Stratigraphy and Sedimentology of Early to Middle Miocene Strata, Western Taumarunui Region, King Country Basin

A thesis
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of
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by

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ABSTRACT

The study area of this thesis is located in the King Country Basin, North Island, New Zealand. It contains a 400 m thick marine sedimentary succession of Miocene age and Quaternary ignimbrites. The field area comprises 900 km^2 of steep to rolling farmland and some large patches of native forest, and includes the towns of Ohura in the west and Taumarunui in the east. There is limited outcrop exposure in the study area, and the sedimentary succession is often weathered.

The study area is cut by numerous faults that have formed in an extensional regime behind the modern volcanic arc (Taupo Volcanic Zone). The major fault is the Ohura Fault, which has changed its sense of displacement (reverse to normal) in response to changing stress regimes during the Neogene.

No basement is exposed in the field area, which lies wholly in Early Miocene (Otaian Stage) Mahoenui Group and Mokau Group sediments, and Middle Miocene Mangarara Formation, Otunui Formation, and Mt Messenger Formation sediments. The Mahoenui Group comprises the Taumarunui Formation, characterised by flysch deposits, and the Taumatamaire Formation, a massive mudstone that interfingers with the Taumarunui Formation in the field area. These Early Miocene units represent rapid subsidence and basin formation, with accumulation in outer shelf to slope environments. The Mokau Group comprises the Bexley Sandstone, Maryville Coal Measures, and Tangarakau Formation, which represent an overall marine transgression. The Mangarara Formation is unconformable on the Mahoenui Group, and represents marine transgressive onlap across a land surface cut into the Mahoenui Group during the late-Early Miocene. This unit is overlain by the Otunui Formation, which represents the development of a shelf succession, and which in turn is overlain by the Mt Messenger Formation which represents deposition in slightly deeper waters. Quaternary ignimbrites have a scattered distribution on hill tops in the study area.

Seven lithofacies have been identifed in the study area, and these have been sub-divided into 14 sub-facies. These range from massive mudstone deposited in a bathyal environment, to coal measures deposited in estuarine/swamp/flood plain environments. The facies have been described and interpreted within formations, and the environments for facies associations are inferred. The Mahoenui Group sediments represent deposition in a bathyal setting, and the Mokau Group was deposited in environments ranging from shoreface to inner shelf environments. The Mangarara Formation was deposited in a near shore environment, and the Otunui Formation accumulated in a shelf to uppermost slope setting. The Mount Messenger Formation, which overlies the Otunui Formation mainly south of the field area, occurs at one locality in the study area.

The King Country Basin developed in response to transpression and crustal shortening related to the inception of the modern plate boundary system through New Zealand during the Early Miocene. The sedimentary succession of the Mahoenui Group, Mokau Group, Mangarara Formation, Otunui Formation and Mt Messenger Formation has developed in response to the coupled effects of tectonism associated with this plate boundary system, and changes in relative sea level.

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CHAPTER 1: INTRODUCTION

1.1 STUDY AREA

The study area is situated within the King Country Basin, and includes a wide range of geologic units, chiefly of Cenozoic age. Mesozoic greywacke and argillite basement rocks form the fault-bounded Hauhungaroa Range to the east. The Oligocene Te Kuiti Group lies unconformably on this basement succession. The Te Kuiti Group is in turn overlain by the Early Miocene Mahoenui and Mokau Groups, and also the Middle Miocene Otunui Formation. Quaternary volcanic deposits (ignimbrites, lahars and other volcaniclastic sediments) predominantly originating from the Taupo Volcanic Zone overlie the Miocene succession to the east of the field area. The Early to Mid-Cenozoic sediments have a low angle of dip to the northwest, generally less than 10° (van der Sijp, 1958).

The area that has been mapped measures about 30 km by 30 km, covering an area of 900 km^2 in the Ohura-Taumarunui region of the King Country. The western boundary of the map is the Waitewhena Valley road and the road south of Ohura, while the eastern boundary is State Highway 4. The northern and southern boundaries are defined by the top and bottom of the S18 and R18 topographic maps, respectively (Fig. 1.1).

The topographic maps that cover the area are NZMS 260 R18 and S18. Hay's (1967) 1:250 000 geological map, Sheet 7, Taranaki includes the field area. Grange (1927) mapped the area on a 1:63 360 scale, while parts of it were re-mapped by Gerritsen (1994) on a 1:50 000 scale. Advances in technology, such as the introduction of GPS and the development of mapping software, introduce opportunuities for mapping the rock units at finer scales and digital form.

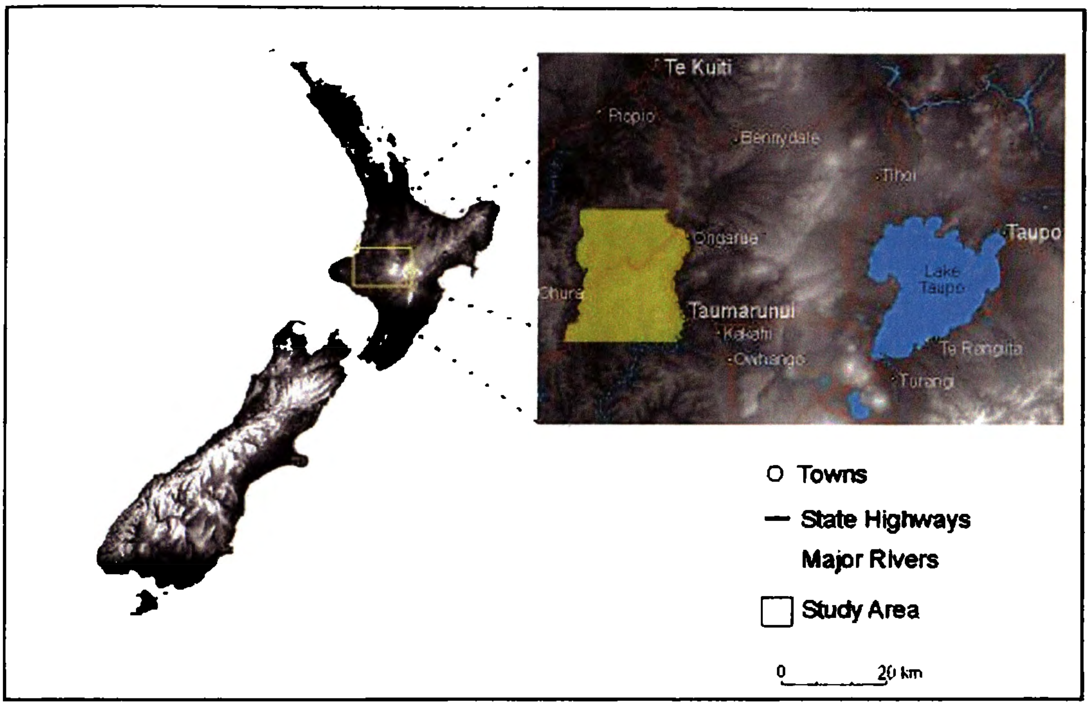


Figure 1.1: Digital Elevation Model showing location of study area.

