.6-1.4% CaO, 0.1-0.3% MgO and 13-17% water and organic material.

The thick beds in the Little Onahau area are probably the major economic deposits of clay. These are exposed in a small area around the present quarry, but prospecting beneath the thin Pleistocene cover could well extend the reserves of workable clay. There are several thin beds at Rangihaeata (e.g. fig.7) and Waikoropupu River, and isolated thick beds on the east side of the Takaka valley (e.g. Pohara and Gibson Creek sections).

Coal

Coal-mining began at Motupipi in the 1850s (Fleming, 1959a) and continued in the Takaka valley in a desultory way until 1939. Between 1890 and 1939, 6770 tons of coal were mined (Sara, 1972), but the inferior rank, small reserves and high sulphur content compared unfavourably with PakawauGroup coal from Puponga.

Wellman (1945) lists several proximate analyses of the coals, which are of medium sub-bitumenous rank. Sulphur content at Motupipi and Paynes Ford, the most important mining areas, ranges between 4.5 and 5.7%, coal seams in Gibson Creek contain 0.6-0.9% sulphur. Ash content ranges between 2.4% and 11.2%.

As Wellman (1945) pointed out, the steeply dipping seams on the east side of the Takaka valley have been well prospected, but the gently dipping coal measures covered by Pleistocene gravels on the west side of the valley are relatively unknown. Facies interrelationships (fig.23) suggest that any buried coal measures in the Anatoki River-Paynes Ford area belong to facies association mb_1. This association in One Spec Creek and Anatoki River contains highly carbonaceous sandstone and mudstone, but only thin coal seams of 100-200mm thickness. Coal reserves could be elucidated by a small number of exploratory drill-holes, but prospects are not encouraging.

Gold

Despite a long history of goldmining of the Quartz Wash Member, present high prices for gold prompt a reassessment of the remaining economic potential.

The first substantial gold rush in New Zealand took place in the Aorere valley between 1857 and 1859. Gold was won from Recent stream deposits, Pleistocene terrace gravels and the older Quartz Wash Member.

Quartz Wash gold in the Quartz Ranges is fine and rounded, with irregular nuggets commonly 2-3 dwt. and rarely up to 1 oz. (Bell et al., 1907:53). Gold was won from all horizons within the member; surface deposits at Golden Gully proved very rich, with 40,000 oz. being won in a few months (Hector, 1892).

Much of the Quartz Wash Member is remote from substantial quantities of water, and full exploitation of the member was delayed until the advent of hydraulic sluicing and large water-races in the 1890s and 1900s. The Parapara Hydraulic Sluicing Co. sluiced large areas of conglomerate at Parapara, Glen Mutchkin and Appo's Creek, sometimes using elevators. The Quartz Ranges Sluicing Co. constructed an elaborate water-race from Boulder River to the Quartz Ranges, but sluicing met with limited success, due probably to poor management (Bell et al., 1907). Small-scale mining by individuals took place during the economic depressions of the 1890s and 1930s.

Outside the Aorere valley, the Brunner Coal Measures yielded gold at Rangihaeata from channel scour surfaces in facies association mb_3 (C. Vowless, local resident, pers.comm.). Low hills of mb_5 conglomerate and sandstone west of Rangihaeata Head also yielded gold, but were isolated from a reliable source of water.

It is unlikely that any profitable areas of gold-rich conglomerate suitable for a large-scale venture remain today, except perhaps in areas of deeper ground in Appo's Creek or Parapara beyond the reach of nineteenth century technology. McKay (1896) mentioned a few examples of thin quartz drifts scattered across the peneplain surface, which contained rich quantities of fine gold. Deposits such as these, if not already worked out may be profitable for small-scale mining.

Iron ore

The Washbourn Limonite Member was first prospected in detail by Bell et al. (1907) who predicted reserves of 22.69 million tons of ore averaging 51.8% iron in the northern part (Washbourn Block) alone. Production of pig-iron was begun by the Onekaka Iron and Steel Co. in 1922. Iron ore and marble were quarried at 375m altitude (M25/837466) and transported by aerial tramway to a plant at Onekaka (M25/848486). During the 13 years of operation, the company produced 41,195 tons of pig-iron, but marketing suffered from high production costs and competition from imported steel (Luke, 1955:10). The State Iron and Steel Dept. took over the company in 1937 and carried out a detailed drilling and tunnelling survey. Reserves of 9.5 million tons of ore with 35-50% iron were proven (Luke, 1955:16). The plant was maintained in readiness for wartime production, but was not used again and was dismantled during the 1950s.

A small quarry is sporadically operated near Washbourn Creek. The iron ore is used in small quantities for gas purification, as a special cement additive, and as a pottery glaze material.

Hydrocarbon Potential

The sub-bitumenous coal rank in the Takaka valley indicates that the coal measures there were not buried to a depth sufficient for hydrocarbon generation. However, the facies of the Brunner Coal Measures and their interrelationships may be similar to deeply buried coal measures (Kapuni Fmn.) in the South Taranaki Basin. Although the coarse sand facies would be effective conduits and reservoirs, thick beds of coal and mudstone which might be potential hydrocarbon source rocks are absent in the Brunner Coal Measures in Golden Bay.

Sand

Quartzarenite sand of the Quartz Wash Member occurs in small patches on the Aorere valley flank, but may form larger deposits in the Parapara valley. Much of the sand is iron-stained, but is very pure with only traces of feldspar and mica. A body of quartz sand 30m thick, probably reworked during the Pleistocene, was reported in a drillhole near Blue Pond, Parapara (Bishop, 1971).

In the Takaka valley, mb_3 sand is used in cement manufacture. At present, subfeldsarenite-quartzarenite sand is quarried from Motupipi Sandpit, in an area where sand deposits are very extensive. As fuel costs increase, the deposits in the Pohara area may be worth renewed prospecting.

CHAPTER FOUR

TAKAKA LIMESTONE

Distribution

The Takaka Limestone conformably overlies the Brunner Coal Measures in the lower Takaka valley and in a few places in the Aorere valley; in the upper Takaka valley, Aorere valley and on Gouland Downs it rests directly on a generally smooth basement. A continuous belt of limestone on the east side of the Takaka valley extends offshore northeastwards to the Tata Islands and Taupo Point. Many smaller areas of limestone are exposed in the lower Takaka valley, Rangihaeata Head and Pariwhakaoho River. South of Upper Takaka, limestone forms irregular belts bounded by the Pisgah and Karamea Faults and abruptly changes laterally to Matiri Formation in the headwaters of Leslie River.

Isolated hills of limestone dot the peneplain surfaces in the Aorere valley and Gouland Downs. These are conspicuous by their thick cover of bush in an otherwise tussock - or scrub - covered landscape (fig.5a,b).

Outside the study area (fig.26), Takaka Limestone is exposed on the coast between Cape Farewell and Kahurangi Point (Titheridge, 1977) where it overlies Abel Head Formation shallow marine sandstone and mudstone: at Heaphy River (Leask, 1977), Kohaihai Bluff and Stony Creek (German, 1976) overlying Brunner Coal Measures: and at Oparara River (German, 1976) and Cuckoo River where it rests on basement.

Bryozoan limestone of similar age, lithology and thickness has been found in offshore wells in the south Taranaki Basin: 61m of glauconite sandy limestone with common bryozoa in Tasman - 1 (van Oyen and Campbell, 1970); 33m of glauconitic foraminiferal limestone in Cook - 1 (van Oyen and Branger, 1970); 63m of medium-coarse sandy limestone in Fresne - 1 (NZ Aquitaine Petroleum, 1976a); 81m of sandy bryozoan limestone and interbedded calcareous sandstone in Surville - 1 (NZ Aquitaine Petroleum, 1976b). Further to the north and west the formation apparently grades to a deepwater limemudstone ("Cobden Limestone" of Pilaar and Wakefield, 1978).

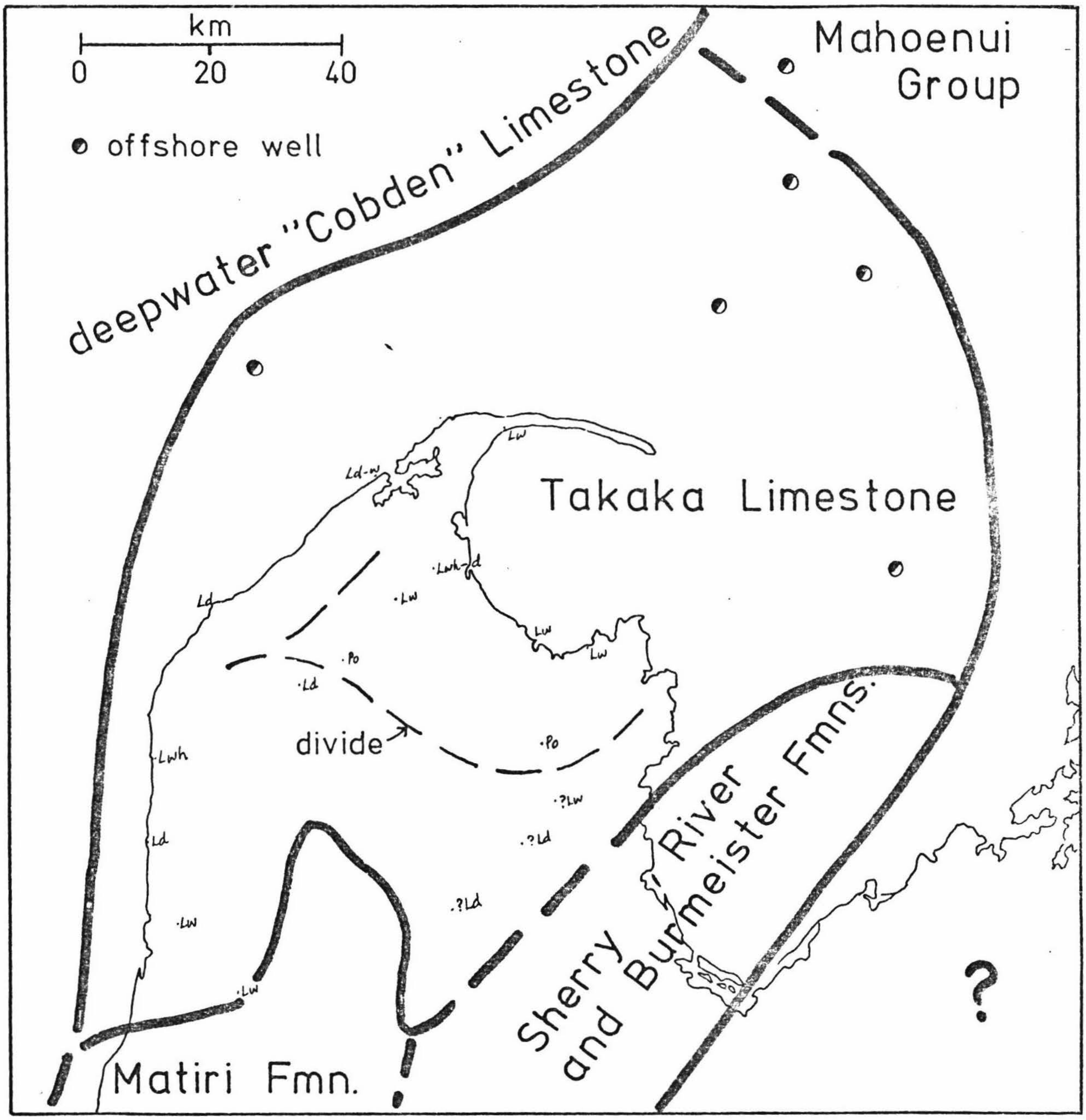


Fig.26: The maximum extent of the Takaka Limestone during Duntroonian-Otaian time, with the major adjacent time-equivalent formations (after Pilaar and Wakefield, 1978; Andrews et al., in prep; Wellman et al., 1973; Johnston, 1971). Ages of basal Takaka Limestone are shown

East of the study area, the former extent of the Takaka Limestone is unknown. Waitakian-Otaian sediments on the western edge of the Moutere Depression consist of deepwater mudstones (Willis, 1962).

Age

The Takaka Limestone is generally of Waitakian-Otaian age (fig.3); the lower contact varies from Whaingaroan to Otaian in age, but the upper contact is consistently basal Altonian. The age-range of the basal limestone (fig.26) indicates a marine transgression converging from the north and south, probably drowning the whole region during Otaian time.

Age control on the limestone is difficult because of the hardness of the rock. Foraminifera and coccoliths have been extracted from rare samples within the formation, but are more easily extracted from adjacent formations. Macrofossils are generally long-ranging species, although the bivalve Athlopecten athleta, which is restricted to the Waitakian, is common in basal limestone in the Takaka area. Possible indicators of Otaian age in younger limestone include Notocallista parki and Lima colorata colorata.

Mr. S. Nathan (pers.comm.1979) has shown that Takaka Limestone in the Karamea area (e.g. Huia River, Oparara Quarry) is Waitakian in age and unconformably overlain by Altonian Blue Bottom Group. The general absence of reliable Otaian dates in Golden Bay suggested to him that the Otaian unconformity extended throughout the northwest Nelson area. However, the following evidence indicates a conformable sequence:

(1) At many sections (fig.41), the Takaka Limestone grades up over a few metres to Tarakohe Mudstone. Sharp contacts are found in other sections (e.g. at Tarakohe), but there is no evidence of submarine hardgrounds, eroded surfaces or lithoclasts.

(2) Basal limestone at Brown River is dated by foraminifera as Otaian (M26/f71; R.H. Hoskins, pers.comm. 1979).

(3) In most sections the uppermost limestone is facies nt_5, interpreted below as a slowly-formed, in situ deposit. Therefore a long period of time could be represented by a thin, pure limestone.

Nathan's evidence for an Otaian unconformity in the south is not disputed, and therefore the northerly limit of this unconformity needs to be established. Wellman (1950b) described a gradational contact between Takaka Limestone and Blue Bottom Group at Heaphy River. German (1976) referred to a conformable contact between Takaka Limestone (Waitakian age; his Stony Creek Limestone) and Blue Bottom Group (Pareora age; his Oparara Member) at Stony Creek, but his stratigraphic column shows that the contact is obscured. The limit to the unconformity may be in the Karamea-Heaphy area.

LIMESTONE FACIES

The Takaka Limestone is divided into eight facies, based on field and hand specimen characteristics. Some of these facies have been given member status in recent theses (Table 2), but the present divisions can be used for the entire Takaka Limestone both outside and within the study area. The divisions are necessarily arbitrary as the sequence is continuous and boundaries gradational.

nt_1 : Glauconitic limestone

nt_2 : Calcareous conglomerate and sandstone

nt_3 : Mollusc lime packstone

nt_4 : Bryozoan-bivalve lime grainstone

nt_5 : Bryozoan lime grainstone

nt_6 : Algal lime packstone

nt_7 : Fine sandy calcarenite

nt_8 : Foram-echinoderm lime grainstone

nt_1 : Glauconitic limestone

This is typically a finely speckled dark green and light grey-orange massive glauconitic sandstone-limestone, consisting of well-sorted, medium to fine sand-sized glauconite and well abraded bioclastic debris (fig.27a). Thin horizons of whole or broken shells are sometimes common.

Basal hornfels conglomerate, consisting of well-rounded pebbles and cobbles 50-100mm in diameter in a calcareous sandy matrix, rests on Paleozoic basement at Gouland Downs. An extensive latticework of Ophiomorpha burrows overlies clean quartzarenite sand (Brunner Coal Measures) at Heaphy River; carbonaceous muddy sand and sparsely glauconitic medium sandstone also occur locally. Dark grey-green glauconitic sandstone in the upper Waitui Stream is dominated by well-sorted medium-coarse quartz and lithic sand, with subordinate glauconite and rare plant fragments.

Petrology: Moderately sorted, abraded and bored allochems, medium quartz- (lithic) sand and glauconite are cemented by ferroan calcite spar in a tight-packed grainstone texture (fig.31a). The fauna consists of hemescharan and vinculariiform bryozoa (see Appendix 4), benthonic forams (including Amphistegina and Textularia), echinoderms, red algae and bivalves, all of which are fragmented, rounded and often bored. The facies at Heaphy River (Heaphy Formation, Member A of Leask, 1977) consists of glauconitic packstone, dominated by medium glauconite, fine sand and foraminifera in a faintly laminated micrite or microspar matrix.

The insoluble sand fraction of Gouland Downs sample 14561 consists almost entirely of light-dark green glauconite commonly encrusted by orange iron-oxide, with minor quartz and siliceous foraminifera. The glauconite mainly occurs as lobate grains with shallow sutures, often completely fractured. Ovoidal, discoidal, vermicular and internal fossil moulds occur in minor quantities (terminology after Triplehorn, 1966). The insoluble fraction of Upper Waitui sample 14663 contains subordinate ovoidal glauconite grains.

Interpretation: This basal facies of the Takaka Limestone rests unconformably on fluvial-derived Brunner Coal Measures or Paleozoic basement, and thus represents the initial stage of marine transgression. The presence of Ophiomorpha networks and carbonaceous sand at Heaphy River indicates a shallow marine environment (Frey et al., 1978). However, the overlying foram-glauconite packstone suggests a middle-or outer-shelf deposit with low biogenic productivity.

The glauconitic grainstones within the study area were deposited under strong current or wave activity on the inner shelf, as indicated

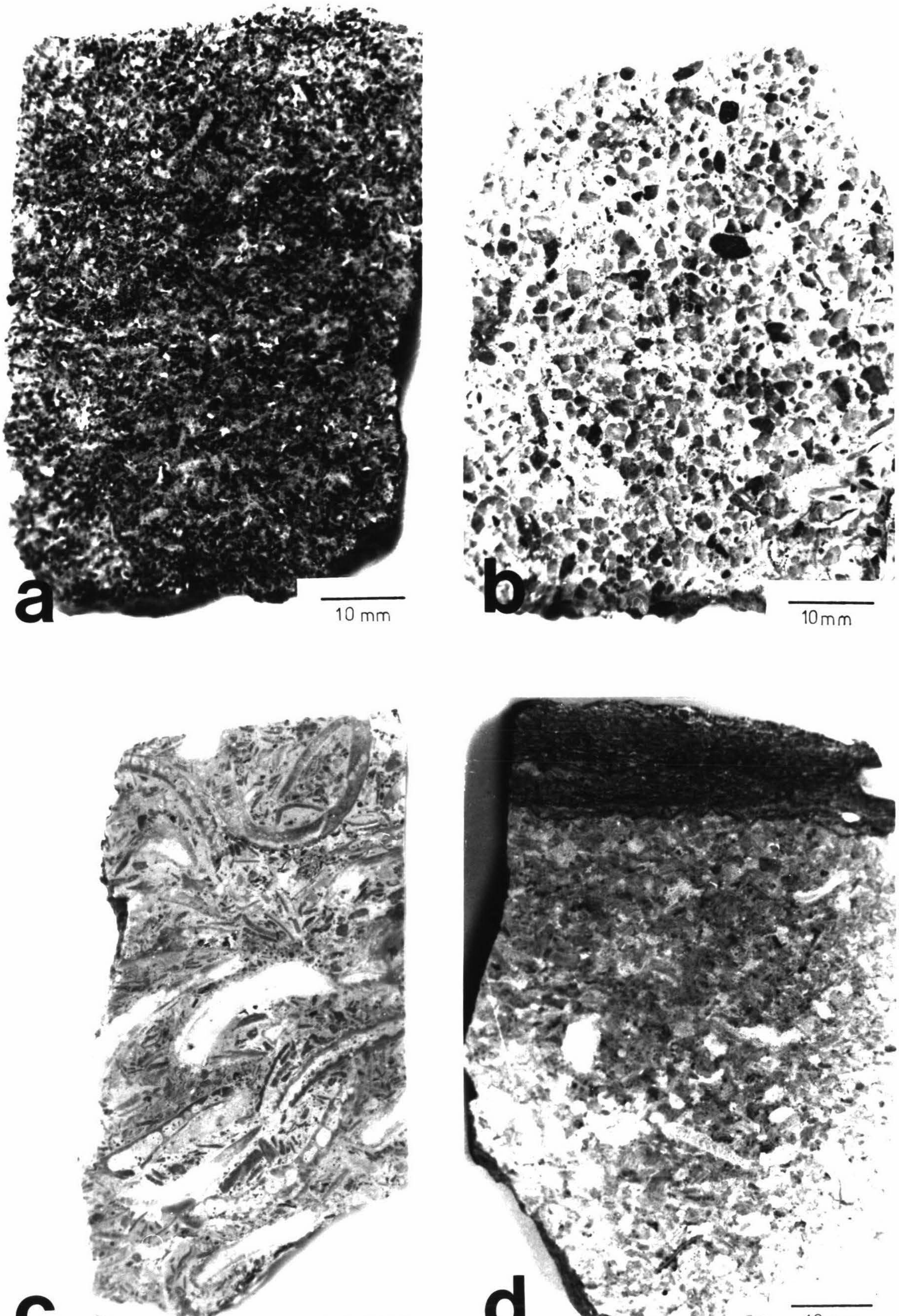
FIG. 27 : REPRESENTATIVE SLABBED SPECIMENS OF FACIES nt_1, nt_2, nt_3 and nt_5

a/ Facies nt_1 glauconite grainstone: a homogeneous assemblage of glauconite and orange-stained allochems.
Gouland Downs sample 14561 (in thin section, fig. 31a).

b/ Facies nt_2 sandstone: bimodal quartz and microcline medium sand and granules mixed in a light yellow micrite matrix.
Gouland Downs sample 14563.

c/ Facies nt_3 bivalve packstone: large shell fragments in a matrix of finely abraded allochems and light green micrite.
Kohaihai sample 14680 (in thin section, fig. 40b).

d/ Facies nt_5 bryozoan grainstone: a bryozoan-dominated flag and a solution seam, a tightly compressed swarm of microstylolites.
Paynes Ford sample 14590 (outcrop fig. 29c; in thin section, fig. 40e).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by the reworking of a diverse shallow shelf fauna. Such extensive fragmentation of the allochems suggests wave action in a shoreface environment. The lack of highly lobate glauconite ("popcorn"-shaped grains) and the fracturing of many lobate grains suggests moderate abrasion and transport and hence a perigenic origin. Glauconite most commonly forms by replacement of fecal pellets or degraded micas, in reducing conditions at the sediment-water interface (McRae, 1972). It is unlikely to form in areas subject to continual turbulence, and this excludes depths shallower than about 15m.

This evidence indicates mixing of shoreface-derived allochems and deeper water-derived glauconite on an inner shelf environment. The abundance of glauconite suggests minimal terrigenous influx and low biogenic productivity.

nt_2 : Calcareous conglomerate and sandstone

This facies comprises white, well-rounded, well-sorted coarse sandstone - pebble conglomerate; calcite-cemented quartzarenite with sparse abraded bivalve and bryozoan fragments.

Granule- and pebble- conglomerate form dark grey blocky cliffs up to 30m high south of Upper Takaka. The vein quartz-dominated pebbles are well-rounded, up to 30mm diameter and rather poorly-sorted in a coarse sand matrix. Giant trough cross-bedding probably about 20m thick in Barron Creek was figured by Cooper (1962: fig.13).

In the lower Takaka valley, the facies occurs as well-sorted coarse sandstone less than 1m thick overlying cross-bedded sand of Brunner Coal Measures association mb_4. At Gouland Downs, bimodal medium-fine and granule quartzarenite in micritic matrix (fig.27b) is characterized by 50mm thick lensoid flags, and grades upwards to mollusc-rich sandy packstone (facies nt_3).

Petrology: No samples are available from the Upper Takaka area.

Tarakohe sample 14645 consists of monocrystalline quartz and rare bryozoa, echinoderms and molluscs cemented by 30-60μm equant calcite spar (fig.31b).

Gouland Downs sample 14563 is strongly bimodal medium and granule sandstone; micritic subfeldsarenite, with well-rounded monoand polycrystalline quartz and microcline granules and rare large mollusc fragments in a matrix of fine sand, fine-grained abraded bioclastic debris and micrite-neomorphic spar.

Interpretation: The small volume of terrigenous sand involved at Gouland Downs and Tarakohe suggests relict near-shore sand reworked and rounded by waves and tidal or longshore currents. The loose, moving substrate was not suitable for marine life and the few allochems present were probably transported from deeper or quieter water. The well-rounded quartz granules at Gouland Downs suggest a long period of sorting and rounding in a beach-nearshore environment before final deposition in a deeper water low-energy environment.

The large volume of sand in the Waitui Stream area and southwards suggests active input of terrigenous material during deposition of the facies. There is no evidence of coal measures having been present in the area, but the source area was probably similar to the Aorere valley peneplain (see discussion of the Quartz Wash Member) in that large quantities of weathering-resistant quartz scattered across the peneplain surface were winnowed and fragmented in the shallow marine environment. The 20m thick cross-bedding at Barron Creek indicates formation of large sandwaves by strong tidal currents on the open shelf.

nt_3 : Mollusc packstone

This is a highly variable facies, characterized by disorientated bivalves, brachiopods, bryozoa and poorly sorted coarse quartz sand in an inhomogeneous micrite matrix. Its most distinctive feature is a thick (100-200mm), blocky flaggy appearance, with irregular horizontal and vertical stylolites (fig.29a).

There is considerable variation in the colour of the rock, which ranges between pink, green, yellow, light brown and blue grey. The proportions of constituent allochems are also very variable. In general, whole unbroken bivalve and brachiopod shells are the most conspicuous components although bryozoa may be the volumetrically dominant allochem type (figs.27c,28a,b,c).

In the lower Takaka valley, 0.5-5m thick lenses of facies nt_3 grade down to, and are sharply overlain by, facies nt_4 grainstones.

FIG. 28 : REPRESENTATIVE SLABBED SPECIMENS OF FACIES nt_3.

a/ Sandy bryozoan-bivalve grainstone-packstone: disorientated allochems and micrite lenses indicate strong bioturbation.
Rangihaeata sample 14614 (compare adjacent nt_4 sample 14613, fig. 30b).

b/ Pebbly mollusc packstone: bivalve and gastropod shells mixed with rounded quartz and feldspar granules-pebbles in a light yellow micrite matrix.
Gouland Downs sample 14565.

c/ Mollusc-bryozoan packstone: moderately sorted bryozoa and mollusc fragments in a pale green micrite matrix.
Silver Stream sample 14622.

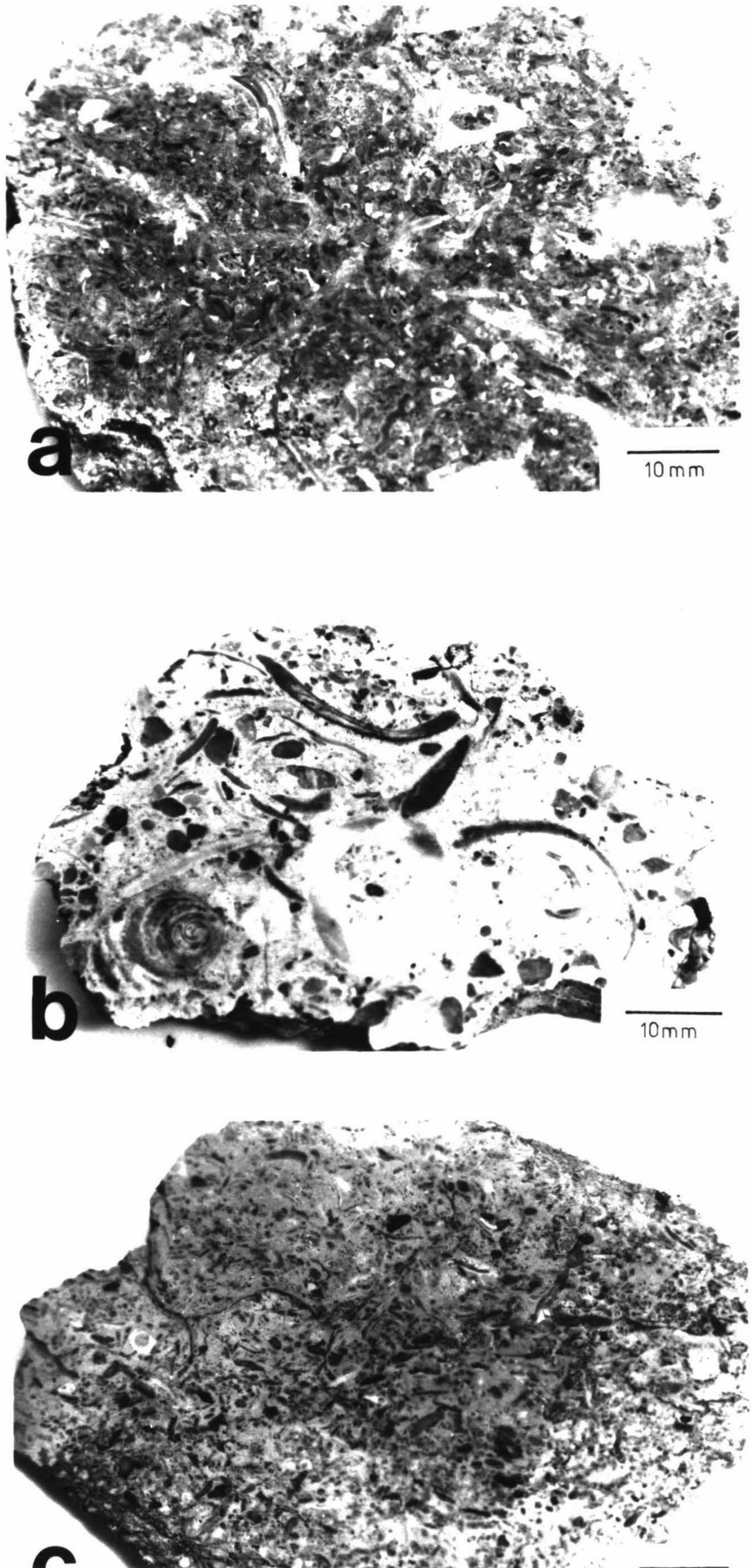
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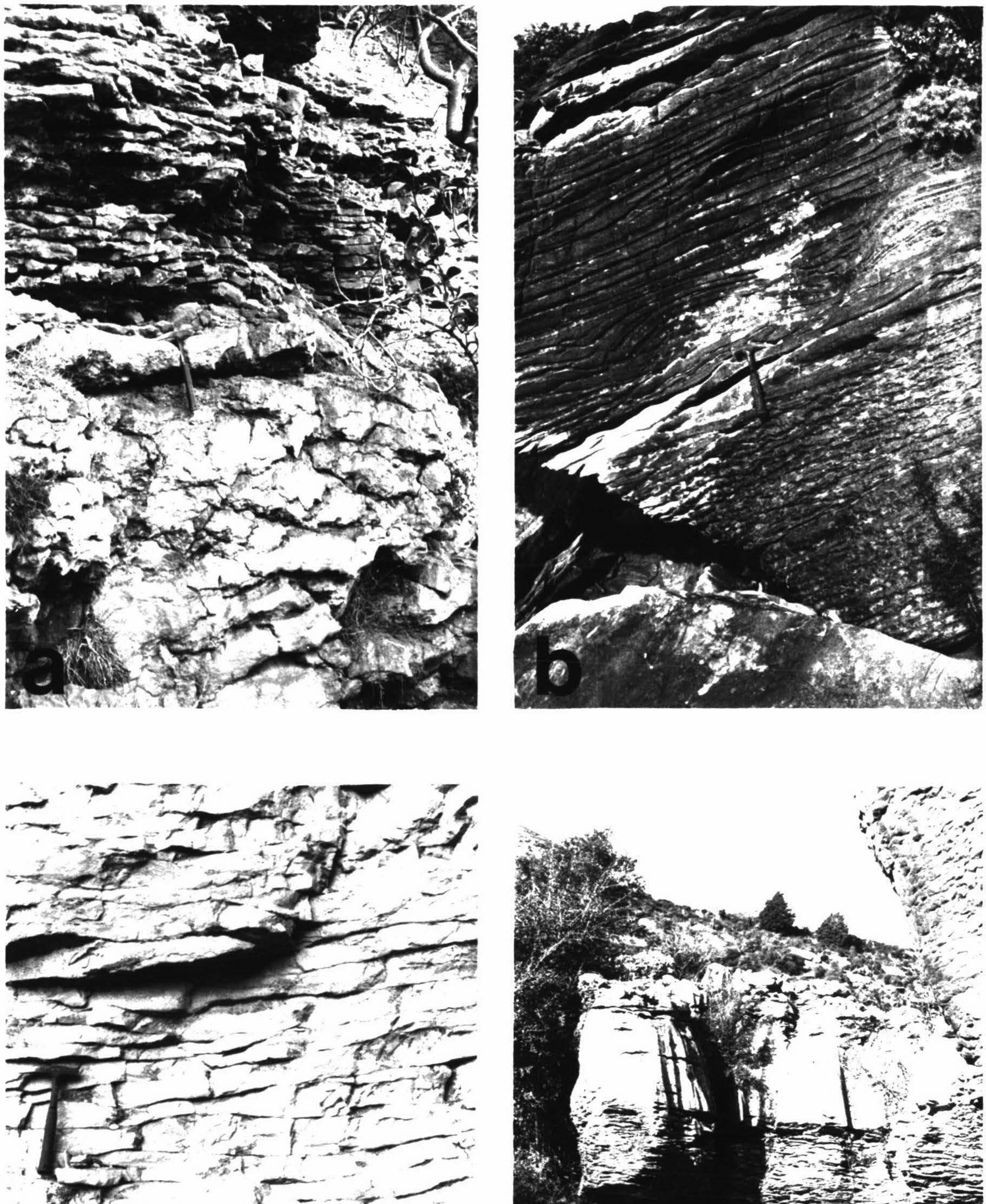
FIG. 29 : FACIES nt_3, nt_4 AND nt_5 AT TARAKOHE, RANGIHAEATA, PAYNE'S FORD AND DRY RIVER

a/ Parallel, planar flags of facies nt_4 grainstone sharply overlie irregular stylolite-bounded blocks of facies nt_3 packstone in coastal cliffs at Tarakohe (N25/013422). Hammer 330mm long.

b/ Planar and lenticular flags of facies nt_4 grainstone at Rangihaeata Head (N25/924452). The flexures in the flags above the hammer head were probably influenced by a primary bedform such as hummocky cross-bedding.

c/ Subparallel flags of facies nt_5 bryozoan grainstone at Irvine's Quarry (N26/944358; location of sample 14590, fig. 27d.). Note the 10-15mm thick seams alternating with flags at the base of the outcrop.

d/ Vertically fluted layers and thinly lenticular flags of facies nt_5 grainstone in the Dry River section (N26/c.979378).


a
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c

An example at Tarakohe (N25/013422; fig.29a) consists of shelly packstone 5m thick with common whole Athlopecten athleta and abundant bryozoa strongly bioturbated in a pink-brown micrite matrix. The rock is broken by irregular horizontal stylolites 100-200mm apart and common vertical stylolites, and contrasts dramatically with the thin parallel flags of the adjacent grainstone (nt_4).

Mollusc packstone is the basal limestone facies at Eureka Bend, West Takaka, parts of the Aorere valley, Cuckoo River and Oparara Quarry. Angular slabs of phyllite up to 0.5m long dominate basal limestone at Little Doctor Creek, and rounded granite pebbles and cobbles occur at Cuckoo River.

Included in this facies are shell beds of horizontal-orientated pectinids, oysters and brachiopods at Kohaihai Bluff (German, 1976) and Heaphy River (Leask, 1977). The shells are closely packed in a green or yellow-brown micrite matrix (fig.27c) cut by stylolites at 10-50mm intervals. Bivalves are generally disarticulated. There is no evidence of strong bioturbation, although the Heaphy River examples form a series of lenses within bioturbated packstone typical of this facies.

Petrology: Allochems and terrigenous sand grains are usually poorly sorted, the former extremely so, as large single bivalve shells may be up to 3 orders of magnitude larger than the smallest bioclastic debris. Allochems commonly range between 0.5 and 4mm diameter or length. Quartz/feldspar sand is usually between medium and granule size and rarely to cobble size. The allochems, dominantly bivalve, brachiopod and bryozoan debris, are sometimes abraded, rarely bored, and typically in an open-fabric packstone texture with little pressure solution apparent (fig.31b,c). The matrix is unlaminated micrite, often with minute blebs of pyrite, or clotted micrite-neomorphic spar. Burrow fill is sometimes distinguished by a darker colour and sharp boundaries.

Thin section analysis reveals two basic textures, the first being mixed packstone-grainstone, with irregular distribution of micrite and

and sparry cement, "umbrella" fabrics and geopetal micrite in shells and cavities. Umbrella fabrics (fig.31f) occur where carbonate mud and allochems are trapped above a large flat-lying shell fragment, but the pore-space beneath the shell remains open and may be filled by coarse-grained sparry cement. Umbrella fabrics may also shelter horizontal-laminated micrite from bioturbation or reworking (e.g. Heaphy sample 14718).

The second type of textural type is a relatively homogeneous packstone lacking pressure solution. The micrite or microspar matrix may contain numerous minute allochems, neomorphosed to microspar or neomorphic spar, and may also contain abundant framboidal pyrite. This textural type contains the only clear evidence of dissolution of aragonitic allochems in the Takaka Limestone. This is furnished by moulds of the original allochem, filled by equant calcite spar and sometimes geopetal microspar. The original shape of the allochem is sometimes preserved intact, but collapsed cavities are also common. Micrite envelopes are common in some mixed packstone-grainstones and are discussed in the section on diagenesis.

Paleoecology: Facies nt_3 and nt_4 contain a diverse, open marine fauna dominated by bivalves, brachiopods and bryozoa, with minor red algae, gastropods, benthonic foraminifera and echinoderms.

The bivalves are dominated by the large, robust pectinids Athlopecten athleta, Serripecten hutchinsoni and Mesopeplum burnetti and the oyster Crassostrea aff. ingens. The pectinids probably occupied the same ecological niche as the modern Pecten, a free-swimming suspension feeder. Their optimum habitat may therefore have been on clean shell gravel at depths of 12-36m (Fleming, 1957).

Brachiopods are represented by the large robust genera "Neothyris", Pachymagas, Rhizothyris and Stethothyris. Their size and bulk suggest adaptation to a moderately high energy environment.

The growth-forms and diversity of bryozoa are quite variable. The most abundant growth-forms are vinculariiform, hemescharan and cellariiform with common celleporiform, reteporiform and eschariform forms and rare membraniporiform zoaria (see Appendix 4). The abundance of cellariiform bryozoa suggests low energy, turbid conditions; vinculariiform bryozoa suggest moderate energy, clear waters.

Foraminifera include Amphistegina, smaller rotaliids and textularids. Pelagic foraminifera are rare or absent. Amphistegina is commonly quoted as a shallow-water indicator, but recent studies (e.g. Crouch and Poag, 1979) indicate that the genus ranges across shelves in tropical latitudes to depths greater than 100m. However, the absence of pelagic foraminifera may corroborate an inner shelf environment.

Interpretation: Facies nt_3 packstones were deposited in moderately deep water, below wave base (greater than c.30m) and at the ends of tidal current transport paths (cf. Johnson, 1978). The relatively homogeneous packstones formed by the slow accumulation of bioclastic debris fragmented and worn by wave or current action in shoals, and eventually deposited in adjacent quiet areas. Well-sorted and rounded mollusc fragments in many packstone units (e.g. Little Doctor Creek section) indicate intensive abrasion and winnowing and suggest derivation from a nearshore site above wave base. The shellbeds at Kohaihai Bluff and Heaphy River contain disarticulated but little-abraded bivalves, suggesting an essentially in situ shellbank environment. Extensive bioturbation was prevented by the close layering of the bivalve shells.

The disorientation of allochems and the inhomogeneity of matrix and cement in the packstone-grainstones of the Takaka valley indicate that these were originally facies nt_4 grainstones modified by bioturbation during a period of minimal deposition in a low-energy environment. Facies nt_4 grainstones are inferred to have been deposited on a tidal-current influenced seafloor (see below); therefore the packstones could have formed when the tidal current waned or was diverted elsewhere.

nt_4 : Bryozoan-bivalve grainstone

Light brownish-grey grainstone is characterized by thin (c.50mm thick) well developed subparallel flags (fig.29a,b,30b). It consists of 0.5-3mm long abraded bivalve, brachiopod and bryozoan fragments

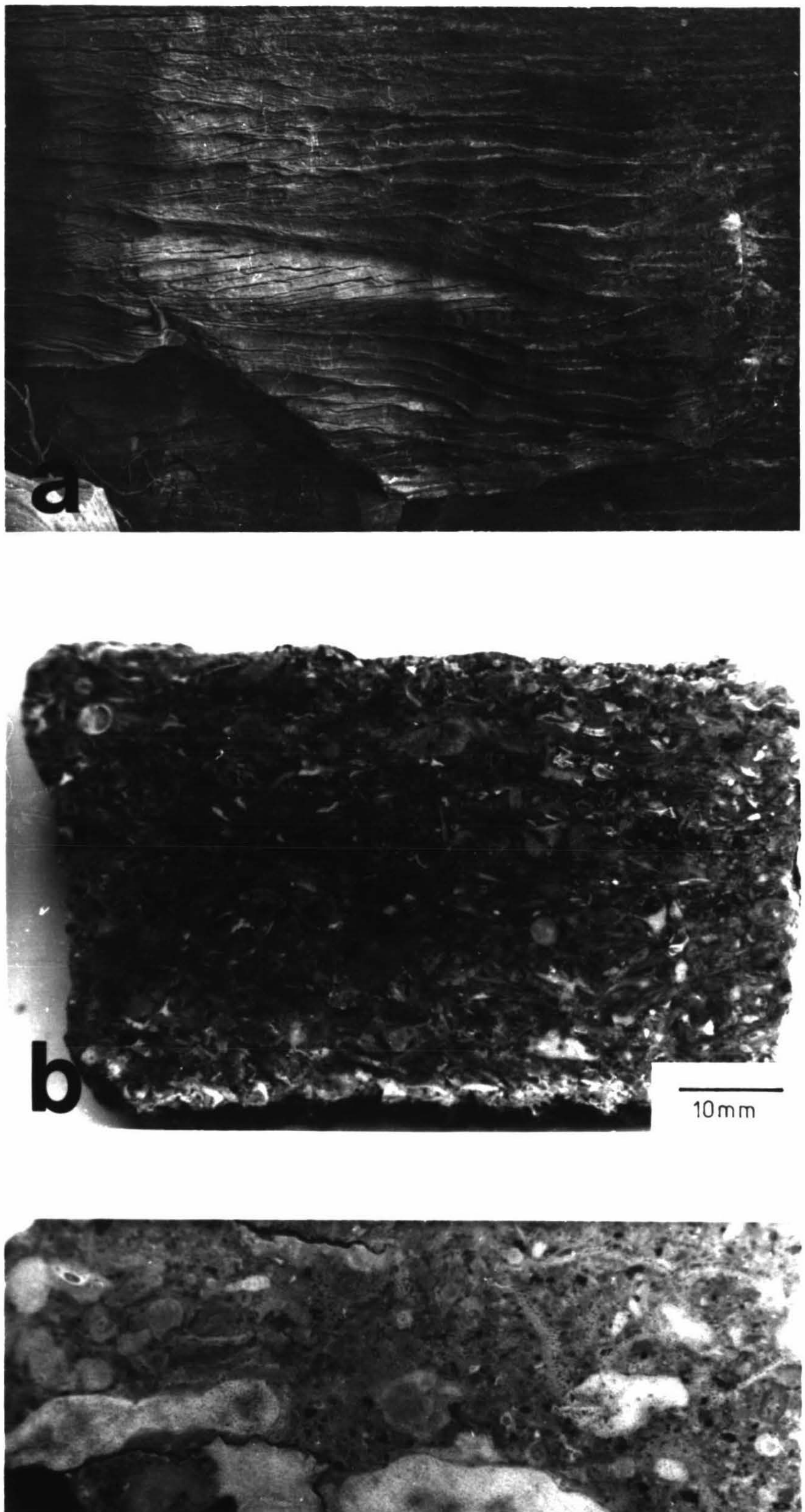
FIG. 30 : FACIES nt_4 AT RANGIHAEATA

a/ Trough cross-bedded facies nt_4 grainstone at Rangihaeata Head (N25/924450).
Hammer (far left centre) 330mm long.

REPRESENTATIVE SLABBED SECTIONS OF FACIES nt_4 AND nt_5.

b/ Facies nt_4 bryozoan-mollusc grainstone: large, loose-packed bryozoan, mollusc and echinoderm allochems in a horizontal lamination.
Rangihaeata sample 14613.

c/ Facies nt_5 bryozoan packstone: large vinculariiform and reteporiform (upper right) bryozoa in a poorly sorted matrix of fine-grained allochems and micrite.
Tarakohe sample 14654.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10mm
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aligned parallel to bedding, and common moderately sorted medium-coarse quartz sand. Seams of calcareous sandstone 5-20mm thick are sometimes interbedded with the flags. Low-angle foresets up to 40cm thick are common at Rangihaeata Head (fig.30a), but are very rare elsewhere.

Facies nt_4 is distinguished from nt_5 by its thinner flags, moderate sorting and lamination, abundance of bivalves and brachiopods and abundance of terrigenous sand. It is distinguished from facies nt_8 mainly by its coarser grainsize and more prominent flagginess.

Petrology: Moderately sorted and abraded allochems average 0.5-3mm long are composed of bivalves, bryozoa, echinoderms, brachiopods, benthonic foraminifera and red algae, in approximate order of abundance. Moderately sorted medium-coarse quartz and feldspar sand is common. Elongate allochems are generally horizontally oriented. Typically the rocks have a moderately open fabric (fig.31e,f) with cementation dominated by echinoderm syntaxial overgrowths, with subordinate equant spar. However, some samples show extensive over-packing and allochem inter-pretation indicating strong pressure solution.

Calcareous sandstone seams contain well sorted medium-fine sandstone and consist of stylolitic calcite-cemented subfeldsarenite. The carbonate fraction is dominated by medium sand sized echinoderm fragments with syntaxial overgrowths.

Paleoecology: The faunal content is similar to that of facies nt_3, although a higher proportion of bryozoa relative to bivalves is common. The most abundant bryozoa are vinculariiform, celleporiform A and hemescharan growth forms with minor eschariform and reteporiform types. There are no large, intact, colonies that might suggest growth in situ.

Bioturbation appears to have been generally absent, but two types of trace fossils were recorded at Rangihaeata Head:
(1) ? Keckia, networks of subhorizontal branching burrows 20-30mm wide and up to 40cm long with meniscoid filling.

FIG. 31: PHOTOMICROGRAPHS OF FACIES nt_1, nt_2, nt_3 and nt_4.

a/ Facies nt_1 glauconite grainstone: glauconite and echinoderm fragments cemented by ferroan calcite spar. Gouland Downs sample 14561.

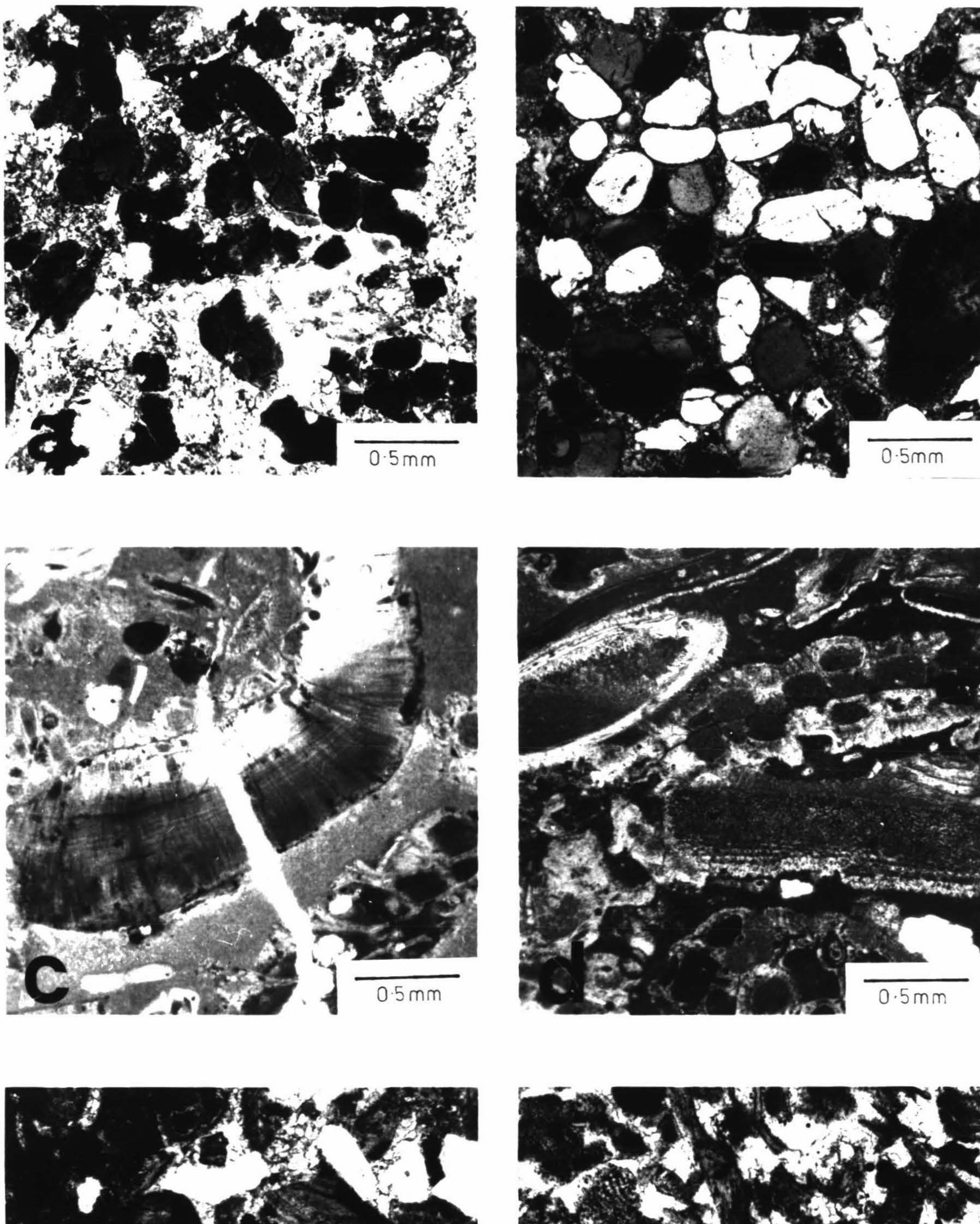
b/ Facies nt_2 sandstone: well-rounded, well-sorted, medium quartz grains in finely crystalline equant calcite spar. Tarakohe sample 14645, cross-polars.

c/ Facies nt_3 mollusc-bryozoan packstone: poorly sorted, disorientated allochems in a micrite matrix cut by stylolites and cement-filled fissures (see also fig. 39a). Heaphy River sample 14718.

d/ Facies nt_3 sandy mollusc packstone: bryozoan, echinoderm and mollusc fragments in two generations of micrite matrix. The shell at top left contains geopetal micrite, followed in time by fibrous fringing cement and later infilled by a dark micrite.
Motupipi sample 14577.

e/ Facies nt_4 sandy mollusc grainstone: well-rounded mollusc fragments and medium quartz sand cemented by calcite spar. Doctor Creek sample 14541, cross-polars.

f/ Facies nt_4 echinoderm-bivalve grainstone: "umbrella" fabric of well sorted bryozoa, echinoderms, bivalves and quartz sand.
Tarakohe sample 14649.



a
0·5mm
0·5mm
c
0·5mm
d
0·5mm
0·5mm
f
0·5mm

(2) Planolites, gently sinuous horizontal burrows 3-8mm wide and up to 60mm long.