1.2 GEOLOGIC AND TECTONIC SETTING

The boundaries of the King Country Basin are hard to define. Nelson and Hume (1977) define the boundaries as extending "from about the latitude of Kawhia Harbour in the north to Stratford in the south. It is bounded by structural highs of Mesozoic basement rocks, which form the Rangitoto-Hauhungaroa-Kaimanawa Ranges in the east, and the Herangi and its southerly subsurface continuation, the Patea-Tongaporutu High, in the west." The width of the basin increases gradually from ~40 km in the north to ~80 km in the south.

The west coast of the North Island of New Zealand also contains two other basins – Taranaki Basin and Waikato Basin. As with the King Country Basin, their boundaries are also hard to precisely define, and the history of the basins are linked, particularly for the Taranaki and King Country Basins. Sedimentary successions in these basins are of similar age, although Taranaki Basin contains slightly older units extending back to the Cretaceous. The oldest units within the King Country Basin are the Oligocene Te Kuiti Group (Figs. 1.2, 1.3). There is a pronounced southward migration of the depocentre within King Country Basin and into Wanganui Basin from the Oligocene through to the Pleistocene (McQuillan, 1977; King and Robinson, 1988). The transition into the Wanganui Basin is marked by onlap on to basement, there being no structural high separating the two basins (Kamp et al., 2002)

Faults in the King Country Basin can be divided into two groups – major and secondary (Fig. 1.4). Secondary faults often form connecting or splinter faults off, or between the major faults. They have strikes from 25° to 80°, and usually have throws of several hundred metres. Major faults run parallel to sub-parallel to the strike of the Mesozoic basement units, and have strikes of 0° to 20°. Reversal of fault movement is also common (Nelson and Hume, 1977).

The major tectonic event that has influenced deposition and deformation of units in the King Country Basin is the formation of the Pacific-Australian convergent plate boundary through New Zealand since the start of the Miocene. This boundary started to form during the mid to late Oligocene as a plate boundary (King and Thrasher, 1992). During the Duntroonian (28 Ma) transpression on the eastern margin of the Taranaki Basin began (Nelson et al., 1984; King and Thrasher, 1992; McQuillan, 1977), locally affecting the Te Kuiti Group in the vicinity of the Awakino Gorge, but the effects in the rest of this basin were very minor. Overthrusting of basement on the Taranaki Fault was a marked event during the earliest Miocene (Otaian Stage) and this reflected the development of the through-going plate boundary in its current position (King and Thrasher, 1996).

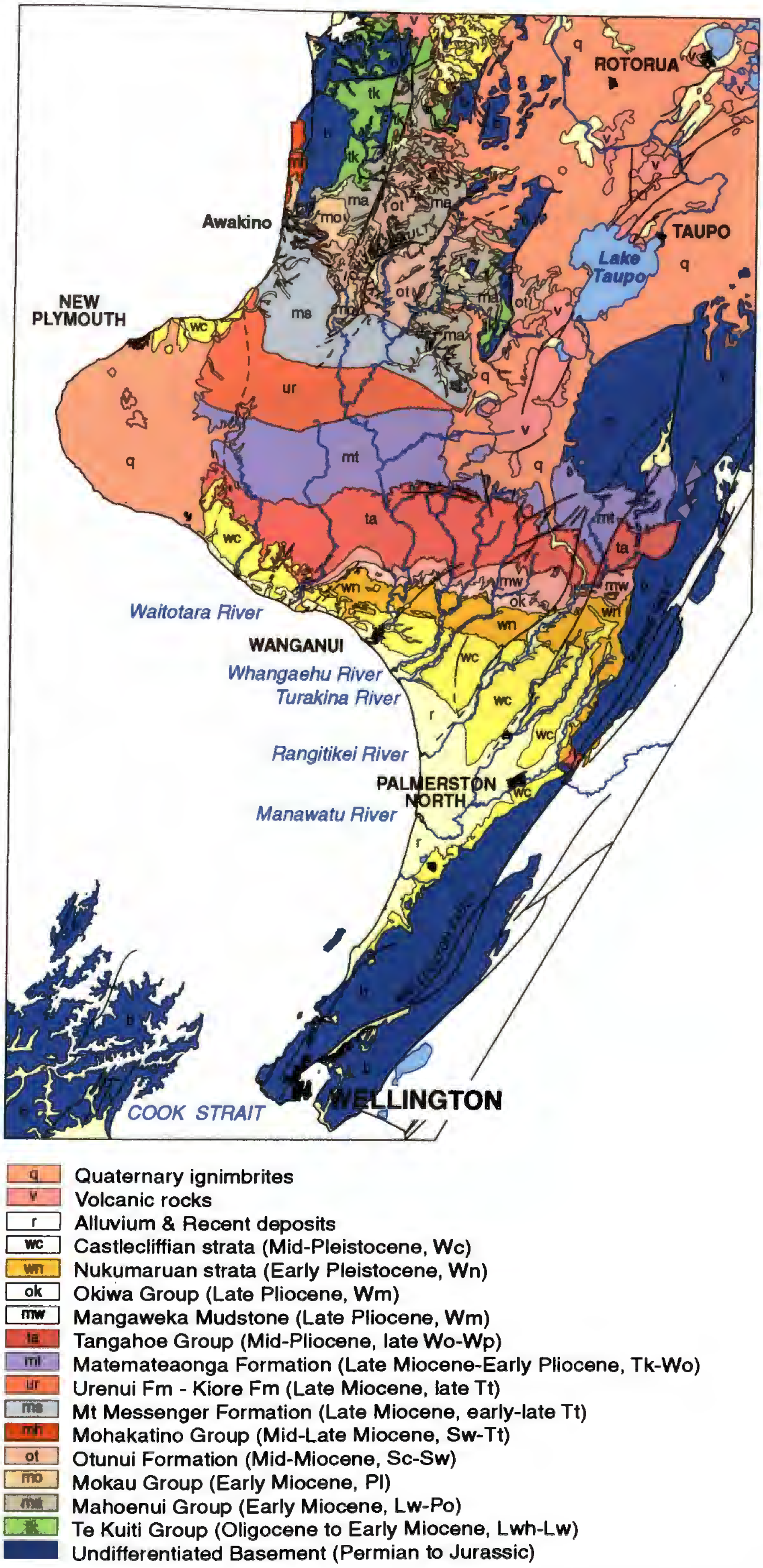


Figure 1.2: Geological map of the Wanganui, Taranaki and King Country basins (from Kamp et al., 2002)

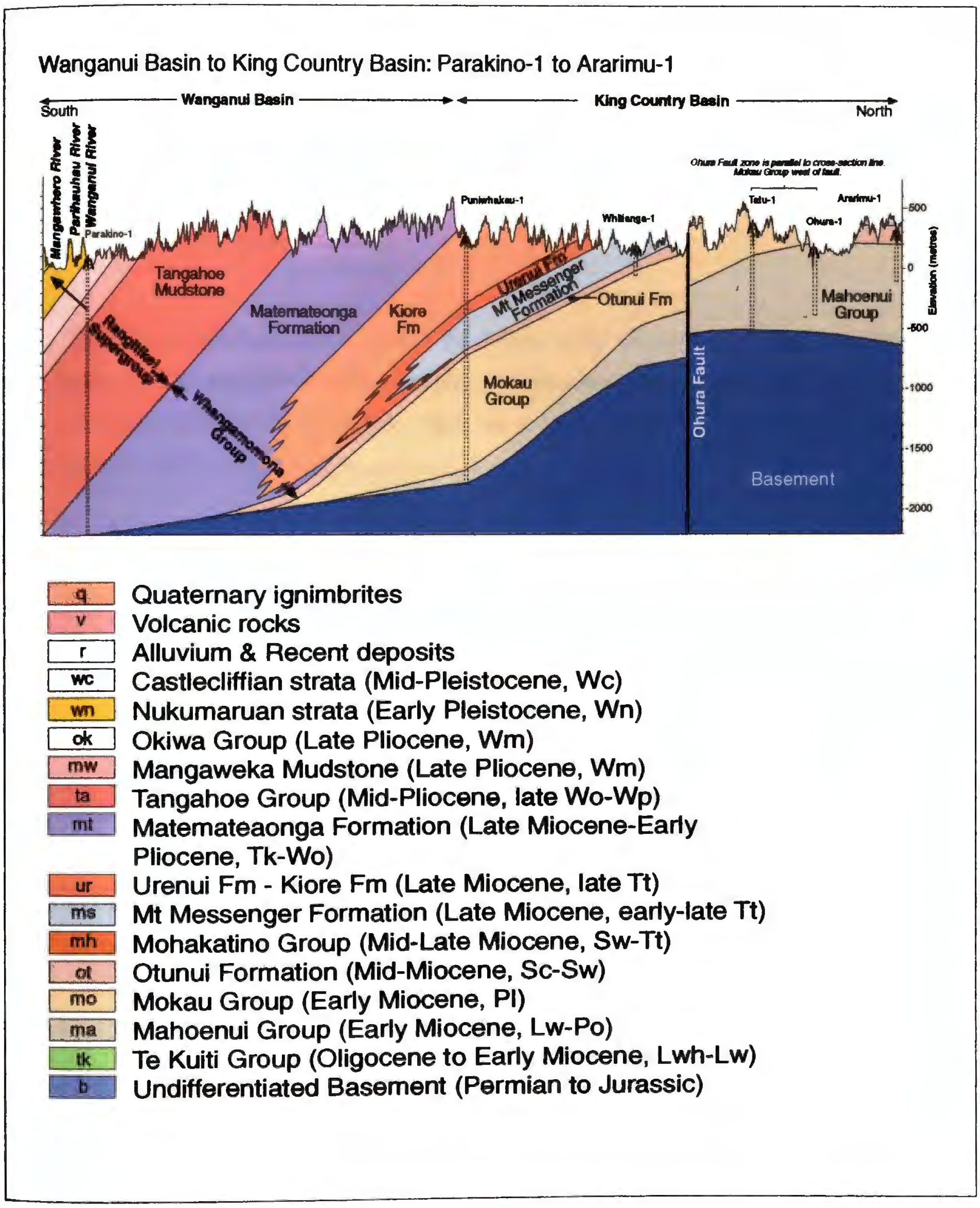


Figure 1.3: Wanganui Basin to King Country Basin (Parakino-1 to Ararimu-1) stratigraphic panel built up from well-to-well correlations, and related time-stratigraphic cross-section (from Kamp et al., 2002).

Gravity surveys in the area have revealed regional anomalies. Hunt (1980) documented the Ohura and Hauhungaroa Faults, and concluded that no large amounts of strongly magnetised volcanic rocks were likely to exist within the Cenozoic sediments in the basin.

1.3 Previous Geological Work in the Vicinity of the Field Area

Henderson and Ongley (1923) were the first to study the geology of the Taumarunui area. They studied the physiography and structure, as well as the general and economic geology of the region. This work formed the basis of the review of the Mokau Subdivision, Geological Survey Bulletin No. 24.

Grange (1927) mapped the area at a 1:63360 scale, and studied the geology of the area in greater detail than previous workers. This work was included in the Tongaporutu-Ohura Subdivision, Geological Survey Bulletin No. 27.

Interest in the King Country Basin as an oil-producing province resulted in a number of oil company reports being prepared. Glennie (1958) discussed the distribution, lithology, age and origin of the flysch deposits in the Taumarunui region. Van der Sijp (1958, 1959) produced petroleum reports for Shell BP Todd Oil Services, which included maps and columns of the Taumarunui region. Stainton and Gibson (1964) wrote reports for various petroleum companies, focussing on the stratigraphy, palaeogeography, age, tectonics, and oil and gas indications of the region.

Hay (1967) mapped and compiled Sheet 7 – Taranaki, as part of the 1: 250,000 scale geologic map series of New Zealand. Haddock (1970) described the geology of the Tangarakau Gorge-Heao-Tatu area, North Taranaki. As well as producing a map, he investigated the structure and geologic evolution of the region. Nelson and Hume (1977) analysed the composition of the sedimentary succession in the King Country