Interpretation: Parallel-lamination of sorted, abraded allochems and terrigenous sand indicates intensive winnowing and transport in sand patches or possibly sand ribbons on a tidal current-swept seafloor. It will be argued later in the chapter that the sub-parallel flags are largely diagenetic in origin and bounded by microstylolite swarms. The shape of the flags is influenced partly by burial load and partly by the uniform orientation of the allochems. It seems unlikely that large primary structures such as scours, channels or sandwaves would have been totally obliterated during diagenesis, and the absence of these features suggests that the original sediments were parallel-laminated, possibly ripple-laminated, with occasional cross-beds. Deposition in sheet-like sand patches (Johnson, 1978) is probable.

The value of the paleoecological data is questionable, because most allochems were probably transported from their original habitat. The dominance of erect, rigid forms suggests an environment of moderate-intensity currents deeper than 35m (Schopf, 1969) while the abundance of celleporiform A bryozoa might indicate high-energy conditions.

nt_5 : Bryozoan grainstone

This is a very pure (95-98% $CaCO_3$) bryozoan-dominated limestone, characterized by evenly spaced, prominent, subplanar flags 100-150mm thick (fig.29c,d), rarely with interbedded seams of terrigenous-enriched limestone 5-20mm thick (fig.27d) but sometimes showing a wide variety of flagginess (fig.29d). It is usually light brown or very pale grey, although quarry exposures are often light blue-grey or green-grey. The rock is very homogeneous and its composition is often indeterminable in the field. The facies in the lower Takaka valley is commonly dominated by large, white vinculariiform bryozoan colonies 5-30mm in diameter and over 150mm in length (fig.30c). Whole bivalves and brachiopods are sometimes common. Terrigenous sand is sparse or absent, but a pebble horizon in the upper part of the Paynes Ford section (e.g. sample 14589) contains disorientated, wellrounded pebbles of quartz, chlorite schist, sandstone and dolomite averaging 25mm in diameter.

Petrology: A tightly packed, diverse fauna is dominated by large bryozoa with lesser echinoderms, bivalves, brachiopods, benthonic foraminifera and red algae (fig.32a,b). The allochems are very poorly sorted, show little evidence of abrasion and range in size from 0.1mm to over 10mm. Matrix and/or cement is sparse and mainly confined to bryozoan zooecia. Some samples are packstones or mixed packstone-grainstones, but the bryozoan-dominated, overpacked fabric is the most distinctive feature.

The limestone seams are microstylolite swarms rich in echinoderms, terrigenous clay and sand, glauconite and up to 20% dolomite. They are more fully described in the Diagenesis section.

Paleoecology: Bryozoan faunas are usually diverse, with up to 8 different types recognizable in each sample. Two bryozoan biofacies can be distinguished, one dominated by large vinculariiform colonies, and the other a more diverse population of similar-sized colonies. The first biofacies contains vinculariiform (1), (2) or (3) forms (defined in Appendix 4), with minor hemescharan, eschariform, vinculariiform (4) and reteporiform types (fig.30c). The second biofacies comprises common vinculariiform (1) and (4), hemescharan, celleporiform A, cellariiform and eschariform types, and rarer membraniporiform and reteporiform growthforms. The size and lack of abrasion of bryozoa in both biofacies suggests preservation in situ.

Large, robust bivalves and brachiopods are common and often appear to be preserved in life position. The dominant bivalve species are the suspension feeders Serripecten hutchinsoni and Mesopeplum burnetti.

Foraminifera and coccoliths are poorly preserved and are extracted with difficulty. Collection N25/f10 contains Cibicides perforatus, Elphidium sp. and Notorotalia spinosa, a shallow inner-shelf assemblage (R.H. Hoskins, pers comm.1979). Textularia sp. and Amphistegina sp. are usually sparse but ubiquitous components.

Interpretation: The poor sorting, lack of abrasion and abundance of large, intact bryozoan colonies suggest that this facies represents an in situ community on the inner-middle shelf.

FIG. 32 : PHOTOMICROGRAPHS OF FACIES nt_5, nt_7 AND nt_8.

a/ Facies nt_5 bryozoan grainstone: tightly packed bryozoan colonies with cement mainly confined to zooecia chambers (see also fig. 52d,e).
Takaka sample 14633.

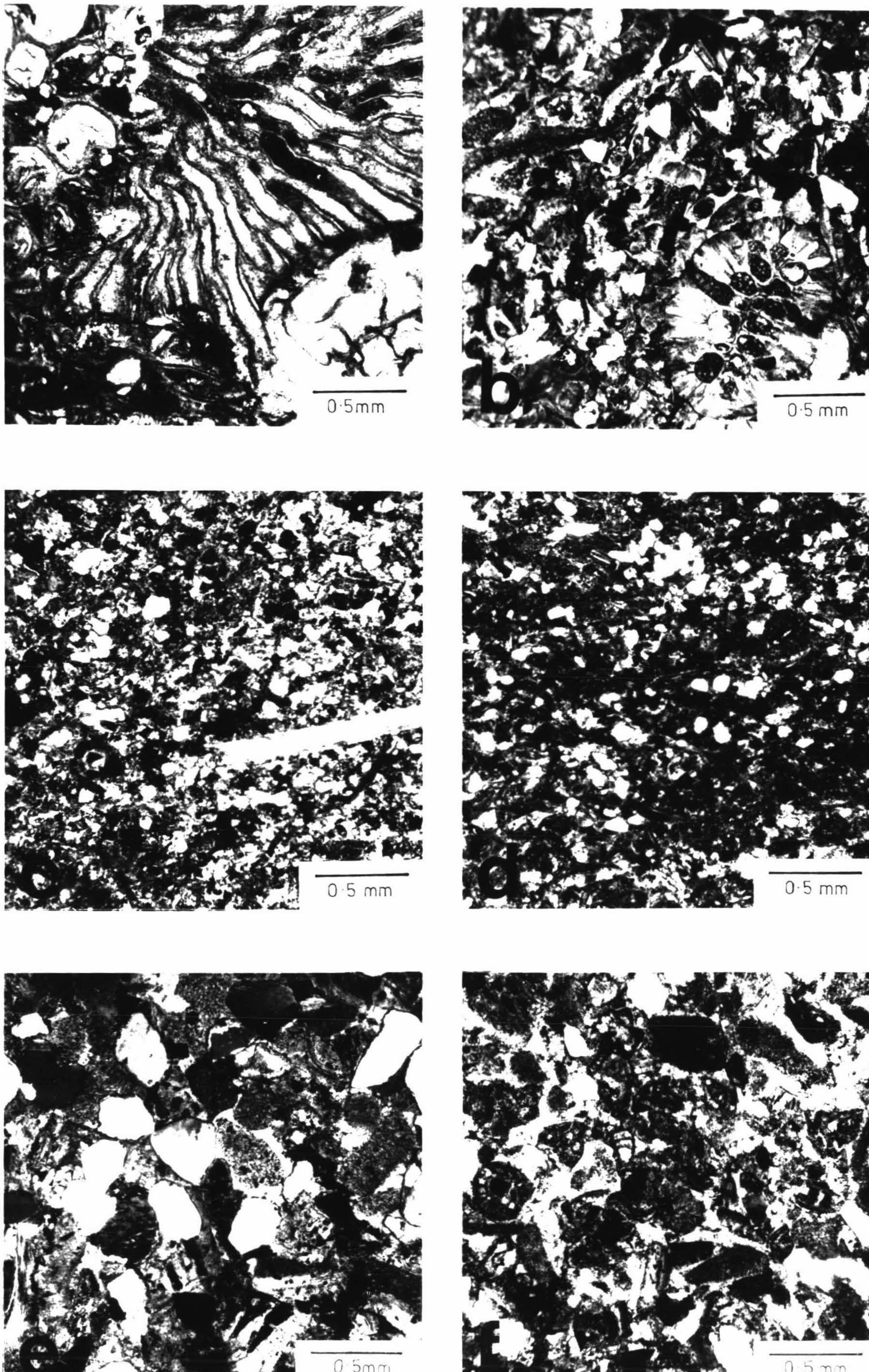
b/ Facies nt_5 bryozoan grainstone: large bryozoa in a matrix of finely abraded bryozoan and echinoderm fragments.
Tarakohe sample 14652.

c/ Facies nt_7 sandy calcarenite: tightly packed fine quartz sand and finely abraded allochems.
Silver Stream sample 14626, cross-polars.

d/ Facies nt_7 sandy calcarenite: finely abraded foraminifera and echinoderms and terrigenous sand and mud.
Te Hapu sample 14688, cross-polars.

e/ Facies nt_8 sandy echinoderm grainstone: tightly packed, well-cemented echinoderm and benthonic foraminifera fragments and angular quartz sand.
Devil's Boots sample 14518 cross-polars (outcrop, fig. 34c).

f/ Facies nt_8 echinoderm grainstone: well-cemented well-sorted echinoderm fragments and foraminifera.
Te Hapu sample 14692, cross-polars.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Vinculariiform bryozoa indicate moderate-low intensity currents, but the heavily calcified large colonies may have adapted to resist relatively high current velocities. Bryozoan colonies were probably attached to former colonies or by rootlets anchored in the sediment. Brachiopods and bivalves may have provided favourable substrates.

A possible modern analogue is the continental shelf of southern Australia. Wass et al.(1970) found the seafloor at many stations almost completely covered by forests of bryozoan communities, with minor sponges, ascidians and algae. The vinculariiform bryozoa were most abundant in depths greater than 180m. but such depth restrictions do not necessarily apply outside that particular region. For facies nt_5, a much shallower depth, in the order of 50m, is more in accordance with the paleoecology of the sparse foraminifera assemblages.

As in facies nt_4, the subparallel or lensoid flags are interpreted as diagenetic in origin, an interpretation which is supported by bryozoan colonies which were occasionally seen to be cut by solution planes. The original sediment was probably massive with few sedimentary structures to indicate wave or current activity. A broad, shallow submarine plateau environment with no terrigenous influx is envisaged.

nt_6 : Algal packstone

Calcareous red algae are minor but ubiquitous components of the Takaka Limestone, but algal-dominated limestone is restricted to the upper 5m of the formation at Eureka Bend, Upper Takaka. Bryozoan grainstone (nt_5) grades into green-grey muddy algal packstone, which forms irregular lensoid flags 30--60mm thick. It consists of white and dark grey rhodoliths, *Amphistegina* and bryozoa. A 1m thick lens of moderately friable greyish green bivalve-rhodolith muddy sandstone occurs within the limestone - the lateral dimensions are unknown but greater than 5m wide. The rhodoliths (Bosellini and Ginsburg, 1971) are spheroidal with bumpy surfaces, and measure 20-50mm in diameter (fig.33a). Disarticulated valves of *Mesopeplum burnetti* are common. The facies also includes a lens of greyish blue foraminifera packstone, crammed with numerous *Amphistegina* tests.

Titheridge (1977:75) recorded rhodoliths up to 30mm in diameter confined to a 1m thick packstone unit at Kahurangi Point.

Petrology: The rhodolith sandstone lens contains rhodoliths composed of wavy, often fractured concentric laminae c.0.2mm thick (fig.33). The laminae often separate to enclose lenses of muddy and/or micritic sediment, frequently comprising terrigenous silt, benthonic foraminifera and fine=grained bioclastic debris. Small algal nodules 2-3mm in diameter, and encrusting celleporiform and membraniporiform bryozoa are also enveloped within the nodule.

The algal packstone consists of irregular globular-laminae growth forms usually 4-10mm in diameter, and stubby branching forms 2-4mm long. These are tightly packed with Amphistegina and textularid tests, abraded brachiopod, bivalve and echinoderm fragments, and hemescharan, celleporiform and reteporiform bryozoa, in a muddy micrite matrix.

The foraminifera packstone consists of moderately sorted, abraded allochems 1-2mm in diameter dominated by Amphistegina. These are closely packed and crudely laminated in a matrix of micrite and neomorphosed 50-100mm bioclastic debris.

Interpretation: In Recent seas, rhodoliths are commonly found in areas of slow sedimentation and intermittent wave or current activity (Bosellini and Ginsburg, 1971). The laminar form of the rhodoliths indicates continual movement, although branching algae and encrustation by bryozoa suggest periods where no movement occurs. The rhodolith sandstone may represent a bioherm (cf. Studencki, 1979) or channel-fill into which the muddy matrix filtered after burial.

The enclosing algal and foraminifera packstones probably formed in quiet water adjacent to the sites of relatively high energy conditions in which the rhodoliths formed.

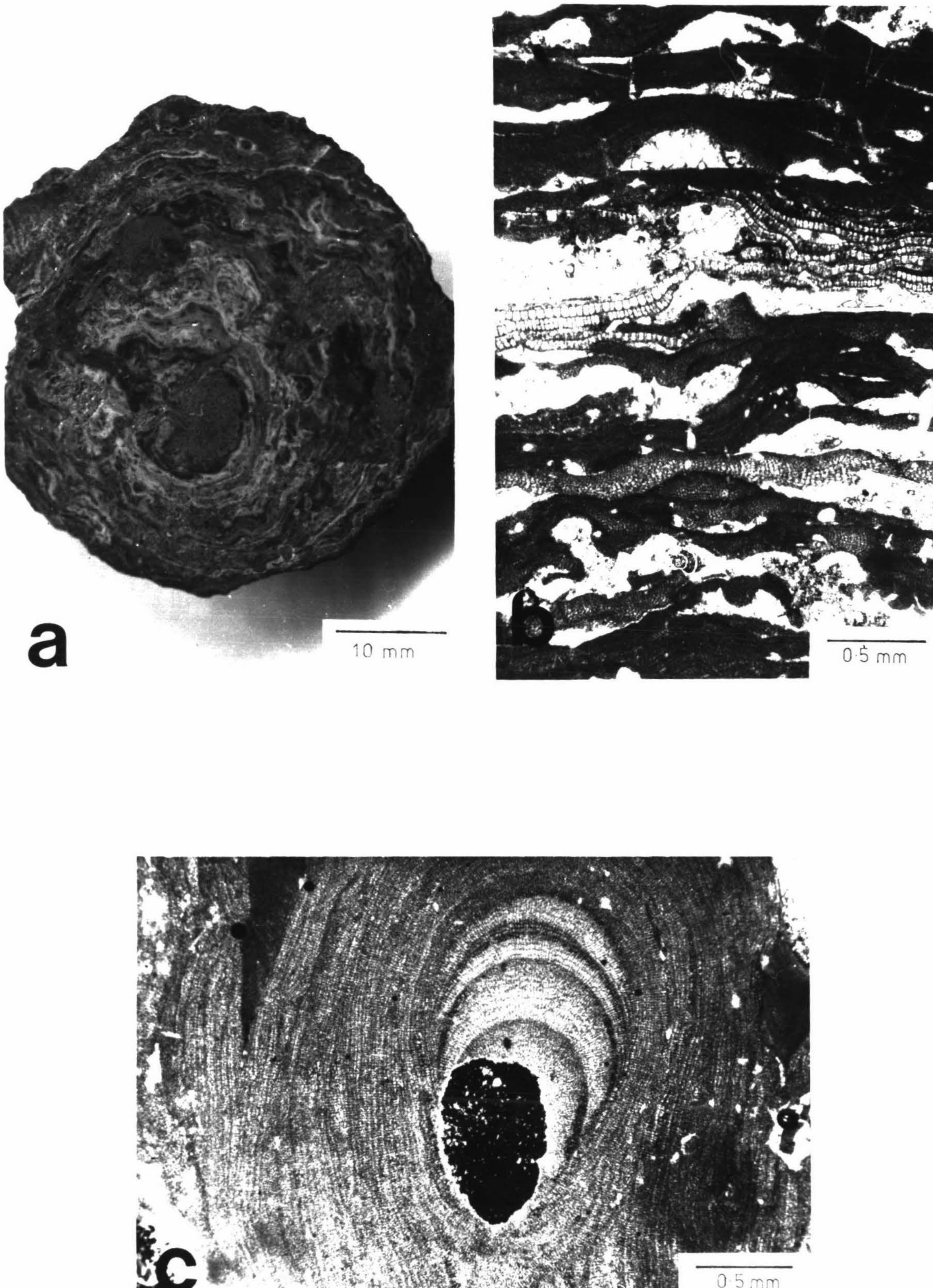
A remarkably similar deposit has been recently described by Studencki (1979), and this also contained rhodolith bioherms, algal-detrital limestones and almost-monospecific acçumulations of amphisteginids. He pointed out the close similarity to the Recent

FIG. 33 : A RHODOLITH, OF FACIES nt_6 AT EUREKA BEND

a/ Slabbed specimen, showing concentric algal laminae varying through smooth, crinkled and convoluted forms.
Eureka Bend sample 14555.

b/ Algal laminae with intermediate bryozoa, foraminifera and terrigenous silt.

c/ Concentric laminae at the centre of a rhodolith.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Mediterranean "biocénose coralligène" and "biocénose du Détritique Côtier" (Pérès, 1967), which occur at depths between 20-40m and 150-180m in areas free of terrigenous influx. Studencki (1979) cited the abundance of Amphistegina and the possible association of sea grass as evidence for a depth range of 20-50m.

Crouch and Poag (1979) summarized studies of an Amphistegina-algal nodule association in depths of 35-55m on submerged carbonate banks off Texas. Amphistegina are attached firmly to rhodoliths of 70-100mm diameter. Sea grasses are absent.

The similarity of facies nt_6 to the Mediterranean and Texas deposits suggests a similar environment of deposition at depths of 20-60m.

nt_7 : Fine sandy calcarenite

This consists of muddy or micritic fine sandy calcarenite (sensu Andrews, 1976), greenish grey to light greyish brown, with common almost-monospecific horizons of brachiopods, bivalves (Lentipecten hochstetteri) or bryozoa (Cellepora sp.). Small shell fragments and echinoderm spines are abundant. Outcrops may be massive or well bioturbated, weakly flaggy with solution planes 50-100mm apart (fig.34), or consist of alternating hard and soft beds. Unlike the other facies, the stylolite swarms stand out in relief on weathered outcrops (fig.34a).

Facies nt_7 and nt_8 are the dominant limestones in the Aorere valley and on the northwest coast between Kahurangi Point and Cape Farewell. Titheridge (1977) differentiated the two facies as the Paturau Member (nt_7) and Anatori Member (nt_8) of the Takaka Limestone. Inthe Aorere valley, the two facies are intergradational and difficult to distinguish: facies nt_8 is harder and generally lighter coloured.

Alternating beds at Silver Stream quarry are formed by 50mm thick streaks of hard dark greenish grey calcarenite (58% $CaCO_3$) with scattered bivalve and echinoderm fragments, which occur at 50-100mm intervals in hard, light greenish grey calcarenite (80% $CaCO_3$). Terrigenous sand:mud ratios for both rock types approximate 3:1.

However, the darker calcarenite is accentuated by the weathering profile and its resistance to erosion may be due to the sheltering effect of the shell fragments concentrated in this rock type. Titheridge (1977:23) described similarly alternating beds 300-600mm thick, in which the more resistant beds have a higher micrite content and less detrital silt than the less resistant beds.

Petrology: These sandy echinoderm grainstones comprise finely comminuted, well sorted bioclastic debris averaging 0.2-0.3mm in diameter and rare larger echinoderm or bivalve fragments. The major constituents are echinoderms and benthonic and pelagic foraminifera. The terrigenous fraction compriseswell sorted, fine to very fine quartz and feldspar sand; terrigenous mud may contribute 5-10% of the total rock. Matrix and cement are rare; the allochems are tightly packed and extensively pressure-welded.

Paleoecclogy: Facies nt_7 contains a very distinctive macrofauna, with a signifant infauna not present in the coarser-grained facies. Recognizable shells are confined to thin horizons dominated either by Lentipecten hochstetteri, a free-swimming suspension feeder, brachiopods, and the celleporiform B bryozoan Cellepora sp. The brachiopods and the Cellepora typically are found in disorientated, jumbled accumulations suggesting transport during periodic storms.

A fossil collection from Silver Stream quarry (M25/f37) contains, in addition to the above taxa, the burrowing bivalves Panopea worthingtoni, Dosina uttleyi and Notocallista parki. An early collection (S8/f488) includes Maoricardium coxi, Hedecardium cf. greyi, Dosinia sp., Kuia aff. vellicata and ? Eumarcia sp. Crinoid ossicles, spines of Prionocidaris sp (a cidarid) and Schizaster rotundatus (spatangoid) have also been collected.

Interpretation: Facies nt_7 is interpreted as a shallow shelf deposit formed below wavebase in depths of 10-30m. and periodically stirred up and reworked by large storms. The terrigenous and carbonate sandgrains were probably wellsorted, abraded and rounded by wave action and eventually deposited in deeper, quieter waters. The abundance of infaunal bivalves suggests a packed, stable seafloor, while the morphology of the celleporiform bryozoa suggests low to moderate current intensities and sedimentation rates (see Appendix 4).

The relatively high proportion of terrigenous sand and mud suggests continual terrigenous influx, probably from erosion of a small or distant landmass.

nt_8 : Foraminifer - echinoderm grainstone

This consists of white to light greenish grey, wellsorted medium to coarse sand sized limestone, often sparsely glauconitic and rarely with scattered large shell fragments. Outcrops are moderately flaggy with wavy solution planes 20-40mm apart. (fig.34c,d).

Facies nt_8 is most extensive along the northwest coast between Kahurangi Point and Cape Farewell (Anatori Member of Titheridge, 1977), where it appears to be very uniform in thickness, texture and composition. At the Devil's Boots section, facies nt_8 sandy limestone fills cracks and hollows in schist basement with up to 0.6m relief. The surface of the schist is encrusted with numerous colonies of celleporiform A bryozoa. At West Takaka, nt_3 packstone grades up to nt_8 glauconitic grainstone which in turn grades to bt_1 muddy sandstone. Variation upwards through the 4m thick limestone includes a regular decrease of bryozoa and increase of foraminifera, glauconite and terrigenous content, suggesting deposition under increasing sedimentation rates.

Petrology: These echinoderm grainstones consist of wellsorted, abraded and commonly bored allochems c.0.5mm in diameter, and common moderately sorted medium sand-sized quartz, feldspar and glauconite. The allochems comprise echinoderms, benthonic forams, bivalves, bryozoa and brachiopods in order of relative abundance. Large (10mm and longer) bivalve and gastropod fragments are sometimes present. The grainstones have an open fabric cemented by poikilotopic echinoderm overgrowths and lesser ferroan calcite spar.

Interpretation: Moderately sorted and well abraded allochems in a mud-free grainstone texture indicate deposition on an open inner to middle shelf by high-intensity currents. The facies

FIG. 34 : FACIES nt_7 AT DOCTOR CREEK

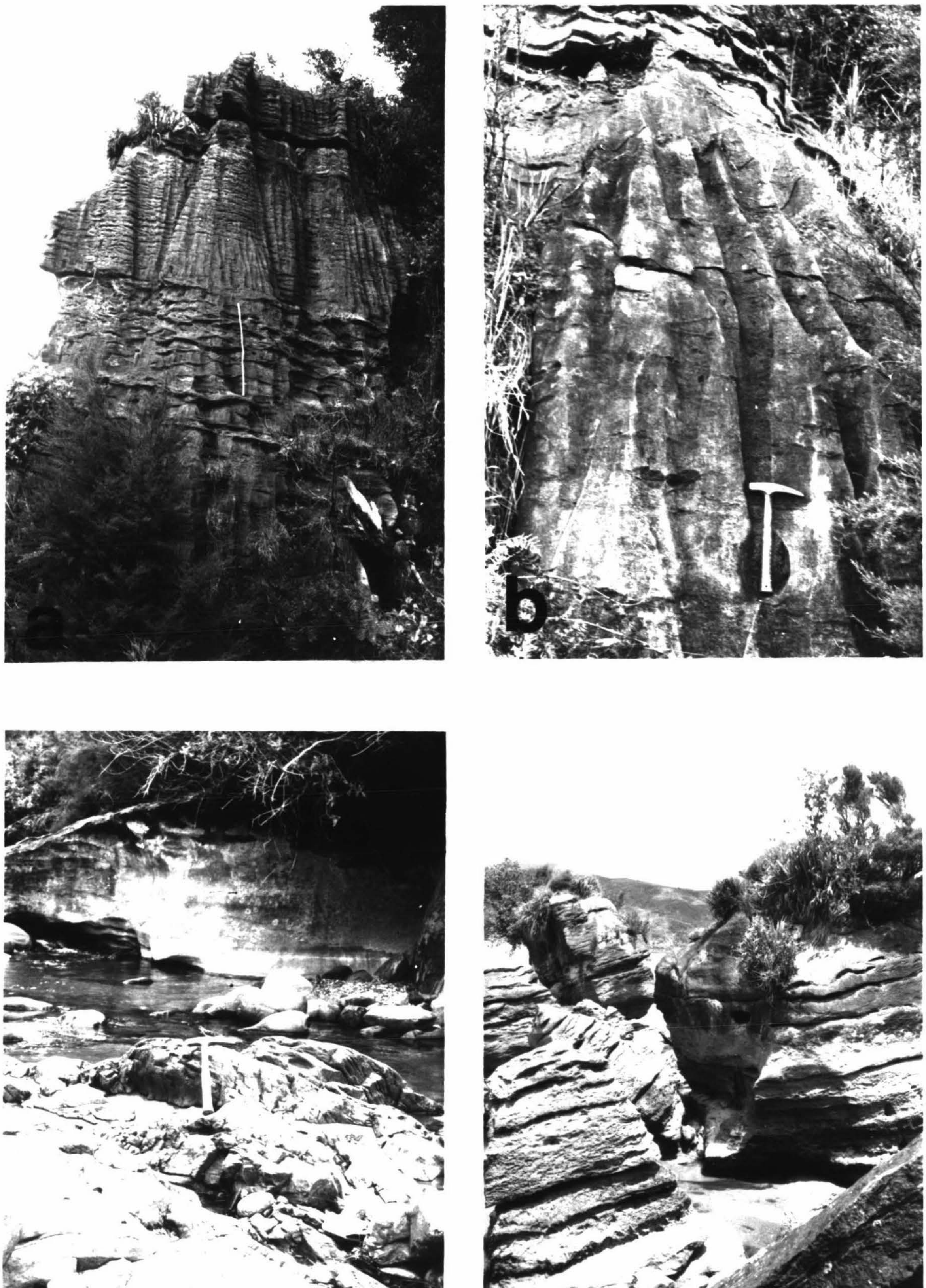
a/ Wavy low-amplitude solution planes in facies nt_7 calcarenite at the Doctor Creek section (M25/764483). Solution seams in the middle rock unit stand out as positive relief (whereas facies nt_4 and nt_5 seams are recessed).
Staff 1.50m long.

b/ Vertically fluted outcrop at the Doctor Creek section. Hammer 330mm long.

FACIES nt_8 AT DEVIL'S BOOTS AND PARAPARA

c/ Facies nt_8 grainstone in the foreground overlies an uneven schist surface with up to 0.6m relief, and grades up to facies nt_7 calcarenite (background). Appo's Creek (Devil's Boots section, M25/791519).

d/ Blocks of facies nt_8 grainstone with 200mm thick flags, Parapara Inlet M25/823543.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were deposited under higher energy conditions and under lower terrigenous influx than facies nt_7, and possible on a more open shelf remote from land. The relative absence of bryozoa compared to the texturally-similar facies nt_4 suggests a shallower-water, higher-energy environment of deposition.

FACIES INTERRELATIONSHIPS AND ISOPACH DISTRIBUTION

Carbonate analyses

Each limestone facies is characterized by a distinctive range of $CaCO_3$ and terrigenous mud percentages (fig.35). Although the bubbles representing each facies are based on so few data, they indicate the range of each facies and the intergradion between different facies. Facies nt_1 and nt_6 are each represented by only two widely spaced samples; no bubbles are shown on fig.35 as these could be misleading. The significance of the two separate ranges of facies nt_3 is unknown; the group with the higher mud percentage consists of three basal packstones directly overlying basement (samples 14547, 14622, 14674), but the group lower on the graph are quite variable in character (samples 14565, 14624, 14668).

The parameters used in fig.35 are directly relevant to important sedimentological factors. The percentage of mud in the non-carbonate fraction is probably directly proportional to the energy of the environment of deposition. One possible exception is that a dense growth of bryozoa growing under swift current conditions might act as a baffle to trap and bind fine sediment. This could explain the wide variation of mud percentages in facies nt_5.

The proportion of calcium carbonate in each sample is of course the inverse of the proportion of terrigenous material, and would vary with the distance from land, the amount of tectonic uplift on land and/or the rate at which the landmass was submerged during transgression. This does not apply to glauconite-rich rocks, in which the terrigenous fraction is dominated by authigenic glauconite and also siliceous foraminifera tests, thus indicating minimal terrigenous influence and low biogenic productivity.

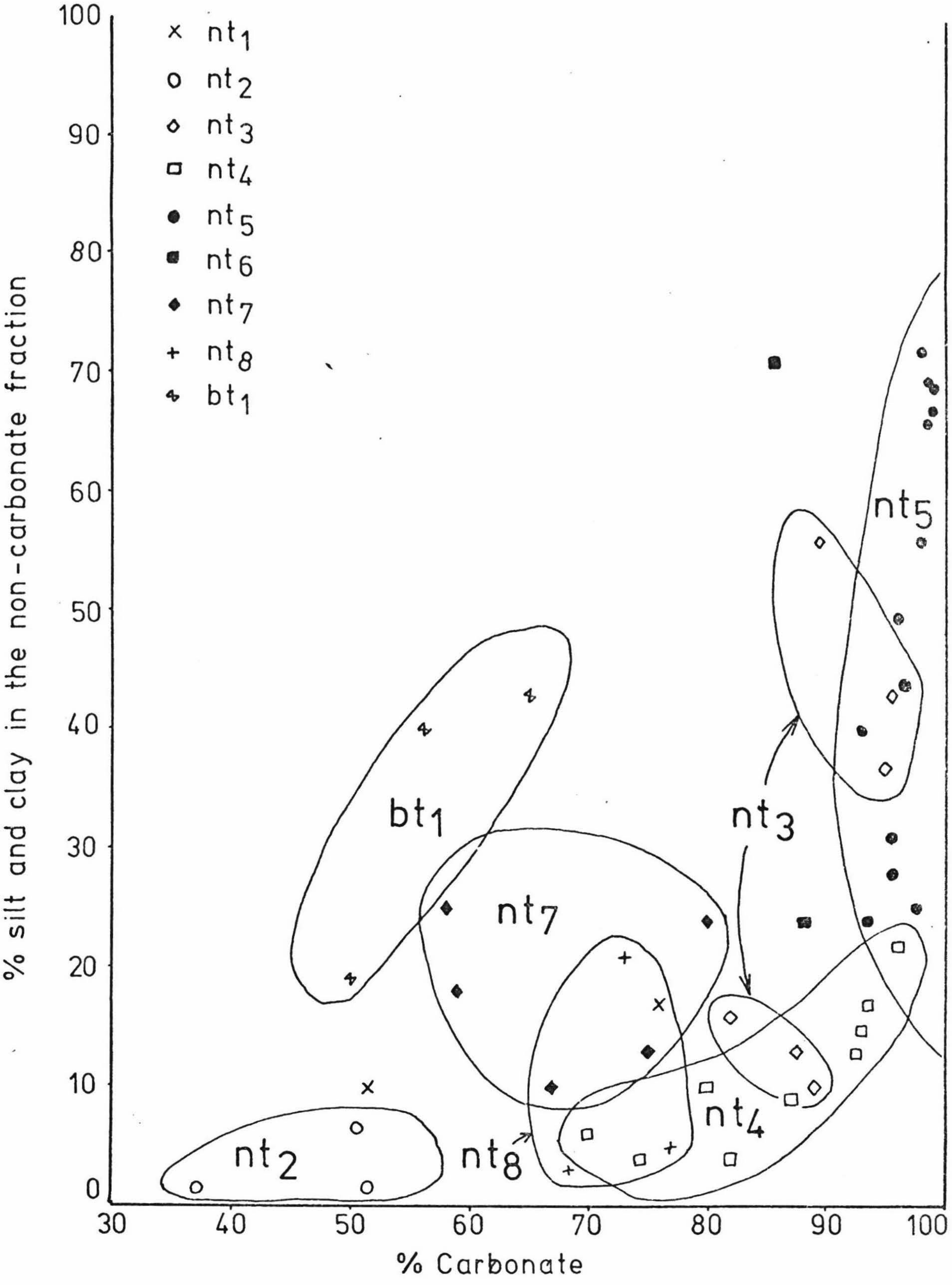


Fig.35: Percentage of clay and silt in the non-carbonate fraction related to the percentage of carbonate in Takaka Limestone and Tarakohe Mudstone (bt_1) samples. Samples of each facies are, where appropriate, grouped together within a ring.

Fig.35 is used solely to demonstrate the percentages of $CaCO_3$ and terrigenous mud in samples of Takaka Limestone, and to emphasize the overlap of different facies types. It is not intended that samples could be identified as belonging to a particular facies simply by these two parameters.

Facies interrelationships

The facies of the Takaka Limestone (fig.36) fall into four basic associations:

(1) nt_1 - nt_2 - $nt_{3/4}$ - nt_5 in Heaphy River - Gouland Downs and Upper Waitui - Mount Arthur Tableland, although Heaphy River is dominated by nt_3 and nt_5, and Waitui Stream by nt_2 and nt_4;

(2) an nt_7-dominated sequence in Aorere valley and the northwest coast, which appears to grade eastwards into:

(3) an nt_4 and nt_5 dominated sequence in the Takaka valley;

(4) nt_3 - nt_4 - nt_5 in the Karamea-Cuckoo River area.

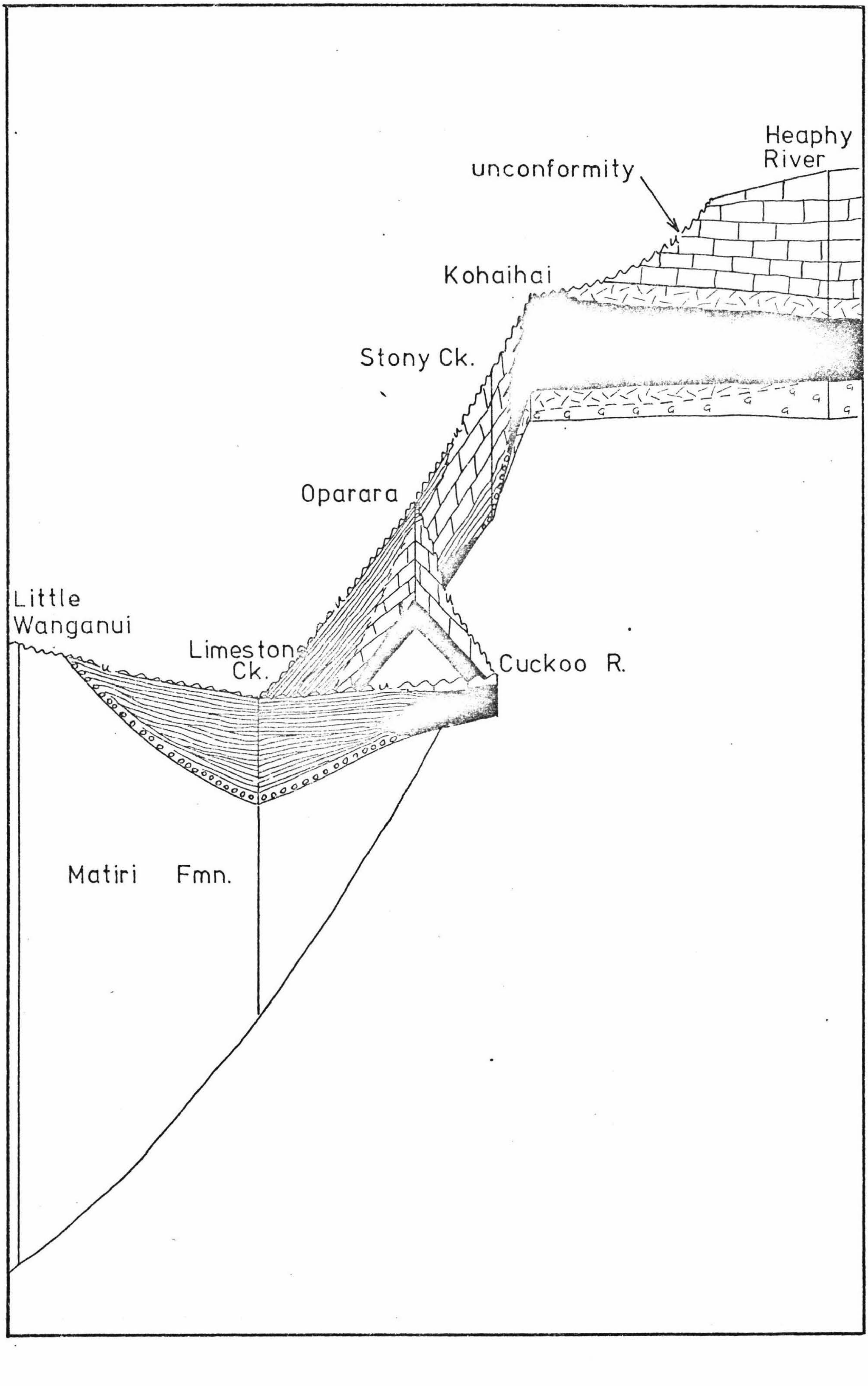
Ages of the basal Takaka Limestone (figs.3,26) indicate that a marine transgression advanced from both north and south, meeting at a divide between Brown River and West Takaka. The similar sequence of facies at Heaphy River and Waitui Stream could indicate similar sedimentation histories under a northwards-heading marine transgression. The Takaka facies sequence was deposited in part by a southwards-heading transgression. The nt_7 dominated sequence may have been influenced by slow erosion of an emergent landmass near the present Aorere valley.

Facies nt_5 is usually the youngest facies in the limestone, and its high carbonate content suggests that it was deposited when the entire morthwest Nelson landmass was submerged.

The implications of the facies distribution are further discussed in Chapter 7.

Isopach Distribution

Thickness measurements of the Takaka Limestone are concentrated along the major valley systems and coastlines; their absence on the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Oparara
Little Wanganui
Limestone Ck.
Cuckoo R.
Matiri Fmn.

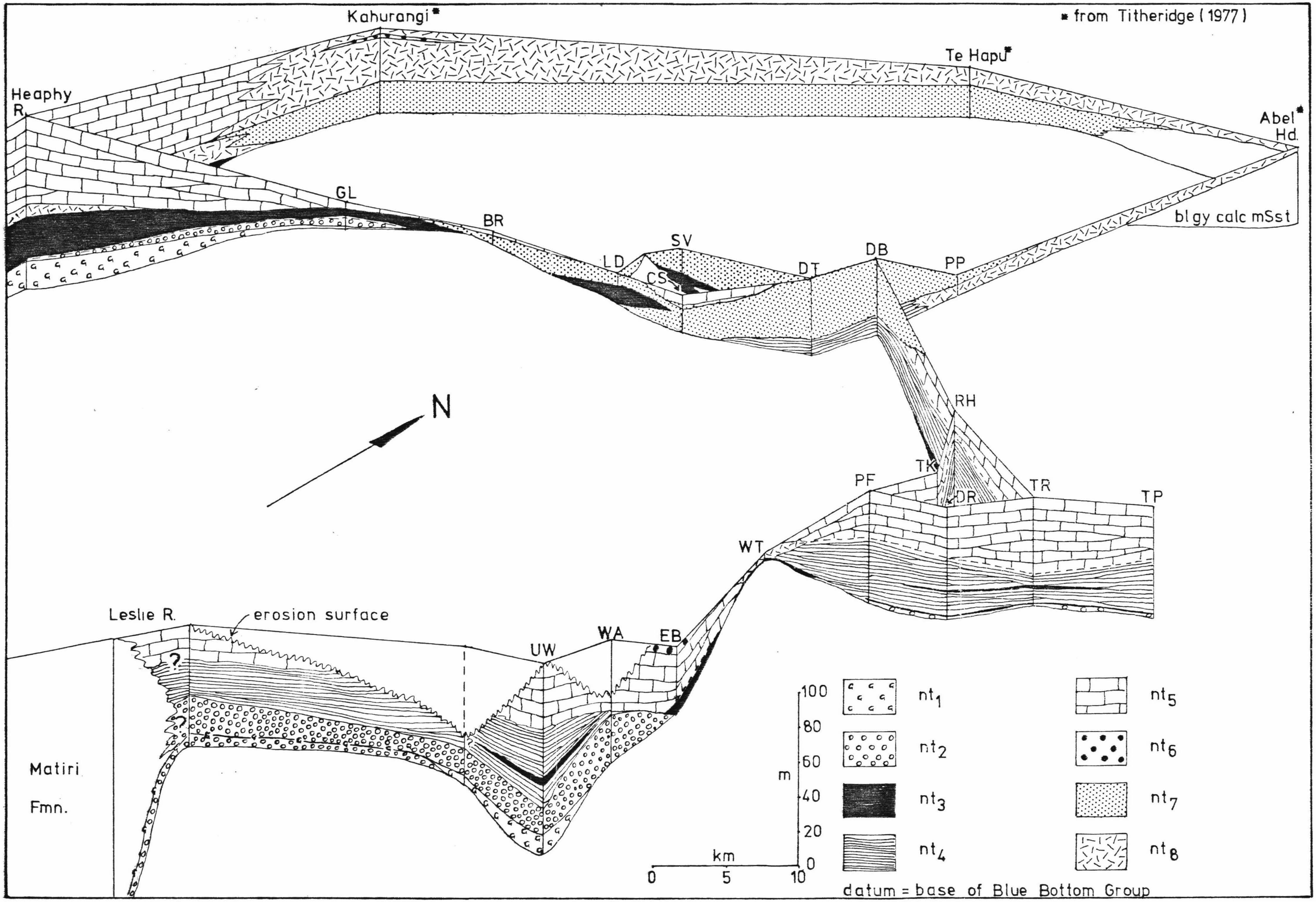


FIG.36 FACIES DISTRIBUTION OF THE TAKAKA LIMESTONE IN NORTHWEST NELSON

mountainous inland region of northwest Nelson compels the isopach distribution (fig.37) to be largely interpretative, based on the Miocene-Recent structural configuration of Golden Bay (cf. fig.1). The low proportion of terrigenous material in the formation indicates a general tectonic quiescence during the Duntroonian to Otaian Stages, and so the isopach maxima correspond to broad areas of downwarping, later to be intensified as monoclinal folds and reverse faults.

The validity of these assumptions is indicated by the agreement of isopach data with the assumed structural configuration. An explanation is necessary for the isopachs in the northern and northwest part of the map (outside the present study area). The Kaipuke Siltstone (Bishop, 1971) is Waitakian-Otaian in age and therefore a lateral equivalent of the Takaka Limestone within the study area. No thickness data is available for this formation other than by Wellman et al. (1973), and therefore it is not represented on the isopach distribution. On the other hand, a wedge of blue grey calcareous muddy sandstone of Waitakian age underlies Takaka Limestone at Abel Head; inclusion of this unit in fig.37 is justified because it demonstrates the northwards deepening of the incipient Aorere Syncline (cf.fig.1).

It should be borne in mind that the original thicknesses of the limestone prior to deep burial might have been as much as 100% greater than the present thickness, due to bulk volume reduction by pressure solution. Volume reduction is unlikely to have been uniform throughout the limestone, but estimates of relative compaction could only be speculative.

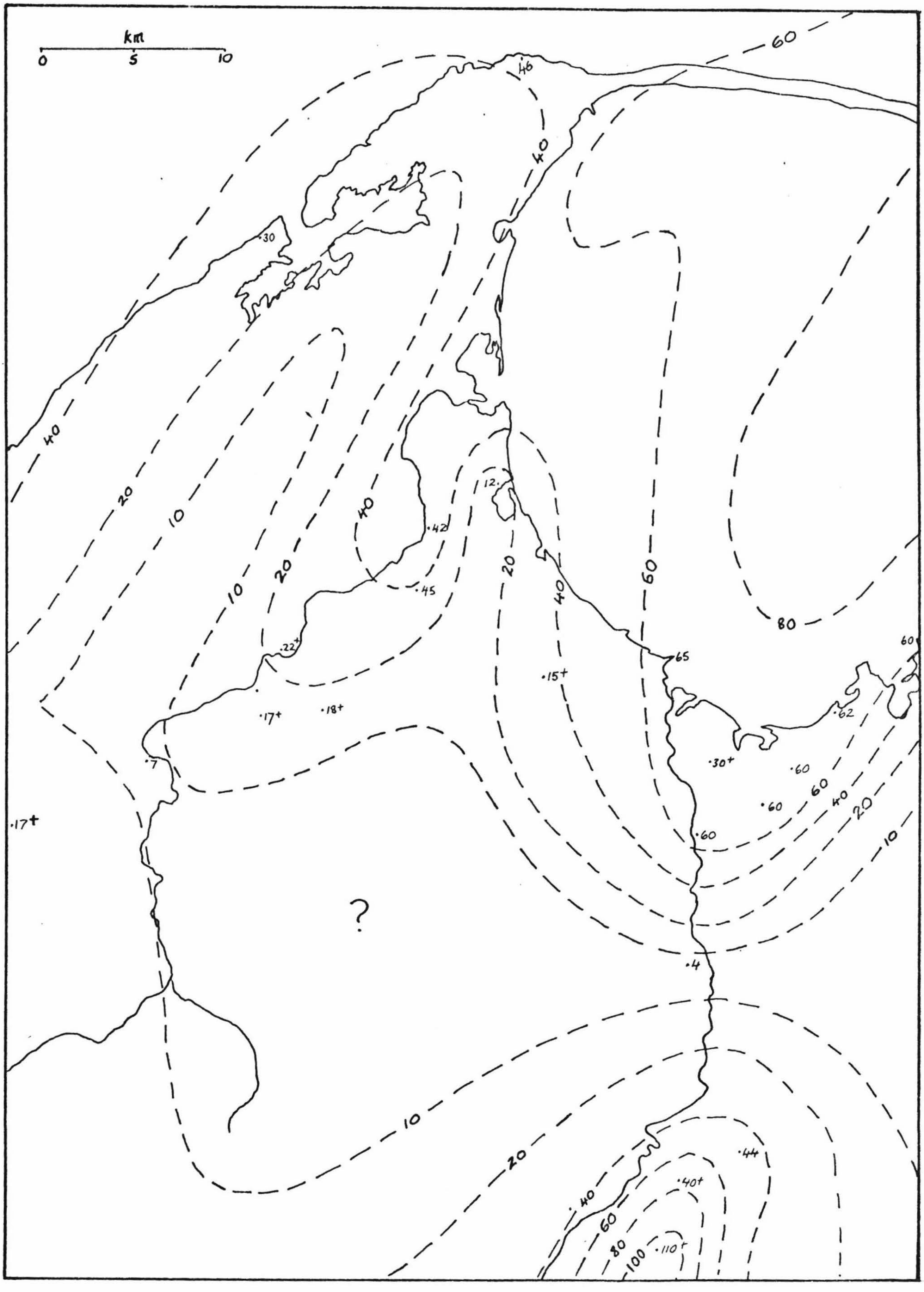


Fig.37: Isopach distribution of the Takaka Limestone in northwest Nelson. Thickness data are in metres; data with "+" are minimum thicknesses, where an upper contact is not exposed.

DIAGENESIS

A wide variety of diagenetic features occur and are listed below.

Stabilization of aragonite and magnesian calcite

The original carbonate sediments consisted of allochems composed of aragonite, high-magnesian calcite and low-magnesian calcite. These minerals formed the skeletons of the following organisms:

aragonite : some bivalves and gastropods (although many bivalves contain alternate layers of aragonite and calcite);

high-magnesian calcite : red algae, echinoderms, most bryozoa, some foraminifera (Bathurst, 1975);

low-magnesian calcite : bivalves of the families Pectinidae, Limidae, Ostreidae and Anomiidae, gastropods of the Epitoniidae (Beu et al., 1972), brachiopods, foraminifera of the families Elphidiidae, Amphisteginidae, Globigerinidae and Globorotaliidae (Bathurst, 1975:42) and possibly some bryozoa.

The carbonate mud preserved as micrite in some facies was probably derived from abrasion and disintegration of these skeletal grains (Nelson, 1978).

Aragonite and high-magnesian calcite are thermodynamically unstable polymorphs of $CaCO_3$, and are altered during early diagenesis to stable low-magnesian calcite (e.g. Bathurst, 1975). Evidence for aragonite dissolution in Takaka Limestone is restricted to packstones in which dissolution moulds were later filled by sparry calcite, or rare grainstones which contain micrite envelopes (see Aragonite Dissolution section below).

Aragonitic and high-magnesian calcitic allochems were rarely calcitized by low-magnesian sparry calcite. Criteria for distinguishing such neomorphic spar from precipitated sparry cement are listed by Bathurst (1975:487); those particularly applicable to this study are wavy intercrystalline boundaries, concentration of the smallest crystals along the shell margins, and linear patterns of inclusions (fig.38a,d). Many dissolution moulds are readily identified by basal accumulation of geopetal micrite.

High-magnesian calcite allochems such as echinoderms and bryozoa were stabilized by incongruent neomorphism, in which magnesium ions were flushed from the skeletal structure without changing the skeletal texture.

Carbonate mud was stabilized to low-magnesian calcite, and lithified as a mosaic of polyhedral, equant micrite crystals 2μm in diameter. Magnesium ions expelled from the mud particles were retained as a "cage" around each micrite crystal and poisoned crystal expansion (Folk, 1974:48).

The relative timing of these stabilization reactions is discussed in the following three sections.

Fibrous fringing cements

Fibrous cements commonly fringe allochems in bioturbated packstone-grainstones (figs. 38b,c,d). Crystals are acicular, close-packed and 20-70μm, rarely 100-200μm long. Crystal outlines are blurred and sometimes associated with linear arrangements of darker inclusions. In rare occurrences the cement is buried by micrite (fig. 38c; samples 14577, 14665).

Discussion: The crystal habit suggests that the cement was originally high-magnesian calcite (e.g. Folk, 1974). The absence of distinct crystal outlines and the inclusions suggest that the cements were recrystallized as low-magnesian calcite. Burial of the cements by carbonate mud indicates that cementation took place on the sea-floor or during very shallow burial, in a stable sediment not affected by rapid deposition, erosion or intense bioturbation.

Fringing cements are prominent in a nodular limestone (facies nt_8) underlying a well-exposed disconformity at Kohaihai Bluff (cf. German, 1976; University of Canterbury samples 7451E,F). This early cementation, together with probable large borings in the upper contact, moderate bioturbation and the irregular nodular appearance suggest that this nodular limestone was originally a submarine hardground.

Aragonite dissolution

Spar-filled cavities in most packstones and micrite envelopes in rare packstone-grainstones are moulds of dissolved aragonitic allochems. Most cavities faithfully reproduce the original grain shape but some are partially collapsed. Geopetal micrite is common in cavities, sometimes filling an entire mould, and is probably derived either from collapse of the cavity roof or from carbonate mud sifting downwards.

Rocks with micrite envelopes are rare but widely distributed. The micrite envelope is a dense dark regular line (fig. 38d,f), sometimes fringed by fibrous cement. Borings can be distinguished from the surface envelope by colour and texture (fig. 38d). Fracturing and disaggregation of envelopes is indicated by randomly orientated "envelope" fragments (fig. 38f), probably caused by bioturbation or compaction. Quartz grains are also rimmed by a dark micrite layer.

Discussion: Cement-filled allochem moulds are a widespread diagenetic feature attributed to dissolution of the original aragonite skeleton (e.g. Bathurst, 1975). The high proportion of intact cavities and micrite envelopes suggests that aragonite dissolution took place in a generally undisturbed sediment, probably below the zone of bioturbation. The presence of geopetal micrite suggests that the cavities were empty for an unknown period of time before calcite precipitation began.

The smooth texture of the micrite envelopes, their occasional disaggregation, and encrustation of quartz sand as well as allochems, indicate that the envelope was originally an organic coating. Bathurst (1975) emphasized that the micrite envelope "is a centripetal replacement and not a centrifugal accretion. Nowhere does it lie on an unaltered smooth surface of a skeleton, as something attached to it or added to it. Everywhere the contact between the envelope and the skeletal core is irregular, transecting the fabric of the skeleton" (p.384). It is clear that the micrite envelopes seen in this study are fundamentally different to those discussed by Bathurst.

FIG. 38 : DIAGENETIC FEATURES OF THE TAKAKA LIMESTONE

a/ Coarse neomorphic spar has destroyed the original shell texture of a gastropod shell (see lower left of fig. 28b). Gouland Downs sample 14565, cross polars.

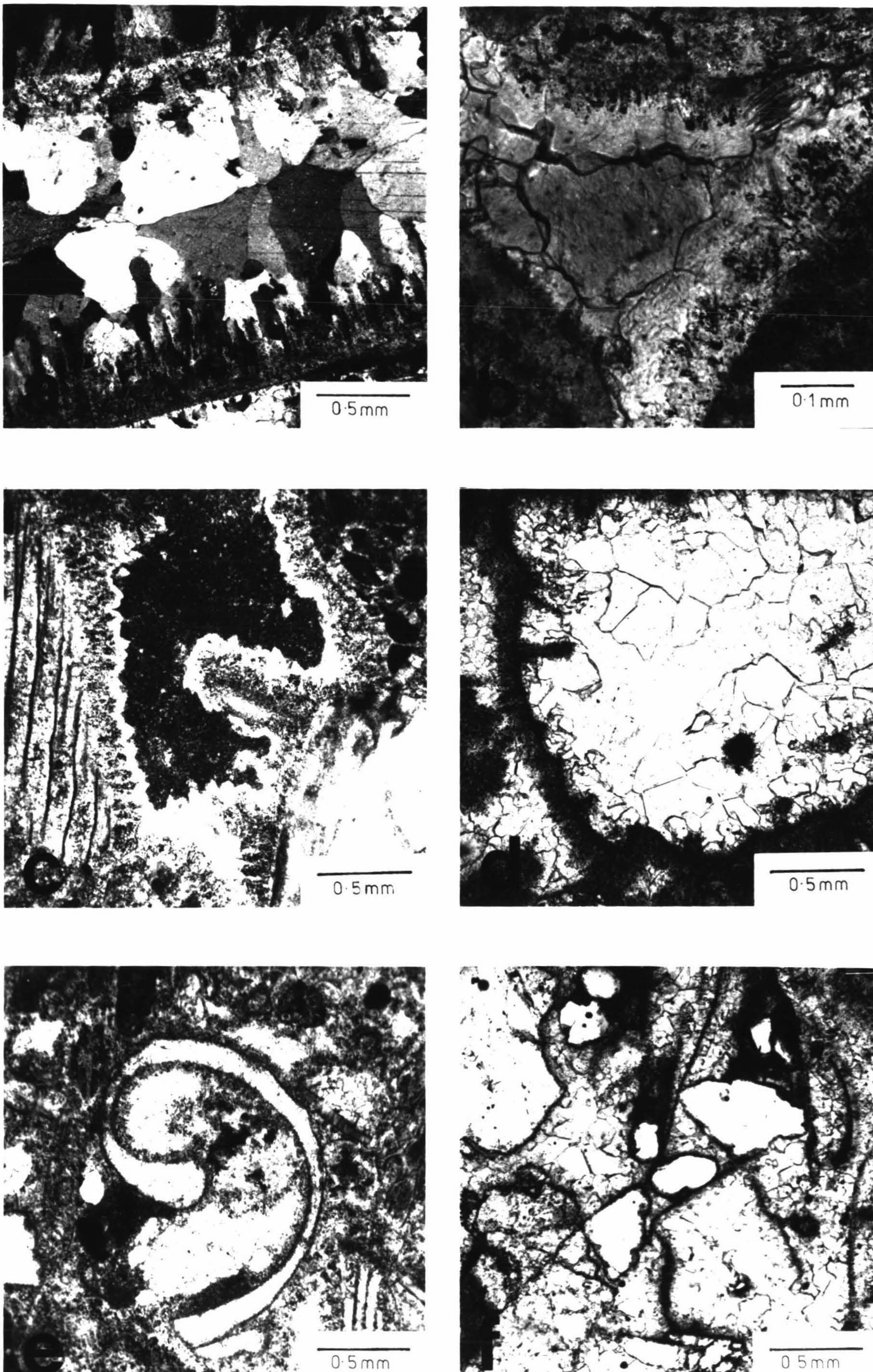
b/ Neomorphosed fibrous fringing cement succeeded by equant sparry cement.
Rangihaeata sample 14613.

c/ Bryozoan and mollusc grains encrusted by fibrous fringing cement, later buried by dark, probably clay-rich micrite.
Upper Waitui sample 14665.

d/ A shell fragment recrystallized to neomorphic spar is encrusted by a dark organic layer and a fringe of fibrous cement. The neomorphic spar is distinguished by the abrupt size variation and the abundance of wavy intercrystalline boundaries.
Sample 14665.

e/ A "Micrite envelope", a dissolution mould enclosed by a thin dark film of (?) "minimicrite". Allochems and envelope are encrusted by fibrous fringing cement.
Sample 14665.

f/ Fragmented micrite envelopes. Note the dark organic film also encrusts quartz sand grains.
Takaka sample 14630.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0·5mm
e
0·5mm
f
0 5mm

Shearman and Skipwith (1965) described transparent mucilage coatings on carbonate sand grains in the Trucial Coast which they considered to be secretions by colonies of blue-green algae. These coatings were still present in similar lithologies of Pleistocene age, even after the original aragonite skeleton had been replaced by calcite.

Winland and Matthews (1974) found similar algal sheaths binding grapestone in the Bahamas, and showed that the original algal mucilage was calcified to high-magnesian micrite with high birefringence and cryptocrystalline texture.

Micrite envelopes in the Takaka Limestone may be relict mucilaginous films secreted by blue-green algae on sand grains. Such films would have been susceptible to oxidation and decay, but they may have been calcified to magnesian calcite, as described by Winland and Matthews. The dense, dark appearance of the envelope material suggests that it is composed of "minimicrite" (Folk, 1974:49), an original micritic magnesian calcite in which so much magnesium remained during diagenesis that crystals could only grow to c.1μm diameter.

Syntaxial overgrowths

Echinoderm fragments in grainstones are invariably overgrown by an optically continuous rim, sometimes enclosing adjacent grains in poikilotopic texture. The absence of overgrowths in bioturbated packstone-grainstones indicates that overgrowthing took place below the zone of bioturbation. In rare examples, echinoderms are fringed with fibrous cement prior to overgrowth formation.

Overgrowths in limestones with a significant terrigenous clay content mainly consist of ferroan calcite, and the actual echinoderm grain may also consist of ferroan calcite.

"Clean" limestones with low clay content have an initial iron-free calcite cement and up to four more generations of alternating iron-rich and iron-poor calcite. For example, Paynes Ford samples 14591 and 14592 have five generations of syntaxial overgrowths, in order: 12% iron-free; 18% iron-rich; 12% iron-free; 3% iron-rich; 55% iron-free, abutting against equant iron-free spar. The rims generally parallel the original grain surface and zig-zag boundaries are rare. Boundaries between generations may be sharp or gradational.

Discussion: Echinoderm skeletons originally consisted of high-magnesian calcite, but two features suggest that they had recrystallized to low-magnesian calcite prior to overgrowth precipitation: (1) simultaneous precipitation of overgrowths and equant calcite spar (see void-filling spar section), and (2) recrystallization of the skeletal fabric under iron-rich conditions to iron-rich calcite. Overgrowth precipitation preceded, and was relatively resistant to, compaction and pressure solution so that there are many examples of echinoderm grains with extensive overgrowths in an otherwise tightly-packed rock.

Alternate iron-rich and iron-free generations of cement have been often ascribed to fluctuations of Eh in vadose and phreatic environments (e.g. Oldershaw and Scoffin, 1967). However, the environments of deposition envisaged for the limestone require depths of 30m or greater, and there is no evidence to indicate abrupt shallowing that would allow subaerial diagenesis. Multiple cement generations are found throughout the Takaka Limestone and are not confined to any particular facies.

Cementation probably took place during subseafloor burial. Variations in iron content were due to fluctuations of Eh and pH, or else simply the availability of iron.

Pressure-solution

The Takaka Limestone has a characteristic flaggy appearance in which 50-150mm thick layers are separated by solution planes or 1-20mm thick seams. As described earlier in this chapter solution planes vary in appearance, orientation and distance apart between different facies. The effects of pressure solution vary considerably between facies, and in the following ways:

facies nt_1 (glauconitic limestone) : moderately loose packed, non-sutured grain contacts, no stylolites.

nt_2 (calcareous sandstone) : allochems penetrated by quartz grains.

nt_3 (mollusc packstone) : high-amplitude sutured stylolites orientated vertical and horizontal, 100-200mm apart; rare allochem interpenetration.

nt_4 (bivalve grainstone) : usually moderately packed; sutured grain contacts, collapsed bryozoan skeletons; low-amplitude stylolites form subplanar prominent flags 50mm thick. Occasional calcareous sandstone seams comprise interpenetrating allochems, non-sutured stylolites.

nt_5 (bryozoan grainstone) : tight packed; sutured grain contacts, collapsed bryozoan skeletons, rare clay-lined low-amplitude stylolites. Seams consist of clay-lined non-sutured microstylolite swarms, sometimes with concentrations of dolomite rhombs. Flags subplanar 50-150mm thick.

nt_6 (algal packstone) : tight packed; non-sutured grain contacts; low-amplitude stylolites form weakly developed flags 50mm thick.

nt_7 (sandy calcarenite) : close packed, allochems penetrated by quartz grains. Sometimes undulatory non-sutured clay-lined seams 50-200mm apart, often standing out as positive relief on outcrop, sometimes enclosing and accentuating burrow-fill.

nt_8 (echinoderm grainstone) : loose packed, rare grain contacts, weakly developed flags 50-100mm thick.

Pressure-solution features of facies nt_3, nt_4 and nt_5 are discussed below in detail.

<u>Facies nt_3</u>: Single, widely separated stylolites are irregular in orientation, possibly influenced by the random orientation of the larger allochems or of burrow-fill. (Shell-beds at Kohaihai and at Heaphy River are obvious exceptions, and stylolites are strongly influenced by the horizontal orientation of the bivalves). Stylolites are strongly sutured (fig.39a) even when traversing apparently homogenous micrite (fig.39a). Some stylolites open into spar-filled cavities - usually moulds of aragonitic allochems. The sparry cement is likely to have been derived from calcite dissolution along the stylolite.

Facies nt_4: In facies nt_4 and nt_5, the results of pressure-solution depend on the behavioural response of the allochems. Mollusc and echinoderm fragments are relatively resistant to stress, and suffer sutured margins (fig.39c), but many bryozoan types appear to easily collapse and may become totally compacted, unrecognizable nodules (fig.39c,d). Therefore facies nt_4 rocks, rich in molluscs and echinoderms, tend to retain an open fabric. An important consideration is that the porosity in such rocks may have already been significantly reduced, and rock strength increased, by echinoderm overgrowth cementation.

Stylolites in this facies are not easily preserved during thin section polishing. They appear to be low in amplitude and with concentrations of terrigenous sand. A typical seam (Rangihaeata sample 14617) is 20mm thick, with no gradation of grain-size or texture within it. It consists of roughly laminated quartz sand and allochems, the latter dominated by two-generation overgrowthed echinoderms and with rarer bivalves and brachiopods. The composition of sample 14617 is 43% $CaCO_3$, 51% terrigenous sand and 6% terrigenous mud, in contrast to adjacent open-fabric grainstone sample 14618, which consists of 93% $CaCO_3$, 6% sand and 1% mud.

Facies nt_5: This facies is rich in bryozoa, which offer relatively low resistance to collapse. The rocks are commonly tightly-packed, with swarms of low-amplitude sutured stylolites, and with cement mainly confined to bryozoan chambers. Large, robust bryozoan colonies are enclosed, almost boudinaged, by tightly compacted and collapsed colonies outlined by microstylolite swarms (fig.30c).

In other rocks, pressure-solution is mainly confined to the solution planes or seams, while the flagstones maintain a relatively open fabric. This style of pressure-solution is illustrated by Payne's Ford samples 14590 and 14592. Sample 14590 (fig.27d) consists of a flag 65mm thick with a sharply-defined 12mm thick seam; the flag contains 98.4% $CaCO_3$, 0.5% sand and 1.1% mud, and the seam comprises 89.7% $CaCO_3$, 5.3% sand and 5.0% mud. Sample 14592 is a similar flagstone, but with a broadly-defined zone of microstylolites that suggests an incipient stage of seam formation. The textural differences are described below:

Flagstone: This has an open fabric with abundant equant sparry cement and moderately common echinoderms with up to five overgrowth generations. Sutured grain contacts are abundant and there are rare clay-lined low amplitude stylolites.

Incipient seam: This is a zone 25mm thick at the base of a flag, with swarms of clay-lined, non-sutured microstylolites. Rhombohedral dolomite is intimately associated with the seams. Echinoderms, molluscs and Amphistegina have rigid, sutured margins, but bryozoa may be completely crushed, depending on the type and orientation.

Seam: The seam consists of lenses of bryozoan and echinoderm fragments bounded by dolomite-lined non-sutured microstylolites (fig.40e). Echinoderm fragments with large two-generation overgrowths are abundant, in contrast to their minor importance in the flagstone. It is probable that the echinoderms have been concentrated by pressure-solution. It is highly unlikely that the seam corresponds to a primary bed rich in echinoderms, because early cementation would reduce the porosity of that horizon and make pressure-solution impossible.

Variations in the terrigenous mud ratios of adjacent flags and seams were noted in three pairs of samples (Table 3). The percentage of mud in the non-carbonate fraction of the seam is, on average, 67% lower than in the flag. This consistent decrease could be due to breakdown of clay minerals and perhaps dissolution of quartz silt particles in the higher stress concentrations within the seam.

Table 3: Variation of the percentage of mud in non-carbonate fractions of adjacent seams and flagstones.

Facies	Sample	Type	% mud in insoluble fraction (M)	M in seam/ M in flag
nt_4	14618 14617	flag seam	15 10	67%
nt_5	14590	flag seam	69 49	71%
nt_5	14653	flag seam	40 25	63%

FIG. 39 : DIAGENETIC FEATURES OF THE TAKAKA LIMESTONE (CONTINUED)

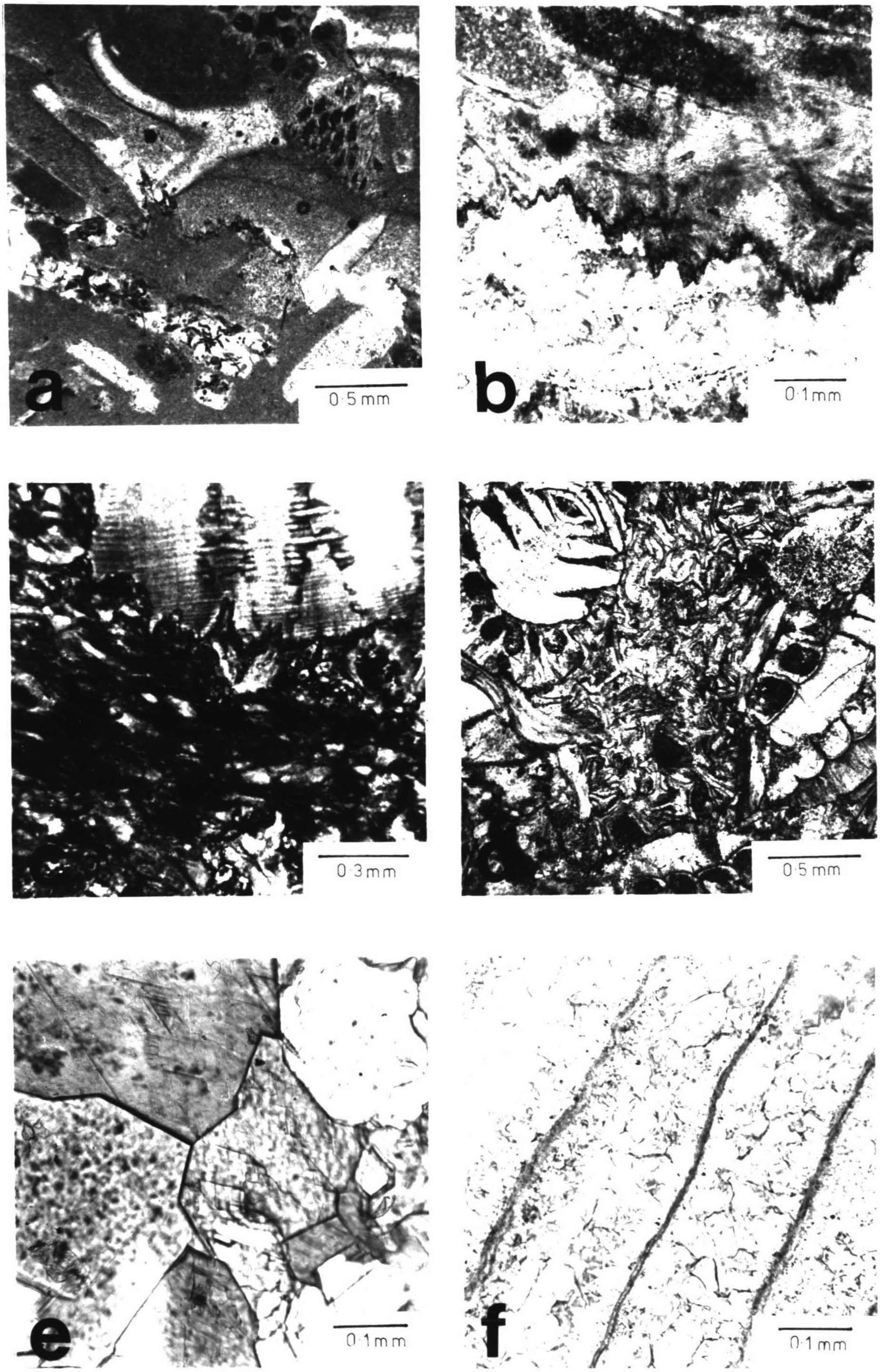
a/ A stylolite cuts both allochems and micrite. Note the strongly bored grain at lower left.
Heaphy River sample 14718.

b/ Stylolitic surface between bryozoan (top) and benthonic foraminifer (bottom).
Rangihaeata sample 14613.

c/ Stylolitic surface between mollusc grain (top) and a severely crushed and collapsed bryozoan colony.
Payne's Ford sample 14592.

d/ A fragmented bryozoan colony enclosed by foraminifera, echinoderm and intact bryozoan fragments.
Eureka Bend sample 14548.

e/ Equant void-filling calcite spar, distinguished by sharp, planar intercrystalline boundaries and common enfacial junctions.
Rangihaeata sample 14614.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Discussion: Wellman (1950c:23) interpreted the limestone flags as primary bedforms, whose wavy surfaces indicated shallow water deposition. Barrett (1964), studying Te Kuiti Group limestones near Waitomo, considered that flagginess was primarily diagenetic in origin. He demonstrated that solution seams may cut obliquely to primary stratification, and that where primary sand layers do occur, they do not weather to produce flagstones. Nelson (1978), discussing Cenozoic limestones throughout New Zealand, contended that the alternation of flagstone and seam corresponded to a primary stratification of alternate terrigenous-rich and terrigenous-poor beds, modified and accentuated by diagenetic processes.

Although solution planes accentuate cross-bedding at Rangihaeata Head, the evidence of the Takaka Limestone favours pressure solution as the cause of the flagginess:

(1) The stylolites and microstylolite swarms are an integral part of pressure-solution features within the limestone;

(2) There are no primary sedimentary features within flags such as gradation of grain-size, burrows extending downwards from the upper flag contact or small-scale cross bedding:

(3) Solution planes sometimes cut through bryozoan colonies.

The formation of solution planes and seams within the Takaka Limestone is attributed to overburden pressure. Primary lamination or shell orientation is a subordinate, but nevertheless significant, influence. Flags are most prominent where the grains within the rock show a clear, horizontal orientation, as in facies nt_4. Irregular horizontal and vertical stylolites result when the rock fabric was disordered by extensive bioturbation (facies nt_3). Poorly developed, lenticular solution planes form in fine-grained limestones with rare horizontal-aligned allochems (facies nt_7).

The regular spacing of the solution planes is not a relict primary stratification, but is probably due to stress gradients within the limestone.

Equant void-filling spar

Equant void-filling spar, 50-100μm in diameter and generally with a low iron content, is distinguished from neomorphic spar by plane intercrystalline boundaries, common enfacial junctions (fig.39e), orientation of crystal axes normal to the initial substrate and multiple generations (cf. criteria listed by Bathurst, 1975:417). Large crystals up to 2mm in diameter occur in umbrella fabrics and in the larger moulds of dissolved allochems.

In limestones with a moderate proportion of clays or glauconite, iron-rich calcite is the dominant cement mineral, often stained a vivid blue. Elsewhere, iron-rich calcite often forms a late-stage cement. Zoned rhombohedral spar with up to three generations of iron-free and iron-rich cement (figs. 39f,40a,b) occurs in some open-fabric limestones and typically in dissolution moulds. A typical zonation sequence (in Eureka Bend sample 14548) is, in order of growth: 20-100μm pink iron-free cement; 10μm bright blue iron-rich cement; 100-200μm light bluish purple moderately iron-rich cement, growing in optical continuity.

Void-filling sparry cement is common in open-fabric limestones, but generally confined to bryozoan zooecia or foraminifera chambers in tightly packed rocks. It is totally absent in seams and other areas of intense pressure-solution. However, it may also be rare in open-fabric echinoderm-dominated rocks in which syntaxial echinoderm overgrowths fill most of the pore space.

Comparison of multiple generation syntaxial overgrowths and sparry cements in the same sample show that echinoderms began to be overgrown before spar was precipitated. In most cases, one or more overgrowth generations had formed before sparry cement appeared. However, it was rare that a late-stage sparry cement had no echinoderm equivalent.

Discussion: Precipitation of sparry cement postdated the initial stages of syntaxial overgrowth formation, and also appears to have been preceded by pressure-solution. Manus and Coogan (1974), in a theoretical study, showed that the most significant aspect of pressure-solution is bulk volume reduction, and that a very large degree of volume reduction is necessary in order to generate a significant volume of cement. The alternation of flaggy limestone with solution planes or seams in the Takaka Limestone suggests the concept of donor and receptor limestones (Bathurst, 1975:451; Nelson, 1978). It is likely that the intense pressure solution concentrated along seams supplied high concentrations of dissolved $CaCO_3$ which precipitated in lower stress regions between the seams.

Folk (1974) considered equant sparry calcite to be a typical product of deep subsurface diagenesis, formed in porewaters of low magnesium content. This requires that the magnesium in buried seawater is either taken up by clays or dolomite, or is flushed out during mingling of seawater and meteoric waters. A detailed study is necessary to elucidate the geochemical environment in which the spar was precipitated, but this is beyond the scope of this thesis.

Neomorphic spar

Replacement of aragonitic and high-magnesian calcite allochems by neomorphic calcite spar has already been discussed. It is also common for micrite to have recrystallized to equant neomorphic spar up to 60μm in diameter, commonly in areas of matrix adjacent to original space (fig.40c). Often finely abraded allochems are also neomorphosed. The neomorphic spar has a finely clotted texture with numerous patches of relict micrite. The crystals are distinguished by their slightly curved, wavy, intercrystalline boundaries and the gradation into micrite. Neomorphic spar frequently abuts against precipitated sparry calcite, and the precise boundary between the two is usually indistinct.

Discussion: Folk (1974) suggested that micrite formed when magnesium ions were expelled from high-magnesian calcite mud. These ions formed a "cage" around each micrite crystal, thus poisoning further crystal growth, but if they were removed, by freshwater flushing or incorporation into clays, the micrite crystals were free to grow into neomorphic spar.

The distribution of neomorphic spar in the Takaka Limestone indicates that its formation was closely related to original pore space. The need for magnesium-deficient porewaters is similar to the conditions required for precipitation of sparry cement, and suggests that the two types of spar formed in the same subsurface environment.

FIG. 40 : DIAGENETIC FEATURES OF THE TAKAKA LIMESTONE (CONTINUED)

a/ Mollusc and bryozoan fragments encrusted by equant iron-free calcite (stained pink), and later-stage iron-rich spar (stained blue).
Eureka Bend sample 14548.

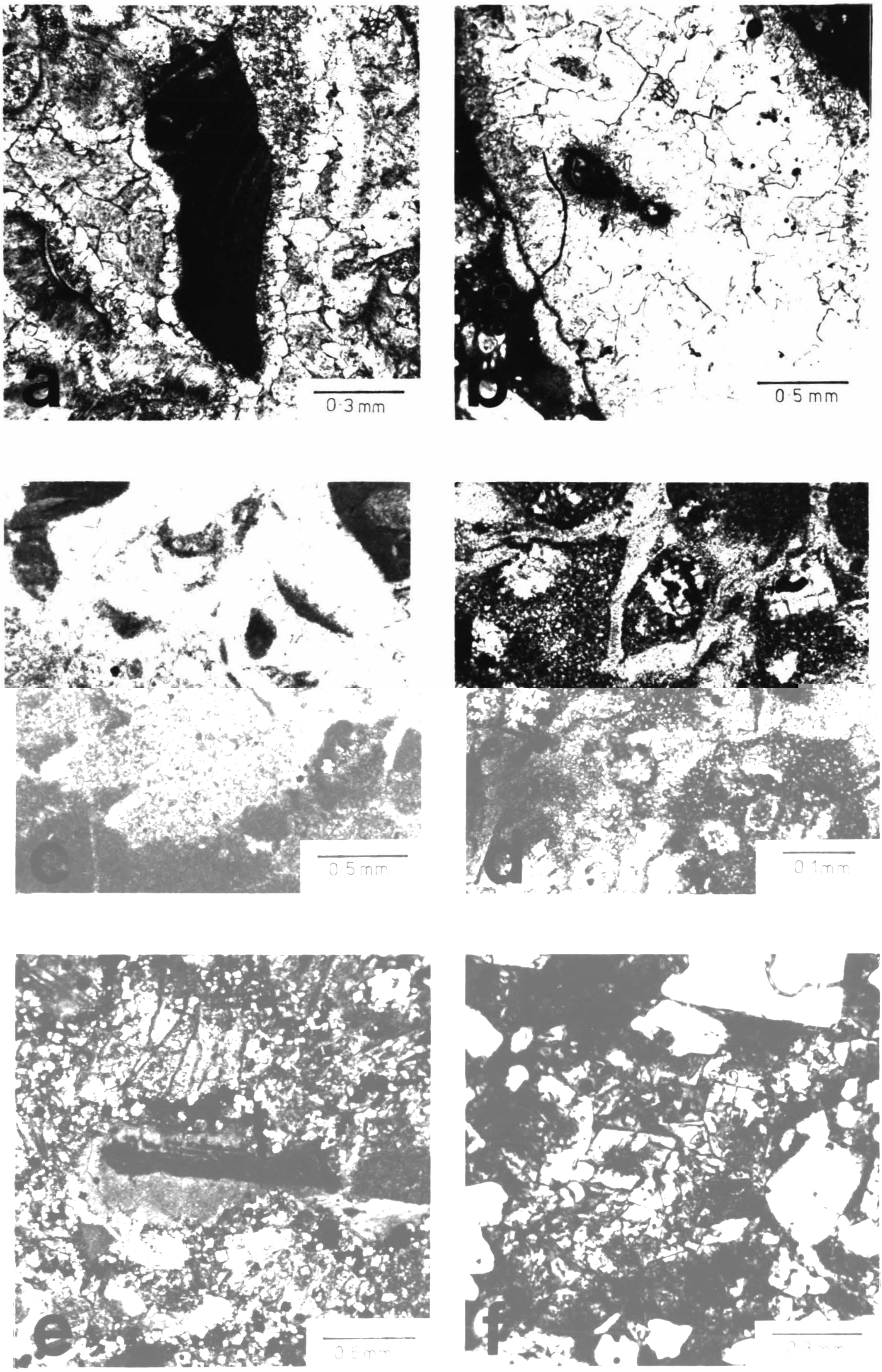
b/ Zoned rhombohedral spar grew from both the walls and the borings of a dissolved aragonitic shell mould. Successive generations of spar are (1) reddish-purple, grading to (2) blue, sharply followed by (3) pink, sharply followed by (4) bluish-purple, which grades to (5) pink.
Kohaihai sample 14680.

c/ Pore-space filled by micrite (base), neomorphic spar (centre) and sparry cement (top).
Rangihaeata sample 14614.

d/ Corroded dolomite rhombs and dark-rimmed neomorphic spar in bryozoan zooecia.
Rangihaeata sample 14616.

e/ An echinoderm grain with syntaxial overgrowth (centre), bryozoan fragments and numerous small dolomite rhombs in a solution seam.
Payne's Ford sample 14590, cross polars.

f/ Dolomite rhombs, corroded along cleavages by poikilotopic calcite spar, are enclosed by a red-brown matrix of dedolomite-micrite.
Payne's Ford sample 14585.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Dolomite and dedolomitization

Dolomite occurs in the Takaka Limestone in two distinct situations, the first being a dolomitic limestone in which dolomite is restricted to bryozoan zooecia and microstylolite swarms. Dolomitic limestone is scattered through facies nt_4 and nt_5 grainstones in the Takaka valley in minor proportions not exceeding 20% of the rock. Numerous dolomite rhombs, 40-80µm in diameter, are confined to bryozoan zooecia and concentrated along microstylolites. Rarely, the rhombs have iron-rich dolomite centres. They appear to have completely obscured the microstylolite and are clustered through the immediately adjacent rock (fig.40e). Dolomite rhombs within bryozoan zooecia are surrounded by neomorphic spar (fig.40d), each crystal of which has a thin dark rim, possibly of iron oxide.

Dolomite of this type is common in Paynes Ford samples 14588-14592, and rare in Rangihaeata sample 14616, Takaka sample 14630 and Tarakohe samples 14652-14654. The dark-rimmed neomorphic spar is present in most facies nt_4 and nt_5 samples and some nt_8 samples, but is absent from the other facies.

The second dolomite occurrence, as a dolostone with few relict calcite components, occurs in only one small lens within the Takaka Limestone, found in the basal 1m of the limestone at Payne's Ford (sample 14585). Outside the study area, dolostone has also been found at the base of the Huia Formation (on the west side of the Moutere Depression) and sporadically within the basal Matiri Formation and Garibaldi Sandstone (Andrews et al., in prep.) in the Karamea Bend area.

The Paynes Ford example (fig.40f) consists of fine to coarse, quartz and feldspar sand in a matrix of neomorphic calcite spar and intensely corroded dolomite. From this matrix, large uncorroded dolomite rhombs up to 200µm in diameter extend into scattered areas of pore space filled by very coarse, often poikilotopic calcite spar. A similar but less-corroded dolostone, Huia Formation sample 14725, consists of a coarse dolomite mosaic with brown relict red algae, echinoderms and benthonic foraminifera. The rhombs fringing the calcite-filled pore space are often corroded.

Discussion: The origin of the dolomite closely confined to seams and bryozoa may be closely linked to pressure solution. Microstylolite swarms and bryozoan zooecia were probably the most porous and permeable conduits available during intense pressure solution. An increase in the Mg/Ca ratio of the porewaters, perhaps caused by breakdown and dissolution of magnesium-rich clays or dissolution of bryozoa (containing 4-10% $MgCO_3$), could trigger dolomite formation in these conduits.

An alternative theory was put forward by Folk and Land (1975): "Incongruent dissolution of Mg-calcites can cause dolomitization at nearly constant salinity by increasing the Mg/Ca ratio of the pore-waters. Only minor amounts of dolomite, restricted to Mg-calcite allochems or their internal pores, can be produced by this method, however" (p.65). The same theory was invoked by Folk and Siedlecka (1974) for dolomite concentrated inside bryozoan and crinoid skeletons; in their examples, the pores of the bryozoa were plugged by micrite, thereby creating magnesium-rich microenvironments. The application of this theory to the Takaka Limestone would imply that the dolomite in the microstylolite swarms was the residue from intensive bryozoan dissolution. The theory is not favoured because (1) there is no indication that the bryozoan zooecia were closed off from the interstitial porewaters; (2) the dolomite rhombs in the seams are not associated with squashed bryozoa, but with the microstylolites, and (3) they show no signs of corrosion by pressure-solution.

Dolomite of this type is most commonly found in fresh quarry samples (the Paynes Ford and Tarakohe samples). Nevertheless, partial corrosion of the rhombs and rhombohedral pores and the ubiquitous association with dark-rimmed neomorphic spar indicate dedolomitization probably during outcrop weathering (Evamy, 1967). The presence of this neomorphic spar throughout most of the facies nt_4 and nt_5 suggests that it indicates the former presence of dolomite over a much greater extent than at present.

The second dolomite occurrence, as dolostone, is consistently restricted to the base of limestones overlying Brunner Coal Measures. This could be related to mixing of connate sea water within the carbonate sediments with connate fresh water percolating upwards from the fluvial-derived coal measures, causing a reduction in salinity, but maintaining the original Mg/Ca ratio (Folk and Land, 1975). The Mg/Ca ratio could also have been raised by recrystallization of the high-magnesian calcite allochems to low-magnesian calcite. The patches of calcite spar scattered throughout the rock do not resemble the much smaller sparry mosaics common in most Takaka Limestone samples. The relative timing of this cementation is uncertain, but could have been during uplift in a freshwater subaerial environment.

Silicate dissolution

Quartz and feldspar grains in many limestones are replaced along rims and cleavages by fine-grained neomorphic spar, which does not take Alizarin Red-S stain. Common dissolution does not appear to be restricted to any particular rock types or horizons.

Discussion: Dissolution took place in porewaters undersaturated with respect to silica, and supersaturated with calcium carbonate. The reason for the unstained calcite is not known.

Sequence of Diagenesis

The diagenetic history of the Takaka Limestone is based on petrographic relations which are quite tenuous. The following sequence should be regarded as a broad outline rather than as an established history.

(1) Fibrous fringing cement formed on areas of seafloor where deposition was negligible.

(2) Stabilization of aragonite and magnesian calcite took place below the zone of bioturbation, probably under tens of metres of burial. This resulted in some allochems replaced by neomorphic spar, dissolution moulds and micrite envelopes.

(3) Echinoderm grains, recrystallized as low-magnesian calcite, had the potential to be overgrown by calcite cement. Syntaxial overgrowths were preferential sites of calcite nucleation, and probably developed as dissolved $CaCO_3$ was made available during early stages of pressure-solution.

(4) The gradual increase in burial load led to critical levels of stress, dependent on the specific composition of the particular

sediment, and probably under hundreds of metres of overburden. Pressure solution, which initially took place as intergranular solution, was concentrated along stylolites and microstylolite swarms. Dissolution of $CaCO_3$ was simultaneous with precipitation of equant sparry calcite. Precipitation of dolomite took place in areas of suitable porosity at a relatively late stage of deep burial.

(5) The relative timing of dolostone formation is unknown, but could have been during relatively shallow burial.

(6) The timing of neomorphic spar formation is also unknown, but on petrographic evidence would appear to be closely linked to equant spar precipitation.

(7) During uplift and subaerial exposure, microstylolite swarms were preferentially weathered to produce the characteristic flagginess of the limestone. A typical karst topography evolved, but is not discussed in this thesis. Dedolomitization of dolomitic limestones and dolostones took place.

Thus the diagenesis of the Takaka Limestone is considered to have mainly taken place during deep sub-surface burial. The Takaka Limestone was probably buried to a maximum of 1000m, depending on the thickness variation of the Blue Bottom Group, which except for offshore deposits detected by seismic profiling, is quite speculative. The maximum depth of burial was probably reached during the late stages of marine regression which could have been during Lillburnian time, about 5-10 million years after deposition of the carbonate sediments.

Nelson (1973) suggested that limestones of the Te Kuiti Group were lithified during shallow burial beneath a shallow marine environment. Nelson (1978) extended this conclusion to New Zealand Oligocene limestones generally. Criteria used by Nelson (1973:510-512) are:

(1) high amplitude stylolites are absent;
(2) there is no correlation between pressure solution features and depth;
(3) delicate bioclastic grains e.g. bryozoa are completely uncrushed;
(4) sparite grain coatings were precipitated in a submarine environment;
(5) collapsed micrite envelopes are uncommon;
(6) lithoclasts were bored and cemented prior to erosion;
(7) seam formation predated limestone dyke emplacement;
(8) a submarine hardground was cemented in submarine conditions.

In the Takaka Limestone, criteria (1), (3) and (5) are invalid, and criteria (6) and (7) have no Takaka Limestone equivalent. Criteria (4) and (8) are irrelevant to the main phase of cementation in the limestone. The second criterion is probably also invalid because the total thickness of the Takaka Limestone (c.60m) is insignificant compared to the 1000m of total burial.

Nelson's criteria for cementation during shallow burial do not appear to be applicable to the Takaka Limestone, and a diagenetic history mainly influenced by deep burial is preferred.

CHAPTER FIVE

TARAKOHE MUDSTONE

Distribution

The Tarakohe Mudstone conformably overlies Takaka Limestone in the Takaka and Aorere valleys and along the coastal fringe between Parapara and Rangihaeata. It is characterized by subdued topography and thick Pleistocene cover, and consequently few measurable sections are available (fig.45).

The formation is at least 900m thick at Pariwhakaoho River, 400m thick at Aorere River and at Rangihaeata, and 350m thick in the Upper Takaka area, but an upper contact is preserved only at the latter locality.

Age

The base of the formation is consistently basal Altonian in age (see Appendix 2). Clifdenian ages are obtained from the youngest beds in the Aorere valley (S3/f524 and S7/f501), and Clifdenian-Lillburnian ages from the Pariwhakaoho River (S8/f585,586). However, the youngest dateable horizon at Upper Takaka, c.50m below the top of the formation, is Altonian in age (N26/f9).

Facies

The Tarakohe Mudstone is subdivided into six facies.

bt_1 : Glauconitic calcareous sandstone

bt_2 : Massive mudstone

bt_3 : Alternating sandstone-mudstone

bt_4 : Laminated and bioturbated sandstone

bt_5 : Micaceous sandy siltstone

bt_6 : Cross-bedded sandstone

bt_1 : Glauconitic calcareous sandstone

The basal facies of the Tarakohe Mudstone consists of massive or faintly laminated, well-sorted, fine sandstone and muddy sandstone. The rock is moderately hard and greenish-grey or brown, and contains abundant glauconite, benthonic foraminifera and sometimes bryozoa and bivalves. Some bt_1 rocks are technically limestones (fig.35), but their relative softness and high terrigenous content contrast sharply with the underlying Takaka Limestone.

Lithological variation and stratigraphic relationships are shown in fig.41. The contact with the Takaka Limestone is sharp or gradational, and is considered conformable throughout the study area. The facies grades upwards into massive siltstone of facies bt_2.

The sand fraction of the rock consists mainly of fine quartz, glauconite and mica. Glauconite chiefly occurs as light green or dark green ovoid grains of medium to fine sand size, also as lobate grains and foraminifera casts.

In most rocks macrofossils are rare, although where present, allochems are whole and unabraded. The notable exception to this paucity is the 2m thick bed at the base of the formation at Tarakohe, long known in paleontological literature as the "Bryozoan Bed". This name is not formalized because the unit is not exposed outside Tarakohe. The "Bryozoan Bed" is a moderately soft, muddy sandy limestone (65% $CaCO_3$), dominantly composed of intact bryozoan colonies, large brachiopods and a variety of bivalves.

Paleoecology: Brown (1952) identified 35 species of cheilostome bryozoa in the "Bryozoan Bed" and found a predominance of vinculariiform, adeoniform, cellariiform and celleporiform types. with minor reteporiform and membraniporiform types. He noted that there were a very much larger number of cyclostome bryozoa, but referred only to the abundance of *Heteropora*, a stout vinculariiform colony (see Appendix 4). Brown suggested that the abundance of *Cellaria tenuirostris* (found at 80m depth in Bass Strait), the predominance of adeoniform and vinculariiform colonies and the absence of free-living lunulitiform colonies indicated deposition in sheltered waters c.80m deep with negligible wave or current action.

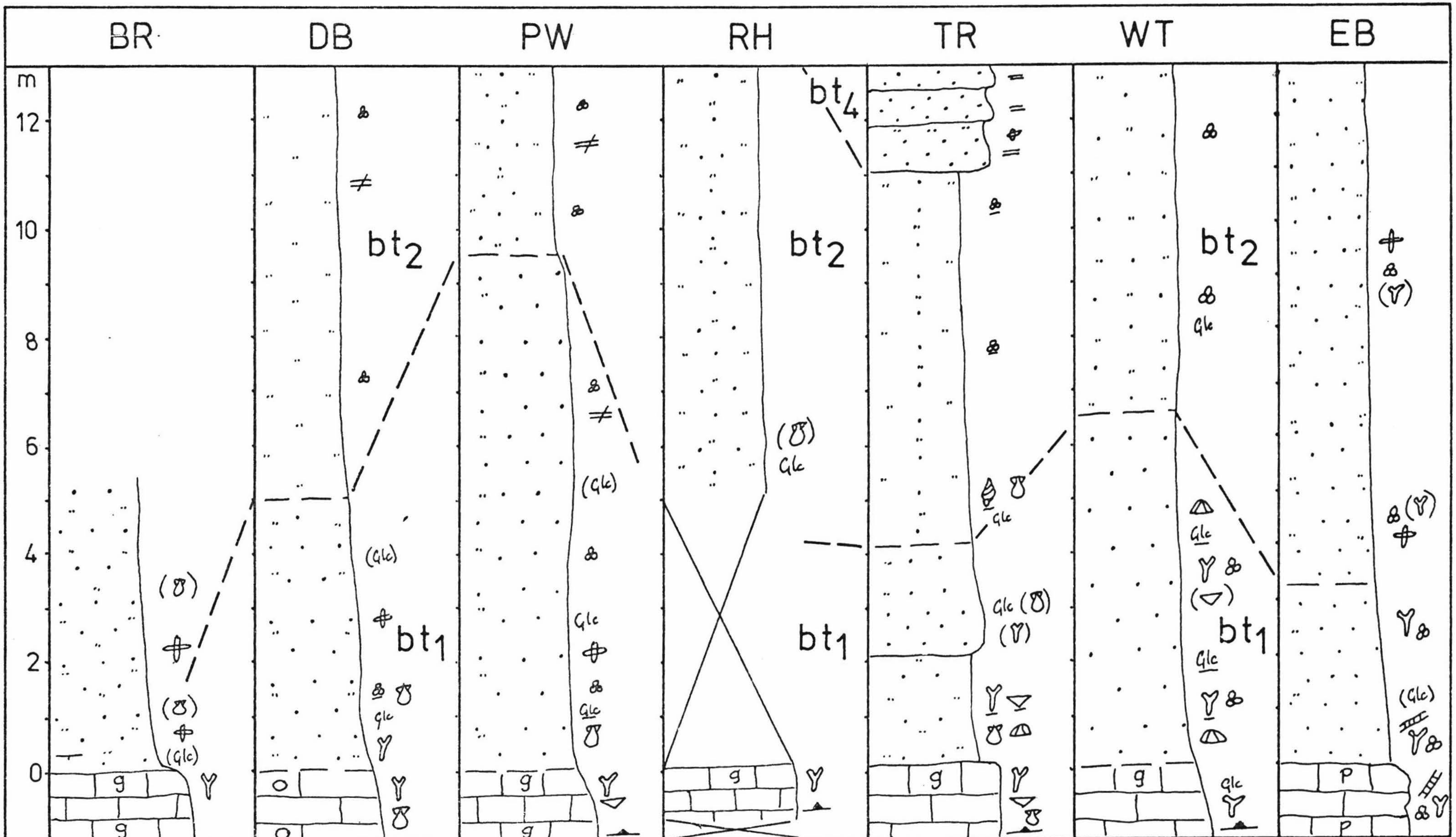


Fig.41: Detailed sections of basal Tarakohe Mudstone. For legend, see Appendix 1

This interpretation is still largely valid. The association of cellariiform bryozoa with muddy or micrite-rich limestones has already been noted and suggests turbid waters. The suggested 80m depth is suspect, as it is not based on a systematic survey; Wass et al.(1970) found that adeoniform and retcporiform bryozoa were dominant at depths of less than 50m on the southwest Australian shelf. Bryozoan growth forms are probably most influenced by water energy, turbulence and substrate rather than depth (Schopf, 1969), so Recent depthranges may not be directly applicable to ancient deposits.

Bryozoa of the "Bryozoan Bed" appear to be generally smaller and more delicate than those in the underlying facies nt_5 (bryozoan grainstone). The very large vinculariiform colonies common in nt_5 become much reduced in size, in facies bt_1. Conversely, the abundant adeoniform colonies of bt_1 are not recognized in the underlying limestone. Outside the "Bryozoan Bed", bryozoa in facies bt_1 are fragmented and abraded, indicating reworking or transport. Free-living celleporiform B bryozoa are common in the Aorere valley.

Large, robust brachiopods of the genera Pachymagas, Rhizothyris, Stethothyris and Liothyrella are abundant in the "Bryozoan Bed" but absent elsewhere in facies bt_1. Bivalves commonly found in the Bryozoan Bed" are Mesopeplum burnetti, Serripecten hutchinsoni, Lentipecten hochstetteri and Lima colorata. Both brachiopods and bivalves indicate a life assemblage on a coarse substrate on the continental shelf. Other macrofossils found include echinoids, notably Brochopleurus australiae (a 10mm diameter sea urchin), the nautiloid Aturia cubaensis, solitary corals, crabs and shark teeth.

Foraminifera are abundant in facies bt_1. Three samples (S8/f508,524,571) were analyzed by Scott (1971). S8/f508 and f524 fall into Scott's Group B, in which the benthonic foraminifera are dominated by species of Cibicides. Both samples have low diversity (24-27 taxa) and low ratios of planktonic to benthonic foraminifera, suggesting an inner shelf environment. S8/f571 belongs to Group A, in which Euuvigerina miozea is the dominant benthonic foraminifer; its high diversity and high ratio of planktonic to benthonic foraminifera are more characteristic of facies bt_2 collections.

Interpretation: Facies bt_1 rocks appear massive but have probably been disturbed by intensive bioturbation. Deposition took place in turbid, low energy conditions below wavebase and sheltered from strong current action.

The high density of intact bryozoan colonies in the "Bryozoan Bed" suggests a moderate-intensity current-swept environment favourable for dense colonial growth, similar to that suggested for deposition of the Takaka Limestone. The bryozoan thickets acted as baffles to trap terrigenous sand and mud suspended in the fairly turbid waters. Greater influx of terrigenous material stifled bryozoan growth (and also growth of other filter-feeders, such as pectinids and brachiopods).

bt_2 : Massive mudstone

This is the most widespread facies of the Tarakohe Mudstone. It consists of massive mudstone or sandy mudstone, bluish-grey or greyish-green, moderately hard and typically spheroidally-weathered. Large, tabular, calcareous concretions are locally abundant.

Although most exposures appear massive, moderately bioturbated rock is sometimes found, with mottling and thin horizontal and vertical burrows 1-5mm in diameter. Faintly graded bedding is accentuated by weathering in a coastal exposure near Onekaka Inlet (discussed in a later section (fig.44b,c). Beds 50-100mm thick grade from siltstone at the base to claystone at the top; internal depositional structure is destroyed by moderate intensity burrowing.

Six mudstone samples from widely-spaced locations were analyzed by X-ray diffraction; all comprised quartz, sodic-plagioclase, muscovite or illite, and chlorite. Facies bt_2 mudstones are usually medium blue grey, but mudstone in the lower Takaka valley are commonly greyish green. The difference in colour may be due to higher iron content in the green mudstones. In addition, X-ray diffractograms of the latter contain subdued peaks in the 7-14 angstrom range, possibly indicating highly degraded mica.