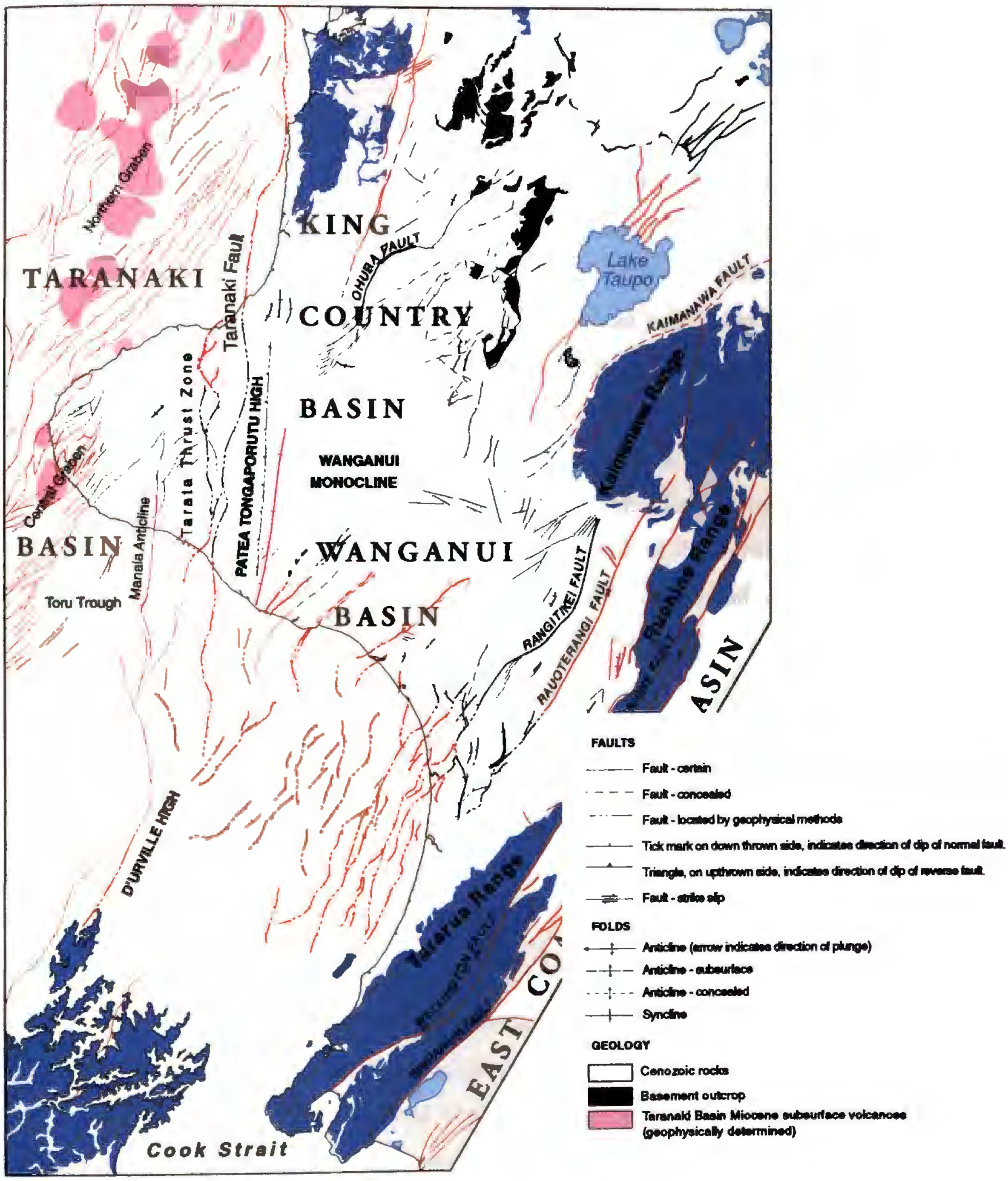


Figure 1.4: Structure Map of the Wanganui, Taranaki and King Country basins (from Kamp et al., 2002).

Basin and established a timetable of relative tectonic events for the Cenozoic sediment.

McQuillan (1977) used the data from 16 exploration wells to produce isopach maps of the 8 major 'formations' in the North Wanganui Basin. He also discussed the structure and hydrocarbon potential of the basin. Topping (1978) studied in detail the foraminifera of the Mahoenui Group for his PhD thesis. He also looked at the lithostratigraphy and used the information gained from analysis of the foraminifera to give details of age, palaeoecology and paleogeographic reconstruction of the Mahoenui Group. Manhire and Phelps (1988) studied the stratigraphy, structure and resources of the Ohura-Tangarakau Coalfield. Gerritsen (1994) mapped and interpreted Miocene sedimentary successions in part of the Taumarunui/Ohura area. Simms (1999) provided a regional stratigraphic framework of the northern part of the Mahoenui Group in the King Country Basin. Vonk (1999) conducted a detailed study of the Mokau Group sediments within the King Country Basin.

This previous work, and their relationships to each other, are shown in Table 1.1.

1.4 PHYSIOGRAPHY

1.4.1 STEEP HILL COUNTRY

The majority of the field area can be classified as steep hill country (Fig. 1.5). This country forms where the underlying geology is either the Otunui Formation or the Mokau Group, due to the presence of sandstone units with these deposits. Slope angles vary from 30° to 50°. Slips and bluffs are common in the area, allowing for some good exposure of the units. Land has been cleared and is used for farming sheep, cattle and deer. There are small pockets of native bush left scattered throughout the field area.

1.4.2 Moderate Hill Country

Only small parts of the field area can be classified as moderate hill country. Here slope angles are usually less than 30°. This forms where Mahoenui Group sediments outcrop due to their lesser induration than the Otunui Formation and the Mokau Group sediments (Figs. 1.6 and 1.7).

1.4.3 River Flats

River flats vary in width from tens of metres to up to a kilometre. They are present in all the main valleys (Fig. 1.8). Along the Ongarue River terraces of Taupo Pumice up to 10 m thick occur.

1.4.4 Dip Slopes

Dip slopes have formed on the Mahoenui Group sediments as well as on the Maryville Coal Measures of the Mokau Group. There is a general dip at a low angle (<10°) to the northwest. Dip slopes are evident in the Mangapapa valley, and have formed in Taumarunui Formation sediments. This land has been cleared and is used for farming. In the Waitewhena Valley the coal seams of the Maryville Coal Measures have formed dip slips, which like the previous ones, are used for farming and are very evident in the landscape (Fig. 1.9).

1.5 Thesis Content

Chapter 2: Geological Mapping and GIS

The geological mapping chapter describes the process of geological mapping – in the field as well as in digital form, using ArcGIS. It also discusses the spatial variations shown by the geological map.

Figutre 1.5 (top-left): Steep hill country in the King Country Basin. Looking south from the top of Pukepoto.

Figure 1.6 (top-right): Moderate hill country in Mahoenui Group sediments. Looking north from Te Angaanga.

Figure 1.7 (2nd from top): Moderate hill country in the Ohura region.

Figure 1.8 (3rd from top): River flats along the Mangakahikatea Stream, looking towards feature Birch.

Figure 1.9 (bottom-right): Dip slopes of the Mokau Group Maryville Coal Measures in the Waitewhena Valley. The coal seams are forming the flat tops of the hill. Looking south along the Waitewhena Valley Road.

Chapter 3: Lithostratigraphy

This chapter describes the lithology of the field area, including a geological map (back pocket) and stratigraphic columns (Appendix 1), and descriptions of the lithological units.

Chapter 4: Facies Associations

The lithofacies chapter describes individual facies occurring within the sedimentary succession and groups them into lithofacies associations based on the dominant lithology. Each of these facies is interpreted as part of a specific depositional environment.

Chapter 5: Basin Development

This chapter outlines a synthesis of the evolution of the basin, and puts the environment of deposition of the sediment into context.

Chapter 6: Summary and Conclusions

This chapter summarises the main conclusions drawn from this study.

Table 1.1: Previous workers in the King Country Basin.