Paleoecology: The largest macrofaunas collected from the Tarakohe Mudstone were obtained from a massive sandy siltstone unit overlying facies bt_1 at Tarakohe. Collection S8/f498 (also f532 and N25/f9) contains 53 taxa, including large gastropods (Opella hendersoni, Xenophora sp., Echinophoria sp.), bivalves (Lima colorata, Spissatella trailli), minute gastropods and bivalves and a well-preserved crayfish, Jasus flemingi. Fleming (1970) pointed out the presence of the gastropod Perotrochus marwicki and the bivalve Euciroa ulrichi, both of which belong to genera now living mainly in the bathyal zone below the edge of the continental shelf. However, the evidence of the associated fauna and the adjacent rock units indicate a shelf environment.

Elsewhere in facies bt_2, minute gastropods and bivalves are locally abundant. Minor components include large thin-walled bivalves, crab fossils, echinoderms and thin calcareous worm tubes.

The study of foraminiferal paleoecological trends by Scott (1971) has already been mentioned. For 14 samples within Sheet S8, Scott counted 200 benthonic foraminifera and incidental pelagic specimens and determined their diversity and equitability and the ratio of planktonic to benthonic foraminifera. Classification by cluster analysis divided the samples into two groups, distinguished by an abundance of Euuvigerina miozea in Group A, and predominance of Cibicides spp. in Group B. Facies bt_2 samples generally fell into Group A, and typically showed high diversity, high equitability and high planktonic to benthonic ratios. Scott (1971) suggested that Group A was a 'basinal' biotope, deposited at depths comparable to modern shelf environments (see further discussion in Chapter 7).

Interpretation: The massive character and occasional mollusc horizons within facies bt_2 indicate that most of the sediments accumulated by hemipelagic deposition (in the sense of Rupke and Stanley, 1974:31). Apart from the foraminifera and molluscs, the mudstones are entirely terrigenous, carried offshore in suspension and deposited in deep water. Scott (1971) has suggested a depth range in the order of 80m based on the microfaunal assemblage. Fleming (MS), from the macrofaunal evidence, suggested an outer shelf environment in depths exceeding 90m.

The graded bedding in weathered mudstone at Onekaka suggests that at least part of facies bt_2 was deposited by low-density, low-velocity turbidity currents (cf. Moore, 1969; Rupke and Stanley, 1974). Rupke and Stanley distinguished turbidite layers by their grading, delicate basal lamination and their homogeneity. Moore (1969) described low-velocity turbidity currents, or "turbid layers", as wide, relatively thin sheets of turbid water moving diagonally across the shelf under the influence of coastal currents and downslope gravity flow superimposed on the to-and-fro movement of the swell.

It is likely that both turbiditic and hemipelagic mechanisms were responsible for mud deposition, but the relative extent of the two types has been obscured by extensive bioturbation and spheroidal weathering.

bt_3 : Alternating sandstone and mudstone

This facies consists of medium-bedded fine sandstone and mudstone, with sand:mud ratios varying from 1:3 to 2:1. Bouma sequences Tc-e or Td-e (fig.42) are well-exposed at Rangihaeata, where a typical sequence comprises a sharp base, in-phase and climbing ripple laminae overlain by horizontal laminated sandstone grading up to massive mudstone. Mudstone flames are sometimes observed. At Pariwhakaoho River, sandstones up to 200mm thick appear massive or faintly laminated and grade up to massive mudstone. These beds do not fit Bouma sequences; the reason for the absence of lamination in the sandstones is unknown.

Interpretation: These beds are interpreted as distal turbidites, deposited from waning relatively high-density, turbidity currents.

bt_4 : Laminated and bioturbated sandstone

Facies bt_4 is characterized by horizontal-laminated or low angle cross-bedded sandstone beds 0.2-0.6m thick (figs.43,44a,b). The top of each bed may be strongly bioturbated, or may be overlain

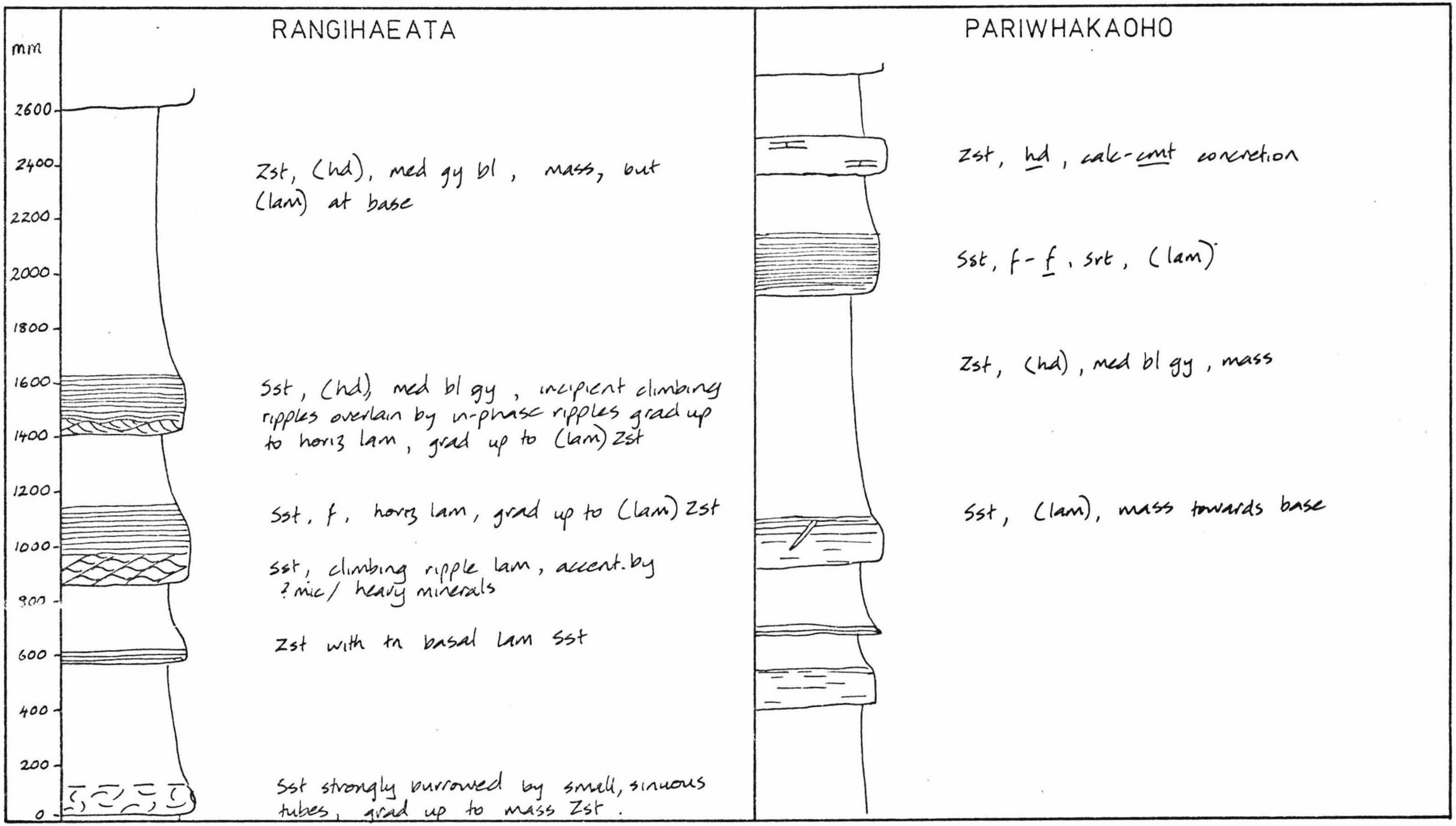


Fig. 42: Representative composite sections of facies bt_3 at Rangihaeata and Pariwhakaoho River.

by interlaminated sandstone/mudstone. The lower part of each bed consists of wellsorted fine sandstone, moderately soft to hard, and greyish green to medium grey. The beds are typically horizontal-laminated, but low angle planar foresets, low angle trough cross-bedding and climbing-ripple lamination commonly occur. The base of each bed is sharp but not irregularly scoured. At Tarakohe and Pariwhakaoho River, the upper half of each bed is a strongly bioturbated muddy sandstone, which may grade up to sandy siltstone (figs.43,44b). At Rangihaeata, Patons Rock and Pariwhakaoho, the sandstone bed is overlain by 10-100mm thick interlaminated sandstone/siltstone, which is usually wavy-laminated. Numerous burrows may extend downward into the sandstone beds (fig.44).

The sandstones are micaceous quartzarenites or subfeldsarenites, often with finely comminuted shell fragments or specks of plant material. Fine-grained ovoidal glauconite is sometimes present. Heavy minerals in N25/S4 from Rangihaeata include abundant epidote and white and non-magnetic opaques, and traces of garnet, zircon, hornblende, rutile and monazite (D. Smale, pers.comm. 1979), suggesting a mixed granite and metamorphic source area.

Paleoecclogy: Three types of trace-fossil are common:

(1) Ophiomorpha cf. nodosa, vertical knobbly shafts 20-30mm in diameter (fig.44a). One possible modern analogue for these burrows is the burrow system of the shrimp Callianassa major, which is best known on beaches and nearshore sublittoral sand, but also found on shoals, tidal flats and lagoon and bay floors (Frey et al., 1978).
(2) Skolithos, isolated, smooth, vertical tubes 100-200mm long and 10mm diameter. Skolithos is interpreted as a worm burrow in shallow marine environments (Alpert, 1974).
(3) Arenicolites, smooth sinuous tubes 1-3mm in diameter, forming vertical U-shaped burrows (fig.44a). It is closely associated with Ophiomorpha at Rangihaeata.

Microfauna sample S8/f512 from Tarakohe was examined by Scott (1971). Benthonic foraminifera are moderately diverse, with high equitability. The ratio of planktonic to benthonic foraminifera is low, and sparse Amphistegina are present. An inner to middle shelf

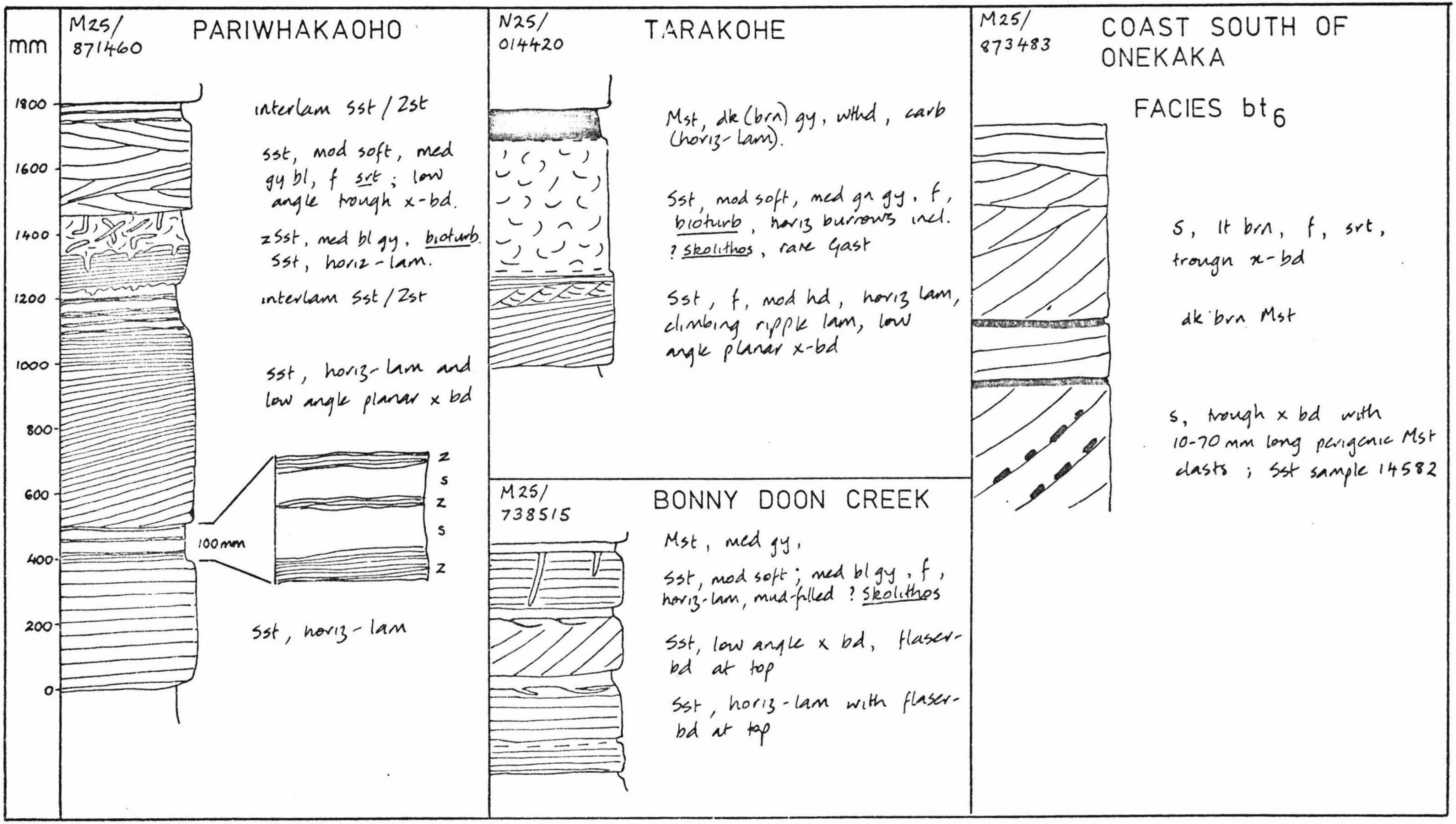


Fig. 43: Representative composite sections of facies bt_4 and bt_6 at Pariwhakaoho River, Tarakohe, Bonny Doon creek and the coast south of Onekaka.

FIG. 44 : FACIES bt_4 AT RANGIHAEATA AND TARAKOHE

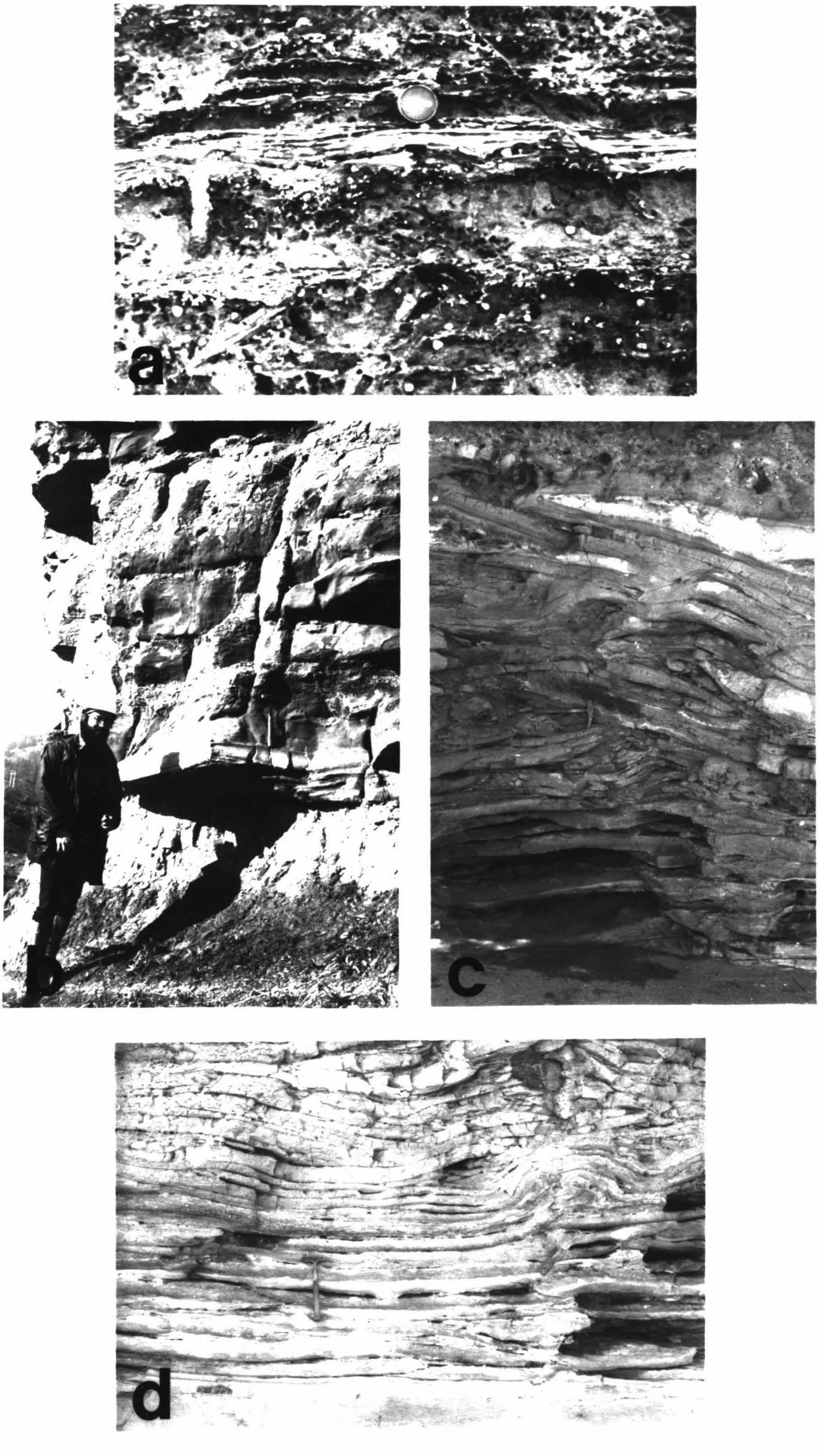
a/ Interlaminated sandstone/mudstone alternating with medium sandstone. Ophiomorpha burrow at left. Rangihaeata, N25/917455.
Lens cap 60mm diameter.

b/ Low-angle cross-bedded sandstone, strongly bioturbated sandstone (beside hammer) and carbonaceous mudstone (at the level of the figure's helmet) comprise the basal fining-upwards sequence of facies bt_4 at Tarakohe (N25/014420). Higher sequences are usually less varied.
Hammer 330mm long.

WEATHERING CRUST ON TARAKOHE MUDSTONE
(Coastal cliffs between Onekaka Stream and Little Kaituna Stream, M25/854513)

c/ Buckled, fragmented anticlines occur at irregular intervals enclosed by sharply delineated lenticular beds.

d/ Subhorizontal bedded mudstone with a convoluted anticline at right.


a
b
c
d

environment is probable.

Microfauna collections S8/f585 and f586 from facies bt_5 at Pariwhakaoho River, closely associated with facies bt_4, indicate shallow, nearshore conditions (Scott, 1971).

Interpretation: The laminated sandstones resemble sublittoral sheet sandstones formed by storm activity on the open shelf (cf. Goldring and Bridges, 1973; Johnson, 1978). Each bed may record a single storm event which comprised (1) initial erosion by storm-generated waves and currents, (2) deposition under upper-flow regime (horizontal lamination) and transitional regime (low-angle cross bedding) during the waning stages of the storm, and (3) fair weather bioturbation and mud deposition (Johnson, 1978). The environment of deposition probably ranges from middle shelf (Tarakohe ?) to the inner shelf (Rangihaeata, Pariwhakaoho). The trace fossil types described above all indicate shallow marine conditions.

The interlaminated sandstone/mudstone resemble similar strata described by Goldring *et al*. (1978) from the Eocene of England. They interpreted this facies as a sublittoral channel deposit, similar to such sediments on the Dutch and German North Sea coasts.

bt_5 : Micaceous sandy siltstone

This facies is closely associated with bt_4 at Pariwhakaoho River. It comprises bioturbated sandy siltstone, medium brown to light grey and commonly iron-stained. The rock is rich in mica and is moderately carbonaceous. It is extensively mottled, but a faint horizontal lamination is often preserved. Finely interlaminated very fine sandstone and siltstone at the top of the Rangihaeata section might represent the same sediment undisturbed by bioturbation.

Paleoecology: Foraminifera collections S8/f585 and f586 from this facies were analyzed by Scott (1971), who found low diversity (9-15 taxa), low equitability and very low planktonic to benthonic ratios. S8/f585 is dominated by *Astrononion parki*, f586 by *Euuvigerina miozea*.

Interpretation: Textural and paleoecological features indicate deposition in a low-energy, nearshore environment, possibly in a bay restricted from oceanic circulation, or else a very restricted tidal mixed mud-sand flat.

bt_6 : Cross-bedded Sandstone

A single outcrop of cross-bedded sandstone occurs on the coastline north of Pariwhakaoho River mouth. It consists of soft, moderate-well sorted, fine sandstone; sublitharenite, rich in schist fragments, and occurs in 120-400mm thick trough cross-beds (fig.43). Carbonaceous mudstone drapes up to 3mm thick, and perigenic mudstone clasts 10-70mm long are present.

Interpretation: This facies may be a river or estuarine deposit, derived from a schistose hinterland.

Facies interrelationships

Three broad associations within the Tarakohe Mudstone (fig.45) are, in order of age:

(1) basal facies bt_1, formed on the low-energy middle shelf;

(2) facies bt_2, formed by hemipelagic and turbid layer deposition, with rare lenses of bt_3 distal turbidites;

(3) interrelated facies bt_4, bt_5, and bt_6, interpreted as inner shelf, estuarine, bay, and possibly fluvial deposits. These latter facies could possibly be mapped as a separate formation, but at present present the exact relationships and boundaries with facies bt_{1-3} are unknown.

Weathering crust on Tarakohe Mudstone

In coastal cliffs between Onekaka Inlet and Little Kaituna Stream (M25/854513), 2.5-3.0m of weathered brownish-orange mudstone sharply overlie fresh greenish grey mudstone and are overlain by Pleistocene Kaituna Gravels. The distinctly bedded nature of this weathered horizon is in sharp contrast to the underlying strongly bioturbated and spheroidally jointed fresh mudstone. The weathered mudstone occurs in beds 50-100mm thick with moderate bioturbation and internal gradation from siltstone up to claystone. The beds are

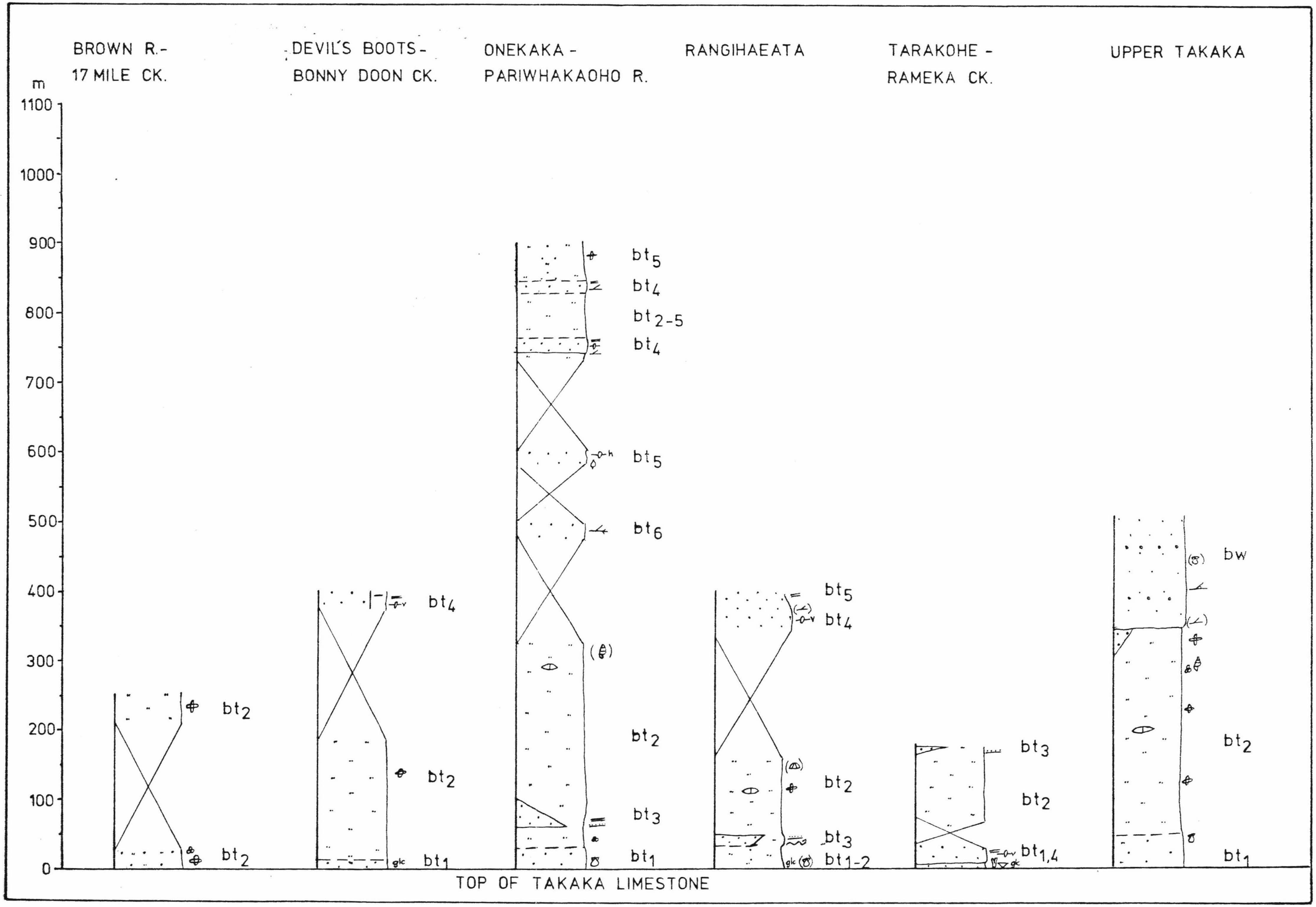


FIG. 45 STRATIGRAPHIC COLUMNS OF BLUE BOTTOM GROUP IN GOLDEN BAY

generally horizontal-layered, but they swell and lens out over short distances and at irregular intervals are buckled upwards in domed or inverted V-shaped structures (fig.44c,d, cf. diagenetic anticlines or "teepee" structures).

The bases of many beds are coated with a rough layer of iron oxide (? hematite). Thin section study of sample 14580 shows that the mudstone is impregnated with iron oxide along horizontal planes and around burrow fillings.

Interpretation: The extent to which the mudstone layers reflect primary bedding is uncertain, but the fining-upward texture of each bed is undoubtedly a primary feature. The "teepee" structures and the abrupt thinning of the beds are interpreted as Recent weathering features because of their absence in the fresh mudstone.

Teepee structures, or diagenetic anticlines, have been reported in Recent and ancient carbonate sediments. They occur in shallow submarine hardgrounds in the Persian Gulf (Shinn, 1969), sabkhas (Burri et al., 1973), and subaerial caliche in desert areas (e.g. Reeves, 1970). Anticlinal structures in the hardgrounds form by bedding expansion due to the force of calcite crystallization. In sabkhas and caliche deposits, they form as large sheet cracks widened by repeated thermal expansion and contraction, and are preserved by infilling of fine sediment and calcite cement precipitation. In all the above examples, the teepees occur in polygonal patterns; the weathering crust at Onekaka is not exposed in three-dimensional outcrops, but a similar polygonal distribution of teepee structure is likely. At Onekaka, the upper few metres of the mudstone were probably weathered during prolonged exposure below the Kaituna terrace surface, during the late Pleistocene. The oxidized nature of this horizon indicates that it was sited above the water table, and therefore subject to alternate wetting and drying. Under such oxidizing conditions, leaching of iron from both the parent mudstone and the overlying Kaituna Gravels would have been probable, and transport in solution during temporary reducing conditions or organic complexing may have been possible (cf. Stanton, 1972:408). Alternate wetting and drying could have accentuated the primary stratification of the rock and caused evaporative precipitation of the iron as iron oxide. The force of crystallization along horizontal laminae and joints would have expanded the beds, causing swelling, lengthening, and buckling. Examination of fig.44 would suggest that each bed expanded and moved relatively independently of its neighbours, thus further accentuating the "bedding".

CHAPTER SIX

WAITUI SANDSTONE

Distribution

The Waitui Sandstone is restricted to a 450m high hill between Aaron Creek and Waitui Stream south of Upper Takaka (fig.6c). Cooper (1962) considered the formation to overlie the Tarakohe Mudstone with a slight angular unconformity, but observations by the present writer indicate a conformable contact. It is unconformably overlain by a well-cemented marble breccia (scree from the adjacent Pikikiruna Range) of unknown age.

Content

163m of sandstone were measured in a tributary of Waitui Stream (the "Hope Creek" of Cooper, 1962). The formation mainly comprises moderately soft, light brownish grey, well sorted medium-coarse sandstone, much of which appears massive. Indistinct large-scale cross-bedding is seen near the base of the formation, and at higher levels 0.5m thick low angle cross-bedding accentuated by granule-pebble laminae is common. Hard, calcite-cemented sandstone forms steep bluffs in the middle horizons of the formation. Rare horizons of well-leached shell fragments are found in this interval.

In composition the sandstone varies from micaceous quartzarenite to feldsarenite to feldlitharenite. Quartz grains are monocrystalline with sharp extinction and feldspar mainly comprises microcline, with minor plagioclase. Muscovite, biotite, sericite and chlorite are often common. Rock fragments include granite, schist and quartzose sandstone. Pebble lithologies consist of biotite granite, aplo-granite with fine garnets, quartz or quartzite, and schist (Cooper, 1962). It is probable that the source area of this mixed granite-schist-quartzite assemblage was the Pikikiruna Range to the east and northeast.

A thin section of sample 14557 contains a few indeterminate allochems, probably molluscs, and is cemented by equant iron-free calcite spar 100-200μm in diameter.

Age and Paleoecology

Two microfauna collections, S13/f540 and N26/f10 were obtained from the calcareous sandstones. The latter contains poorly preserved Cibicides perforatus and is not age-diagnostic (R.H. Hoskins, pers. comm. 1979). S13/f540 contains a number of foraminifera taxa including abundant Sigmoidella, Elphidium and Amphistegina, indicating a shallow shelf environment (Cooper, 1962). The age of the fauna is Clifdenian to Tongaporutuan, probably Lillburnian to Waiauan (R.H. Hoskins, pers. comm. 1979).

S13/f540 was collected approximately 80m above N26/f9, of Altonian age, and 30m above the base of the formation. It is possible that the age range of the Waitui Sandstone is Clifdenian to Lillburnian.

Interpretation: The Waitui Sandstone offers few environment-diagnostic features, but the apparent massive appearance of much of the formation may be deceptive. The environment of deposition suggested by the foraminifera and the low-angle trough cross-bedding is a shallow inner-shelf deposit laminated and rippled by wave action, and fed by an abundant supply of terrigenous material. The large scale cross-bedding seen at the base of the formation may have been deposited by tidal currents.

CHAPTER SEVEN

SYNTHESIS

Brunner Coal Measures

The formation of a subdued, deeply weathered landmass in the Golden Bay area by mid-Eocene time has been shown by features characteristic of peneplanation, the formation of gossans on gold and base metal deposits and the accumulation of bog iron deposits (Washbourn Limonite). The paleogeography prior to coal measures deposition indicates a tectonically quiescent structural block, perhaps 130km from the nearest coast (Pilaar and Wakefield, 1978: fig.10).

Pre-Oligocene sedimentation in the southern Taranaki Basin (Pinchon, 1972: time contour map for H_3-H_6 interval[1]) was dominated by considerable thicknesses of fluvial sediments deposited in fault-angle wedges west of the Wakamarama Fault (Pakawau Group, Late Cretaceous-Paleocene) and west of d'Urville Island (? Late Cretaceous). Elsewhere in the basin, and mainly in Tasman Bay, are a number of smaller fault-bounded depressions of Eocene age[2] (e.g. 433m of Runangan coal measures in Surville-1 well; NZ Aquitaine Petroleum, 1976b; Raine, 1979). However, pre-Oligocene sediments are thin or absent on a 40km wide plateau from Golden Bay east across the basin.

Within this regional context, and substantiated by isopach paleocurrent and provenance data (figs. 24,25), it is probable that Brunner Coal Measures sedimentation in Golden Bay was controlled by normal block faulting. Coal measures deposition began in the Takaka valley, in response to subsidence along the Pikikiruna Fault and probable uplift and erosion of the Separation Point Batholith along Wainui Shear Zone (figs. 25, 46a). Approximately 200m of coal measures accumulated at Dry River during Bortoman-Kaiatan time;

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1 H_6 represents basement. H_3 represents Takaka or "Cobden" Limestone, but varies in different wells as to the top (Tasman-1) or the base (Maui-4) of the limestone (Pinchon, 1972).

2 This discussion does not include the thick accumulations of Kapuni Formation (Brunner Coal Measures Equivalent) in the Maui gasfield and Taranaki Peninsula (Pilaar and Wakefield, 1978).

the inferred environment of deposition was a floodplain dominated by peat swamps and lakes with rather small meandering streams creating point-bars, levees, ox-bow lakes and crevasse splays.

Bortonian-Kaiatan* strata are rather localized in extent, and substantial thicknesses are only found near the Pikikiruna Fault (Dry River, Gibson Creek, probably Motupipi). During the Runangan and Whaingaroan Stages (figs. 46b,47a), coal measures deposition became more widespread over the valley, totalling 90-150m thickness. This may have been due to subsidence along a proto-Golden Bay Fault which modified the original fault-angle depression into a graben, or else in response to a gradual rise in base level caused by regional subsidence. Runangan strata in the Takaka valley are mainly interpreted as meandering stream and floodbasin deposits, but the thick sequence of cross-bedded sand (facies association mb_3) at Rangihaeata is probably also of Runangan age.

Also during Runangan time, swamp deposition adjacent to incipient fault scarps took place in the Aorere and Parapara valley areas.

During Whaingaroan time, two distinctly different styles of sedimentation took place, apparently simultaneously. In the Takaka valley, a complex estuarine environment formed in response to ever-increasing marine influence. An environment of deposition similar to the modern Ord River-Cambridge Gulf region of northwest Australia (Wright et al., 1973) is suggested, dominated by broad, shallow braided channels, adjacent tidal mud-sand flats and perhaps mangrove swamps, and offshore subtidal channels and shoals.

At the same time, large quantities of metamorphic-derived gravels and sands were transported northwards by braided rivers in the Rangihaeata area (association mb_5) and on the southeast flank of the Aorere valley (Quartz Wash Member). These deposits were probably caused by uplift on a proto-Golden Bay Fault and on a north-east trending fault or fault system paralleling the Aorere valley (fig. 25).

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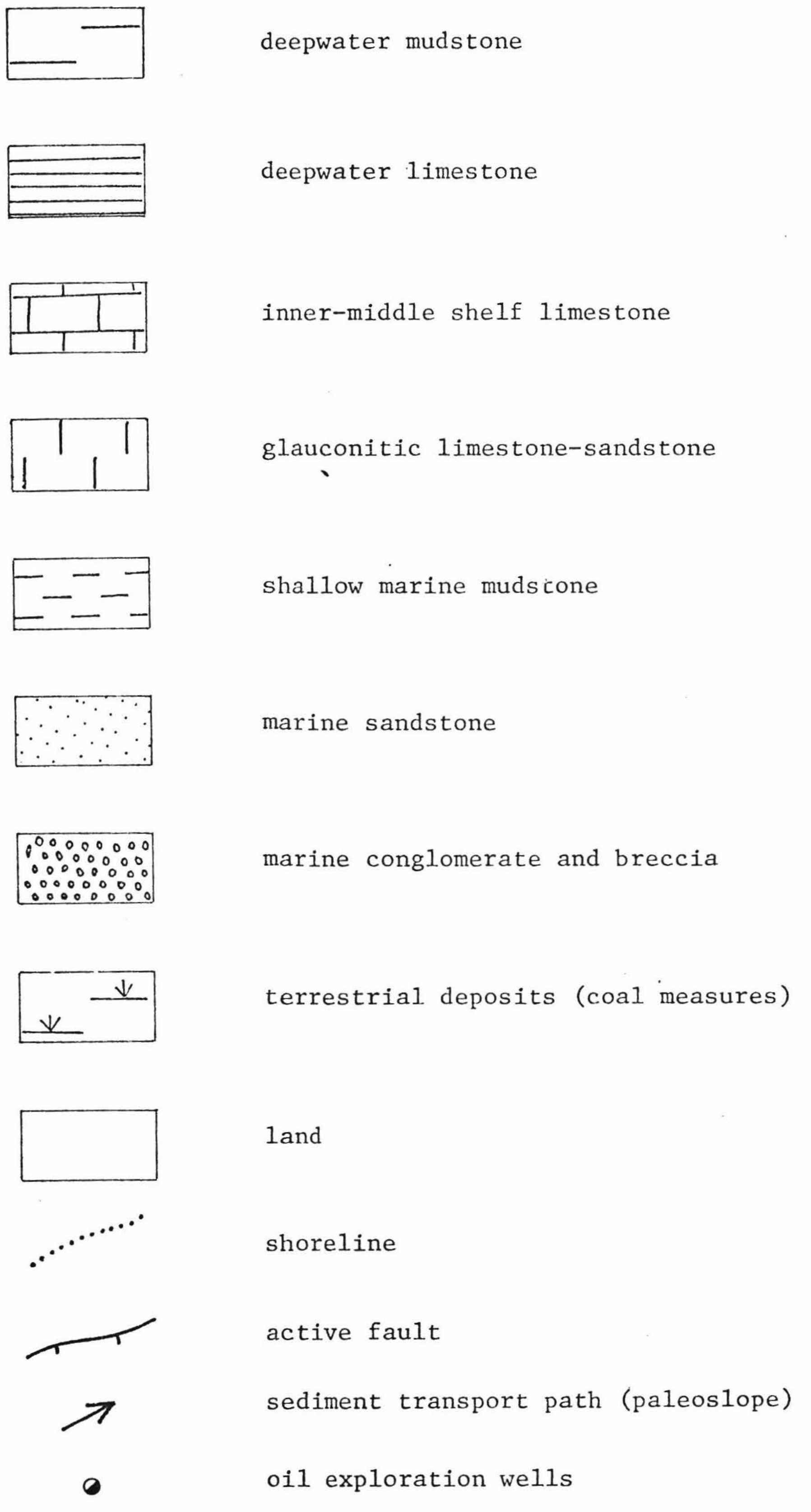
* The Bortonian and Kaiatan Stages cannot be distinguished by pollen biostratigraphy (Raine, 1979).



Legend for paleogeographic maps (figs. 46-49). Off-shore data based on Pilaar and Wakefield (1978), Pinchon (1972) and well completion reports (van Oyen and Campbell, 1970; van Oyen and Branger, 1970; N.Z. Aquitaine Petroleum, 1976a,b). Onshore data based on the present study, plus Johnston (1971), Wellman <u>et al.</u>(1973), German (1976), Titheridge (1977) and Andrews <u>et al.</u> (in prep.).

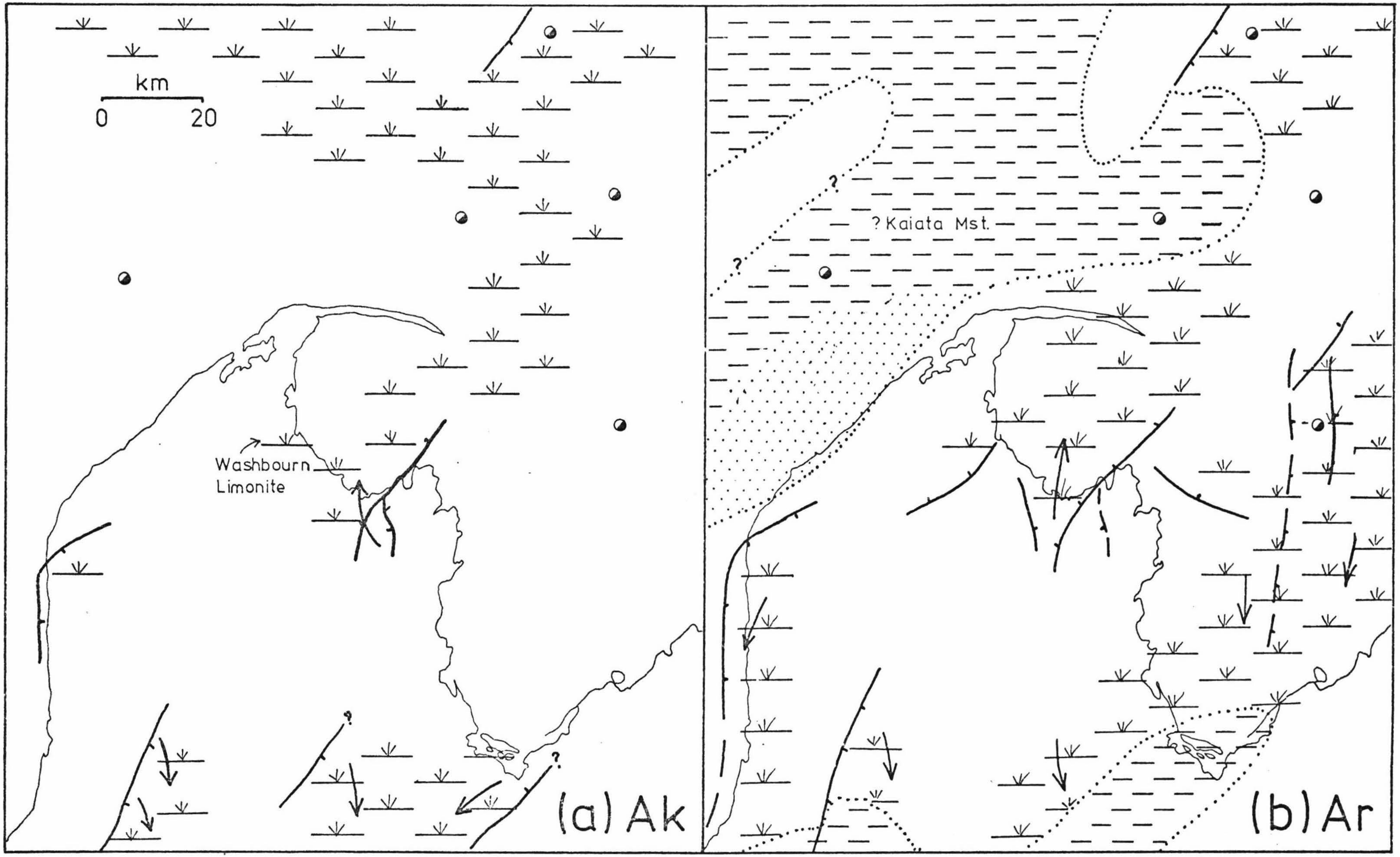


Fig. 46: Paleogeographic interpretation of northwest Nelson during (a) Kaiatan and (b) Runangan time.

The Quartz Wash Member is interpreted as a series of alluvial fans by coarse gravelly braided streams which graded distally to sandy streams and swamps. Association mb_5 is interpreted as a sandy braided river deposit which may have built out across the Takaka valley estuarine complex as a delta. The uppermost sands of the Brunner Coal Measures at all Golden Bay sections are very well sorted and well rounded quartzarenites and indicate extensive reworking and winnowing of the Brunner sediments during initial marine transgression.

Elsewhere in Nelson (fig. 47), large-scale block faulting and rapid subsidence characterized Whaingaroan-Duntroonian time. The Kongahu Breccia south of Karamea consists of limestone and breccia units emplaced by turbidity currents, grain-flow, submarine slumping and sliding (German, 1976). The Garibaldi Sandstone in the Karamea River area contains in its upper half very thick-bedded sandstone and breccia lenses inferred to be grain-flow deposits (Andrews et al., in prep.). In northwest Nelson, a tongue of fluvial sediments prograded across the dominantly shallow marine sands and muds of the Abel Head Formation (Titheridge, 1977). However, the Golden Bay area essentially formed a structural "high" between the rapidly subsiding basins to the south and east and the subsiding Western Platform (Pilaar and Wakefield, 1978) to the northwest.

Takaka Limestone

In the mid Oligocene to early Miocene (Duntroonian-Otaian), a combination of three factors led to the formation of a thick shelf limestone across the entire study area:

(1) relative tectonic quiescence;

(2) completion of a New Zealand-wide marine transgression;

(3) plate tectonic displacement between Australia and Antarctica produced a gap which funnelled a high-energy, nutrient-rich current onto New Zealand (Carter and Landis, 1972).

The northwest Nelson region probably formed a structurally stable plateau surrounded by relatively deepwater basins (fig.26). The sea converged onto the study area from the north and south (fig.49b), meeting at a topographic divide between Kahurangi, Brown River and West Takaka (figs. 26,36) which probably existed until late in the Waitakian Stage. Contrasting limestone facies were

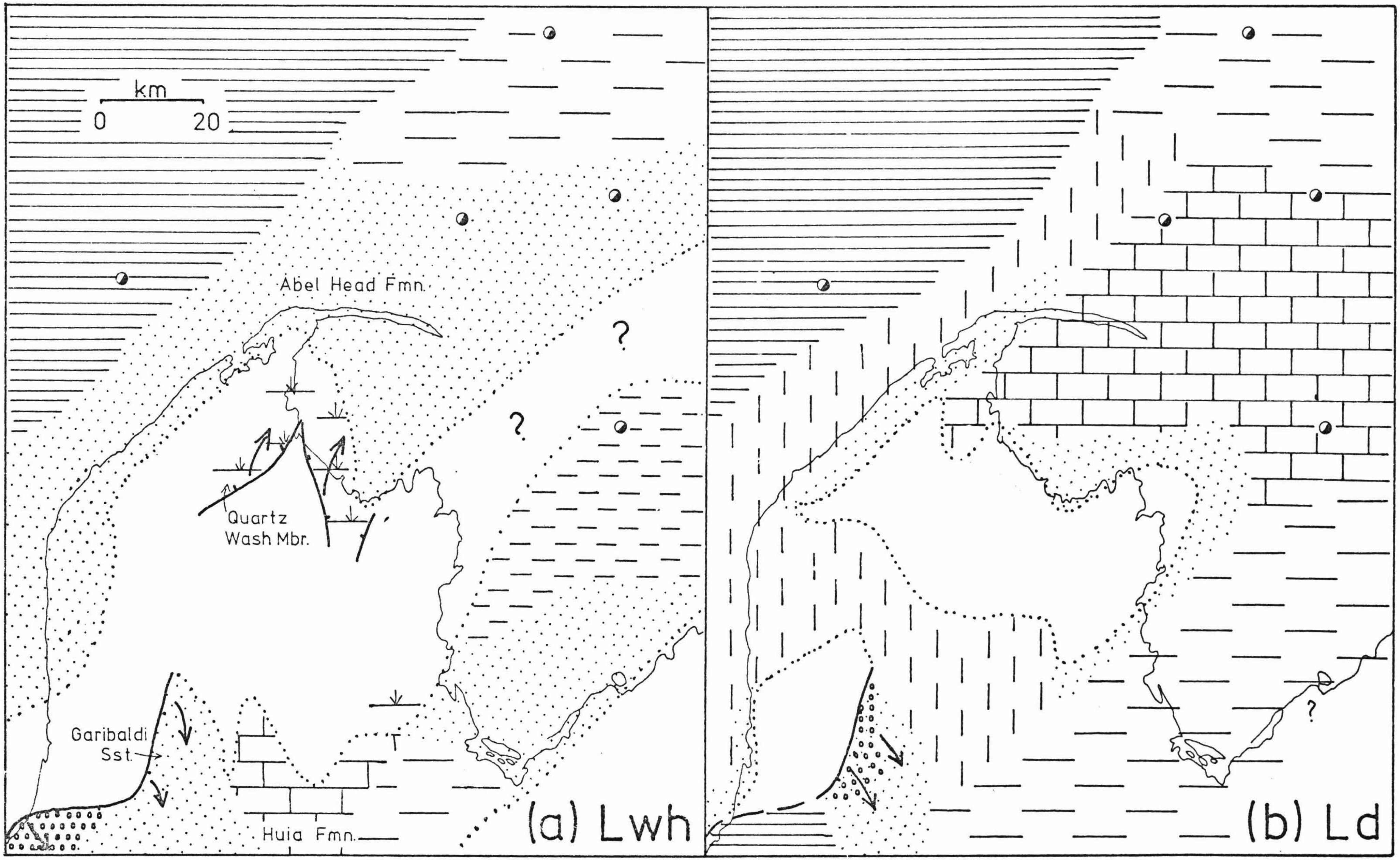


Fig. 47: Paleogeographic interpretation of northwest Nelson during (a) Whaingaroan and (b) Duntroonian time.

deposited on either side of the divide. To the south and west (at Waitui Stream, Gouland Downs and Heaphy River), the basal facies are greensand of Duntroonian age overlain by calcareous sandstone or conglomerate (fig. 47b). The composition of facies nt_1 suggests minimal terrigenous influx and low biogenic productivity, which would corroborate the concept of a continental shelf swept by high-energy, calcium carbonate-undersaturated currents (Carter and Landis, 1972). The sharp change to facies nt_2 sandstone may have been caused by a reduction of oceanic current intensity and/or renewed influx of terrigenous material. As peak transgression was approached, the sediments changed to deeper-water, bioclast-dominated carbonate sands. The distribution of facies nt_3 and nt_4 might be explained by the superposition of the marine environment on the valleys and ridges of the original topography, which funnelled and diverted the high-energy tidal currents. For example, the thin packstone horizons in the limestone in the Takaka valley area formed during temporary diversion or cessation of the tidal current conditions that winnowed the interbedded grainstones. Peak transgression probably occurred during the Waitakian Stage (fig. 48a) and the purity of the younger limestone suggests that this involved near-total submergence of the northwest Nelson landmass.

A small landmass is postulated in the Aorere and northwest coast area in order to supply the relatively high terrigenous content of facies nt_7. A source area in the Parapara River area would separate the contrasting facies of the Aorere and Takaka valleys and ensure a continuous shelf between the Aorere valley and the northwest coast. Alternatively, a landmass could have been present in what is now the central Wakamarama Range, around which an apron of terrigenous material was deposited (fig. 48a).

Following peak transgression, the Golden Bay area is envisaged as a broad submarine plateau, probably not more than 50m deep. The absence of terrigenous material and the exposure of the plateau to tidal current activity promoted the growth and diversity of seafloor epifaunal communities, in particular erect, rigid bryozoa colonies (facies nt_5). Deposition of this facies probably extended through late Waitakian and Otaian time (fig. 48b). The Otaian stage in the

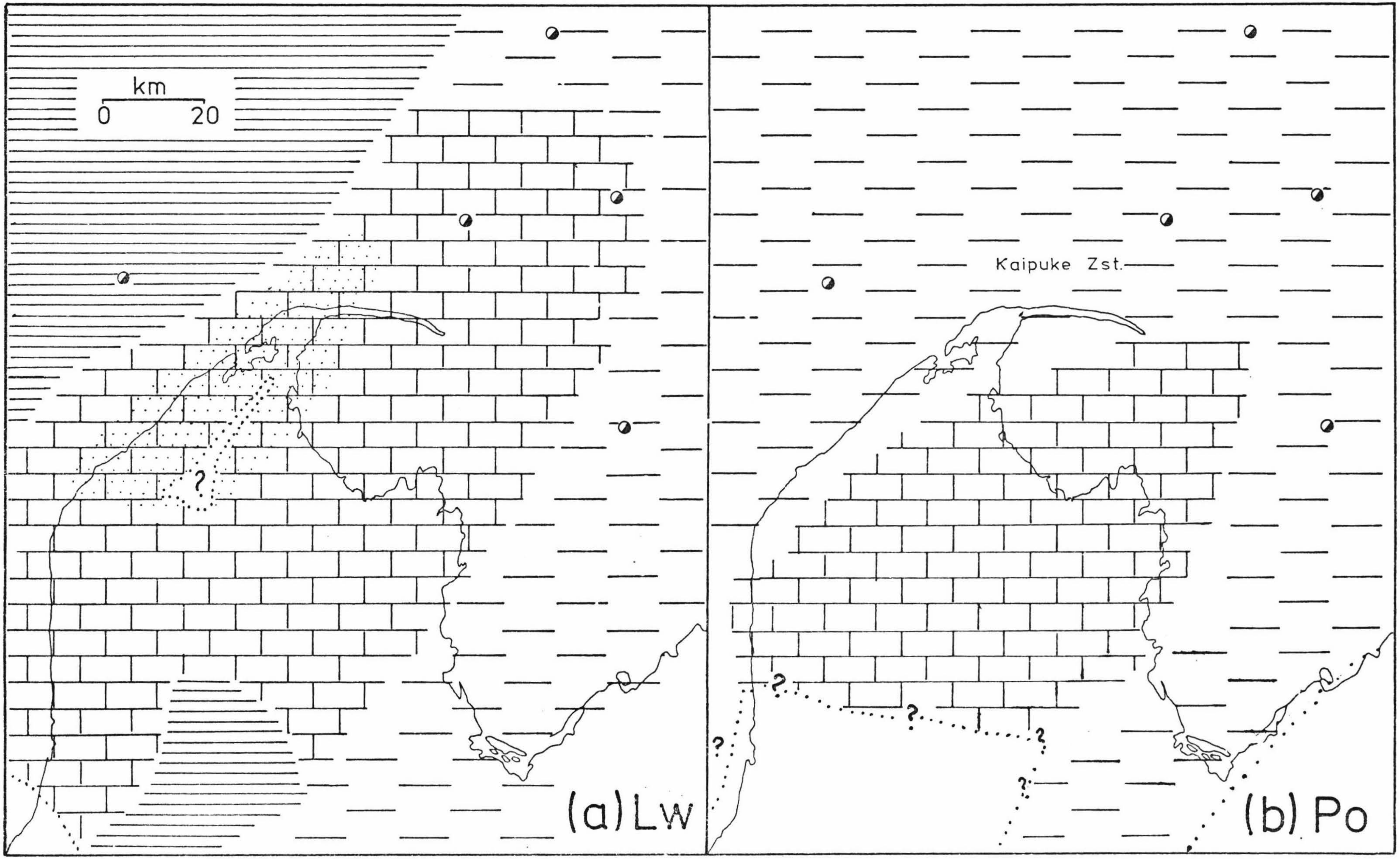


Fig. 48: Paleogeographic interpretation of northwest Nelson during (a) Waitakian and (b) Otaian time.

region southwest of the study area is represented by a disconformity.

Blue Bottom Group

During earliest Altonian time, carbonate sedimentation was rapidly and extensively choked by a renewed influx of terrigenous sand and mud. The Tarakohe Mudstone is dominated in its lower half by massive mudstone 300-400m thick (fig. 45), which is interpreted as a hemipelagic and low-density turbid layer-deposited sediment (facies bt_2). Rare, thin lenses of graded sandstone and siltstone are interpreted as distal turbidites (facies bt_3).

Facies bt_2 samples studied by Scott (1971) generally fell into a "basinal" biotope except for samples at Clark River (Upper Aorere valley) and Tarakohe which were part of a "marginal" biotope. The significance of these groups is not clear, but Scott suggested (p.131) that the "basinal" biotope was deposited in an open marine environment at depths no deeper than modern shelf environments (100-200m ?). The samples used in his analysis were solely from Sheet S8 and thus the study suffers from absence of data to the north and south. Few paleogeographic conclusions are possible.

In seismic profiles of the southern Taranaki Basin (Pinchon, 1972), a horizon H2 divides the post-Oligocene strata. At Maui-4 well it marks the boundary of a lower sandy unit and an upper silty unit (Pinchon, 1972), but in Golden Bay this reflector is most likely to represent the change from facies bt_2 mudstone to facies bt_{4-6} sandstones.

The H_2-H_3 interval is characterized by fairly uniform isochrons averaging 300 milliseconds two-way-time, with few dramatic variations. The eastern side of the Taranaki Basin during this interval (probably Altonian time; fig. 49a) was broken by the initial stages of the South Taranaki Graben (Pilaar and Wakefield, 1978), while in Golden Bay subsidence began along the Wakamarama, Pikikiruna and "Puramahoi" faults (fig. 49a). Pinchon (1972) also showed that H_2-H_3 strata in western Tasman Bay onlapped onto basement, suggesting a landmass in what is now the Abel Tasman National Park and the Arthur Range (fig.49a).

Tarakohe Mudstone facies bt_2 was succeeded by facies bt_{4-6} in late Altonian-Clifdenian time, but the nature of this transition is unknown because of the large gaps in the stratigraphic columns (fig.45).

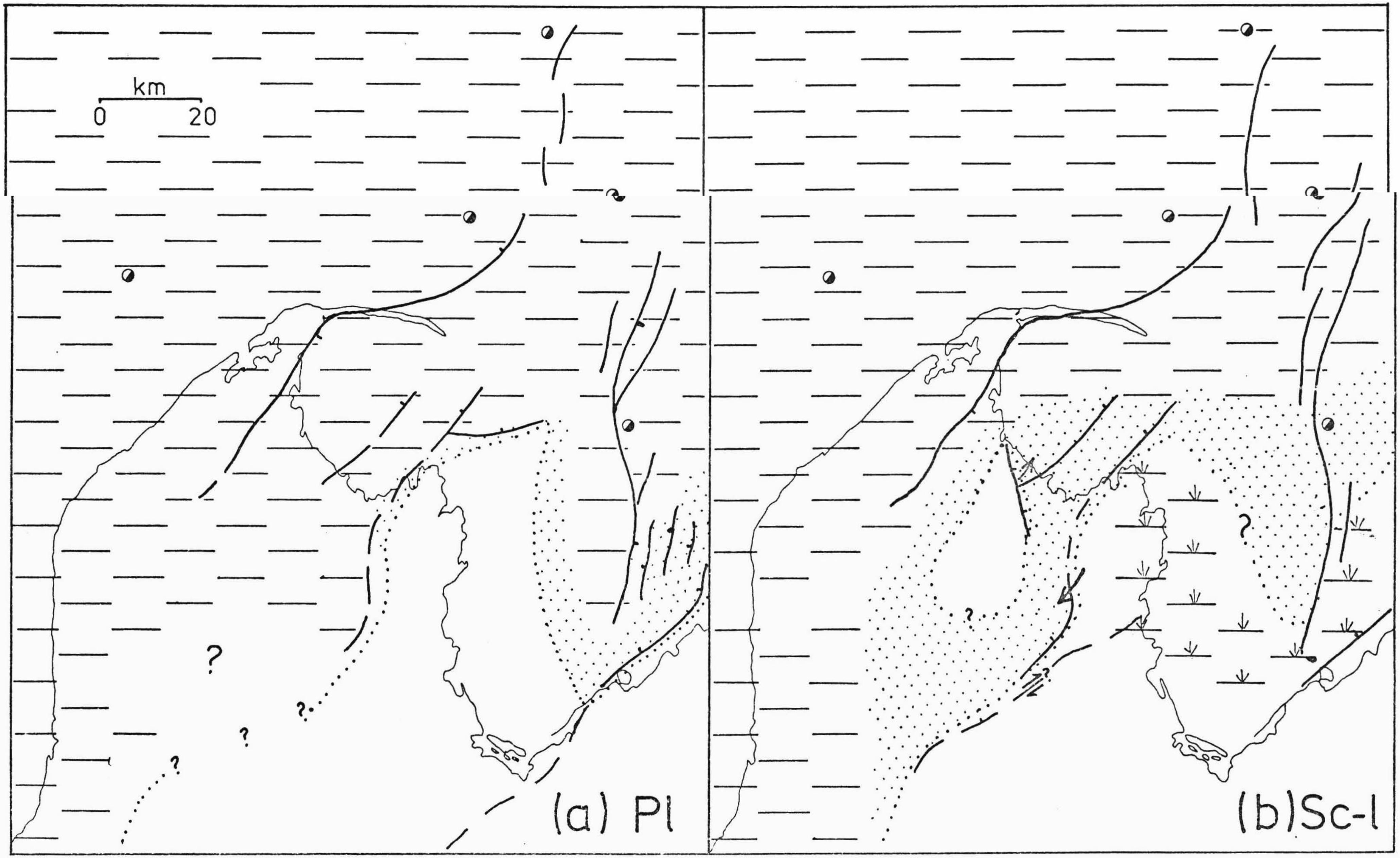


Fig. 49: Paleogeographic interpretation of northwest Nelson during (a) Altonian and (b) Clifdenian-Lillburnian time.

The Waitui Sandstone in the upper Takaka valley is underlain by an interval of strongly bioturbated quartz sand and mudstone, although the actual base of the formation is a sharp contact. These sandstone-dominated facies contain sedimentary features and faunas of shallow marine origin and indicate marine regression, probably to the north and west (fig. 49b). The Waitui Sandstone contains granite and schist pebbles suggesting derivation from the Pikikiruna Range to the northeast, while facies bt_6 was probably derived from the Onekaka Schist to the west or southwest. Two landmasses are postuated in the Pikikiruna Range area and central Golden Bay to supply this sediment (fig. 49b); the latter is drawn as an island, because the alternative, a long, narrow inlet up the Takaka valley, seems an unlikely coastal profile.

East of the study area, the coal measures drawn in the Tasman Bay area (fig. 49b) are also hypothetical, but not inconceivable as Miocene-Pliocene terrestrial sediments were found in Surville-1 well.

No Tertiary sediments younger than Lillburnian age are known in Golden Bay, and it is probable that the whole study area became an emergent landmass soon after this time. Within west Nelson, marine deposition continued in the Karamea area until the early Pleistocene (Grindley, 1961), but in the study area and in the southern Taranaki Basin (Pilaar and Wakefield, 1978) a widespread erosion surface truncates Lillburnian-Waiauan strata.

Conclusions

Tertiary sedimentation in Golden Bay can be summarized as an Eocene to Miocene marine transgression and regression sequence, controlled by movement along three major monoclinal folds/faults: the Wakamarama Fault, the Pikikiruna Fault and the Golden Bay Fault. Two structural episodes were important, the first occurring from mid Eocene (Bortonian-Kaiatan) to mid Oligocene (Duntroonian) time. This involved normal block faulting, and accumulations of coal measures in rather localized fault angle depressions.

Following tectonic quiescence during the Waitakian and Otaian Stages, and consequent deposition of a thick, pure limestone across northwest Nelson, a second structural episode developed. This was a wrench faulting regime in which the South Taranaki Graben and Cape Egmont Fault Zone developed (Pilaar and Wakefield, 1978). In Golden Bay it appears that a number of shallow anticlines and synclines formed, as a response to basement fault movement, and these became markedly asymmetrical, eventually steepening into monoclinal folds. Where the limb of the monocline became locally oversteepened, reverse faults, such as the three named above, formed. Mudstone deposition took place during the initial stages of folding, and the shallow marine sandstones of Clifdenian-Lillburnian age may have been deposited during the steepening of the folds.

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APPENDIX ONE

STRATIGRAPHIC COLUMNS

The format, symbols and abbreviations used in the following stratigraphic columns are based on those of Andrews (1976). Two types of column are used, Summary Sections of 1:1000 scale (1mm = 1m) and Detail Sections of 1:200 scale (1mm = 0.2m). The location of each section is shown in fig.50.

Formations and facies are indicated on the left side of the column by the codes introduced in Chapters 3-5.

mb Brunner Coal Measures

mb_1 Alternating sand, fine sandstone and mudstone
mb_2 Bioturbated muddy sandstone
mb_3 Cross-bedded sand
mb_4 Thick-bedded sand and gravel
mb_5 Alternating sandstone/conglomerate and mudstone
mbq Quartz Wash Member
mbw Washburn Limonite Member

nt Takaka Limestone

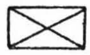
nt_1 Glauconitic limestone and sandstone
nt_2 Calcareous sandstone and conglomerate
nt_3 Mollusc lime packstone
nt_4 Bryozoan-bivalve lime grainstone
nt_5 Bryozoan lime grainstone
nt_6 Algal lime packstone
nt_7 Fine sandy calcarenite
nt_8 Foram-echinoderm lime grainstone

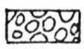
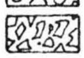
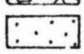
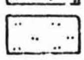
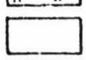
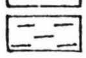
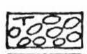
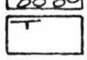
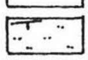
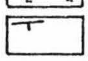
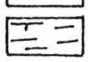
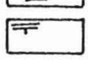
bt Tarakohe Mudstone

bt_1 Glauconitic calcareous sandstone
bt_2 Massive mudstone
bt_3 Alternating sandstone - mudstone
bt_4 Laminated and bioturbated sandstone
bt_5 Micaceous sandy siltstone
bt_6 Cross-bedded sandstone

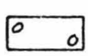
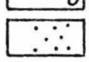
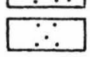
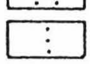
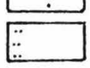
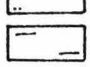
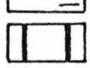
bw Waitui Sandstone

Symbols, Terms and Abbreviations

Symbol	term	abbreviation
	rock type unknown	
	HARDNESS	
	cemented	cmt
	friable	fri
	hard	hd
	very hard	$\underline{\text{hd}}$
	plastic	plas
	soft	soft
	WEATHERING (FRESHNESS)	
	unweathered	unwthd
	slightly weathered	(wthd)
	moderately weathered	wthd
	intensely weathered	$\underline{\text{wthd}}$
	COLOUR	
	black	blk
	blue	bl
	brown	brn
	green	gn
	grey	gy
	olive	olv
	orange	orng
	pink	pk
	white	wh
	yellow	yel
	dark	dk
	light	lt
	moderate	mod
	mottled	mtl
	weathering	wth

Symbol	term	abbreviation
	TEXTURE	
Modifiers for size grades:	very coarse	<u>crs</u>
	coarse	crs
	medium	med
	fine	f
	very fine	<u>f</u>
Sorting terms:	very well sorted	<u>srt</u>
	moderately well sorted	srt
	poorly sorted	(srt)
	<u>Terrigenous Sediments</u>	
	Gravel	G
	Breccia	Br
	Sand	S
	Silt	Z
	Mud	M
	Clay	Cl
	Conglomerate	Cgl
	Sandstone	Sst
	Siltstone	Zst
	Mudstone	Mst
	Claystone	Clst
	Shale	Sh

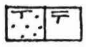
Homogeneous mixtures of size grades are shown thus:

	gravelly, pebbly, conglomeratic	g,pbl,cgl
	very sandy	<u>s</u>
	sandy	s
	slightly sandy	(s)
	silty	z
	clayey, muddy	cl,m
	carbonaceous	carb

Underlining means "very", as in "<u>s</u>" for very sandy.
Parentheses mean "slightly", as in (s) for slightly sandy

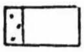
Symbol | term | abbreviation

Interbedded Rock Types



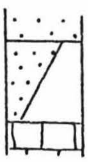
sandstone/shale

The relative proportions of the alternating lithologies can be shown by proportionate subdivision of the log, e.g.



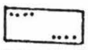
25% sand, 75% mud

A gradual change in relative proportions of the alternating lithologies can be shown by an oblique dividing line:

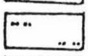


sand increasing from 20% to 70%

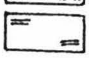
When the proportion of the smaller component becomes less than 10%, the symbols for streaks and lenses should be used:



sand streaks or lenses — Strk,Len

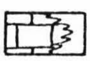


silt streaks or lenses



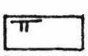
mud or clay streaks or lenses

Lateral transitions of one lithology to another are shown:

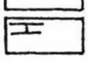


lateral transition of limestone to mudstone

CEMENTS



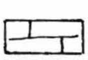
quartz cemented



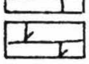
calcite cemented

Composition

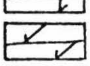
CARBONATE ROCKS



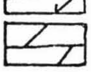
Limestone (90-100% calcite, 0-10% dolomite)



Dolomitic limestone (50-90% calcite, 10-50% dolomite)



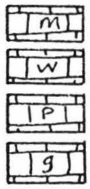
Calcitic dolomite (10-50% calcite, 50-90% dolomite)



Dolomite (or dolostone) (0-10% calcite, 90-100% dolomite)

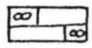
Symbol term abbreviation

<u>Carbonate Texture</u> (Dunham, 1962)

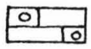


lime mudstone Mst
lime wackestone Wkst
lime packstone Pkst
lime grainstone Grst

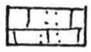
Limestone with indeterminate texture:



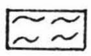
calcisiltite (lime siltstone), particles 20-63μm



calcarenite (lime sandstone), particles 63μm-2mm

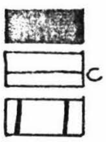


sandy limestone sLst



soft argillaceous limestone (marl) Mrl

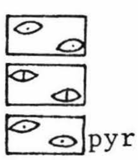
COALS



Coal in general C
Thin coal bed
Carbonaceous formation, coal streaks C strk

For slightly carbonaceous formation show vertical band on one side of column only

CONCRETIONS AND NODULES



Concretions, nodules in general Conc, Nod
Calcareous concretions
Pyrite nodules

MINERALS

Biotite	Biot	Mica	Mica
Calcite	Calc	Muscovite	Musc
Dolomite	Dol	Plagioclase	Plag
Feldspar	Fld	Pyrite	Pyr
Glauconite	Glc	Quartz	Qz
Kaolinite	Kao		
Limonite	Lmn		

For adjectives derived from any of these, use lower case, e.g. glc for glauconitic

FOSSILS

The following symbols are plotted to the right of the graphic log.

	Algae	Alg
	Bivalves	Biv
	Brachiopods	Brac
	Bryozoa	Bry
	Corals	Cor
	Crinoids	Crin
	Echinoids	Ech
	Foraminifera	Foram
	Foraminifera, larger benthonic	
	Gastropods	Gast
	Plant remains	Plt Rem
	Vertebrates	Vrtb
	Shell concentrations (to be shown on log)	

STRATIFICATION

These symbols are placed to the right of the graphic log.

Thickness of bedding

millimetre	bedded	1mm-1cm	mm-bd
centimetre	bedded	1cm-10cm	cm-bd
decimetre	bedded	100cm-1m	dm-bd
metre	bedded	1m -10m	m-bd

General terms

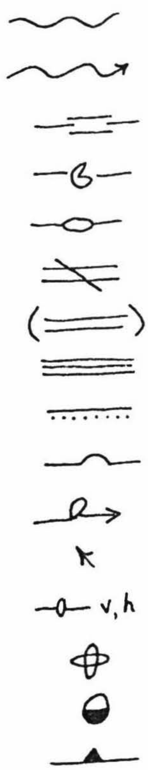
thick	tk
thin	tn
blocky	blky
flaggy	flg
laminated	lam

LARGE SCALE SEDIMENTARY FEATURES

These symbols are placed to the right of the graphic log.

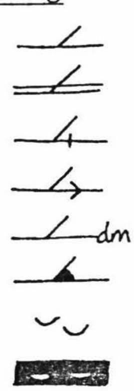
wedge-shaped layers
lenticular layers
unit with concave bottom and flat top

SEDIMENTARY STRUCTURES



symmetrical ripples
asymmetrical ripples
parting lineation
shell lineation
pebble lineation
no apparent bedding; massive — mass
faintly bedded
well bedded
graded bedding
convolute bedding
pebble imbrication
plant root tubes
burrows, vertical, horizontal
bioturbation
geopetal fabric
stylolites

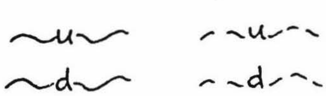
<u>Cross-bedding</u>



cross-bedding in general — x bd
ripple drift, climbing ripples
planar cross-bedding
trough cross-bedding
thickness of set should always be shown
low angle ($< 10^{\circ}$) cross-bedding
flaser bedding
lenticular bedding

UNCONFORMITIES

certain conjectural



angular unconformity
disconformity (non-angular unconformity)

Key to Figure 50

BR	Brown River
CS	The Castles
DB	"Devils Boots"
DR	Dry River
DT	Doctor Creek
EB	Eureka Bend
GD	Golden Gully
GL	Gouland Downs
GS	Gibson Creek
KT	Kitty Creek
LB	Lightband Gully
LD	Little Doctor Creek
LG	Ligar Bay
LO	Little Onahau River
MP	Motupipi
ON	Onekaka
OS	One Spec Creek
PF	Payne's Ford
PO	Pohara
PP	Parapara
PW	Pariwhakaoho River
QR	Quartz Ranges
RM	Rangihaeata
SV	Silver Stream
TK	Takaka
TP	Taupo Point
TR	Tarakohe
UW	Upper Waitui Stream
WA	Waitui Stream
WP	Waikoropupu River
WT	West Takaka

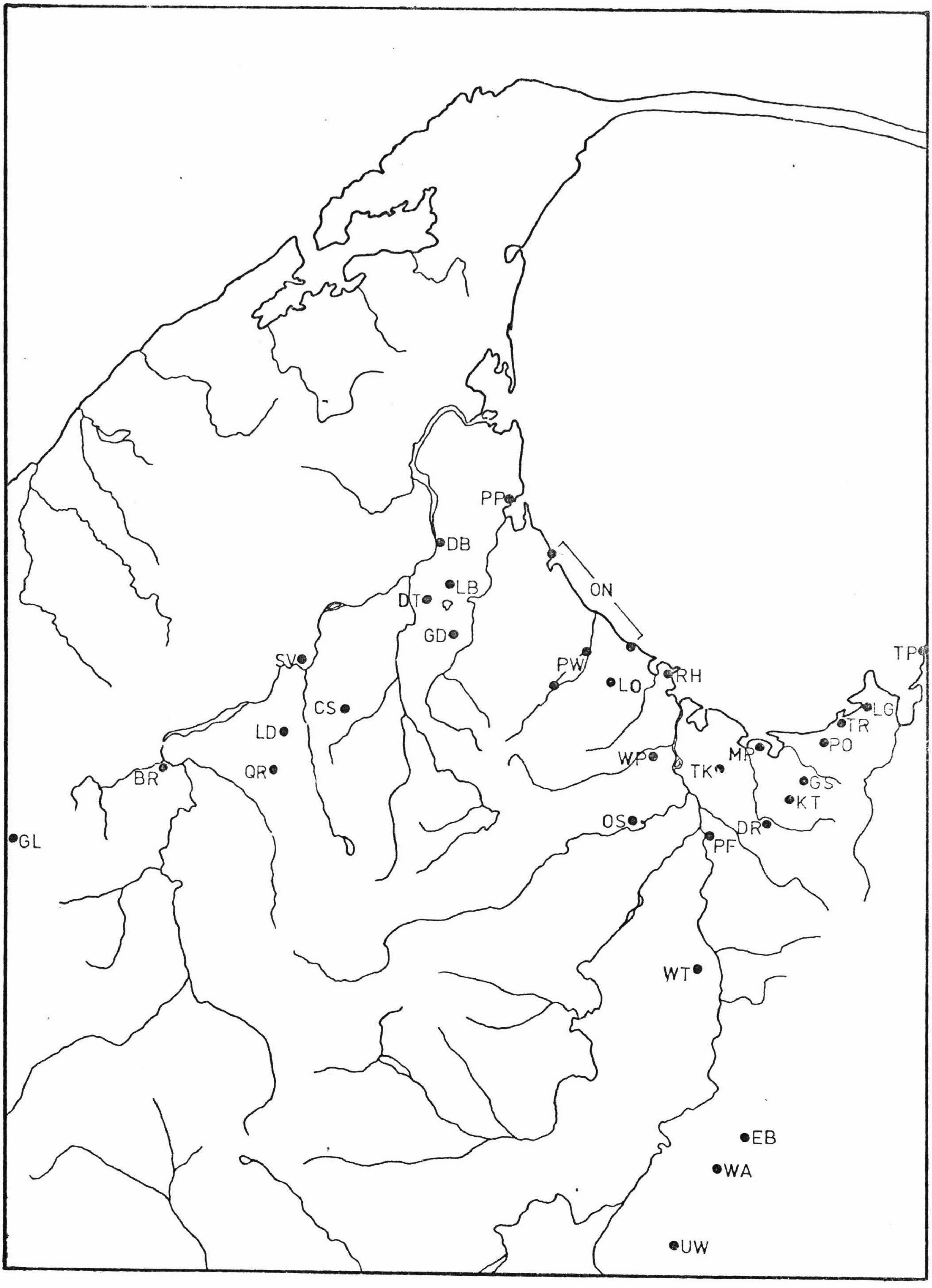
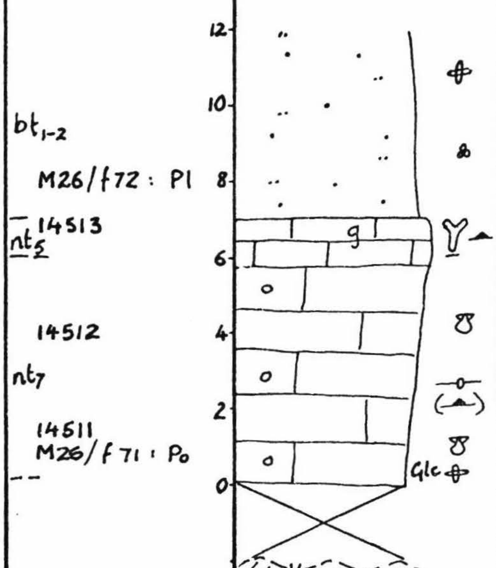


Fig. 50: Locations of 32 measured sections of Tertiary strata in Golden Bay.

Detail section: BROWN RIVER

Terrace edge south of Brown River on Heaphy Track (M26/636391-636392)



zSst, (soft), med gy bl wthring lt gy brn, f, Calc, strongly bioturb

Bry Grst, hd, lt gy, small Bry, rare Biv, Flags 30mm tk ; tn wispy stylolites, grades to :

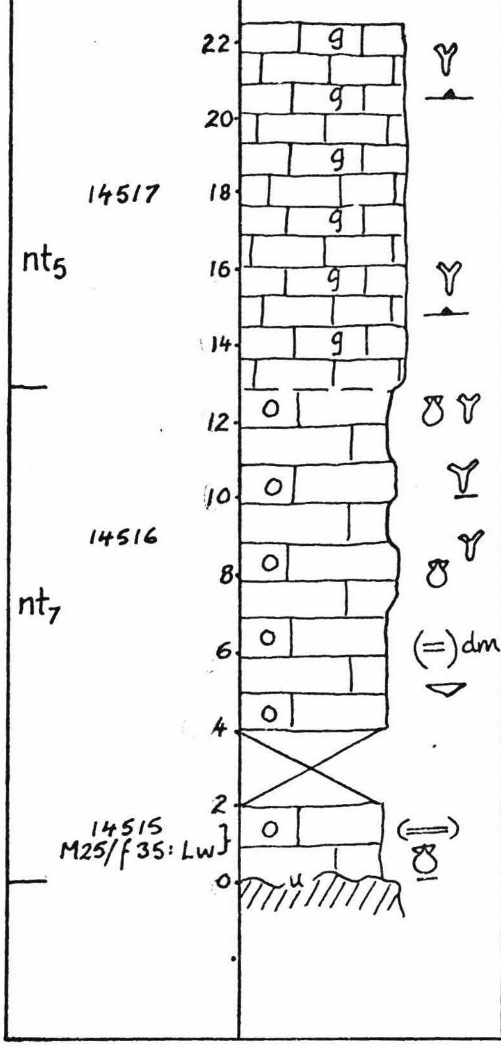
Biv calcarenite, (hd), med brn gy, Biv frags, worm tubes, grades to :

s calcarenite, hd, lt brn gy, 10mm diam ovoid burrows, rare <u>Lentipecten</u> <u>hochstetteri</u>, f-med glc

basal contact not seen

Detail section: THE CASTLES

Cliffs on the west side of the Castles, approx. M25/735417. Basal contact seen on Boulder Lake Track, M25/740433



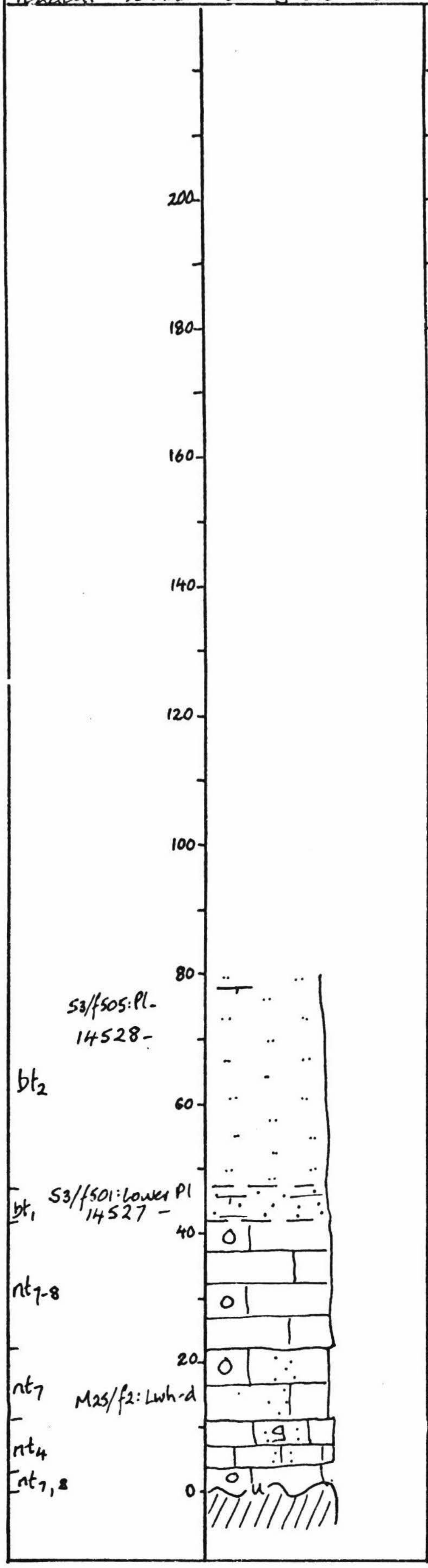
Bry Grst, hd, lt gn, tight packed fabric predominantly Bry; 50-100 mm spaced soln planes accentuated by wthring

Calcarenite, hd, lt gy brn - lt gy, horizons rich in *Cellepora* (Bry), bivalves or Brac; faint 100 mm horiz-bd

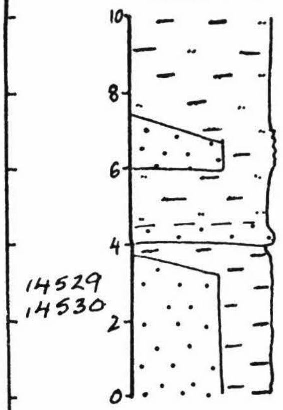
M25/740433:
Calcarenite, with abundant *Lentipecten hochstetteri*, unconformably overlies Bay Schist.
Bell *et al*. (1907 : 53) report Quartz Wash Mbr underlying Lst: pbl-cgl 3.6 - 4.5 m tk, pinching out to north & south.

Summary section: DEVIL'S BOOTS

Stream and cliff outcrops (M25/791519 – 793521) and a disused quarry (789519) along lower Appo's Creek, riverbank outcrops along Aorere River (789522 – 785530) and roadcut beside Bonny Doon Ck. (738515).



BONNY DOON CK (M25/738515)



zClst, mod hd, bl gy, with brn

Alt Sst/Mst

Alt Sst/Mst: Sst, bl gy, f, lam, rare flaser-bd at top, rare low angle x-bd, 50-200 mm bd; Mst - Clst, gy bl, (lam) or burrowed, 5-200 mm - bd, spls Foram.

Full thickness of Aorere Valley strata may be c. 400 m. At least the lower 200-300 m are probably Zst (cf. wthd Zst outcrops along MacKay Pass Road). Alternating sst/Mst of facies bt4 (Detail Section above) exposed in roadcut beside Bonny Doon Ck.

S3/f524 from Marble Ck (northwest flank Aorere Vly) is Sc in age.

–[youngest strata exposed in Aorere River]

Zst, mod hd, dk bl gy, common Forams, mass or faint cm-bd.

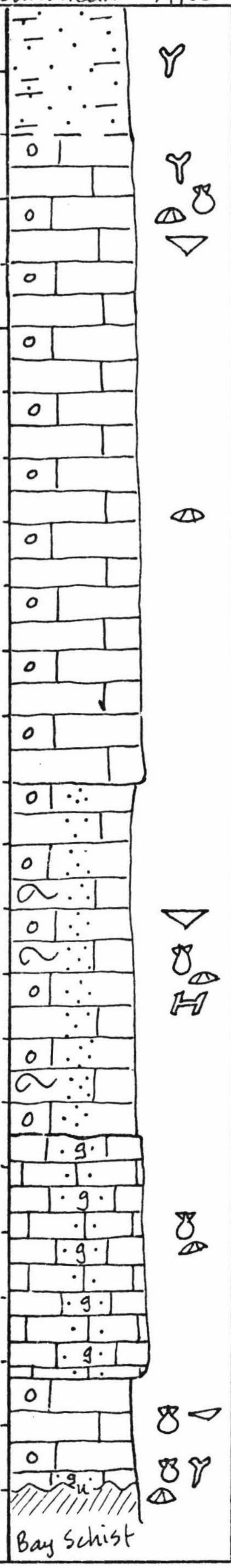
mSst, mod hd, dk gn gy, calc, glc; Biv, Bry, bioturb.

Calcarenite, hd, dk olv gy - gn gy, abundant horizons of Biv, Brac, Ech, wispy soln seams at 20-80 mm intervals (see Detail Section overpage).

s Moll Grst, hd, lt gy-wh, rnd s & pbls, Moll & Ech frags calc-cmt; Basal calcarenite and Biv s Grst unconformably overlie Bay Schist

Detail section: DEVIL'S BOOTS

Composite section from stream and cliff outcrops in lower Appo's Creek (M25/791519 - 793521), disused quarry at 789519, riverbank outcrops east bank Aorere R. downstream Appo's Creek mouth (c. 789522).



S3/f501: lower Pl

44

bt1

14527 -

(50.2% CaCO3, 40.3% sand, 9.5% mud)

42

14526

[59.0% CaCO3, 33.7% sand, 7.3% mud]

40

14525 - 38

36

34

nt7-8

32

14524 - 30

[74.9% CaCO3, 21.9% sand, 3.2% mud]

28

26

24

14523 -

22

20

14522 -

[67.1% CaCO3, 29.6% sand, 3.3% mud]

18

nt7

M25/f1,2: Lwh-d 16

M25/f31: Lwh-Sw

14

14521 -

12

10

14520 - 8

nt4

[82.0% CaCO3, 17.2% sand, 0.8% mud]

6

4

nt7

14519 - 2

nt8

14518 - 0

[76.9% CaCO3, 22.0% sand, 1.1% mud]

mSst, mod hd, dk gn gy, calc, glc, scattered pectinids & *Cellepora*, abundant burrows c. 20 mm diam.

Calcarenite (m-s Ech Grst), hd, dk olv gy - pal olv, *Cellepora* up to 17 mm diam common in upper 2 m, scattered pectinids (incl. *Serripecten hutchinsoni*); Brac, Ech; burrows incl. tn vertical worm tubes and tk rnd-elongate echinoid burrows c. 50 mm diam, accentuated by irreg. wispy soln seams around edge of burrow-fill. Soln seams 20-80 mm spaced, stand out as positive features on some wthd outcrops

sCalcarenite (s Foram Grst), hd, gn gy with pal brn, med-f srt Qz S; abundant shell horizons, mainly with Bracs, also Biv, Ech spines; sharp base, grade upwards. Rare vert. burrows 5-10 mm diam. Soln seams stand out on wthd outcrops. M25/f1 cetacean fossil.

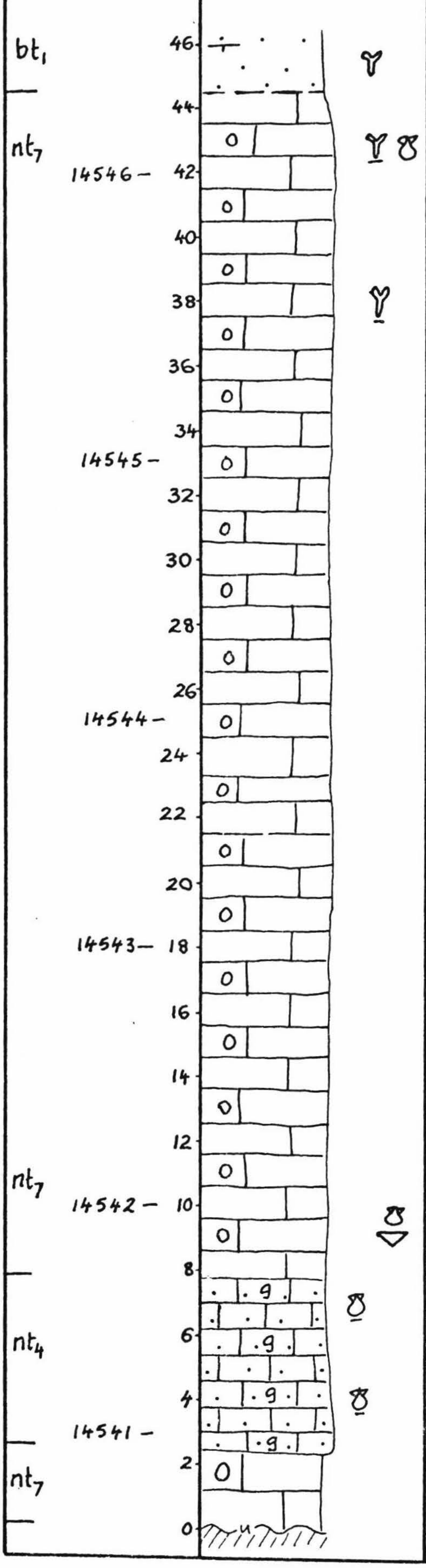
s Moll Grst, hd, lt gy-wh; med s - pbl, rnd, crs Moll (? Biv) and Ech rnd frags in equant calcite spar; faint soln planes at 60-80 mm spacing, outcrops vertically fluted

Calcarenite (Ech sGrst), mod hd, olv-brn (wthd), med-f Qz s, common Biv & Brac frags up to 10 mm long

Biv sGrst, hd, dk bl gy with lt gy; med-f Qz-Fld-Schist sand, Biv, Bry, Ech; rests directly on uneven basement with 0.6 m relief.

Detail section: DOCTOR CREEK

Composite section on the 2 southernmost Lst hills in the Aorere caves area, on both sides of 4wheeldrive track. Hill west of road M25/764483, lower 25 m of section well-exposed, good access. Hill east of road M25/764486, 46 m strata



Sst, lt gy gn, calc, glc

sLst, hd, lt gy gn, glc, abundant disoriented *Cellepora*, common Biv, especially *Serripecten hutchinsoni*, mod bioturb.

abundant *Cellepora* above 35 m

Calcarenite, lt gn gy, soln planes spaced 100 - 200 mm, many tn shell horizons

Calcarenite, lt gn gy, some concentrations of Biv or Brac frags; soln planes spaced 40-50 mm

Calcarenite, lt gy wthd/lt brn, med s, shell horizons of disorientated Brac or Biv, Soln planes 50-100 mm spaced.

Moll sGrst, hd, lt gy, srt med Qz s, granules - pbls up to 13 mm diam, srt Moll frags 2-5 mm diam, rnd; soln planes 60-100 mm spaced.

Sharp contact on

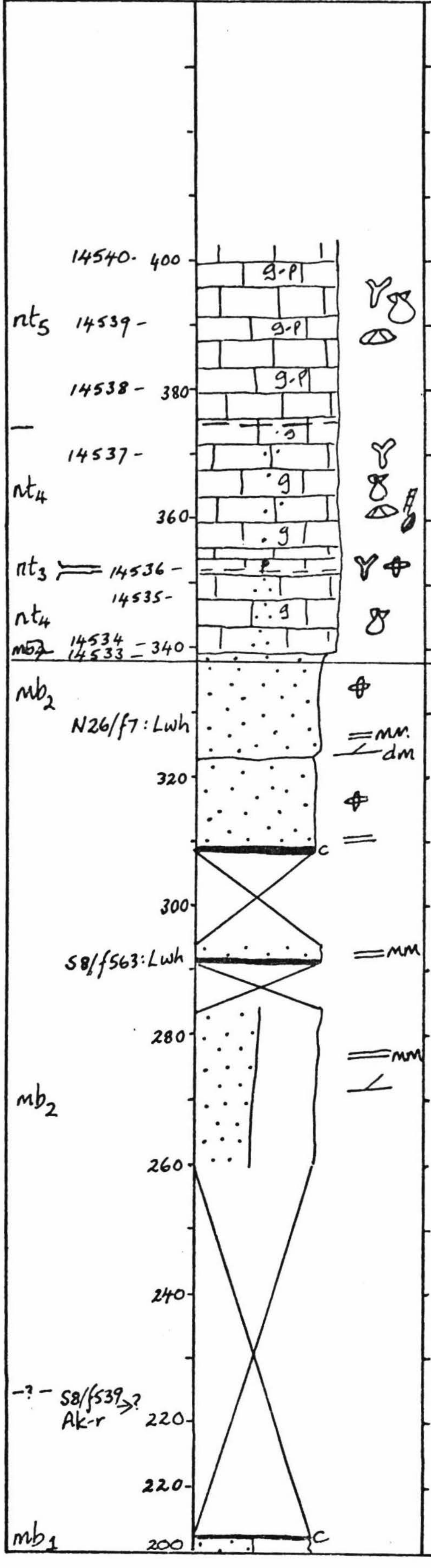
Calcarenite, lt gy, sandy.

Some areas of Lst may be underlain by thin patches of Quartz Wash Mbr sand & cgl.

Waingaro Schist.

Summary section: DRY RIVER

Brunner Coal Measures measured in stream outcrops of Dry River, from N26/975364 to 971367; Takaka Limestone (see Detail section) measured across escarpment west of north branch Dry River (N26/981375 to 979378).



Moll - Bry Pkst, hd, lt gy, common large ?cellepora, abraded Biv, Brac, Ech frags, sparse f S on sol^n planes; Flags 30-60 mm tk with very prominent seams at 1-2 m spacing

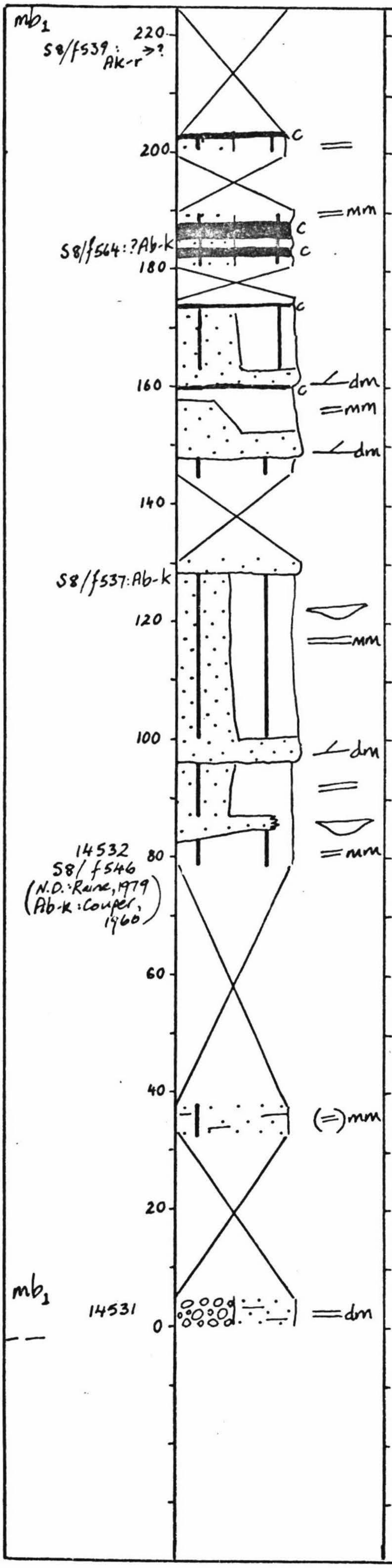
s Bry Grst, speckled pal yel - pal olv, large Bry frags, Biv shells, also Ech, Alg, foram, f-med (srt) Qz-Fld; 30-40mm tk Flags, rare low-angle x-bdg.

s Bry Pkst - Grst at 353-354m, bioturb, 100mm tk Flags

s Biv Grst, lt brn, crs (srt) S; med-pbl S, Qzarenite

Lateral shift 1.3 km northwest along Lst escarpment.

mSst, mod soft - mod hd, dk brn, carb & mic, strongly bioturb,
grades down to lenticular bd f Sst and dm-trough x bd med-crs S
(see detail section fig. 11)



Alternating interlam Sst/Zst, carb Mst and coal; minor x bd S.

Interlam Sst/Zst, mod hard-soft, lt gy f Sst often jarosite-stained; dk gy brn carb Zst; mm or cm horiz-bd or wavy-bd.

Mst, mod hd, dk brn, carb, massive or horiz-lam

Coal, hd, blk, usually bright.

S, lt gy, Lmn-stnd, feldsarenite; med-crs S, (srt), indistinct dm-trough x-bd.

See Detail Section, fig. 11

Interbd mSst/sG-sCgl,

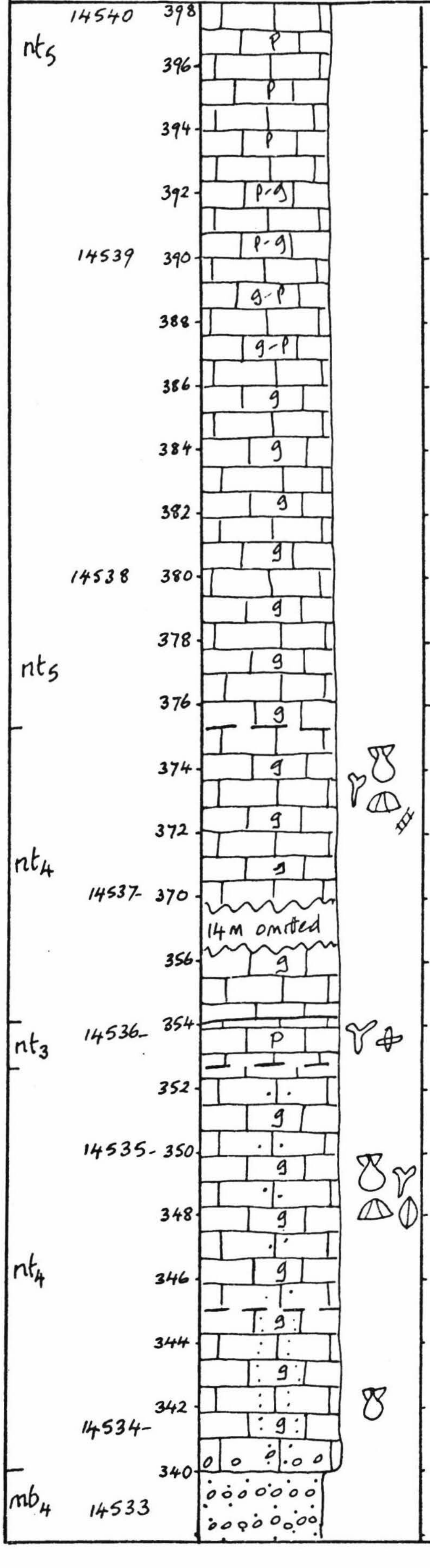
sG-Cgl, lt gy, mod soft, 30-100 mm pbls of Qz, wthd Mst & Sst, rnd, equant-prolate, clast-supported in med s matrix.

mSst, mod soft, bimodal crs & f mS, micaceous feldsarenite

Base not seen, possibly faulted

Detail section: DRY RIVER

Section from escarpment above north branch of Dry River (N26 / 981375) westwards across ridge into Packard's property, south of Kitty Creek.



Moll - Bry Pkst, lt gy ; common large ? Cellepora bryozoa among rel- fine-grained abraded Biv, Bry, Brac, Ech frags ; sparse srt med-f Qz-Fld S on sol^n planes ; Flags 30-60 mm tk with very prominent seams at 1-2 m spacing.

grades to

Ech- Bry Grst & Brac- Bry Grst, as above ; terrigenous sand scarce and echinoderms abundant cf. underlying facies nt4.

grades to

Bry- Moll Grst, speckled pal yel - pal olv ; (srt) allochems mainly Bry (3-8 mm diam.) , Biv, Ech, Foram, Alg ; med-f (srt) Qz-Fld S ; 30-40 mm tk Flags, rare low angle planar x-bds c. 200 mm tk at 370 m.

[ridge crest at 370 m]

s Bry Pkst - Grst ; wh ; (srt) Bry, Biv, Ech, Foram & med srt Qz- Fld S, bioturb. Blocky 100 mm tk Flags.