Henderson & Ongley	Stainton & Gibson	Hay	Haddock	Gerritson	Vonk	Evans
Geology of the Mokau Subdivision. 1923.	Geology of Central Taranaki: A Compilation Report. 1964.	Geological Map of New Zealand. Sheet 7. 1967.	Geology of the Tangarakau Gorge - Heao - Tatu. MSc Thesis, University of Auckland. 1970.	The Regional Stratigraphy and Sedimentology of the Miocene Sequence in the Ohura - Taumarunui Region. 1994.	Stratigraphic Architecture and Sedimentology of the Early Miocene Mokau Group, North Wanganui Basin, N.Z. 1999.	Stratigraphy and Sedimentology of an Early-Mid Miocene Sequence, King Country Basin.
Mohakatino Beds	Mohakatino Formation **Kohu Series** Mudstones, tuffaceous in the lower half. 400 - 750 ft	Mohakatino Group **Tawariki Mdst Formation** Tuffaceous mdst and interbedded sdst. 90 m	Mohakatino Group **Heao Mudstone Formation** Massive grey tuffaceous mudstone, interbedded with sandstone units. 204 m	**Otunui Formation** Blue - grey, massive argillaceous sandstone. 250 m	**Otunui Formation** Fine - medium grained, mod soeted argillaceous sandstone. Blue - grey in colour. 20 - 30 m	**Mt Messenger Formation** Interbedded sandstones and conglomerates. Cross-bedded sandstones.
	Tatu Series Sandy mudstones. 200 - 550 ft	**Ferry Sdst Formation** Sdst and occassional mdst with slump dep. 60 m				**Otunui Formation** Massive, blue - grey sandstone with concretions, indurated sandstone layers, redeposited channel fill deposits, and conglomerates. 200-240 m
		Purupuru Tuff Formation Well bedded tuffaceous sdst and mdst. 45 m				
	Te Ahi Series Argillaceous sandstone to sandy mudstones. Glauconitic at base. 390 - 440 ft	**Mangarara Sdst Formation** Sandstone with basal congl. and occassional limestones. 45 m		**Pongahuru Limestone Member** Sandy limestone. 1.2 m	**Mangarara Formation** Limestones, sandstones, shell-beds and glauconitic mudstone. 2 - 3 m	**Mangarara Formation** Shelly conglomerates, sandy limestones. 4 m
Mokau Beds **Upper Unit** Well bedded argillaceous sandstone. < 170 m	Mokau Formation **Upper Mokau** Argillaceous sandstone, base marked by a greywacke conglomerate. 435 ft	Mokau Group **Upper Mokau Sdst Formation** Well bedded argillaceous marine sdst with congl and hard shelly lenses. 170 m	Mokau Group **Tangarakau Sandstone Formation** Fine grained sandstone, shellbeds, mudstones and conglomerates. 39 - 204 m	Mokau Group **Mangakara Formation** Argillaceous, massive sdst with basal conglomerate. 5 - 120 m	Mokau Group **Tangarakau Formation** Sandstone with congl. and coal measures. 200 - 250 m	Mokau Group **Tangarakau Formation** Sandstone with congl. and coal measures. 150 m
Coal Measures Coal & shale seams separated by massive sandstone.	**Middle Mokau** Carbonaceous sandstone & mudstone, coal bearing. 305 ft	**Maryville Coal Measures** Two coal zones separated by 50 ft of massive carbonaceous sdst. 40 m	**Maryville Coal Measures** Shale and coal seams separateed from sandstone and coal seams by massive carbonaceous sandstone. 92 m		**Maryville Coal Measures** Lower and upper coal seams separated by massive sandstone beds. 50 m	**Maryville Coal Measures** Lower and upper coal seams separated by laminated or wavy bedded sandstone and mudstone. 20 m
Lower Mokau Massive, slightly argillaceous sandstone. 120 m	**Lower Mokau** Coarse sandstone, gritty, thin mudstone bands towards the top. 180 ft	**Lower Mokau Sdst Formation** Argillaceous sdst with many mdst laminations and few concretions. 120 m	**Lower Mokau Sandstone** Grey coloured, massive, well cemented,fine - grained, slightly argillaceous sdst. 100 m	**Huhatahi Formation** Massive sandstone with interbedded sanstone and mudstone beds 5 - 70 m	**Bexley Sandstone** Massive, amalgamated and current - bedded sandstone. 60 - 150 m	**Bexley Sandstone** Massive and cross-bedded sandstones. 40 m
Mahoenui Series	**Mahoenui Formation** Massive siltstone, interbedded sandstone and argillaceous siltstone.	**Mahoenui Group** Mudstone, sometimes alternating with sandstone.		Mahoenui Group **Taumarunui Formation** Alternating sandstone and mudstone beds (Flysch deposits).		Mahoenui Group **Taumarunui Formation** Alternating mudstone/sandstone beds (Flysch deposits).
				Taumatamaire Formation Blue - grey calcareous massive mudstone with sdst lenses.		**Taumatamaire Formation** Mudstone with occasional 30 cm thick redeposited sandstone beds.

Chapter 2: Geological Mapping and GIS

2.1 Introduction

The Geological Map presented in this thesis (Appendix 2) makes up part of the Waikato Sheet of the GNS QMAP geological mapping programme. The first edition of the 1:250 000 Geological Map Series of New Zealand was published between 1957-67, and is the most widely used source of information on New Zealand geology. However, due to consequent research and the development of new concepts, it is gradually becoming inadequate for modern geological and Earth Sciences needs. As a result, the Institute of Geological and Nuclear Sciences has been tasked with the revision and preparation of a second edition 1:250,000 geological map series (QMAP). For practical purposes, the New Zealand map area has been divided into 21 map sheets (Figure 2.1), each of which has a designated compiler who is responsible for the organisation of work, standardised compilation of maps, and preparation of the final published map and text.

2.2 Geographic Information Systems

GIS is a computer system with the capability of assembling, storing, manipulating, and displaying geographically referenced information (data identified according to their geographic positions. GIS is an information system that is designed to work with data referenced by spatial or geographic coordinates, and is a facility for the presentation and interpretation of data pertaining to the surface of the Earth.

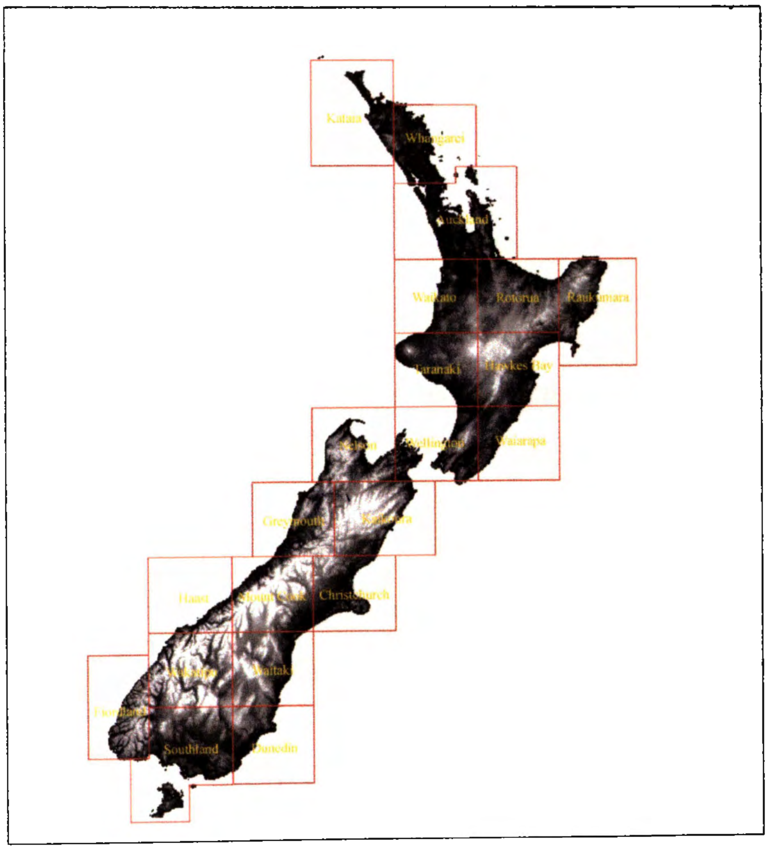


Figure 2.1: Map of New Zealand showing how it has been divided into 21 Map Sheets (Rattenbury and Heron, 1997).

Following is a short glossary of terms used in GIS and which will be used in this chapter (Minami et al., 1999):

Attribute

A characteristic of a map feature. Attributes of a river might include its name, length, average depth, and so on.

Attribute Table

Information about features on a map, stored in rows and columns. Each row relates to a single feature; each column contains the values for a single characteristic.

Class

A group or category of attribute values.

Coordinate System

A method for specifying the location of real-world features on the surface of the earth.

Coverage

A vector data storage format for storing the location, shape, and attributes of geographic features. One of the primary vector data storage formats for ArcInfo. Coverage's are stored in an ArcInfo workspace.

Feature

A representation of a real world object in a layer on a map.

Feature Class

1. A classification describing the format of geographic features and supporting data in a coverage. Coverage feature classes for representing geographic features include point, arc, node, route-system, route, section, polygon and

region. One or more coverage features are used to model geographic features; for example, arcs and nodes can be used to model linear features such as geological horizons.

2. The conceptual representation of a geographic feature. When referring to geographic features, feature classes include point, line, area, and surface. In a geodatabase, an object class that stores features and has a field of type geometry in a geodatabase.

Feature Dataset

A collection of feature classes in a geodatabase that share the same spatial reference. Because the feature classes share the same spatial reference, they can participate in topological relationships with each other such as in a geometric network. Object classes and relationship classes can also be stored in a feature dataset.

Geodatabase

A geographic database that provides services for managing geographic data. A geodatabase is hosted inside a relational database management system, and contains feature datasets.

Layer

A collection of similar geographic features – such as rivers, lakes, counties, or cities. A layer references geographic data stored in a data source, such as a coverage, and defines how to display it. One can create and manage layers as one would any other type of data in one's database.

Shapefile

A vector data storage format for storing the location, shape, and attributes of geographic features. A shapefile is stored in a folder and contains one feature class.

2.3 Field Mapping

Field mapping was undertaken using NZMS 260 1:50 000 topographic maps. Mapping at this scale will ensure that the final QMAP 1:250 000 Waikato Sheet of the Geological Map of New Zealand will be accurate, even though it will not show as much detail as the 1:50 000 field maps. All geological contacts, faults etc were drawn on to a NZMS 260 map to make GIS data input easier. However, the finished 1:250 000 map sheet will not use the 1:50 000 topobase as some layers of the map are not available in digitised form, and are too detailed/too expensive to use.

When in the field, geology was drawn on to NZMS 260 topographic maps which were later scanned and imported into the ArcMap project as JPEG files. Once these images were in the right place relative to the programmes' basemap the geology was traced over as polygons, which could then be filled with the appropriate colour depending on the type of geology.

GPS was used to mark sites (known as a 'waypoint') in the study area that was of particular significance. These were sites of stratigraphic columns (Appendix 1), sites where fossils were collected or just sites where observations on the immediate area's geology were made. A table of the waypoints marked in the study area is included in Appendix 3.

2.4 Data Capture

The fundamental goal of the QMAP Programme is to create an integrated GIS that will be a national geologic database for the next ten years (Rattenbury and Heron, 1997). Due to the nature of GIS the geological map will only form a small part of the database – data collected about the geology will make up the majority of the database.

There are three stages in the compilation of a GIS database. The first involves data compilation, the second data entry into the GIS, and the third the map production.

2.4.1 Data Compilation

Geological data were compiled on to 1:50 000 topographic maps, called a compilation sheet, ready for digitisation into the GIS. Other information (stratigraphic logs etc) were of course recorded in field note books for later reference. For final compilation into the QMAP map sheet, GNS will draw our maps on to gridded permatrace overlay for digitising. As these processes are part of GNS mapping procedure and past the scope of this study, I will not go into them.

2.4.2 Data Entry

GIS data are organised into feature classes and feature datasets, and these are stored in a geodatabase, with specific layers being established for the QMAP GIS. Feature classes used within my map were geological mapping units, faults, horizons, fossils, and landslides. Associated with each feature class is an "attributes" table, which stores information about particular layers. The attributes within a table can be changed depending on the type of coverage that is being attributed.

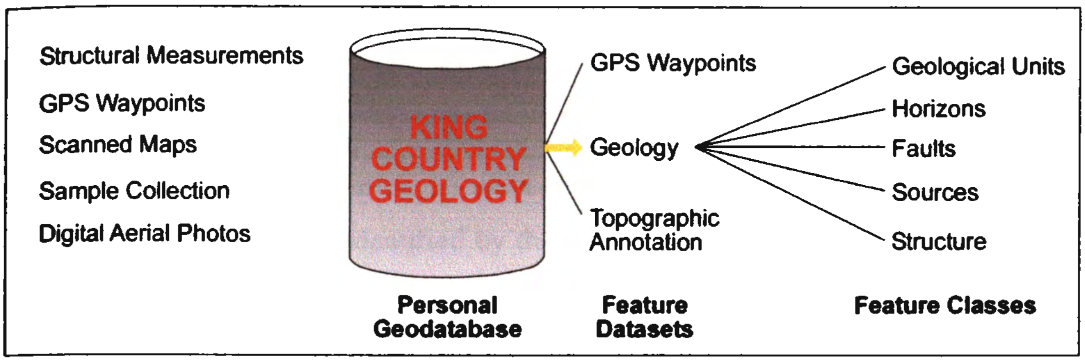


Figure 2.2: Schematic diagram illustrating the structure of the geodatabase in this project. Various input sources combine to produce a database of the geology of the King Country. The data are then arranged into broad groups of similar features, which are further subdivided into specific geological properties (e.g. geological units, faults).

GEOLOGICAL UNITS

An important part of the data entry process is the differentiation of the different geological units. As units can be described by many characteristics, such as lithostratigraphy, biostratigraphy, age and rock type, it is easier to use just one characteristic for ease of mapping. For QMAP, a lithostratigraphic approach has been used. The advantage of using mapping units based on their age/rock type is that it doesn't clutter the map. A geological unit is typically thicker than 5-10 metres, if thinner than this it should be omitted.