Moll Grst, wh ; srt Biv, ? gast, Bry, Ech, Forams (*Amphistegina*), srt, rnd crs Qz- Fld S ; 30-50 mm tk Flags,

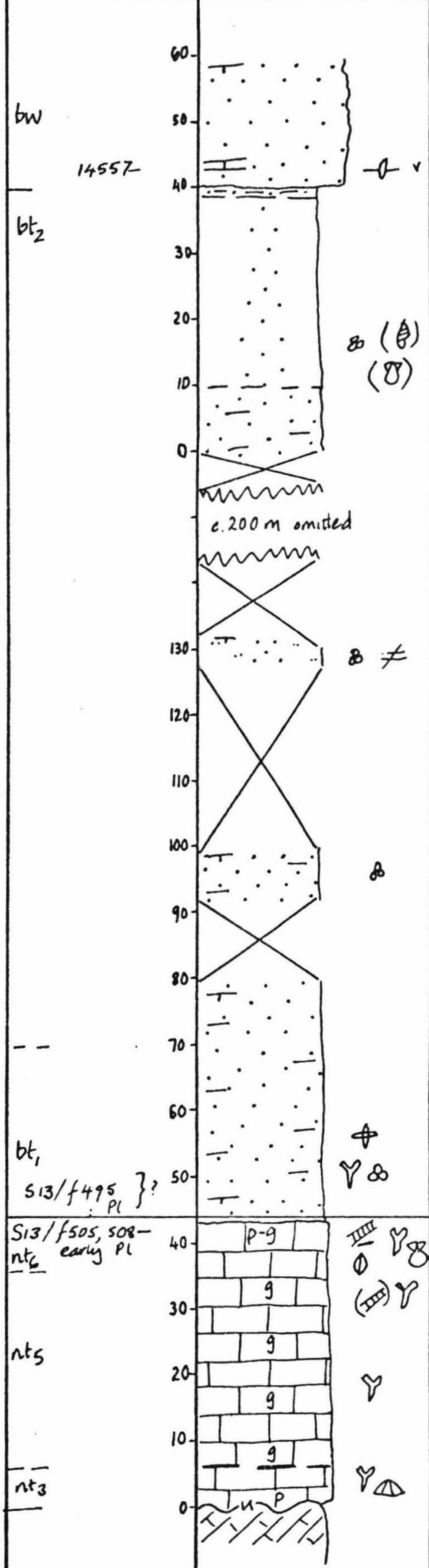
grades to

Biv - sGrst, lt brn gy - lt yel brn ; shell frags up to 6 mm long mainly Biv, Bry, Ech ; crs srt Qz-Fld S, 10 mm pbls at base ; 40-80 mm tk Flags.

S, wh, med-crs, srt, rnd ; Pbl lam with pbls up to 15 mm diam ; Quartzarenite

Summary section: EUREKA BEND

Composite section from Aaron Creek and Takaka Hill Road (H'way 60). Upper part in south branch Aaron Ck. (base bw c. 955165). Lower part bt in east branch Aaron Ck (50 m level at c. N26/966181. Lst section on Hill Rd (see detail section).



Aaron Ck inaccessible above 60 m..

Sst, (hd), wh, crs, srt, Feldsarenite: hd calc-cmt bd 1 m above base cmt by iron-free 100-200 μm calcite spar, contains a few indet. allochems

- 1 m med mSst; med Qz s in med bl gy m matrix

sMst, (hd), med gy bl, Foram, Shell Frags

mSst, med gy gn, f, bioturb

See Waitui Stream section

sZst, (hd), med bl gy, Foram-rich, mass.

mSst, (hd), med bl gy, f; Forams, rare Bry, mass

mSst, (soft)-(hd), med gy bl, f, bioturb.

grad to

Sst, med gn gy, (hd), f-f, Bry, Foram

Lower part section on Takaka Hill Rd.

Alg Pkst, hd, med gn gy; Rhodoliths in (soft) sM matrix,

Bry Grst, (hd), weakly cmt, Algal content significant above 35 m, grad down to

Bry Grst, hd, lt brn yel, homogeneous Bry-dominated matrix, lenticular flags 40 mm tk

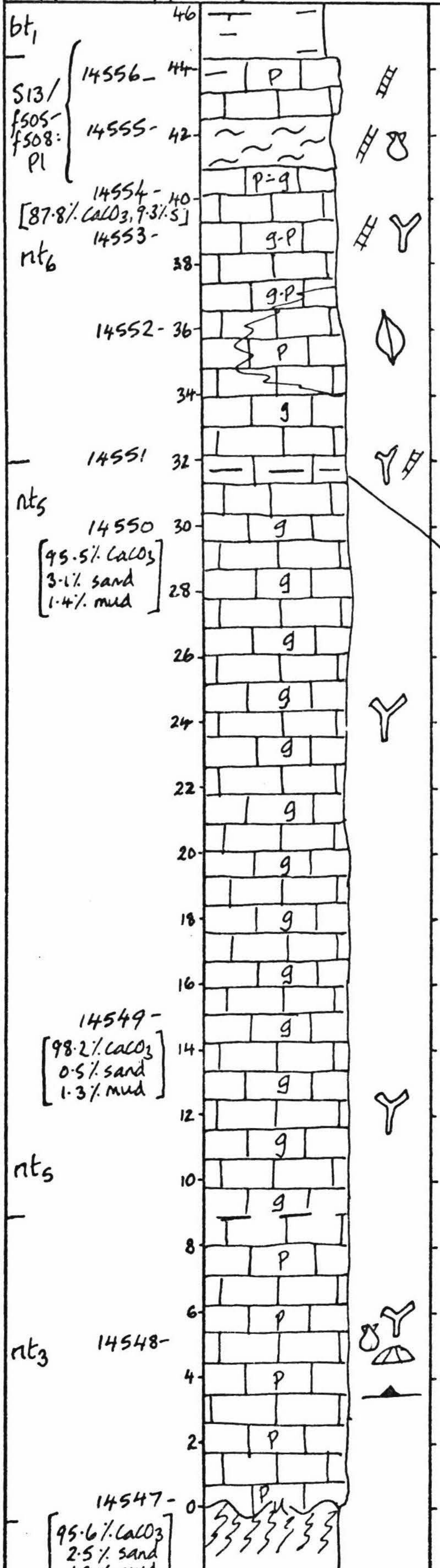
Bry Pkst, hd, pk, blocky nodular flags 150-200 mm tk,

unconformity on Arthur Marble

See Detail Section

Detail section: EUREKA BEND

Lower 35m of section measured in valley at base of Takaka Hill road (N26/ 967195-965192); upper 12 m in road cuttings at and near Eureka Bend (N26/ 970181 – 970184).



mSst, med gn gy, mod soft, f-f, common Bry, dm-horiz bd.

Alg Pkst, med gn gy, wh rhodoliths, wispy sol^n seams [85.5% $CaCO_3$, 4.9% sand, 9.6% mud]

Rhodolith mLst, mod soft, dk gn gy, rhodoliths up to 40 mm diam, scat. Mesopeplum burnetti (see fig. 34)

Alg-Bry Pkst, lt-med gn gy, hd, Bry & Alg in terrigenous mud matrix; 35-45 mm tk flags

Lens of Foram Pkst, lt bl gy, hd, crammed with Amphistegina; flags 30 mm tk.

Alg-Bry Grst, lt yel gy, hd, 10-20 mm diam rhodoliths, Bry; 50-100 mm subplanar flags, grades over c. 2m to

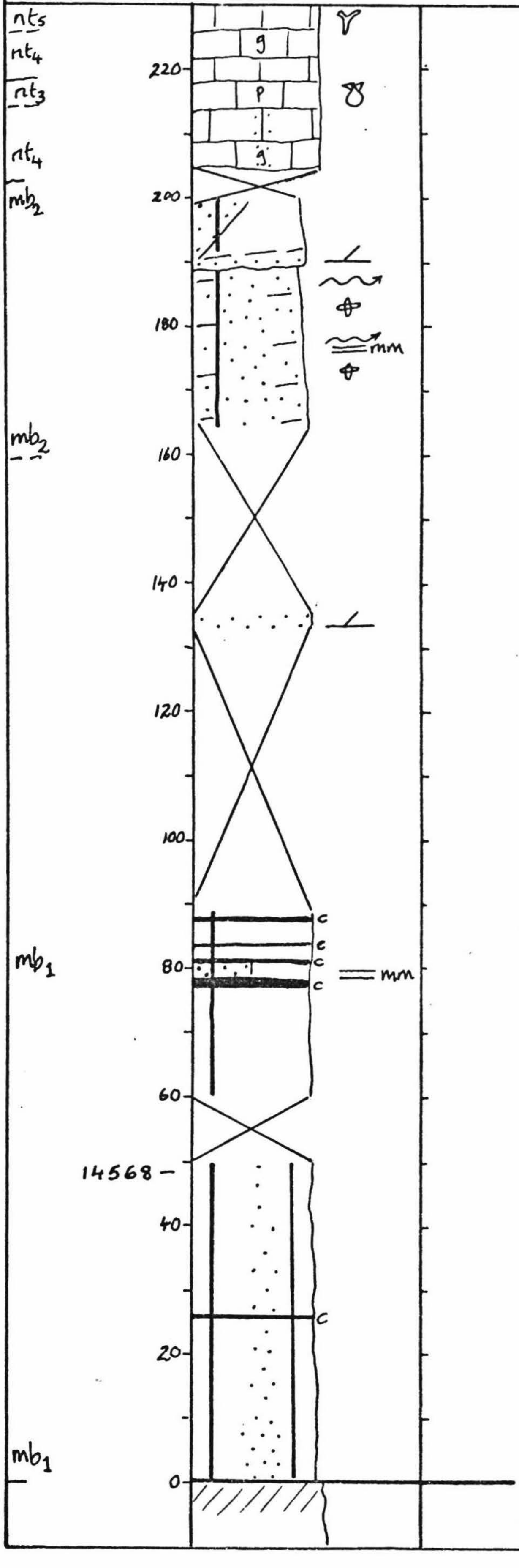
Bry Grst, med yel brn, hd; Bry prominent on outcrop surface, Biv frags; lenticular flags 20-40 mm tk., also vertically fluted outcrops, rare planar flags 50-100 mm tk at c. 15 m

Ech-Bry Pkst, lt yel, hd, large Bry, Ech spines, Biv (? oysters), med Qz-Fld S, inhomogeneous: tight-packed & open-packed; jagged stylolites border nodular-lenticular flags 30 mm tk at base, 150-200 mm tk 0.2 – 9 m.

unconformity on unwthd Arthur Marble.

Summary section: GIBSON CREEK

Stream outcrops in Gibson Creek (N25/997391 - 993393)



Lst not measured in detail; Total thickness c. 60 m, overlain by withd mSst c. 290 m.
Upper Lst is Bry Grst, hd, lt gy, 40-80 mm tk flags
c. 216 m: Biv Pkst, lt yel, flags 40-100 mm spaced;
Basal sLst, wh-lt gy, 10 mm flags.

Alternating
mSst, mod hd, dk brn gy, bioturb., and interlam Sst/Zst: Sst, lt yel, f, ripple-bd or horiz-bd or wavy-bd; Zst, dk brn, carb, horiz-bd.
Minor med x-bd Sst, carb Mst, tn coal seams

Sst, soft, orng, med-crs, (srt), x-bd.

Interbd carb Mst, mod hard, dk brn, Plt Rem; coal, seams up to 1 m tk, hd, blk, bright; minor interlam Sst/Zst, horiz-bd.

Scattered stream & farmtrack outcrops of Mst - sMst, wh-lt gy, withd, plastic; grad to
Mst, dk brn, carb, Plt Rem;
coal, usually fragmented; traces of old workings at c. 26 m.

FAULT
Arthur Marble

Detail section: GOULAND DOWNS

East & west sides of limestone hill between Cave Brook and Shiner Brook (composite section. M26/553349 (waterfall & cave system, west side), 555348 (cave near Downs Hut):

14567 / 96% $CaCO_3$, 3% s / M26/f69: N.D. (16)

nt$_3$?-4

nt$_5$ 14566 - (12)

14565 / M26/f70: N.D. (10)

nt$_3$

14564 (8)

14563 - (51.5% $CaCO_3$, 48% sand)

nt$_2$

14562 (?S7/f498: Lw-P)

nt$_1$

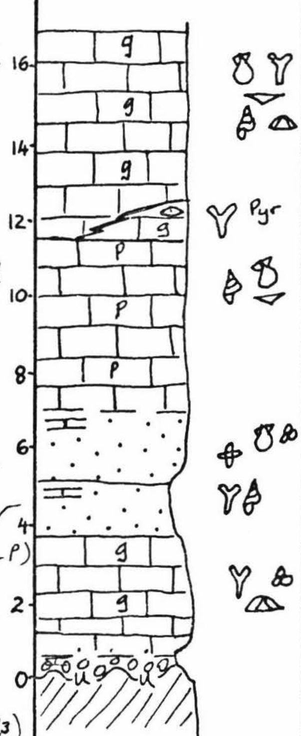
14561 -

M26/f68: Ld -

14560 - (0)

S7/f499: Ld

(14561: 76% $CaCO_3$ 20% sand)



Mollusc Pkst-Grst, lt yel with dk gy, hd, abundant large Biv, mainly collapsed micrite envelopes & dissoln. moulds; lenticular Flags 50-100 mm apart

Bry-Ech Grst (at 555348), lt gn, with lt brn, Bry, Biv, 3 mm diam Pyr Nod., soln seams 50mm apart

Pbl-Mollusc Pkst, lt gy, large Biv, Gast, Brac?, rnd Qz-Fld granules - pbls, in lt yel micrite matrix, grad down to Mollusc-sPkst with med-crs s; lenticular & irreg., blocky Flags 50-100 mm tk, grad to

Sst, lt gy, hd, bimodal med & granule s in micrite matrix, rare allochems incl. large Bry.

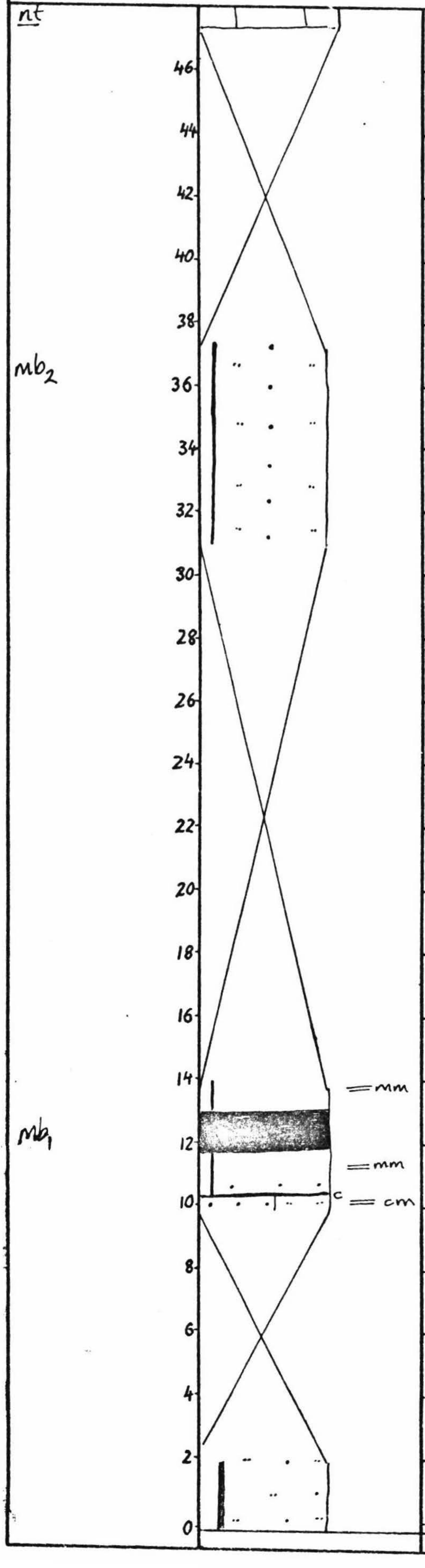
Glc-Grst, lt gy/dk gn, hd-(soft); Bry, Ech, Foram only identifiable in thin section, mass, blky, 40-100mm spaced soln planes.

Cgl, hd, calc-cmt pbls 50-100 mm diam.

Aorangi Mine Fmn.

Detail section: KITTY CREEK

Stream outcrops in Kitty Creek (N25/ 985380)



approx. base Lst

sMst, dk brn, carb

Mst, dk brn, mm-lam

1·5m coal, blk, shiny, jointed perp. to bd

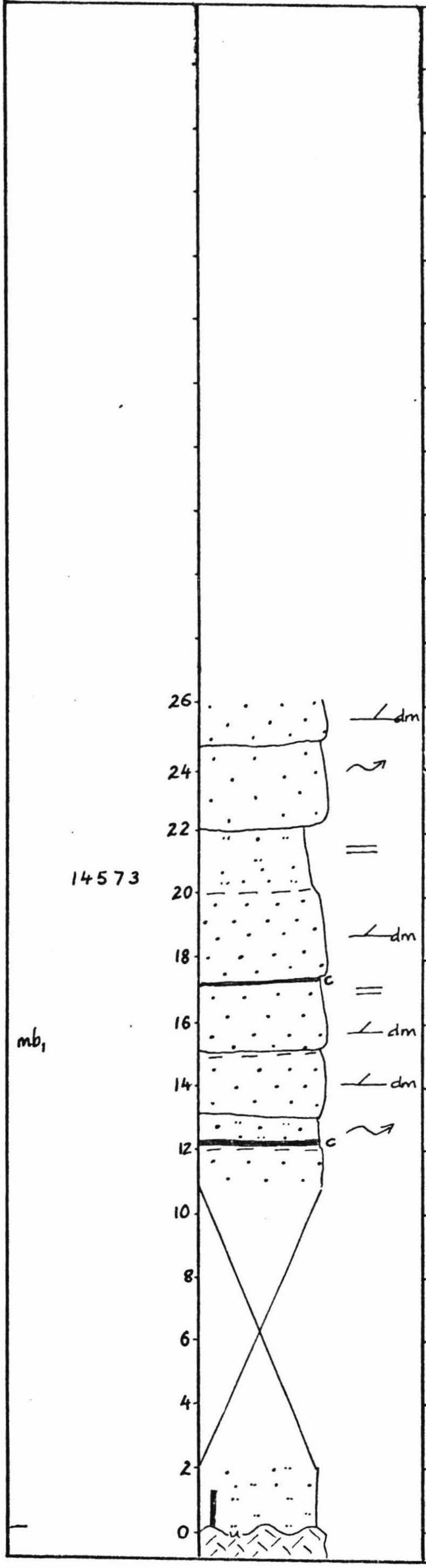
Mst, dk brn, lam ; Alt carb med-crs Sst & dk brn Mst, cm-horiz bd ; 100mm coal

sMst, lt brn, cm-horiz bd

FAULT

Detail section: LIGAR BAY

Roadcut at N25/027434



S, lt brn, med, 100-150mm trough x bd

S, lt brn, f, rip-bd

mS - sM, lt gy, horiz-bd

S, lt gy, med-crs, 80-150mm x-bd

coal, 20mm tk, and carb Mst

S, gy, Qz-Mic, f, horiz-bd grad to
S, crs, 100-150mm trough x-bd

S, lt gy, crs, 100-150mm trough x bd

mS, (carb), rip-bd ; carb Mst & coal

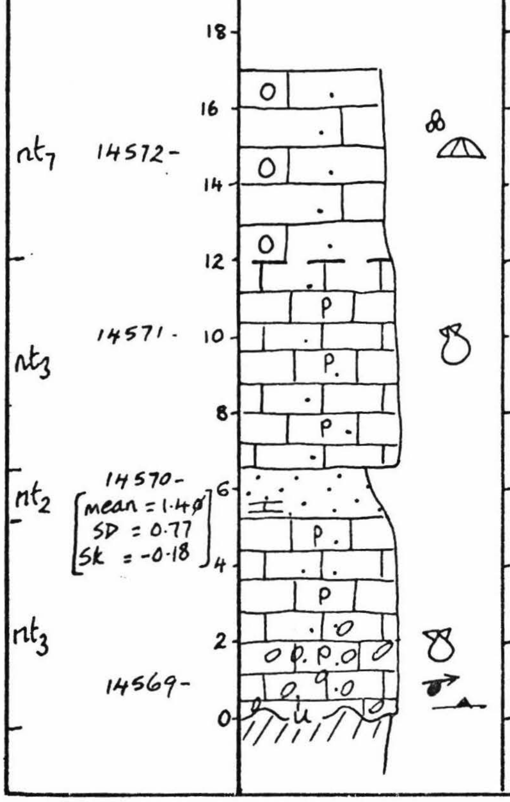
tidal flat

Zst, carb ; wh f mS

<u>wthd</u> Granite, Seperation Pt. Batholith

Detail section: LITTLE DOCTOR CK.

Limestone hill c. 300m west of Quartz Ranges track (M25/702414)



s calcarenite, hd, lt gy, srt f - f s, indeterminate f bioclastic debris, minor qk, faint solⁿ planes 50 - 200 mm spaced, outcrops vertically fluted.

Biv Pkst, hd, lt gn gy: large mollusc frags 5-15 mm long in matrix of crs s-sized Bry, Ech, Brac, Foram frags; rnd srt med s, bioturb.

s - sst, wh, med, srt, rnd, friable at top grad down to hd, calc-cmt sst.

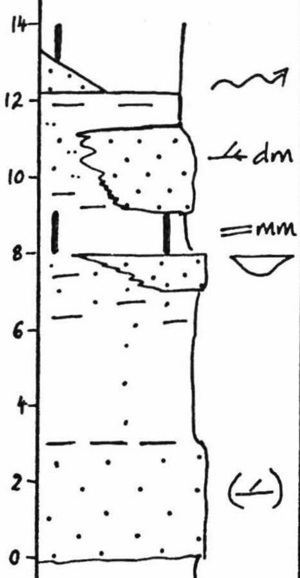
Biv Pkst as above, grades down to

cgl Moll Pkst, hd, lt orng - lt yel gy with gn stylolites; 5-20 mm abraded Moll & Ech frags, srt, rnd med Qz-Fld s, imbricate phyllite slabs average 50mm long, up to 0.5m

Detail section: LITTLE ONAHAU

Composite section at I. MacPherson's claypit (M25/ 899434)

Pollen samples for age determination :
S8/ f589 - 591 (L 6097 - 6099) : NF
S8/ f592 (L6100) : Ar
M25/ f39 (L4489) : N.D. ("upper" mb)
M25/ f40 (L4488) : Ab-k ("lower" mb)



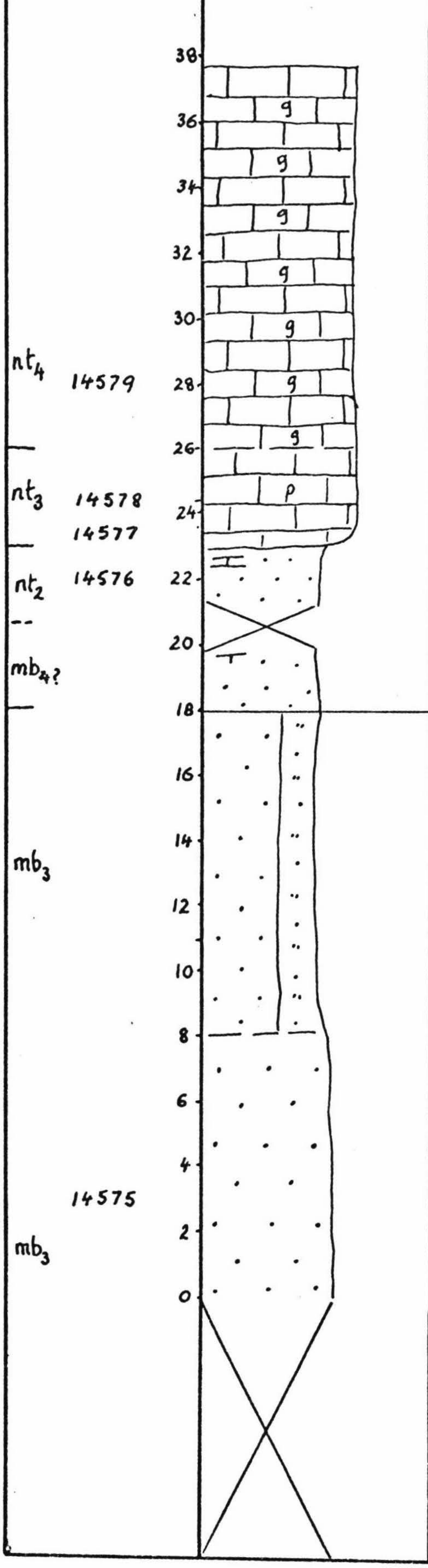
14574 –

Mst, dk-med brn, grad down to
mS, f, lt brn, cm - mm ripples with mud drapes
sM - mS, grad down to
S, crs, feldsarenite, trough x bd up to 200mm tk.
M, lt gy-wh, grad to M, dk brn, <u>carb</u>
S, med, faintly x-bd.
sM - Cl, wh, occasional thin dk brn (carb) horizons & ass<u>d</u> pipe Fe-concretions.
S, lt yel, <u>crs</u> at base grad up to med-f, (srt), indistinct x-bdg.
sM, wh

Base not seen

Detail section: MOTUPIPI

Composite section from 3 widely-spaced locations in Motupipi area: (1) Motupipi River; (2) Motupipi Sandpit, worked by Golden Bay Cement Co.; (3) Trig DD



Motupipi River (N25/965407)

Hochstetter in 1859 collected giant oysters and type specimens of <u>Pecten athleta</u>, <u>P. burnetti</u>, <u>Brissus eximius</u> and <u>Waldheimia lenticularis</u> from "Fossil Point", opposite the public house at Motupipi (Fleming, 1959a).

Bry Grst, hd, lt brn gy, abundant microstylolites, lenticular flags 50-100 mm tk

Biv Pkst, hd, yel-gy, Biv frags and whole shells, micrite-filled dissolution moulds, Bry; Qz-Fld pbls at base grad up to med-crs S; irreg vert & horiz stylolites; mod. bioturb

Sst, calc, hd, lt gy; crs-granule, calc-cmt subfeldsarenite, rnd, srt; Bry

Sst, dk orng, hd, crs-pbl quartzarenite, Fe-cmt

Motupipi Sandpit (N25/971402)

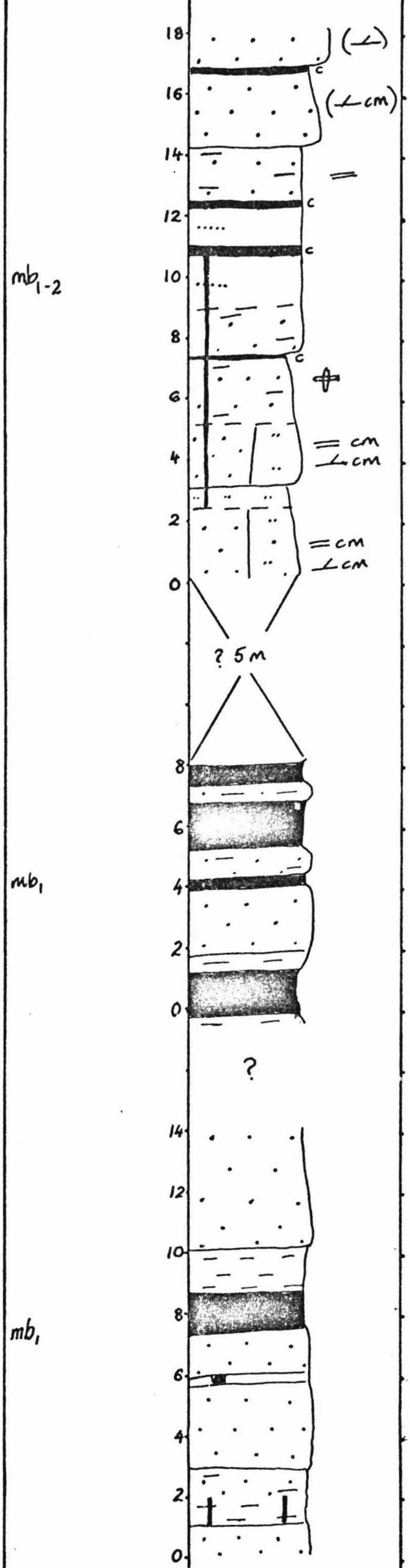
Alt S / mS:

S, wh, f-crs in alternate lam; scour-filling and trough x-bd, bds 30-200 mm tk, sharp basal contact;

mS, lt yel, f, small scale x bd, lenses of pure S; bds 40-100 mm tk, gradational basal contact

S, wh-lt brn, med-crs, srt-(srt) subfeldsarenite; trough and planar x-bd average 500 mm tk

Approx. 100 m very poorly exposed, probably mainly mb_3 x-bd S.



Trig DD (N25/971411)

S, lt gy

S, lt gy, Fe-stnd, med, faint ripple-bd, rare coal lens

mS, med-dk gy, f, (carb), mic, horiz-Lam

Mst, carb, with lt brn gy f Sst Lens

Mst, grad down to

mS, med Qz s in dk (gy) brn m matrix

mS, mottled lt gy - dk brn

S, med-f, cm-ripple bd or horiz lam; dk brn Mst drapes

Zst

Alt S / interlam Sst/Mst ; S, med, 0.5-1m bd, interlam Sst/Mst 50-200mm bd ; horiz-lam or wavy bd.

No. 1 Shaft, Burnett's coal mine (c. 1850) (ref. Fleming, 1959a)

1.55m coal with 130 mm parting

Sst, (soft)

1.4 m coal

No. 2 Shaft, Burnett's coal mine

Sst

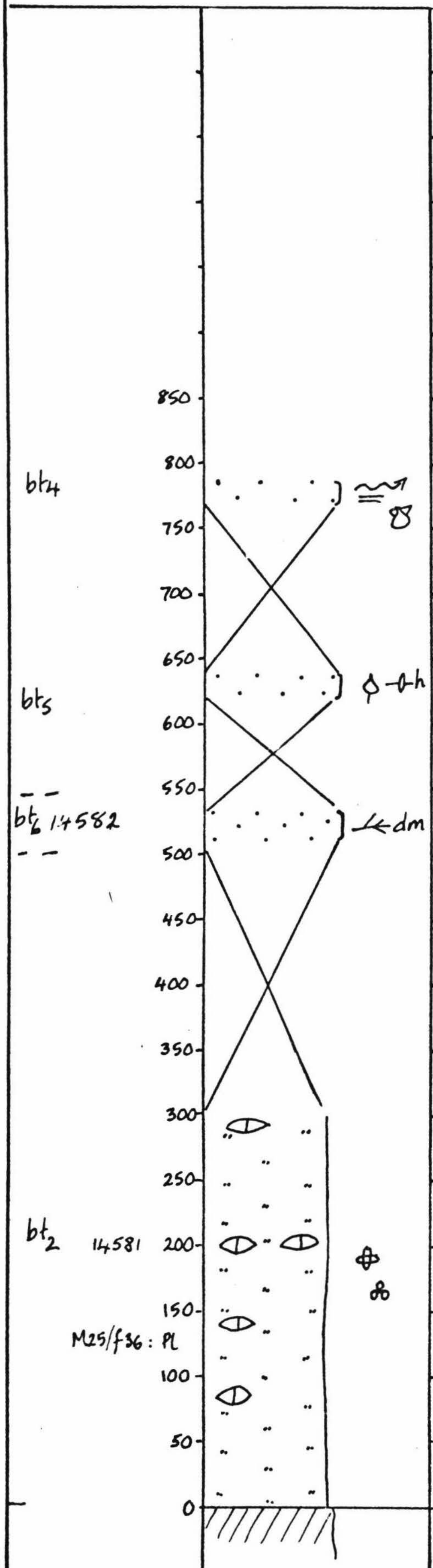
Sh

1.3 m coal

Sst ; 150 mm hd Sst at base

Summary section: ONEKAKA

Coastal cliffs between Little Kaituna Stream and Paton's Rock, road & stream outcrops around Onekaka



At Paton's Rock; sst, lt brn, f, horiz-lam, 100 mm-bd; interlam sst/Zst (facies bt4) (S8/f573: N.D. ; sample 14583). Stratigraphic relation to rest of column uncertain, as sequence may be faulted in Parwhakaoho R. area, otherwise could be as much as 1100 m above base of section.

← [Parwhakaoho Rivermouth]

Sst, lt gy bl, mod soft - mod hd, f, rare shell frags incl. ? *Cuspidaria* sp; horiz-lam and combined flow ripples

Sst, lt gy, mod soft, f - f, (carb), Plt Rem, ellipsoid burrows up to 20 mm diam filled with yel-brn f Sst

Sst, lt gy, mod soft, f, srt, schistose sublitharenite; 120-400 mm trough x bd, 3 mm tk carb Mst drapes and Mst rip-up clasts (see fig. 43)

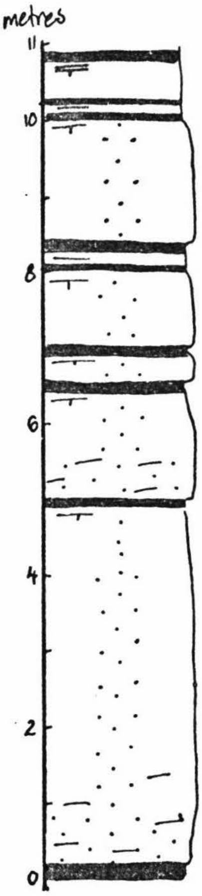
Zst, gn gy, mod hd, rare shell frags of Biv, Gast; common large tabular calc concretions; strongly bioturb, 2-10 mm diam burrows sometimes visible.

GOLDEN BAY FAULT

Onekaka Schist

Summary section: ONE SPEC CK.

Stream outcrops in One Spec Ck. (base N26/906368). Detail section at bend in Anatoki River and adjacent terrace riser(N26/906366).



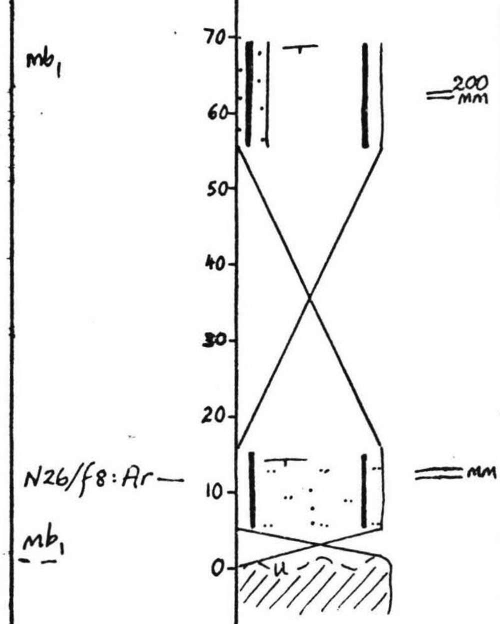
Interbd Sh, dk brn, mm-horiz-lam ; coal, hd, bright

sMst, (hd), dk brn, carb

sMst grad to mSst

sMst grad down to mSst, (hd), dk brn

DETAIL SECTION BESIDE ANATOKI RIVER (N26/908366)

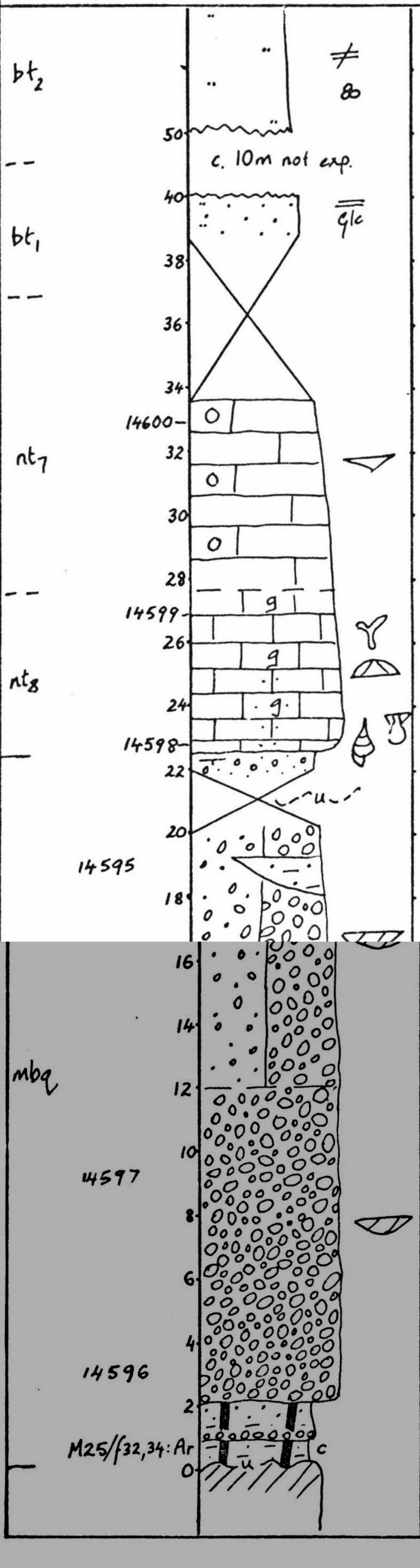


Mst, dk brn, (hd), abundant coal Strks, minor interbedded Sst, f, lt brn, grad up to Mst, c. 200 mm bd.

sZst, dk brn, (hd), carb, mic, coal Strks

Detail section: PARAPARA

Composite section: Quartz Wash Mbr outcrops adjacent to lower Parapara River (M25/825519, 823350, 834519), Blue Pond and east of Washbourn Creek (Washbourn Limonite Mbr. excluded). Takaka Lst & Tarakohe Mst from Parapara Inlet & above Pp. River (823543, 823531)



Zst, (hd), med bl gy, mass

zSst, (soft), brn gy, f-f, srt mic Qzarenite, common lobate Glc; horiz-lam.

Calcarenite (s Brac Grst), lt gy; f, srt Qz s and abraded indeterminate allochems with rare Brac frags up to 20mm long; horiz-lam; Soln planes at 40-200mm spacing accentuated by wthring.

Bry. Ech Grst, med bl gy with olv gy, f, homogeneous, med S-sized allochems and f Qz s; 40-200mm Flags.
grad down to
s Gast Grst, lt gy-gn; large Gast & Biv in matrix of fine-grained allochems incl. Ech, Foram, Bry.

Local angular unconformity suspected

Interbd cgl - pbl Sst / crs-granule Sst; wh, mod hd; Cgl, bimodal disn. (1) 70-160mm diam, (2) 20-30mm boulders-pebbles in (srt) crs S - zS matrix; Sst, abundant pbl up to 10mm diam in crude inclined lam.

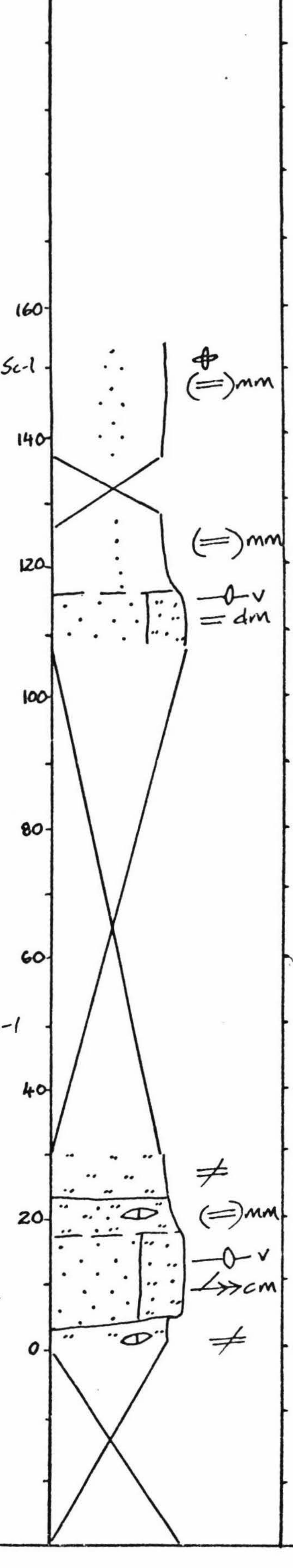
Cgl, mod friable, wh; generally clast-supported; boulders 30-50mm, up to 160mm are well rnd; matrix of soft wh (srt) z-crs S; crude horiz or inclined lam, rare trough-fill. Sometimes with yel-gy Pyr coating. Basal cgl may have ang clasts of schist up to 0.5m long, otherwise cgl entirely vein Qz - Quartzite.

Interbd pbl Cgl, f Sst, Mst; carb, pyr.

wthd Waingaro Schist & Onekaka Schist

Summary section: PARIWHAKAOHO

Lower part of section based on riverbank outcrops (base at M25/855438). Upper part from road cuttings on Highway 60 between McCartney's Hill and Pariwhakaoho River road bridge (base at M25/871460).



← Pariwhakaoho River road bridge

sZst, mod soft, med brn with purp-orng, f, mic, (carb), bioturb or faintly horiz. lam, generally non-calc.

Sst alternating with interbd Sst/Zst

f585 from top of McCartney's Hill may be in equivalent strat. posn to 40–80 m.

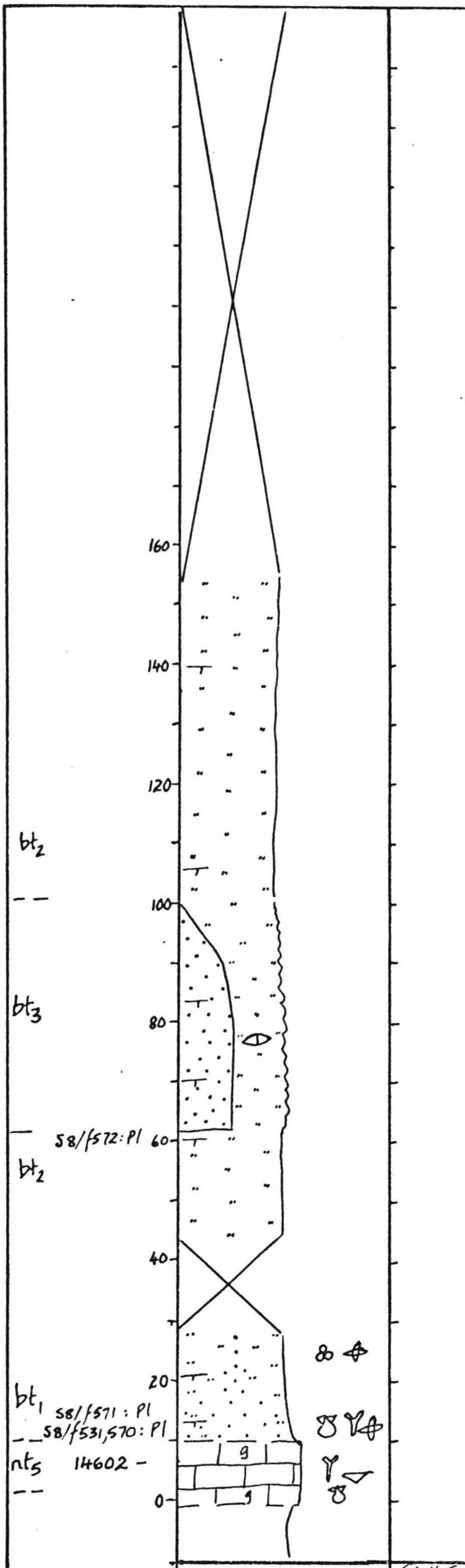
Zst, mod hd, med brn, wthd, mass

sZst, med gy, f srt S, (mm-bd); calc Conc common c. 21 m, grad down to

Sst, med gy bl, f, 100–700 mm horiz-bd or low-angle planar x bd or trough x bd or bioturb (see Detail Section fig. 43); alt. with interbd Sst/Zst.

Zst, med bl gy, small calc Conc, mass

Probably c. 600 m to lower part of section.



Probably c. 600m to upper part of section

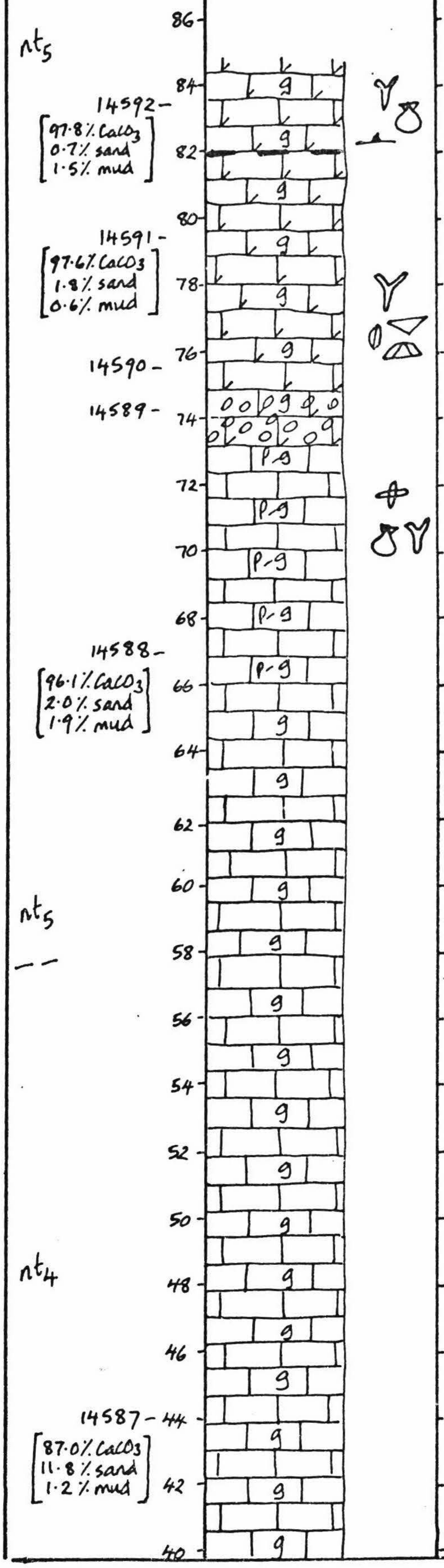
Zst, mod hd, med gy bl, scattered exposures in riverbed and in Turnbull Ck. Micro- & macrofossil collections S8/f527 - f529 (Pl) from Turnbull Creek; f529 prob. from c. 400m above base of section.

Alt. Sst / Zst : Sst, mod hd, 30-200mm average 100mm, massive or horiz-lam, grades up to
Zst, mod hd, med gy bl, average 500mm tk, massive;
Tabular calc Cones up to 100mm tk

mSst, mod hd, dk brn gy, f srt; Glc, Foram, bioturb., grad down to
Sst - slst, hd, dk yel brn, Glc, Bry, Forams average 1 mm diam, inhomogeneous muddy matrix ⇒ burrowing.
Biv-Bry Grst, hd, lt gy, wth lt brn; dkgy wispy soln planes, flags 40mm tk.
Underlain by wthd Lst: med S, Fe-stnd, Glc, Shell Casts, puggy clay, orng, non-calc.

Detail section: PAYNE'S FORD

Composite section : upper 18 m exposed in A.M. Irvine's limestone quarry (N26/944358), rest in Payne's Ford Scenic Reserve (N26/941357). Correlation by water bore (A.M. Irvine, pers. comm. 1978).