The geological unit polygons are stored in a coverage known as **GEOL_UNITS**. These individual polygons should be identified by mapping unit codes (UNIT_CODE). These unit codes should comprise age (e.g. "lMi" for lower Miocene), stratigraphic name (e.g. "Ot" for Otunui Formation) and rock type (e.g. "sdst" for sandstone). Many polygons that share a UNIT_CODE will always have the same dominant rock type MAIN_ROCK but may have differing subsidiary rock types SUB_ROCKS. A shortened version of the unit code should also be included as a label on the map for easy identification of the unit. These unit codes should be consistent with codes used on other maps. Each polygon has its own attribute table where the data is stored. An example of an attribute table for a geological polygon is shown in Table 5.1.

The boundaries between geological units are also included in the **GEOL_UNITS** coverage. They should be identified by their accuracy (e.g. accurate, approximate, inferred or concealed) and type (conformable, uncomformable or faulted). Some boundaries are faulted, and this will involve changes to both the **GEOL_UNITS** and the FAULTS coverage's, which is difficult to achieve unless these two coverage's are made into a discrete coverage in the future. A description of the different attributes of the geological units is shown in Table 5.1, while an example of a polygon attribute table for an Otunui Formation polygon is shown in Table 5.2.

Table 2.1: Geological Units attributes.

GEOL_UNITS.PAT (Polygon Attribute Table)
MAPPABLE GEOLOGICAL POLYGONS

ITEM NAME	INPUT WIDTH	OUTPUT WIDTH	ITEM TYPE	DECIMAL PLACES	DESCRIPTION
UNIT_CODE	8	8	C		A mapping unit letter code eg, eMimt
MAIN_ROCK	32	32	C		A rock type from the rock names list.
SUB_ROCKS	64	64	C		Rock name(s) from the rock names list .
MAP_UNIT	32	32	C		Mapping unit name eg, terraced river gravels.
STRAT_UNIT	32	32	C		Stratigraphic unit name where applicable.
SEQUENCE	32	32	C		Stratigraphic sequence name where applicable.
TERRANE	32	32	C		Terrane name where applicable.
STRAT_AGE	32	32	C		Age from the age list .
NZSTAGE	32	32	C		New Zealand stage from stage list.
[illegible]	32	32	C		Position with New Zealand Stage from position list
ABS_MIN	7	7	N	3	Minimum absolute deposition/emplacement age in Ma.
ABS_MAX	7	7	N	3	Maximum absolute deposition/emplacement age in Ma.
CONFIDENCE	64	64	C		Comment on accuracy of maximum or minimum absolute age.
DESCRIPTION	128	128	C		Description of geological mapping unit.
ROCK_GROUP	32	32	C		A broad rock group name from the group name list.
ROCK_CLASS	32	32	C		A general classification name from the rock class list .

Table 2.2: Example of a polygon Attributes Table.

Attributes

Geological Units

Ot

Property	Value
OBJECTID	663
Geological Unit Code	Ot
Main Rock Type	sandstone
Subordinate Rock Types	<Null>
Mapping Unit Name	Otunui Formation
Stratigraphic Unit Name	Otunui Formation
Sequence Name	<Null>
Terrane Name	Cover
Stratigraphic Age	Middle Miocene
NZ_STAGE	Waiauan
Position within Stage	<Null>
Minimum absolute age (Ma)	<Null>
Maximum absolute age (Ma)	<Null>
Comment on accuracy of age	<Null>
Description of mapping unit	<Null>
Broad rock group name	sandstone
General rock classification	clastic sediment
SHAPE_Length	19898.7821390469
SHAPE_Area	19062859.6468203
Lithostatigraphic Supergroup Name	<Null>
Lithstratigraphic Group Name	Whangamomona Group
Lithostratigraphic Subgroup Name	<Null>
Lithostratigraphic Formation Name	Otunui Formation
Lithostratigraphic Member Name	<Null>
General Sedimentary Environment	Shelf (Neritic)

1 features

FAULTS

Faults can be described by a large number of variables such as type, orientation, movement, displacement, fault rock type, and recent activity. As my study area has undergone large amounts of faulting (with the predominant Ohura Fault running through the middle of the area), this coverage, along with the **GEOL_UNITS**, is one of the largest coverage's in the QMAP GIS. The **FAULTS** coverage includes geometrical, descriptive, and time attributes of each single fault, which due to the large number, have each been designated a number (IDENTIFIER) in the attribute table. As some of the smaller faults will not be included on the new 1: 250 000 scale map, a PLOT_RANK attribute has been assigned so more faults can be stored in the GIS than shown on the finished map. The PLOT_RANK is the smallest scale at which the fault can be viewed at.

A Digital Elevation Model (DEM) was created during the production of the geological map, and was used to help identify faults back in the lab. Figure 2.3 shows how lineations are prominently displayed on a DEM. These lineations could be marked on a map and later checked in the field for accuracy.

HORIZONS

Horizons are discrete and stratigraphically significant rock units that are too thin (< 10 m thick at 1: 250 000 scale) to be mapped as polygons. Due to their geological significance, however, these horizons are portrayed as lines in the **HORIZONS** coverage, although their true thickness may be exaggerated in some cases. Due to my focus on the Mangarara Formation and mapping at a 1: 50 000 scale, I have included this as a horizon. These horizons can also be assigned a PLOT_RANK, just as with the **FAULTS** coverage.

FOSSILS

The localities of key fossil occurrences are shown by a series of dots on the geological map, and kept in the **FOSSILS** coverage. Where applicable, data were taken from the Fossil Record File database maintained by GNS. The attribute table for each locality includes a PLOT_RANK so different localities can be shown depending on the scale.

Figure 2.3: DEM used to identify lineaments in the study area. These may represent faults and were annotated on to a map and later checked in the field.

LANDSLIDES

Landslide boundaries are stored within the **LANDSLIDE** coverage, and the geology of the landslide is included within the **GEOL_UNITS** coverage. As the finished QMAP product will be at large scale, it will only include landslides with deposits thicker than 5-10 m, and that cover an area larger than 100 × 100 m.

GEODATABASE

These layers were stored in a geodatabase.

2.5 MAP PRODUCTION

ArcInfo 8 was used in the production of the geological map. The 1: 50 000 topographic maps were scanned into ArcMap, and then the information on then was digitised to create a geological map. This involved the use of various sources of data, such as aerial photographs, and specifically topographic data, which are organised into layers (e.g. roads have their own layer, as do streams/rivers). For example, in the production of the geological maps, NZMS 260 Topographic Sheets were imported into ArcMap as JPEG files, and then contour, river and road data were overlain on to them. The maps that were used in the field were then scanned and imported into the ArcMap project, georeferenced, and then digitized. Due to the thinness of some of the units such as the Maryville Coal Measures and the Mangarara Formation, they were digitized as horizons and created by using single lines, and were placed in their own layer (Fig. 2.4). The completed geological map is included as Appendix 2.