Biv-Bry Grst, hd, lt bl gy with/ lt gy, abundant large Bry 5-15 mm diam, Biv, Ech, enclosed in boudinage-like microstylolite swarms; common Dol; Flags average 100 mm tk, 5 mm tk dk bl gy seams grades to

Bry Grst, lt bl gy, Bry up to 20 mm diam, Biv, Brac, Ech, Foram. Flags 60 mm tk with 5-10 mm dk gy seams (see fig. 29c)

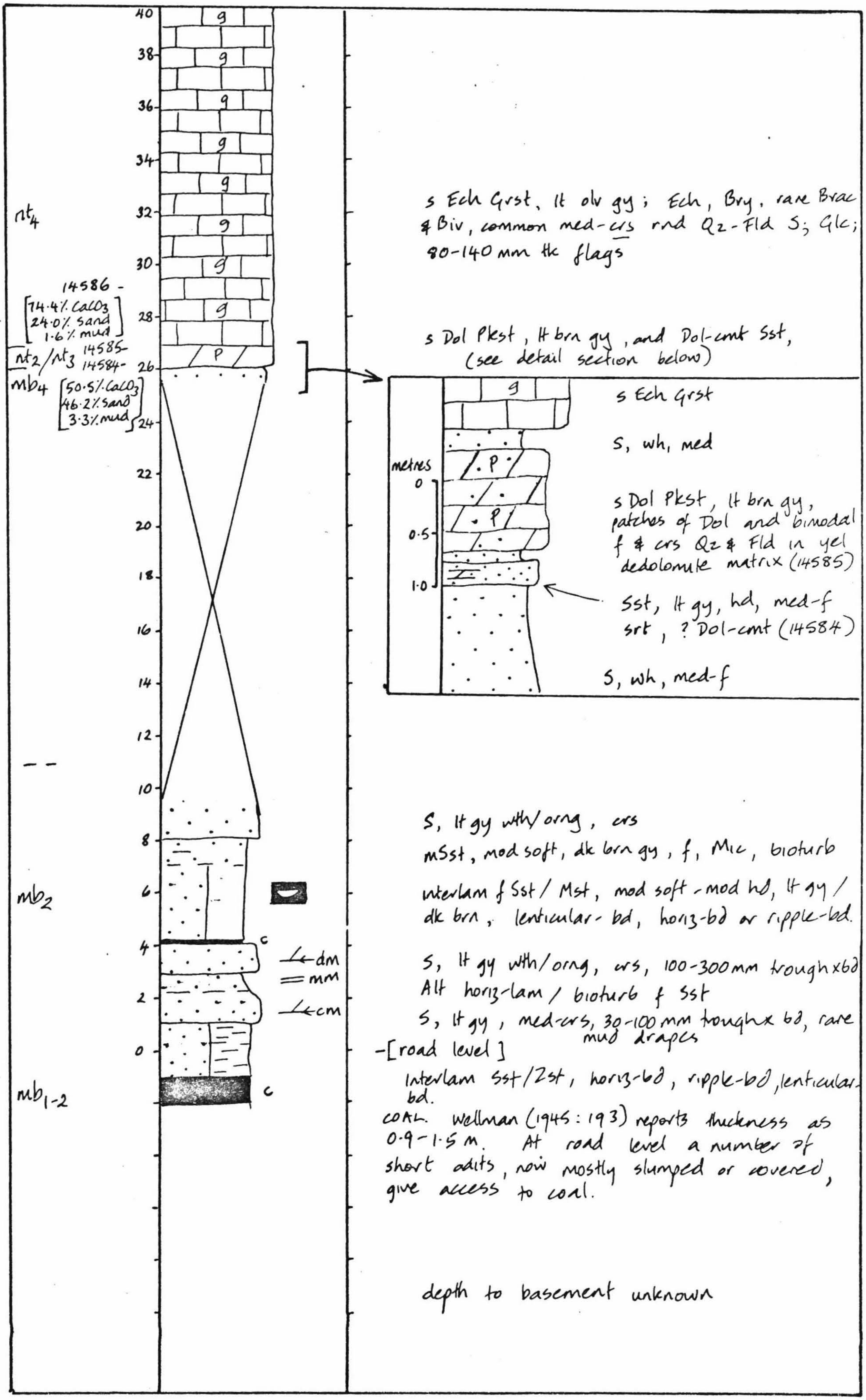
14590: (flag) 98.4% $CaCO_3$, 0.5% sand, 1.1% mud
(seam) 89.7% $CaCO_3$, 5.3% sand, 5.0% mud

Pbl-Bry Grst, lt gy, large Bry, rnd quartzite, schist, dolomitic slate/shale(?) average 25 mm long, disorientated

Bry-Biv Pkst-Grst, lt bl gy, large Biv frags, Bry in patchy Pkst & Grst, mod. bioturb. Flags average 40 mm tk; rock v. suitable for quarrying because large blocks split vertically rather than along horizontal flags as does Bry Grst above

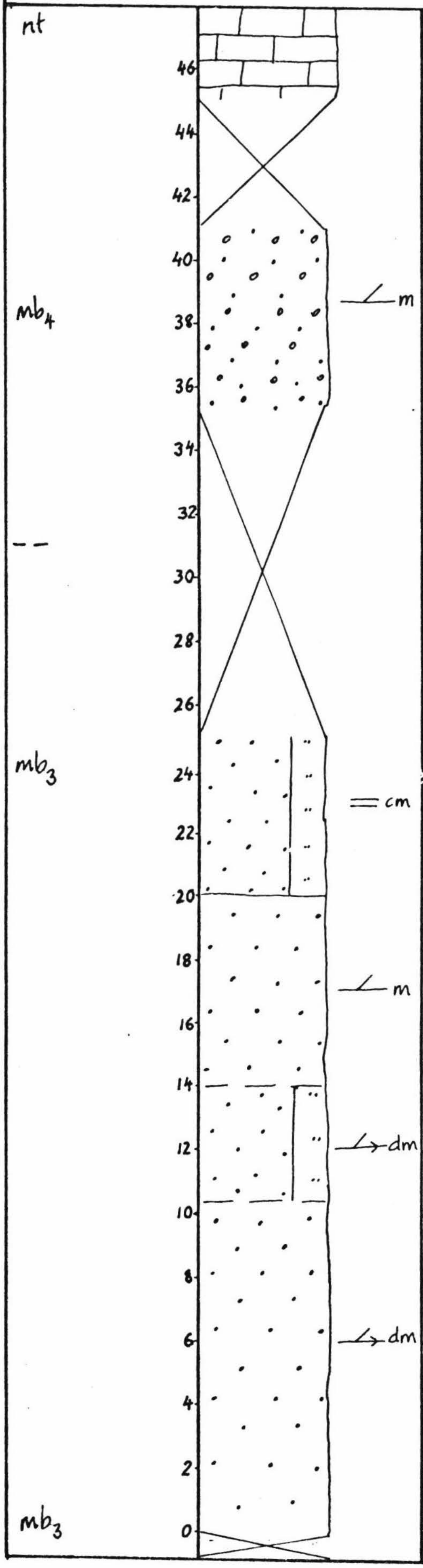
[Base of quarry at 66 m; Payne's Ford section inaccessible above 44 m, but approx. top of cliffs at 70 m. Upper 10 m of cliffs (c. 60-70 m) comprises very flaggy Lst with sol^n planes c. 80 mm spaced.]

s Ech Grst, hd, lt brn gy; med s-sized srt allochems incl. Bry, Ech, Foram; med srt Qz-Fld S; mod. flaggy, 50 mm spaced.


nt4
14586 -
[74·4% CaCO3 24·0% sand 1·6% mud]
nt2/nt3 14585- 14584-
mb4 [50·5% CaCO3 46·2% sand 3·3% mud]
mb2
mb1-2
s Ech Grst, lt olv gy; Ech, Bry, rare Brac & Biv, common med-crs rnd Qz-Fld S; Glc; 80-140 mm tk flags
s Dol Pkst, lt brn gy, and Dol-cmt Sst, (see detail section below)
metres
s Ech Grst
S, wh, med
s Dol Pkst, lt brn gy, patches of Dol and bimodal f & crs Qz & Fld in yel dedolomite matrix (14585)
Sst, lt gy, hd, med-f srt, ? Dol-cmt (14584)
S, wh, med-f
S, lt gy wth/orng, crs
mSst, mod soft, dk brn gy, f, Mic, bioturb
interlam f Sst / Mst, mod soft - mod hd, lt gy / dk brn, lenticular-bd, horiz-bd or ripple-bd.
dm
mm
cm
S, lt gy wth/orng, crs, 100-300 mm trough xbd
Alt horiz-lam / bioturb f Sst
S, lt gy, med-crs, 30-100 mm trough x bd, rare mud drapes
-[road level]
Interlam Sst/Zst, horiz-bd, ripple-bd, lenticular-bd.
COAL. Wellman (1945: 193) reports thickness as 0·9-1·5 m. At road level a number of short adits, now mostly slumped or covered, give access to coal.
depth to basement unknown

Detail section: POHARA

Roadcuts on assess road to Golden Bay cement Co. claypit. Base of section at N25/000411



Lst (see Tarakohe section)

gS, lt gy, f-crs (srt) s & lam of (ang)-(rnd) pbls up to 10mm diam

Alt S / mS ; S, lt gy, Qz-Mic, f, 5-10mm lam horiz-bd 80-120mm tk ; mS, f, lt yel, 10-30mm horiz-bd ; 170mm tk wh sM at base

S, crs, dm-m trough x bd

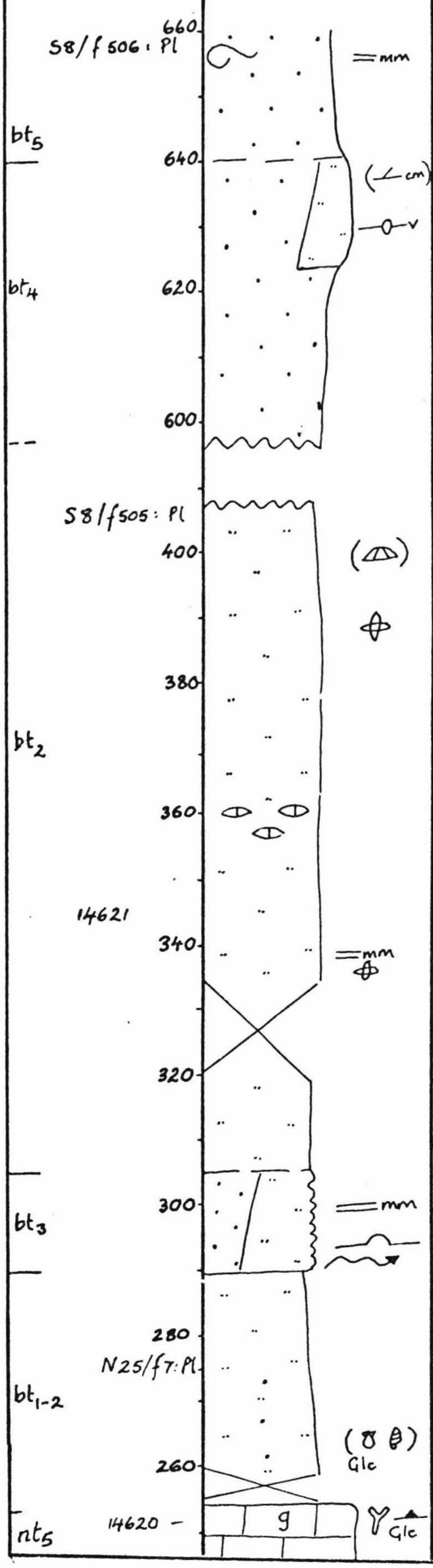
S, med, Qz-Mic, dm-trough x bd with (carb) Mst red-bn interbeds

S, med, lt gy, dm-trough x bd.

prob 100-150m to basement

Summary section: RANGIHAEATA

Top of section at prominent stacks east of Onahau rivermouth, N25/c. 917456. Mst exposed at low tide on beach west Rangihaeata Hd; Lst in cliffs on headland; Brunner CM in cliffs and on beach east of headland. Base of section at N25/920434



Sst, (soft), med gn gy, f srt, lam; 2 restricted shell bds with casts of Gast, Biv

Sst, (hd), wthd med orng, med, srt, indistinct cm-x bd; interbd mSst, cm-horiz-bd; common *Ophiomorpha nodosa*, ? *Arenicolites*

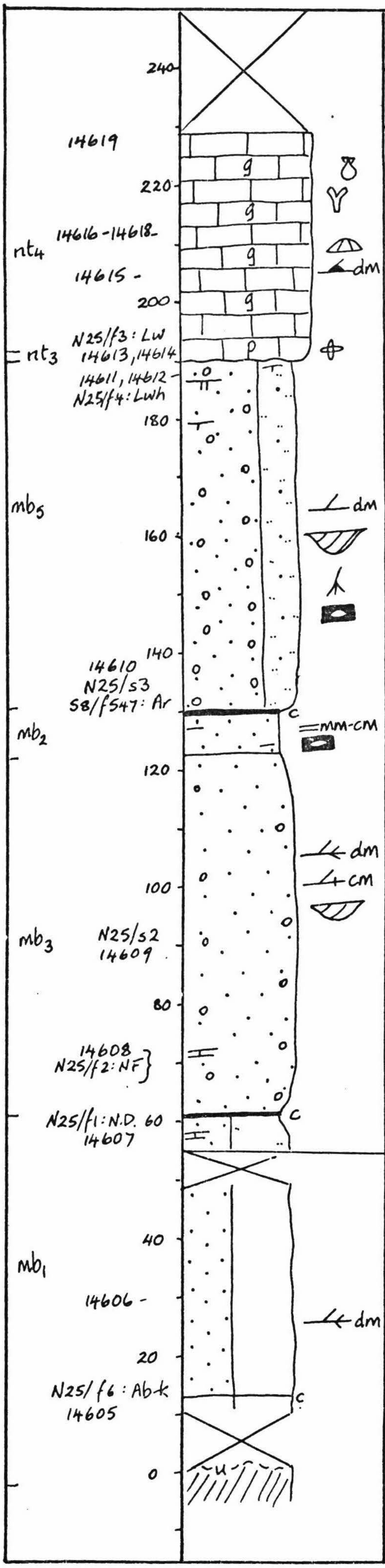
no exposure between 410 and 600 m

Zst, (soft), med bl gy, strongly bioturb; horiz-lam & ripple-lam f Sst-Zst c. 340 m; tabular Calc Conc c. 360 m; rare concns of calc worm tubes, Echs *in situ*

Graded Sst / Zst, (hd), med bl gy; f Sst horiz-bd or rip-bd, grad up to lam or mass Zst; beds 100 - 600 mm tk

sZst, (soft), wthd yel-brn, glc, rare casts of small molluscs, grad up to mass Zst

Bry Grst, med bl gy, hd; (srt) diverse fauna mainly Bry, Ech, Foram; Glc; wispy microstylolites.



s Bry Biv Grst, lt gy - med bl gy, hd, mainly Biv, Bry, Ech, benthonic Foram, srt crs Qz S concentrated on sol^n planes 40-100 mm spaced; seams of calc Sst up to 20 mm tk are common; 200-600 mm tk x bd locally common. See figs 29b, 30a, 30b.

At base: Biv Pkst lens, lt brn, irreg stylolites, bioturb; rnd, (srt) Qz-Fld pbls up to 110 mm diam

Alt Sst/Cgl - Mst, mod hd, wh S, dk brn M: Sst, f-pbl, (srt), 20-80 cm trough x bd. Mst - f Sst, carb, horiz-bd or lenticular-bd, common rootlets.
(see fig. 16)

Sst, med brn-gy, med-f, horiz-bd, ripple-bd flaser & lenticular-bd.

S, lt gy-yel, crs, srt; cm-dm trough x bd, planar x-bd; no Mst at all, but abundant wh Mst perigenic clasts
(see fig. 13, 14)

Coal, x bd med Sst, lam f Sst/Zst (see fig. 9, 10)
lateral shift to Takaka rivermouth (N25/924440)
Base of section on private road south of Holmwood's property (N25/920434).

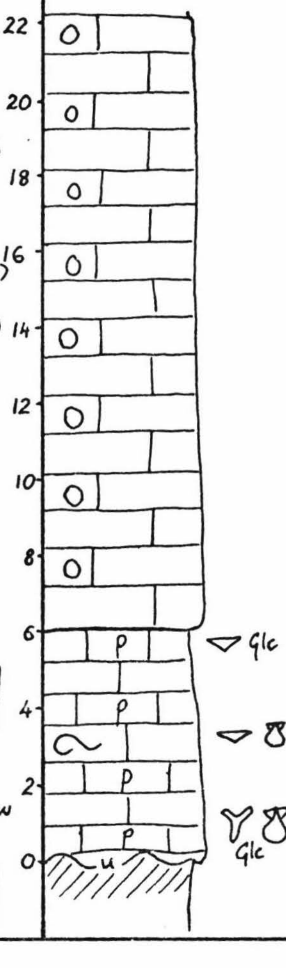
Alt S/M(st), lt gy-wh; S, crs, srt, fld, cm-dm trough x bd, grad up to med f S, horiz-bd or ripple-bd, grad to mass. wh Mst-Clst; sequences 3-10 m tk, of which 1-4 m is x bd S. See detail section fig. 7

base not seen

on wthd Onekaka Schist

Detail section: SILVER STREAM

Quarry at M25/714451.



nt_7

14626

58/f488: Po
M25/f37: ?Po

14627 (58% $CaCO_3$)
14628 (80% $CaCO_3$)

14625

nt_7

14624
[82.0% $CaCO_3$
15.1% sand
2.9% mud]

nt_3

14623

58/f521: Lw

14622
[89.6% $CaCO_3$
4.6% sand
5.8% mud]

sLst (calcarenite), (hd) dk gn gy at top, otherwise alt. bands dk gn gy (14627 : Ech-Biv calcarenite) & med-lt gn gy (14628 Ech-calcarenite); insol s:m % are 31.4 : 10.4 and 15.1 : 4.7 respectively; dk strks are c. 50 mm wide at 50-100 mm intervals. Horizons of Biv, Ech, burrows common. Macrofauna dominated by <u>Lentipecten</u> <u>hochstetteri</u>, unident. Brac, Ech (echinoids, crinoids), leached Biv; blky, wthring med brn.

(main quarry level)

sharp contact

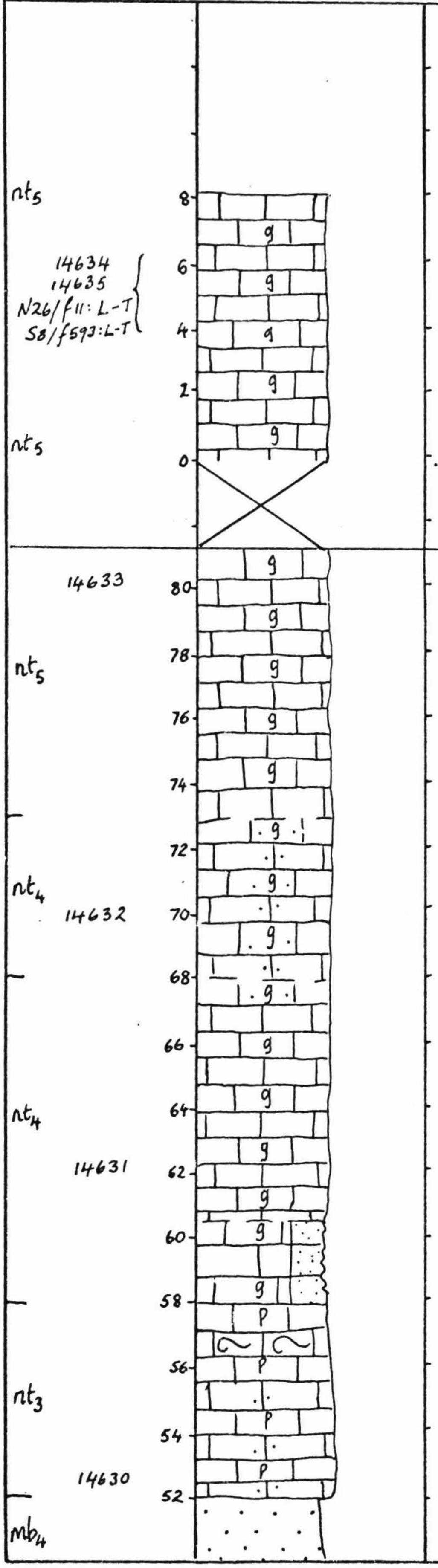
Brac-s Pkst, lt gn speckled dk gn, <u>hd</u>, large Brac & Biv, small abraded Shell Frags, Glc, f-crs Qz-Plag S, in mottled lt gn micrite matrix

300 mm bd : Brac-Biv calcarenite, olv gy, hd, abraded shell frags 10-20 mm long parallel bdg in olv gy f S.

Moll-Bry Pkst, gn, <u>hd</u>, abundant Bry, common Biv, rare rock frags, bioturb. Nodular flags 150 mm tk

Detail section: TAKAKA

Base of section on farmtrack (N26/944394) which climbs to Trig CC (N26/947398). Catchment Bd. quarry at N26/950393.



Nelson Catchment Bd. Quarry (Scott's Quarry).

Bry Grst, hd, lt gy or lt gn, dk gn gy sol^n seams; either homogeneous Bry-dominated or else Pkst with large Bry colonies. Macrofauna dominated by oysters, large pectinids, large Bracs. Also blocks of horiz-lam tightly-packed microstylolitic rock similar to sol^n seams but over 50 mm tk. Stratigraphic rel^nship uncertain; Grst generally flaggy, 20-40 mm spaced.

lateral shift to Trig CC (N26/947398) Strat. distance prob. 0-10 m.

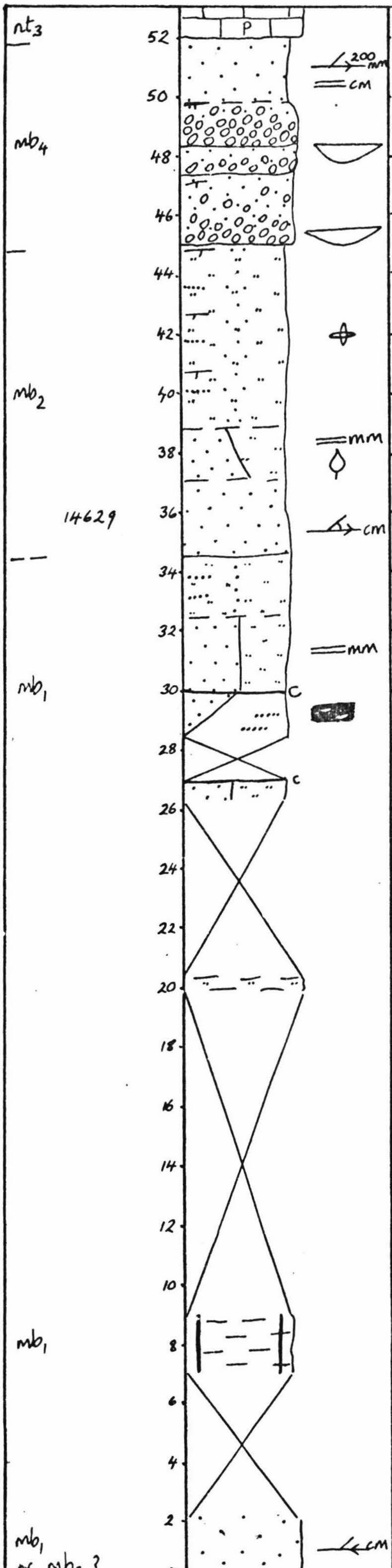
Bry Grst, hd, pal gn; large Bry colonies with branches up to 150 mm long, c. 5 mm diam., radiating from central core, oysters, pectinids, rare Brac; Flags 20-50 mm tk.

Glc Bry Pkst, hd, speckled lt gy-gn; med Glc, crs Qz, f, Qz s (bimodal), Bry, Biv

s Bry Grst, med gy brn; large Bry frags and Brac in matrix of very tight-packed Bry debris, common srt f Qz-Fld sand; Flags c. 40 mm tk

Alt. Moll s Pkst, hd, pink, Flags 50 mm tk, and sLst, (hd)-(soft), Mollusc-rich; Layers 200-300 mm tk; rare burrow traces.

Biv sPkst, hd, gy brn; Biv, Bry, Foram, bimodal med, crs Qz-Fld s, in pink micrite matrix; micrite envelopes & collapsed dissol^n moulds common in thin section; appears massive at base, from 53 m upwards, faint lenticular flags 30-60 mm tk. Shell lag concentration at 57 m.



Biv sPkst

S, srt crs, 200mm trough x-bd & horiz-lam
S, crs-granule, cm-horiz-bd, grad down to
G, 10-20mm diam pbls in med S matrix, on scoured surface

pbl S grad to G

sMst, (soft), wh - lt brn, (carb), med S strks, (bioturb).

Interlam f S / sZ, soft, lt gy - lt brn, 1-2 mm horiz lam, Plt Rem
S, lt yel-wh, srt med-f subfeldsarenite, low-angle trough x-bd, rare perigenic Mst clasts

sZst, dk gy brn, carb, S strks at top, grad down to
interlam S/Z.

300 mm tk coal
Interlam S/Z grad down to Mst, carb, lenticular-bd.

200 mm tk coal,
interlam S/Z

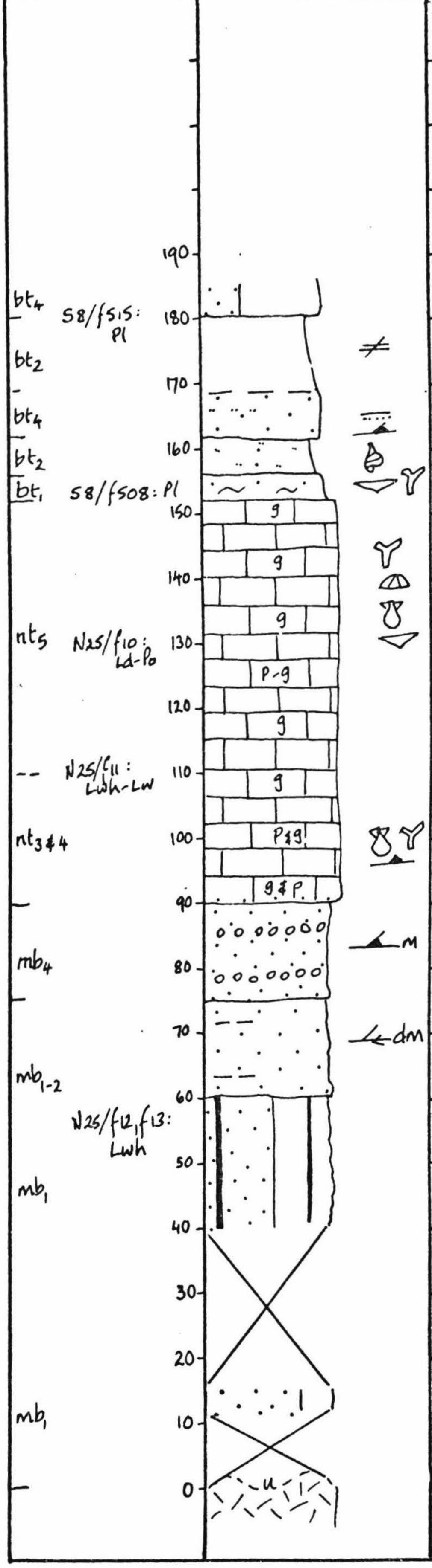
Mst, carb, wthd.

interbd carb Mst, coal

S, lt gy, Fe-stnd, med, cm-trough x-bd, Mic lam,
depth to basement unknown

Summary section: TARAKOHE

Composite section : Golden Bay Cement Co. quarry, roadcuts in Tarakohe area and farm tracks inland from south Ligar Bay.



Alt mSst/Mst, wthd, orng-brn

Mst, med bl gy, mass

f sst, med gn gy, horiz bd – x bd, bioturb, some interbd Mst

sZst, med bl gy; Foram, Gast, Biv; mass

m-sLst & mSst, gy gn, Bry-rich, also Brac, Ech, Biv

Bry Grst, minor Pkst, gn gy wth/pal brn, hd large Bry, whole Biv & Brac, 100-150 mm tk Flags

Bry-Biv Grst, lt brn gy, Biv parallel bdg, common srt med-crs Qz S; prominent 50 mm tk flags;
minor Pkst, lt brn, disorient. Bry & Biv in pk-gy micrite, bioturb, 100-200 mm irreg. flags

S-G, wh-lt gy, (srt) f-crs S, pbls up to 20 mm diam., low-angle x bd.

S, lt gy, med-crs, dm-trough x bd, thin mS interbds

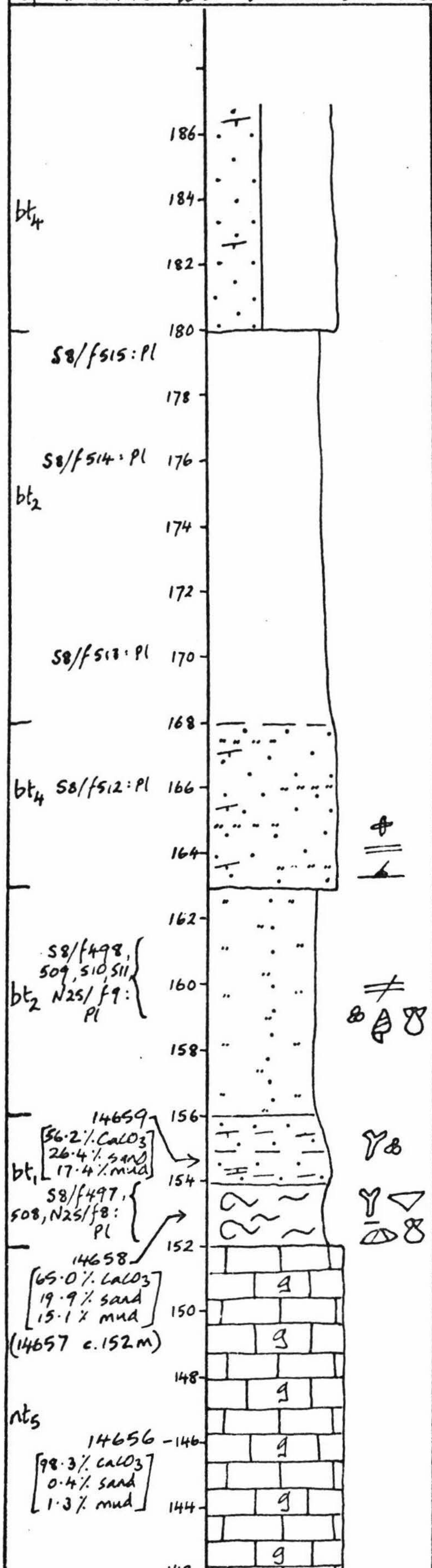
Interbd S, crs, indistinct x bd; Mst, dk brn; sMst, bioturb, carb; thin coal

wthd Sst and wh Mst

leached Separation Pt. Batholith.

Detail section: TARAKOHE

Section above 109 m measured in Golden Bay Cement Co. quarry (N25/014420-014422). Lower 16 m of Takaka Limestone measured in roadside cliffs at N25/013422. Lower 2 m of limestone and Brunner coal measures from roadcuts south end Ligar Bay - 018427.



<u>Type section Tarakohe Mudstone</u>

Alt mSst & Mst, wthd, orng-brn, mod soft

Mst, unwthd, med bl gy, mass

f Sst, med gn gy, hd - mod soft; sharp base, horiz-lam or low angle planar x-bd, climbing ripples, grad up to bioturb Sst, rare long vert. burrows, sometimes grad up to dk gy (carb) horiz-lam Mst; c. 0.5 m-bd.

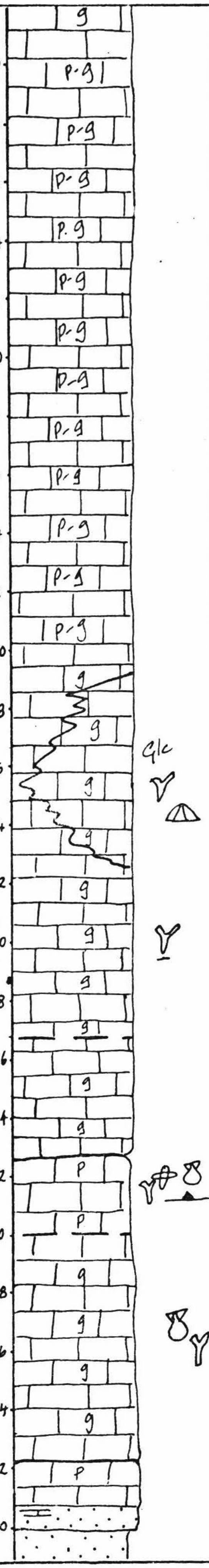
sZst, med bl gy, mod soft, abundant Forams, Gasts, Bivs, mass.

mSst, gn gy with yel, mod hd - hd; sand-sized Glc, Forams, Bry & Biv frags in muddy matrix

"Bryozoan Bed": m-s Lst, gy gn, soft; abundant Bry, Pyr, Biv, Brac, common Ech, Foram, rare crabs, sharks teeth, <u>Aturia</u> (nautiloid), solitary coral

<u>Type section Takaka Limestone</u>

Bry Grst, minor Pkst, gn gy with pal brn, hd; tight packed Bry, Ech, Brac, Biv, benthonic Foram, esp. large wh circular Bry colonies c. 20 mm diam. Bracs (? <u>Pachymagas</u>) and Biv (<u>Serripecten hutchinsoni</u>, <u>Mesopeplum burnetti</u>) usually intact, in prob. life-posn. Subplanar or lenticular flags 100-150 mm tk.



nt5

nt3-5

14655 – 136

[98·2% $CaCO_3$
0·8% sand
1·0% mud]

Bry Pkst - Grst, mod gn gy with lt brn yel; as described above.

N25/f10: Ld-P
14654 – 126

[98·8% $CaCO_3$
0·4% sand
0·8% mud]

[Main quarry level; Lst above here used in cement manufacture; Lst below is too alkaline and is used for harbour fill.]

14653 – 116

3 analyses from this level, 2 flagstones, 92·8% & 93·5% $CaCO_3$; seam 85·8%

Glc

Glc-Ech-Bry Grst, mod gn gy with lt brn gy, dk gn gy seams, similar to above lithology but rel. homogeneous crs-S sized allochems, common med-f srt Qz sand, med-crs Glc; 50-100mm planar - lenticular flags.

N25/f11: Lwh-Lw
14652 – 110

[93·4% $CaCO_3$
5·0% sand
1·6% mud]

[Base of Quarry exposure; lower part of section measured in coastal cliffs at N25/013422 and 018427.]

nt5

nt4

14651 –

Bry - Biv s Grst, as described below.

14650 – 102

nt3

Biv - Bry Pkst, lt brn, disorientated Bry, Biv in pk-gy micrite, bioturb; irregular lenticular - nodular flags c. 100-200mm tk. grad to

nt4

14649 –

[93·5% $CaCO_3$
5·4% sand
1·1% mud]

14648 –

Bry-Biv s Grst, lt brn gy; Biv & Bry frags aligned parallel to bdg, common med, srt, rnd Qz s; 40-60 mm tk subplanar flags

14647 –
[92·5% $CaCO_3$]

nt3

14646 – 92

Bry sPkst, lt brn gy: Bry, Mollusc, Brac, ang f-crs Qz s in bioturb micrite matrix

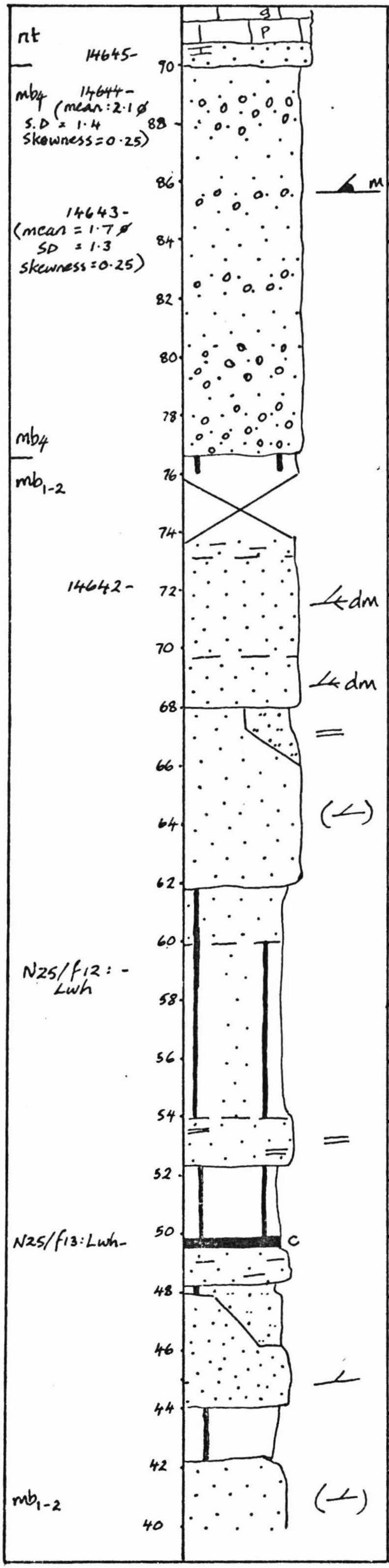
nt2

14645 –
[36·9% $CaCO_3$] 90

mb4

14644 –

Sst, hd, wh, calc-cmt, srt, crs, rnd Quartzarenite



Bry-Biv sPkst
Sst, med, calc-cmt (See Fig. 15a, b : contact between mb and nt)

pbl S – G, (soft), wh- lt gy; S, f-crs, pbls up to 20 mm diam, (srt), rnd; quartzarenite; low-angle trough x-bd, 1-3 m tk.

Mst, dk brn, carb

mS, lt gy wth orng

S, med-crs, lt gy, (srt) Mic-subfeldsarenite, dm-trough x bd

Alt S, crs, Fe-stnd / sZ, wh

S, med, Fe-stnd, faintly x bd

S, brn, f, carb

sMst, dk brn, carb, bioturb
(dinoflagellates in f12 indicate marine influence)

S, crs, Fe-stnd, wh Mst strks

Mst, dk brn, carb
Coal
MS, wh wth orng, f, ?x bd

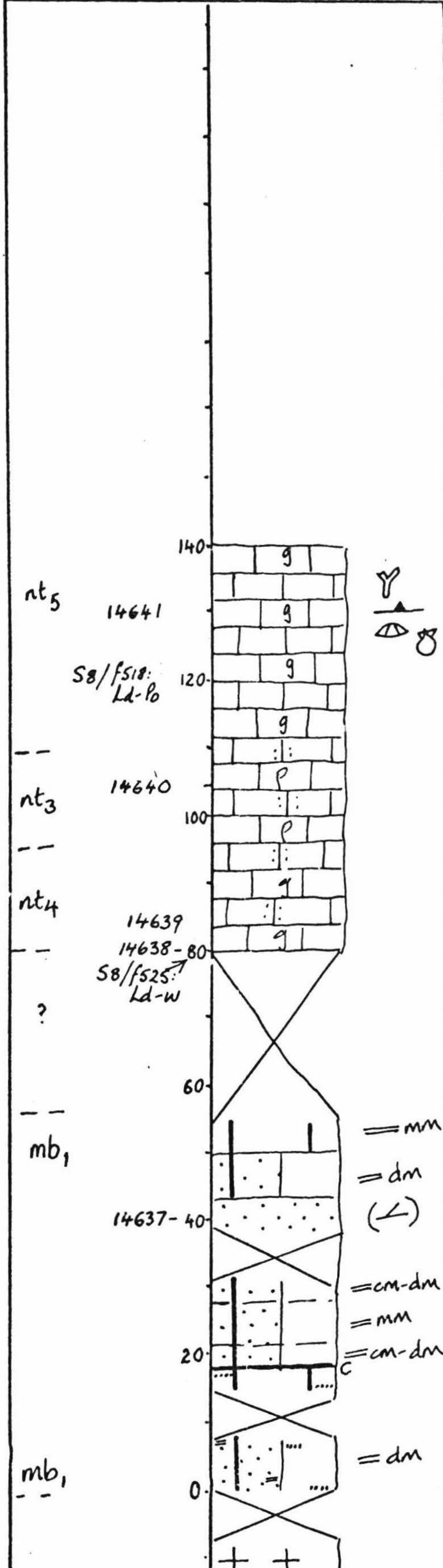
Alt S, 50 mm bd / sM-mS, 100 mm bd, grad up to tn bd dk brn Mst.

Mst, dk brn, carb

S, med, indistinct x bd.

Summary section: TAUPO POINT

Taupo Point and the coastline to the southeast ; base of section N25/063462



Bry Grst, hd, lt gy (wthd), crs s-sized Bry, Ech, Biv, Brac, benthonic Forams, crs Qz s

s Bry Pkst, (hd), wh, wthd, mostly Bry, also Biv, Ech, Foram ; med Qz s ; sol^n planes c. 100 mm apart

s Bry Grst, (hd), wh, wthd, many Bry, Ech, Biv ; sparse med-crs Qz s, srt ; sol^n planes 200 mm apart.

[obscured by Recent dune sands]

Mst, (hd), dk brn, coal & s strks, mm-lam

Intergrad Sst - sMst - Mst ; crs-granule S(st), (srt) feldsarenite, wh-lt brn, horiz-lam ; mSst -sMst - f-granule sand in carb matrix ; Mst dk brn, Plt Rem, s strks ; Sst c. 200 mm tk, transition c. 150 mm ; Mst c. 500 mm tk.

S, med-granule, soft, wthd subfeldsarenite

interlam S/Z, wavy & lenticular bd

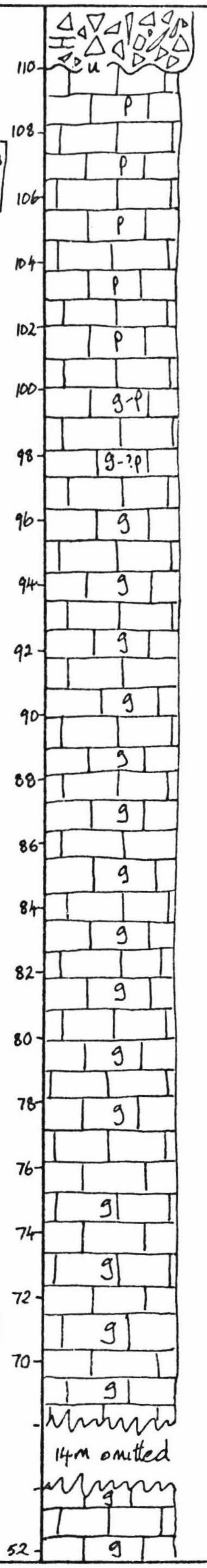
0·5m shiny coal ; Mst, dk brn, s strks

Intergrad Sst - Mst, as described above (similar to that at Waikoropupu, and to Mb5 at Rangihaeata)

wthd Seperation Pt. Batholith granite

Detail section: UPPER WAITUI

Section both sides of limestone gorge in Upper Waitui Stream : difficult access prevented accurate measurements. Base of section at N26/929125



Marble Breccia

nt_{3-5}

14668
[89.0% $CaCO_3$
9.9% sand
1.1% mud]

Bry Pkst, hd, lt brn yel; 1-2 mm diam srt allochems - Bry, Biv, Foram in open micrite matrix; numerous wispy stylolites subhoriz - oblique; flags 40-45 mm tk

[Access not attempted between 80m and 100 m]

nt_5

- - ?

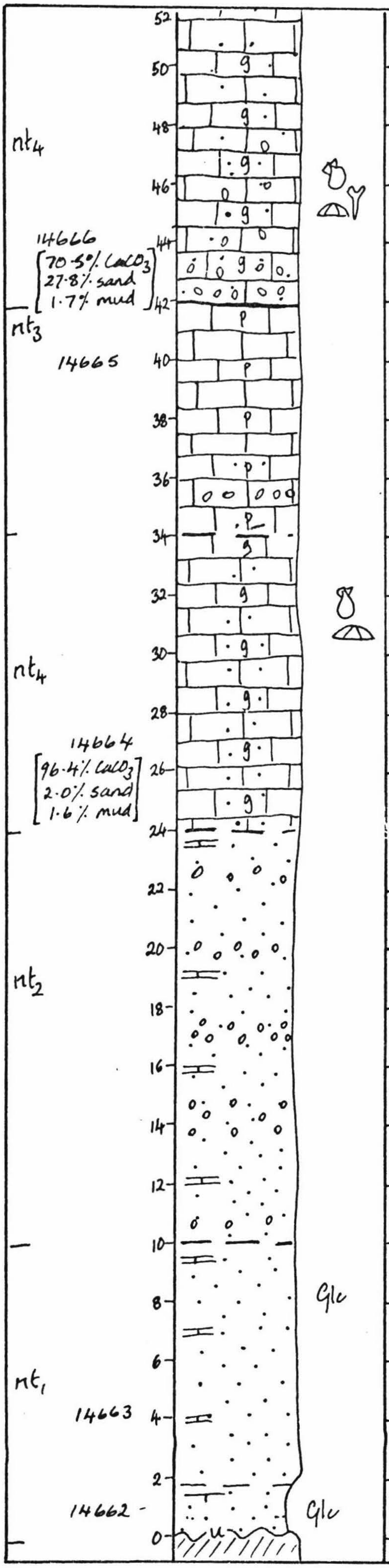
nt_4

Bry - Biv s Grst, hd, lt brn; crs s-pbl Qz & rock frags - rnd, srt, common Biv and Bry. Pbl bds c. 100-200mm tk at rare intervals contain scattered Qz pbls up to 50mm diam, (rnd). Lenticular flags 20-40 mm tk.

14667
[80.3% $CaCO_3$
17.8% sand
1.9% mud]

nt_4

52



s-pbl Biv Grst, hd, gy-yel; allochems 0.5-2 mm, (srt), up to 14 mm long in thin section, mainly Ech, Biv, Bry, Foram; Qz & Lithic s & pbls up to 10 mm, rnd; Glc. Flags 40 mm tk with common 5 mm tk calc sst seams.

[top of lower line of bluffs]

Bry Pkst/Grst, hd, lt gy - lt gn; dominantly Bry, in lt gn micrite matrix.

s Biv-Ech Grst, wh-lt gy; 0.5-1 mm diam allochems (Ech, Biv, Bry, Foram incl. Amphistegina) in open fabric; med-crs Qz s. Lenticular flags 20-40 mm tk, prominent soln planes at 0.5-1 m spacing.

sst, hd, pk-wh with dk gy, crs s-pbl cgl, Qz-Fld, blky, bluff-forming.

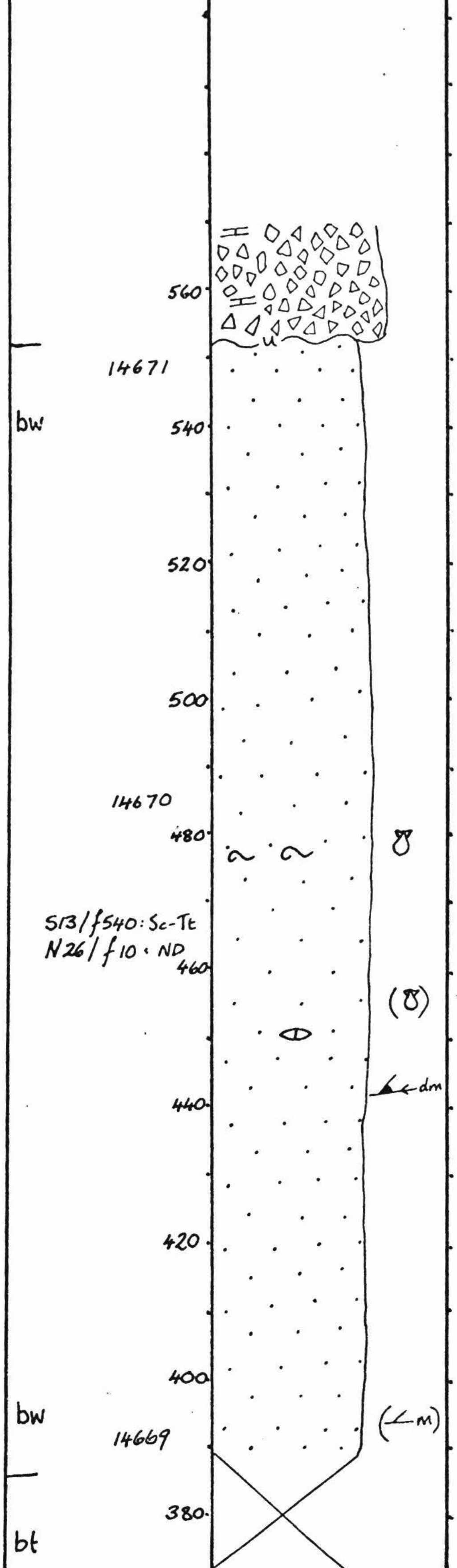
grad over c. 1m to

sst, calc-cmt, glc; abraded, bored allochems = Biv, Foram, Ech; Glc lobate, also allochem moulds. Srt med-crs Qz & Lithic s

zsst, mod hd, dk gy gn, glc, calc, srt med-f Qz-Lithic s, (carb), mass

Summary section: WAITUI STREAM

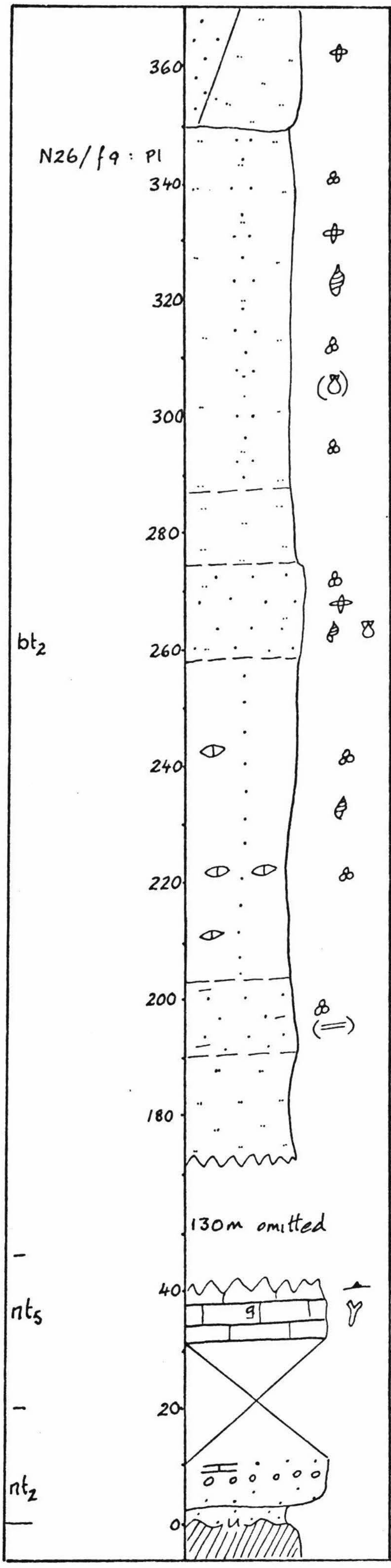
Lst in cliffs near junction east & west branches; rest of section in westwards-flowing tributary (called Hope Ck. by Cooper (1962)) which crosses road at N26/943163



Marble Br, calc-cmt, hd

Sst, (soft) - (hd), lt brn gy, commonly mass or well bioturb; c.450m, 0.5m low-angle trough x-bd with lam & lens of Qz-Fld crs s, granule, pbl up to 10mm diam; c.480m, rare Shell bds with few partially leached frags; bluff-forming 460-480m

Sst, (soft), lt gy brn, med, faint x-bd



Alt Sst / Mst, strongly bioturb; Sst, med, Qz; Mst med gy bl, Shell Frags, worm tubes

sZst, med gy bl, common Forams, rare small shell Frags, strongly bioturb

Zst, med gy bl, mod calc, mass

mSst, med gy gn, mod calc, abundant Forams, Gast & Biv shell Frags, strongly bioturb

sMst, med bl gy, calc, common shell Frags, common large Calc conc

mSst, (hd), med bl gy, f, calc, common Forams, faint horiz-bd

Zst, (soft), med bl gy, abundant Foram, common small shell Frags, mass

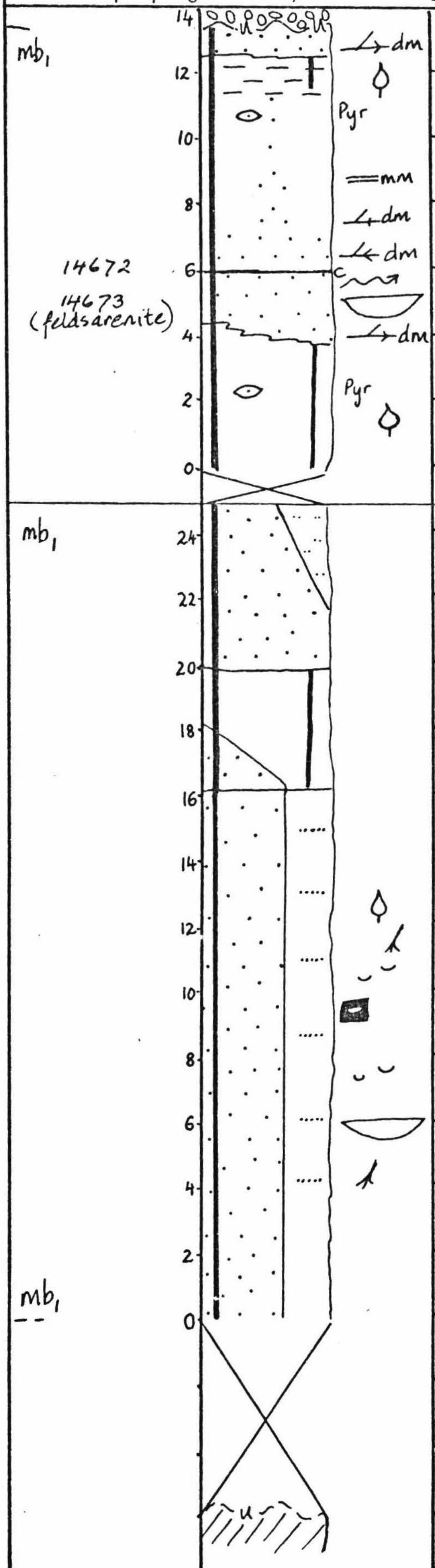
rare exposures of mass sMst in upper 60m

Bry Grst, hd, wh, soln seams c.50mm apart

Sst - Cgl, (hd), lt gy, med-f Qz s, rnd pbls 10-20mm diam in s matrix, shelly, calc-cmt; S, soft, med-f srt on unwthd Wangapeka Fmn.

Detail section : WAIKOROPUPU

Upper part section on farmtrack which meets Pupu Springs Rd at N26/908399 ; Lower part on Pupu Springs Road from roadbridge to sharp right-angle bend, base at N25/912405.



Pleistocene Kaituna Gravels, cgl.

Fining-upward sequence : interbd Mst and coal, dk brn, carb, Plt Rem, grad down to interlam S-Z, lt gy - med brn gy, mm-cm horiz-bd, grad down to S, med-crs, dm-trough x-bd or rare planar x-bd. See figure 8 for detail description & interpretation.

Mst, (hd), dk brn, carb, thn c strks, abundant Plt Rem & Pyr Nod., mass.

lateral shift 0.7 km, stratigraphic interval unknown, but probably not significant.

Interbd S and zSst ; S, med, wh, Fe-stnd, cm-dm x-bd ; zS, (soft), dk-lt brn gy, mic & carb, horiz-lam or ripple-bd

Mst & coal, grad down to f Sst, brn gy, horiz-lam & ripple-bd.

Alternating intergrad Qz Sst and carb mSst.

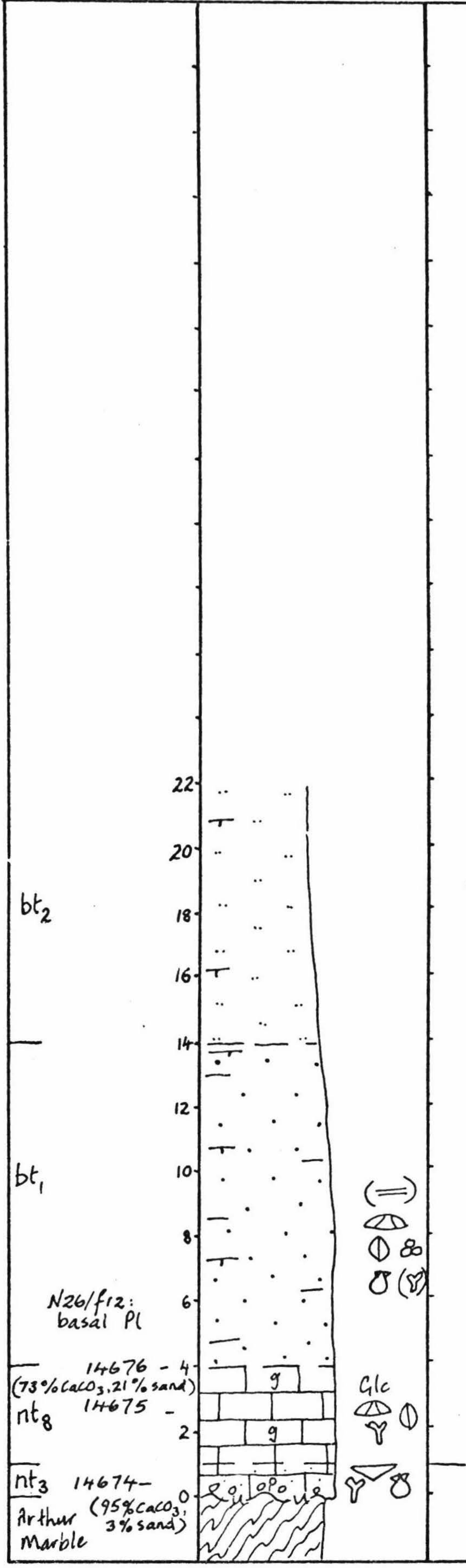
mSst, (hd)-(soft), med-dk brn, coal strks 10-20 mm thk, sand strks, horiz-bd & lenticular-bd.

Sst, (soft), wh-lt brn, med, Qtz-Mic, up to 50 mm thk ripple-bd, sub-horiz-bd, lenses (flasers) of carb mS, sM ; lenses of crs S - pbl gr. Coal strks, Pyr Nod. Beds 100-500 mm thk, average 200 mm.
Channel fill at 5.0-5.5 m, 14 m wide, Sst laminae from med S - 25 mm diam ang-subrnd Qz & Fld pbls.

Onekaka Schist

Detail section : WEST TAKAKA

North-trending gully approx. 1·5 km south of Washaway Ck, and below Trig 891
N26 / 939281



scattered outcrops wthd med brn Zst up to 42 m above base section.

Zst, wthd, (hd), med brn

Sst, (hd), gn gy, calc; crs Glc, Biv, Foram & Bry fragments & f srt Qz s faintly lam in dk brn m matrix

grad to

Glc - Bry Grst, hd, lt yel brn speckled gn, med Glc, Bry & Biv decrease in % upwards to a Bry - Foram Grst; Faint sol^n seam 20 - 40 mm apart.

Brac Pkst, hd, lt brn; large Brac, Biv, Bry, 10 mm diam rnd pbls, med srt Qz s

APPENDIX TWO

INDEX OF TERTIARY FOSSIL COLLECTIONS, GOLDEN BAY

Note (1) A large number of record numbers for which no age determination or fossil list are available is not included in these lists.

(2) Where possible, grid references have been revised in terms of the most recent NZMS 1 and NZMS 260 maps (listed below).

Sheet Fossil Number	Register Number	Grid Reference	Area	Strat. Position	Collector	Age
Sheet S3						
f494	GS746	044924	DT	nt	JP	Lw-Po
500	GS3901	045958	DB	base bt	HWW, ACB	Po-Sl
501	F10502	045958	DB	" +3m	HWW, ACB	lower Pl
502	F10503	114928?	ON	bt	HWW, ACB, RPS	Pl
503	F10504	112927	ON	bt	HWW, etc.	Pl
	GS3902					
504	F10640	043965	DB	base bt + 70m	RPS, DK	Pl
505	F10641	043968	DB	" " + 75m	RPS, DK	upper Pl
506	F10642	094025	Collingwood	bt	RPS, DK	Pl-Sc
	GS4713					
507	GS4716	057058	Marble Ck.	bt	RPS, DK	Pl-Tt
524	F16963	059058	Marble Ck.	bt	DGB	Sc
535	F17569	037945	near DB	Base bt + 6m	DGB	Po-Pl
536	F17570	090986	PP	bt	DGB	Pl

Sheet Fossil Number	Register Number	Grid Reference	Area	Strat. Position	Collector	Age
Sheet S7						
f498	GS2574	785773	GL	f499 + 9m	HWW	Lw-P
499	F -	785773	GL	base nt	HWW	Ld
500	GS3914	876824	Fossil Ck.	base bt	HWW, ACB	Po-Pl
501	F10505					
	GS3915	875834	Welsh Ck.	bt	ACB, RPS	top Pl-base Sc
502	F10506	877818	BR	base bt	HWW, ACB	Po-Pl
Sheet S8						
f488	GS47	c.959881	SV	nt	JP	Po
489	GS261	c.303973	Tata Is.	nt	J. Hector	N.D.
490	GS662	c.303873	Tata Is.	nt	J. Hector	Lw
491	-	293843	TR	nt	RP	? Pl-Sl
493	GS302	c.303873	Tata Is,	nt	J. Hector	N.D.
494	GS1469	290844	TR	base nt	JM	Lw
495	GS1468	290844	TR	? middle nt	JM	N.D.
496	GS1467	c.290844	TR	upper 6m nt	JM, J.Hend	L-P
496A	-	c.293844	TR	? base bt	-	N.D.
497	GS1466	c.293844	TR	base bt	J.Hend,JM	Po-T
498	F8731 F18293 GS1286	c.293844	TR	" + 6m	J. Hend	Pl

Sheet Fossil Number	Register Number	Grid Reference	Area	Strat. Position	Collector	Age
S8/f498A	GS12062	c.293843	TR	base + 6m	BE	Pl
500	GS3916	192876	RH	top nt	RPS,HWW,ACB	Lw-Po
501	GS3917	c.187878	RH	" + 102m	HWW etc.	N.D.
505	F10489	c.186879	RH	" + ?180m	HWW etc	late Pl
506	GS3900	184882	RH	" + c.400m	ACB	Pl
507	GS3918	293843	TR	upper nt	RPS	N.D.
508	F10490 GS3922	293843	TR	base bt + 0 - 4m	HWW	Pl
509	F10491	293843	TR	" + 5m	HWW	Pl
510	F10492 GS3923	293843	TR	" + 6m	HWW	Pl
511	F10493	293843	TR	" + 8m	HWW	Pl
512	F10494	293843	TR	" + 12m	HWW	Pl
513	F10495	293843	TR	" + 18m	HWW	Pl
514	F10496	293843	TR	" + 24m	HWW	Pl
515	F10497	293843	TR	" + 29m	HWW	Pl
516	GS3924	293843	TR	nt (loose fossils)	HWW	
517	GS3925	293843	TR	bt (loose fossils)	HWW	Pl
518	GS3926	342887	TP	upper nt	HWW	Ld-P
521	GS3927	?959881	SV	base nt + 0-5m	HWW	Lw
522	GS3928	?946876	Fifteen mile ck.	" " + 6m	RPS	L-P

Sheet Fossil Number	Register Number	Grid Reference	Area	Strat. Position	Collector	Age
S8/f523	GS3929	c.953882	SV	base nt + 20m	HWW	Po-P1
524	F10498	c.957883	near SV	" " + 65m	ACB,RPS	Po-lower P1
	GS3930					
525	GS3931	342887	TP	base nt	HWW etc.	Ld-w
526	F10499	215785	Rameka ck.	base bt + 18m	ACB,HWW	P1
	GS3932					
527	F10643	?123870	PW	bt	RPS,DK	P1
528	F10644	?123870	PW	bt	RPS,DK	P1
529	F10645	123868	PW	" bt + ?400m	RPS,DK	P1
	GS4715					
530	F10646	125868	PW	bt	RPS,DK	P1
531	F10647	119863	PW	base bt + 1m	RPS,DK	P1
532	F10648	293843	TR	" + 6m	RPS,DK	P1
	GS4714					
533	F10649	293843	TR	" + 10m	RPS,DK	P1
534	GS5051	213813	TK	?base nt	ETA	L
535	L8996	?	DR	top mb - ?	WAS,ETA	Ab-k
536	L8997	244783	DR	" - 125m	WAS,ETA	-
537	L366	247783	DR	" - 215m	WAS,ETA	Ab-k
538	L8998	247781	DR	" - 272m	WAS,ETA	-
539	L9012	247783	DR	" - 122m	WAS,ETA	Ak-r
541	L9013	246783	DR	" - 150m	WAS,ETA	-

Sheet Fossil Number	Register Number	Grid Reference	Area	Strat. Position	Collector	Age
S8/f546	L9011	247781	DR	top mb - 267m	WAS,ETA	N.D.
547	L437	191874	RH	" - 45m	WAS,ETA	Ar
560	GS9195	212775	PF	nt	EP	N.D.
563	L8989	244783	DR	top mb - 45m	DJM,JBW	Lwh
564	L8990	247781	DR	" - 160m	DJM,JBW	?Ab-k
570	F17388	119863	PW	base bt+ 2m	GWG	P1
571	F17389	119863	PW	" + 3m	GWG	P1
572	F17390	120865	PW	" + 60m	GWG	P1
574	F17391	979881	Table Hill	" + 15m	GWG	P1
575	F17392	902822	Clark R.	" + 15m	GWG	P1
576	F17393	900823	Clark R.	" + 30m	GWG	N.D.
577	GS9712	948857	LD	" + 30m	GWG	L-T
584	F17606	199640	Sam's ck.	bt	GWG	P1
585	F17607	133895	PW	bt	GWG	Sc-1
586	F17608	139885	PW	base bt+?900m	GWG	Sc-1
593	GS11228	222818	TK	base nt+?40m	WRG	Ld-Tt
Sheet S13						
f489	GS1455	120475	Grecian Stm.	base nt+18m	?	Lw-T
492	GS2848	-	WA	bt	HWW	P1
495	GS1287	-	Aaron ck.	lower bt	SS	P1

Sheet Fossil Number	Register Number	Grid Reference	Area	Strat. Position	Collector	Age
S13/f496	-	-	WA	base bt+100m	?	Pl
497	-	-	WA	" " +200m	?	Pl
498	-	-	WA	" +270m	?	Pl
505	F10465	238580	EB	top nt	HWW	Pl
506	F10466	238580	EB	" + 3m	HWW	Pl
507	F10467	238580	EB	" + 6m	HWW	Pl
508	F10468	236590	EB	"	HWW	early Pl
540	VUW	212552	WA	base bw+20m	RAC	Sc-Tt
541	VUW	209554	WA	bt	RAC	Pl
559	F17609	206530	WA-UW	bt	GWG	Pl
NZMS 260						
Sheet M25						
f 1	-	789519	DB	base nt+20m	REF	(cetacean)
2	F20375	789519	DB	" "	REF	Lwh-d
13	F20874	846513	ON	bt	NBH	Pl-Sc
31	F -	792520	DB	base nt+20m	SN,WLL	Lwh-Sw
32	L8530	825519	PP	base mbq	WLL	Ak-r
33	L8531	808514	Appo's Ck	" +?5m	WLL	Lwh
34	L8532	823350	PP	"	WLL	Ak-r

Sheet Fossil Number	Register Number	Grid Reference	Area	Strat. Position	Collector	Age
Sheet M25						
f35	VUW	740433	CS	base nt	WLL	Lw
36	VUW,F -	853516	ON	base bt+?200m	WLL	Pl
37	VUW	714452	SV	base nt+10m	WLL,CJB	? Po
38	VUW	714451	SV	" +10-22m	WLL	? Po
39	L4489	900435	LO	"upper" mb	SB	N.D.
40	L4488	899433	LO	"lower" mb	SB	Ab-k
Sheet M26						
f63	L8533	693391	QR	base mbq+8m	WLL	N.D.
68	VUW	553349	GL	base nt+1m	WLL	Ld
69	VUW	553349	GL	" +16m	WLL	N.D.
70	VUW	555348	GL	" +11m	WLL	N.D.
71	F -	636392	BR	base bt- 6m	WLL,RHH	Po
72	F -	636391	BR	" + 1m	WLL,RHH	lower Pl
Sheet N25						
f 1	L8350	923439	RH	base mb+55m	JIR,SN	N.D.
2	-	933441	RH	" +60m	SN,JIR	N.F.
3	VUW	924451	RH	base nt	SN,JIR	Lw (forams N.D.)
4	L8351	921447	RH	top mb -10m	JIR,SN	Lwh

Sheet Fossil Number	Register Number	Grid Reference	Area	Strat. Position	Collector	Age
Sheet N25						
f 5	L8352	925434	RH	near base mb	JIR,SN	N.F.
6	L8353	920435	RH	"	JIR,SN	Ab-k
7	F -	922452	RH	base bt +20m	WLL,SN	upper Pl
8	VUW	014420	TR	" +0-3m	WLL,SN	Pl
9	VUW	014420	TR	" +5-10m	WLL,SN	Pl
10	F -	014421	TR	base nt+35m	WLL,SN	Ld-P
11	VUW	014422	TR	" +20m	WLL,SN	mid Lwh-early Lw
12	L8354	018473	TR	top mb -30m	SN,JIR	Lwh
13	L8355	019426	TR	" -40m	JIR,SN	Lwh
Sheet N26						
f 7	L8405	971367	DR	near top mb	JIR,SN	Lwh
8	L8534	906368	OS	near base mb	WLL	Ar
9	F -	945157	WA	base bw-50m	WLL,RHH	Pl
10	F -	948158	WA	" +70m	SN	N.D.
11	VUW	950393	TK	base nt+?40m	WLL	-
12	F -	939281	WT	base bt+ 1m	WLL,CJB	basal Pl

Collectors

ETA	E.T. Annear	WLL	W.L. Leask
ACB	A.C. Beck	JM	J. Marwick
DGB	D.G. Bishop	DJM	D.J. McIntyre
SB	S. Bunopas	SN	S. Nathan
CJB	C.J. Burgess	EP	E. Page
RAC	R.A. Cooper	RP	R. Page
BE	B. Elliott	JP	J. Park
REF	R.E. Fordyce	JIR	J.I. Raine
WRG	W.R. Green	WAS	W.A. Sara
GWG	G.W. Grindley	RPS	R.P. Suggate
J. Hend.	J. Henderson	SS	S. Sylvester
NBH	N. de B. Hornibrook	JBW	J.B. Waterhouse
RHH	R.H. Hoskins	HWW	H.W. Wellman
DK	D. Kear		

Recent base maps

NZMS 1	Sheet S1 & S3	3rd ed. 1974
	S7	2nd ed. 1971
	S8	3rd ed. 1974
	S13	4th ed. 1974

Metric grids superimposed on NZMS 1 sheets S1-3, S7, S8 and S13 were obtained by courtesy of the N.Z. Geological Survey.

APPENDIX THREE

STAINING TECHNIQUE FOR CARBONATES IN THIN SECTION

This technique is based on the method of Dickson (1965). The purpose of the stain is to distinguish between calcite, dolomite and their iron-rich equivalents. Calcite is stained pink-red, dolomite remains colourless, ferroan calcite is mauve-blue and ferroan dolomite is turquoise. The exact shade of the ferroan carbonates varies with iron content and is useful for detecting several generations of cement etc.

Three solutions are used:

(1) 1.0% HCl solution (all solutions should be prepared with distilled water).

(2) 0.2g of Alizarin red-S and 2.0g of potassium ferricyanide per $1000cm^3$ of 0.1 N HCl solution.

(3) 0.2g of Alizarin red-S per $100cm^3$ of 0.1 N HCl solution.

The thin section is:

(1) etched in 1.0% HCl for 10 seconds;

(2) stained in Alizarin red-S and potassium ferricyanide for 1 minute;

(3) stained in Alizarin red-S for 10-15 seconds;

(4) washed carefully with distilled water. The stain is a surface precipitate and is easily damaged by careless handling. When the thin section is completely dry, a protective cover of polyurethane varnish is sprayed on.

APPENDIX FOUR

IDENTIFICATION OF BRYOZOA

Bryozoa are the major constituents of much of the Takaka Limestone and are potentially valuable for paleoecological studies. Stach (1936), Lagaaij and Gautier (1965) and others have shown that bryozoa can be subdivided into different growth forms which are suited to different environmental conditions. The major environmental influences are the rate of sedimentation, turbulence, type of substrate, salinity, wave and current energy (Schopf, 1969). Ecological information from studies of Recent bryozoa is summarized by Schopf (1969); more recent studies include those by Wass et al.(1970) and Annoscia and Fierro (1973). Ten growth forms are figured by Lagaaij and Gautier (1965:51).

This data has been convincingly applied to studies of fossil bryozoa in poorly cemented or friable sediments in which the growth forms can be directly observed. In well-cemented limestones, the bryozoan forms must be identified from two-dimensional sections. Crabb (1971) approached the problem of identification by subdividing the sectioned bryozoa into groups based on gross morphological features and then allocating these to growth forms. As this method seems unwieldy and some of Crabb's correlations are suspect, an independent approach has been taken in the present study. The definitions used below are those summarized by Schopf (1969).

Cellariiform growth form (fig.51a,b)

Colony erect, flexible (jointed), approximately cylindrical, attached to substrate by rootlets. Internodes consist of numerous individuals; orifices are arranged on all aspects of the surface.

The flexibility of this form enables it to colonize areas of strong wave or current activity and also to colonize turbid waters (Stach 1936, Lagaaij and Gautier, 1965). Annoscia and Fierro (1973) found the form widely distributed across the Golfo dell'Asinara but most abundant in shallow shelf areas affected by wave action.

Distribution: In the Takaka Limestone, cellariiform bryozoa are common or abundant in packstones and also frequently in grainstones at the top of the formation where terrigenous mud is present. They are very abundant in the "Bryozoan Bed" of the Tarakohe Mudstone (facies bt_1), which has a high terrigenous mud content.

These rock types were probably deposited in turbid conditions. The cellariiform bryozoan's ability to passively "shake off" settling mud particles (Lagaaij and Gautier, 1965) could explain its preference for these environments.

Celleporiform growth form

Zooecia are heaped irregularly in multilamellar masses of variable shape. Two distinct variants occur in the Takaka Limestone:

Celleporiform A: Nodular, encrusting forms which bud vertically through eruptive type budding, surround the original structure and generate spirally produced zooids. Their relative symmetry and lack of avicularia for generating feeding and cleansing currents implies that they are limited to high-energy environments with little or no deposition where they can be overturned regularly (Rider and Cowen, 1977).

Celleporiform B (fig. 51c,d): Large inverted-bowl shaped colonies, probably free-living, known as *Celleporaria papillosa* Tenison-Woods or "*Cellepora*" sp.2 (Brown, 1952). The colonies are 50-70mm diameter and 20-30mm high, with zooecia growing outwards on the convex side. Frontally budded zooids arranged in vertical columns indicate a celleporiform B growth form (Rider and Cowen, 1977). Despite a superficial resemblance to lunulitiform bryozoa, the "*Cellepora*" are considerably larger,* and would probably be too large to right themselves if overturned. Like lunulitiform bryozoa, they probably possessed whip-like avicularia to generate feeding and cleansing currents. They probably colonized fine sandy seafloor too unstable or fine-grained for sessile bryozoa, in areas of low to

* lunulitiform bryozoa are 1.5-15mm diameter (Wass *et al*., 1970).

moderate current intensity (cf. Rider and Cowen, 1977).

Distribution: Nodular or encrusting celleporiform A growth forms are widely distributed throughout the Takaka Limestone, but are probably more common in the lower parts of the formation. The schist substrate underlying the limestone at Devil's Boots section is in places encrusted by celleporiform colonies. Dolomite pebbles in a pebble layer within the Paynes Ford section are encrusted by celleporiform colonies; these were probably derived from shallow water. Quartz and schist pebbles in the same layer are not encrusted. While the above two examples suggest a shallow-water habitat for the celleporiform A growth form, other colonies occur in limestones characteristic of a middle shelf environment, therefore the growth form may have a wide depth range.

Concentrations of "Cellepora" are common in the uppermost Takaka Limestone and lower Tarakohe Mudstone in the Aorere valley, and in limestone lenses in the Kaipuke Siltstone (west of the study area). These beds are crowded with whole, disorientated bryozoa, some encrusted by membraniporiform colonies on their concave surfaces. This indicates that the colonies were flipped over, rolled or suspended during periodic storms and concentrated in lag deposits. This also suggests that they were specialized for environments with a particular energy-range and sedimentation-rate.

Eschariform growth form (fig.51e,f)

A strongly calcified, foliaceous bilamellar colony having the orifices of the two layers facing in opposite directions. Little ecological information is available. Stach (1936) considered the growth form to be adapted to sublittoral zones at depths of at least 18m.

Distribution: The cyclostome species allocated to this growth form in the Takaka Limestone is a widespread but never abundant component of facies nt_3, nt_4 and nt_5. Brown (1952) remarked on a virtual absence of eschariform bryozoa in the "Bryozoan Bed" at Tarakohe.

Hemescharan growth form (fig.52a,b)

These are defined as unilamellar, erect colonies having all orifices opening on one surface. Bryozoa of the cyclostome family Horneridae are included in this form although they are not strictly unilamellar. They are moderately large, robust branching colonies with orifices opening in one direction only.

Distribution: Horneridae are a major component of the bryozoan fauna, abundant in most bryozoan-rich limestones and also scattered through mollusc- or sand-dominated rock otherwise devoid of bryozoa. Because of their unilamellar shape, hornerids may present little water resistance to currents hitting the dorsal surface of the colony, and they may therefore be able to colonize moderately high energy environments. Their wide distribution may also be due to the high preservation potential of the heavily calcified, compact skeletons.

Membraniporiform growth form

A unilamellar growth form encrusting a solid substrate. The dorsal wall may or may not be calcified. Stach (1936) considered the growth form to be mainly limited to littoral and sublittoral zones.

Distribution: A minor component in the Takaka Limestone, encrusting larger bryozoa or large bivalve fragments.

"Multi-tiered" ? membraniporiform growth form

Nodular colonies, probably of the cyclostome family Theonoidae, which consist of tiers of unilamellar zooecia, with columns of longer zooecia at regular intervals which support the tier above.

This growth form combines an initial encrusting habit with efficient space utilisation and rigidity, and may have been suited for life in areas of strong current activity.

Distribution: This form has been recorded from only two samples (14562, 14650) from facies nt_2 and nt_3 respectively.

Reteporiform growth form (fig. 52c)

Colony erect, rigid, strongly calcified, fenestrate or reticulate, firmly attached to a solid substrate by a calcareous base.

In the Takaka Limestone, this category is tentatively applied to a unilamellar cheilostome growth form, the dorsal surface of which is thickly calcified and punctuated at regular intervals by fine pores. These pores outline diamond-shaped zooids characteristic of the reteporiform type. No transverse sections have been seen that unequivocally indicate a reteporiform colony; some longitudinal sections (e.g. fig.30c) are folded in a semi-circular shape with the orifices opening on the inside.

Distribution: Reteporiform colonies are common in facies nt_6 and bt_1, but generally rare in facies nt_3, nt_4 and nt_5. Their ecological significance is not understood (Schopf, 1969) although Stach (1936) believed the growth form to be most common in areas of high wave or current activity. Its distribution in the study area may indicate a preference for turbid waters.

Vinculariiform growth form

Colony erect, rigid, consisting of dichotomous subcylindrical branches, firmly attached to a solid substrate by a calcareous base; the orifices open on all aspects of the curved surface. Stach (1936) believed that this growth form was adapted for life in deep or quiet water with minimal current activity. Wass et al. (1970) and Annoscia and Fierro (1973) have also shown that it inhabits deeper water. However, three of the vinculariiform types described below are heavily calcified and up to 20mm diameter and could probably withstand moderate current intensities.

Four types of vinculariiform bryozoa are common in the Takaka Limestone:

(1) An open-latticed cyclostome with laminated, finely-porous walls (fig. 52d,e). Colonies appear to form long branches at least 150mm long and up to 6mm diameter, radiating from a central base. The growing tips of the branches are blunt and rounded.

(2) A stout cyclostome bryozoan of the family Heteroporidae (fig.53a,b), the orifices of which open at regular intervals through a finely porous surface. The external shape of Heteropora colonies is described by Ross (1973), but the numerous long collared autozooecia figured by her are not found in the fossil specimens. On the coast of Washington U.S.A., Heteropora forms hemispherical branching colonies that live from the intertidal zone to 140m depth, but mainly 3.5-35m (Ross, 1973).

(3) A probable cyclostome bryozoan, that could be confused with an erect celleporiform colony. Numerous zooids bud off a central cone, which is commonly squashed flat by pressure-solution (e.g. fig.53b,c). These colonies are heavily calcified, branching forms up to 20mm diameter.

(4) A cheilostome bryozoan, identified in transverse section by petal-shaped zooids branching off a central lattice (fig.53f), and identified in longitudinal section by zooids compartmented between a coarsely porous wall (fig.53e).

Distribution: Vinculariiform growth forms are the most common bryozoa in the Takaka Limestone. Types (1) and (4) are widespread throughout most facies of the formation, but are particularly abundant in facies nt_5. Types (2) and (3) form large colonies that dominate much of facies nt_5 in the Takaka valley and Karamea area.

FIG. 51 : BRYOZOA IN THE TAKAKA LIMESTONE

a/ Cellariiform bryozoa, longitudinal section. (Transverse sections are circular).
Rangihaeata sample 14620.

b/ Cellariiform bryozoa, longitudinal section.
Payne's Ford sample 14592.

c/ Celleporiform B colonies, diameter c.60mm.
Kaipuke Siltstone, Anaweka Rivermouth (M25/c.500510).

d/ Celleporiform B bryozoa, longitudinal section.
Doctor Creek sample 14546.

e/ Eschariform bryozoa, longitudinal section.
Dry River sample 14539.

f/ Eschariform bryozoa, oblique section.
Motupipi sample 14579, cross polars.

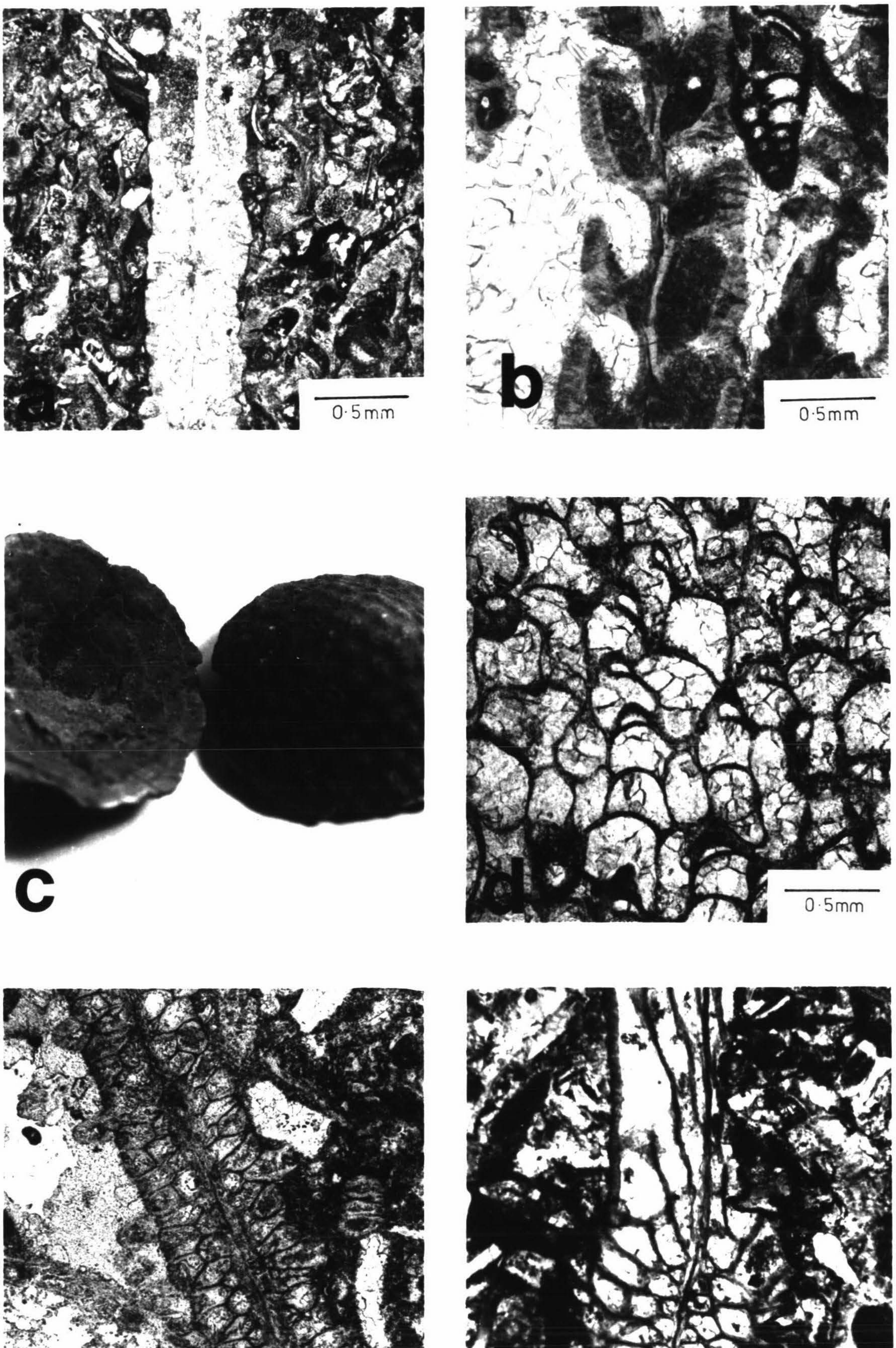

a
0·5mm
b
0·5mm
c
d
0·5mm
e
0·3 mm
f
0·3 mm

FIG. 52 : BRYOZOA IN THE TAKAKA LIMESTONE (CONTINUED)

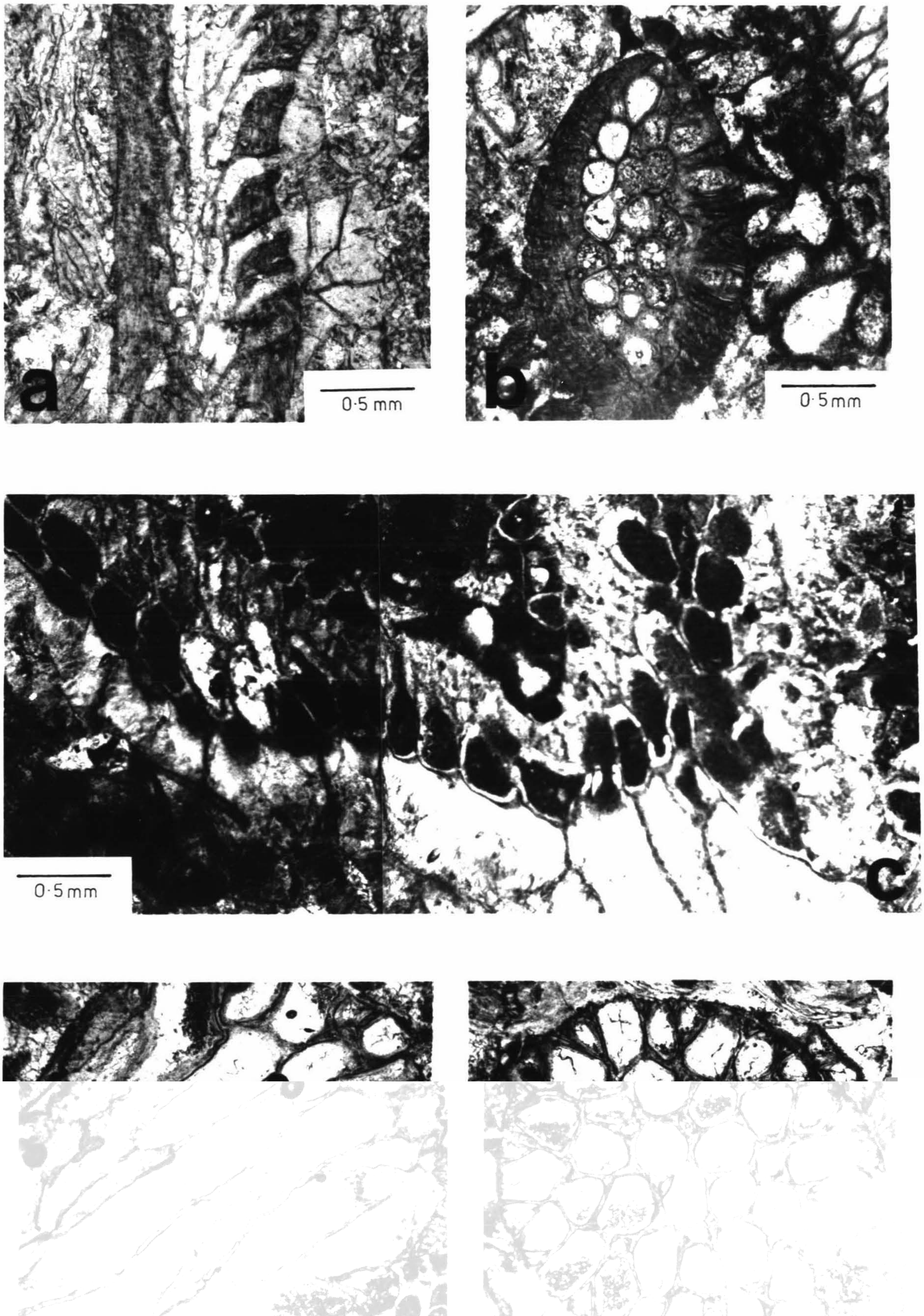
a/ Hemescharan bryozoa (Horneridae), longitudinal section.
Payne's Ford sample 14592.

b/ Hemescharan bryozoa, transverse section.
Payne's Ford sample 14592.

c/ Reteporiform bryozoa, longitudinal section.
Payne's Ford sample 14588. (See example in fig. 30c).

d/ Vinculariiform (1) bryozoa, longitudinal section at colony tip.
Takaka sample 14633.

e/ Vinculariiform (1) bryozoa, transverse section.
Takaka sample 14633.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0·5 mm
b
0·5mm
0·5mm
c
d
e

FIG. 53 : BRYOZOA IN THE TAKAKA LIMESTONE (CONTINUED)

a/ Vinculariiform (2) bryozoa (? Heteroporidae), longitudinal section.
Tarakohe sample 14654.

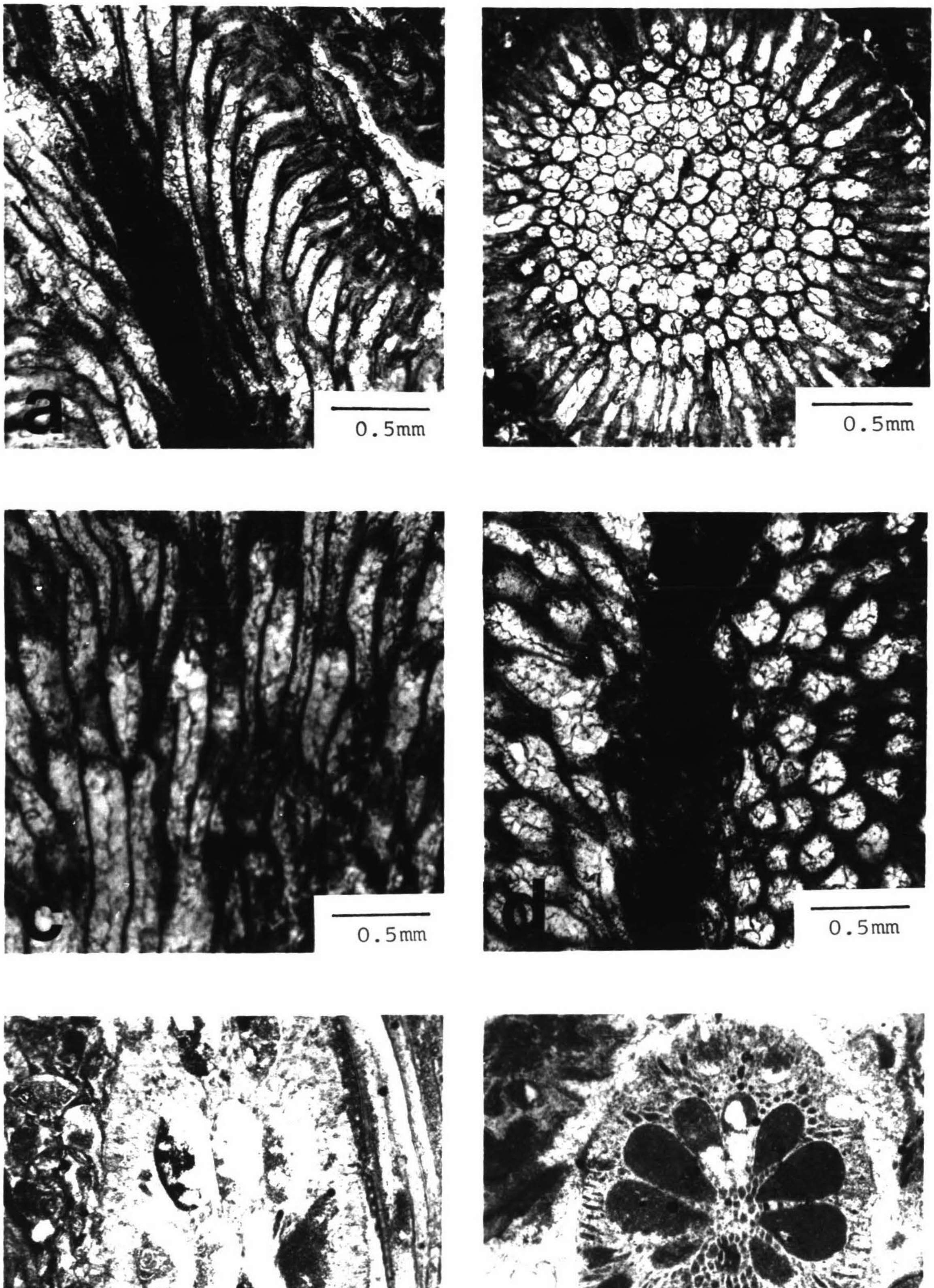
b/ Vinculariiform (2) bryozoa, transverse section.
Payne's Ford sample 14592.

c/ Vinculariiform (3) bryozoa, longitudinal section near colony tip.
Tarakohe sample 14652.

d/ Vinculariiform (3) bryozoa, longitudinal section near colony centre.
Tarakohe sample 14652.

e/ Vinculariiform (4) bryozoa, longitudinal section.
Rangihaeata sample 14614.

f/ Vinculariiform (4) bryozoa, transverse section.
Rangihaeata sample 14616.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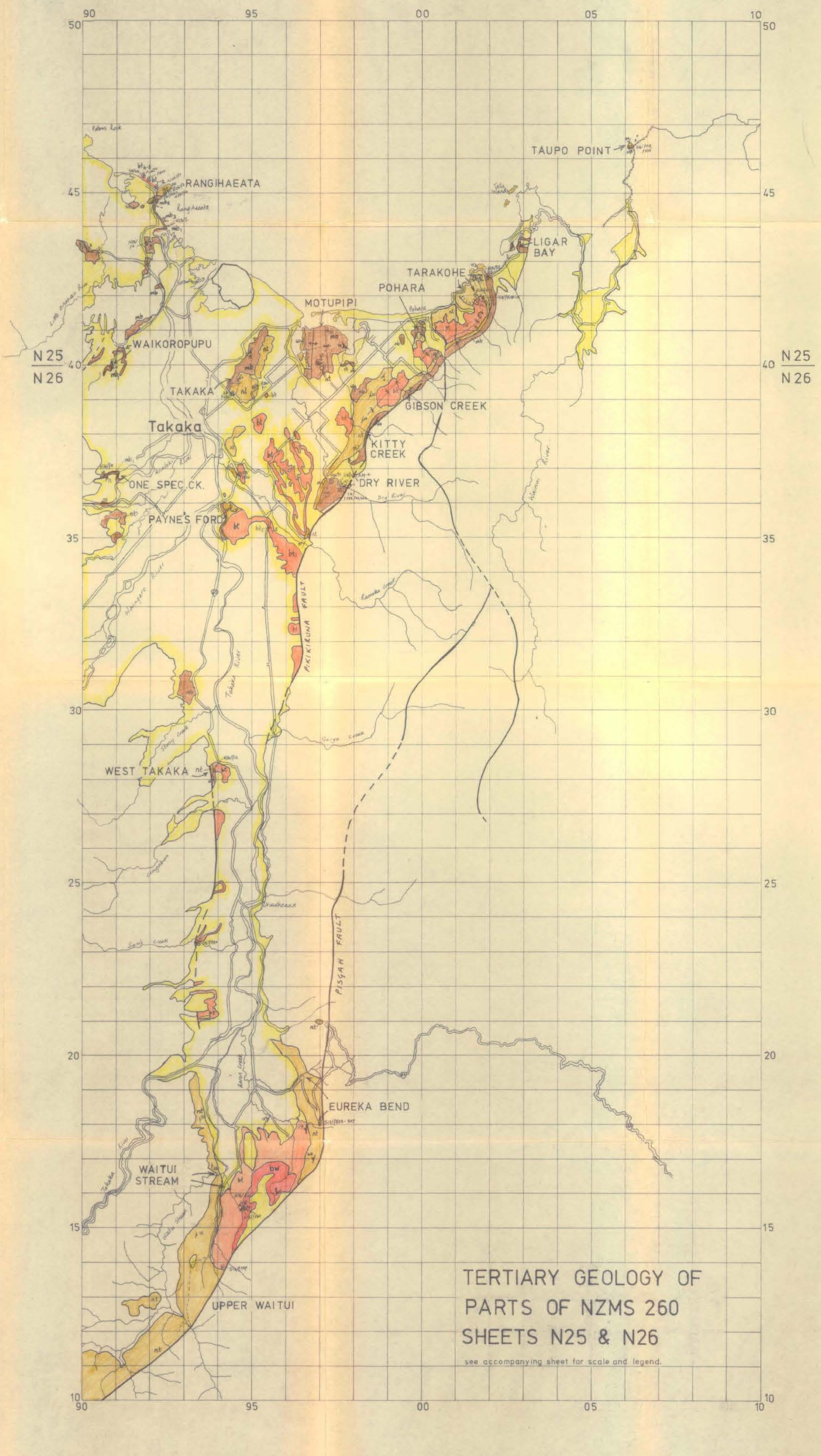
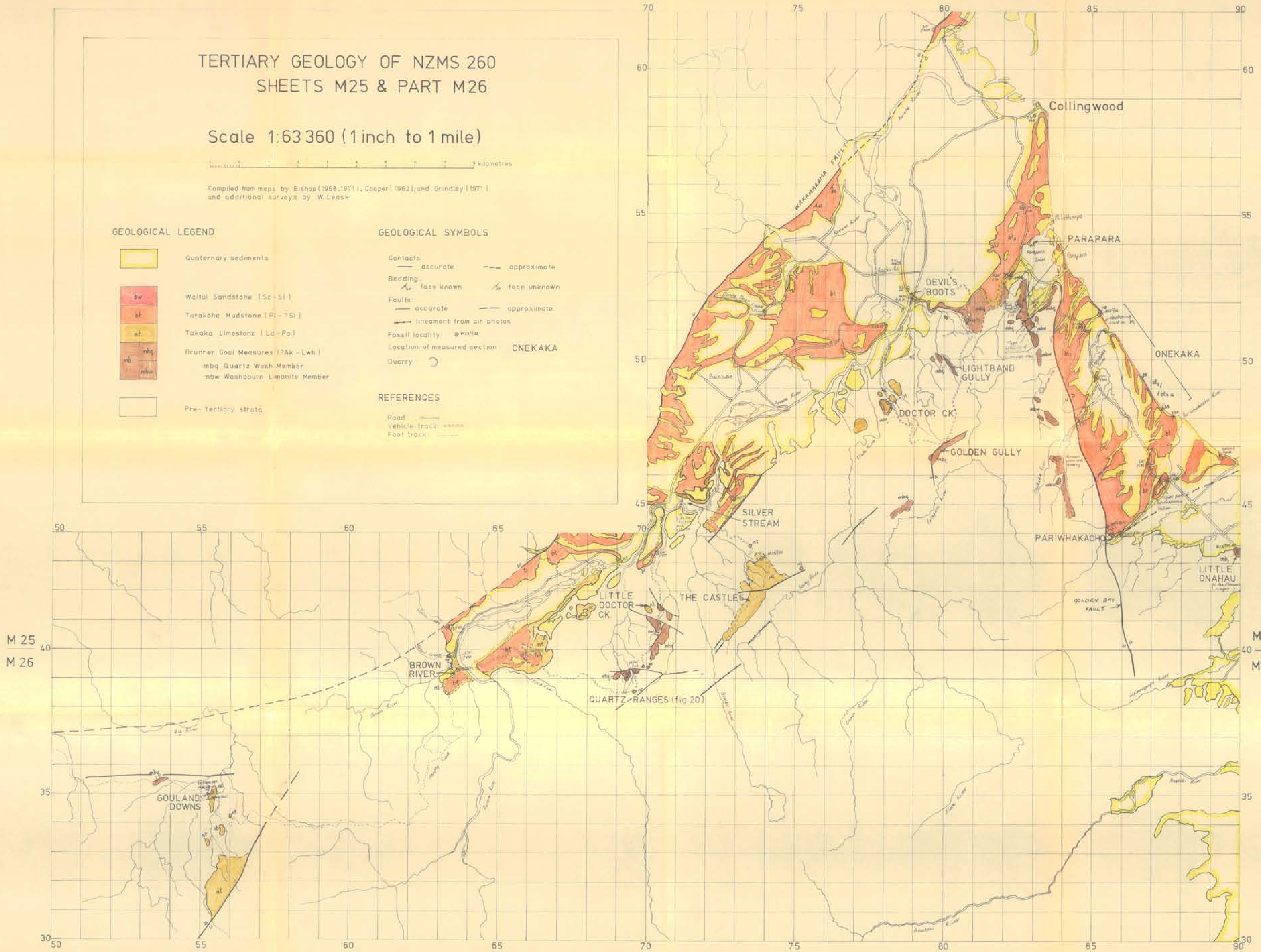


TERTIARY GEOLOGY OF
PARTS OF NZMS 260
SHEETS N25 & N26
see accompanying sheet for scale and legend.
90
95
00
05
10
50
45
40
35
30
25
20
15
N 25
N 26
TAUPO POINT
RANGIHAEATA
LIGAR BAY
TARAKOHE
POHARA
MOTUPIPI
WAIKOROPUPU
TAKAKA
Takaka
GIBSON CREEK
KITTY CREEK
DRY RIVER
ONE SPEC.CK.
PAYNE'S FORD
PIKIKIRUNA FAULT
WEST TAKAKA
PISGAH FAULT
EUREKA BEND
WAITUI STREAM
UPPER WAITUI



TERTIARY GEOLOGY OF NZMS 260
SHEETS M25 & PART M26
Scale 1:63 360 (1 inch to 1 mile)
kilometres
Compiled from maps by Bishop (1968, 1971), Cooper (1962), and Grindley (1971), and additional surveys by W. Leask
GEOLOGICAL LEGEND
Quaternary sediments
bw Waitui Sandstone (Sc - Sl)
bt Tarakohe Mudstone (Pl - ?Sl)
nt Takaka Limestone (Ld - Po)
mb Brunner Coal Measures (?Ak - Lwh)
mbq Quartz Wash Member
mbw Washbourn Limonite Member
Pre-Tertiary strata
GEOLOGICAL SYMBOLS
Contacts: accurate, approximate
Bedding: face known, face unknown
Faults: accurate, approximate
lineament from air photos
Fossil locality
Location of measured section ONEKAKA
Quarry
REFERENCES
Road
Vehicle track
Foot track
Collingwood
WAKAMARAMA FAULT
PARAPARA
DEVIL'S BOOTS
LIGHTBAND GULLY
DOCTOR CK
GOLDEN GULLY
ONEKAKA
SILVER STREAM
PARIWHAKAOHO
LITTLE ONAHAU
GOLDEN BAY FAULT
THE CASTLES
LITTLE DOCTOR CK
BROWN RIVER
QUARTZ RANGES (fig. 20)
GOULAND DOWNS
M 25
M 26