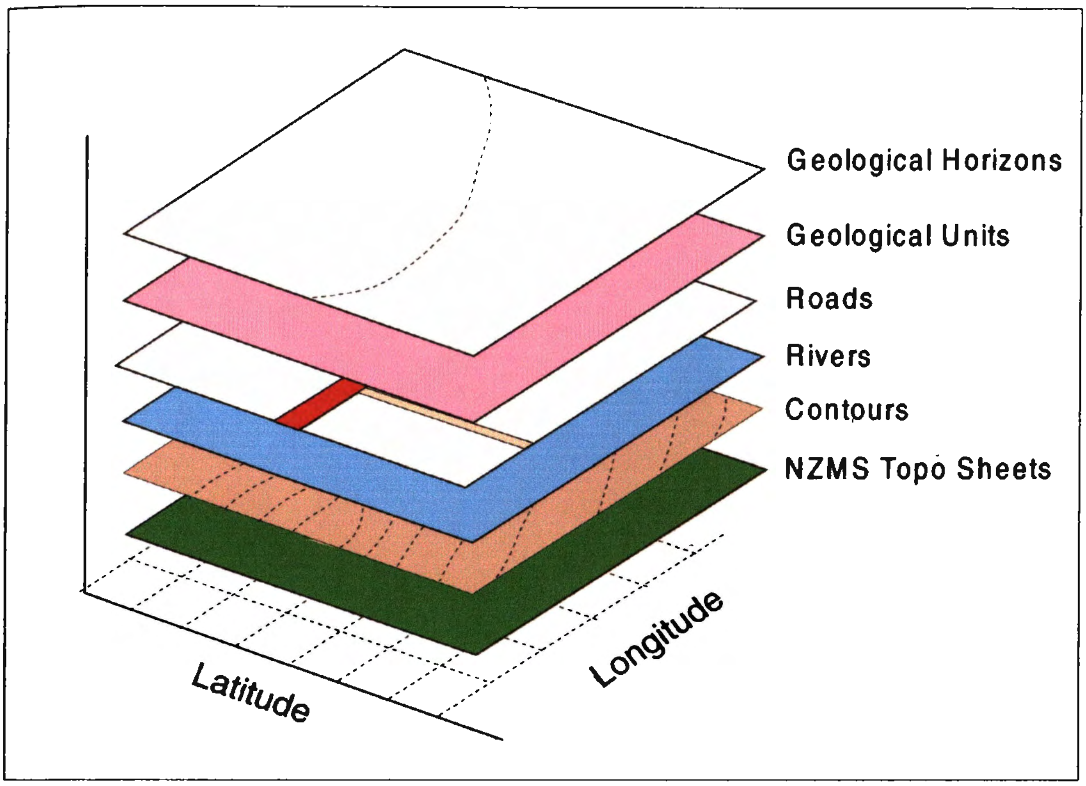


Figure 2.4: Organisation of layers in the ArcMap project used in the creation of the geology map. Layers are successively overlaid by each other, and can be made transparent for the ease of presentation. When layers are imported into a project, they need to be assigned a co-ordinate system so they are put in the right place in the project. Alternatively, as in the case of the field maps, they can be georeferenced and manually aligned with features (e.g. road intersections, spot heights) on the NZMS 260 Topo Sheet basemap.

CHAPTER 3: LITHOSTRATIGRAPHY

3.1 INTRODUCTION

The study area is made up entirely of Cenozoic, predominantly Miocene-aged, sedimentary rocks, with some occurrences of ignimbrite on the tops of hills north of Taumarunui.

Due to extensive work being conducted in the field area since the early 1920's, the stratigraphic nomenclature used to describe the geology of the region has also changed over time. This is in part due to alterations in naming conventions with the creation of the International Subcommission on Stratigraphic Classification (Hedberg, 1976), but also as a result of the better geological understanding that has been developed through these studies.

In this study the widely accepted naming of the Mahoenui Group and its constituent Taumarunui Formation and underlying Taumatamaire Formation have been retained. The use of Mokau Group by Vonk (1999), with the Bexley Sandstone (Formation), Maryville Coal Measures, and the Tangarakau Formation have also been retained. The Otunui Formation of Gerritsen (1994) and Vonk (1999), the Mount Messenger Formation of Hay (1967), and the Ongarue Ignimbrite of Cartwright (in prep.) have been used as well.

I have discontinued the use of the Pongahuru Limestone Member by Gerritsen (1994) to describe the Limestone facies at the base of the Otunui Formation. The Mangarara

Formation name has been used instead to describe this facies. This is due to the varied lithology of the facies throughout the field area. The name 'Mangarara' was first proposed by Hay (1967), and subsequently named the Mangarara Formation by Vonk (1999).

3.2 Mahoenui Group

Definition

The Mahoenui Group within the field area consists of alternating blue-grey mudstone and sandstone (flysch deposits), and massive blue-grey mudstone. The sandstone beds within the flysch deposits contain pronounced horizontal laminations and display normal size grading, being typical features of Bouma divisions of turbidites.

Name Derivation and Type Section

The Mahoenui Group was first described as the "Mahoenui Series" by Henderson and Ongley (1923) as "A series of argillaceous beds, in places at least 600 feet thick, overlying the claystones that form the upper part of the Te Kuiti Series." Kear and Schofield (1959) later changed the series name to Group, but they did not name any Formations within the Mahoenui Group.

Workers such as Glennie (1959), Hay (1967) and Haddock (1970) all noted that there were two lithologically different types of sediment within the Mahoenui Group, but did not propose any classification of these, apart from Hay (1967), although these were not formally defined.

Happy (1971) proposed that the lower massive mudstone be named the Taumatamaire Formation, although the flysch deposits were excluded. The type section of the Taumatamaire Formation north east of Awakino is found at NZMS 260 R17 608828. Nelson and Hume (1977) included the flysch deposits as part of the Mahoenui Group, naming them the Taumarunui Formation, with the type section as "the cliff section exposed on the roadside immediately north of Taumarunui."

Distribution and Thickness

Mahoenui Group sediments crop out to the north of the Ohura Fault, in the northern part of the study area. They also occur throughout the study area in small outliers, where faulting has caused them to be up thrown and thus exposed.

The maximum thickness of the Mahoenui Group within the study area is 100 m, but the actual maximum thickness is probably greater as the base of the Group is not seen in the study area.

Age

Hay (1967) records the Mahoenui Group as being of Waitakian to Otaian age. Nelson and Hume (1977) record the age of the Taumarunui Formation as Otaian to Altonian. Topping (1978) gives the age of the Taumarunui Formation as Waitakian to Otaian, but suspected the age of the outcrop was probably Otaian due to the presence of certain species of foraminifera: *Globorotalia obesa*, *Textularia semicarinata*, *Melonis simplex*, *Ehrenbergina willetti*, *Haeuslerella hectori*, and *Globorotalia obesa*.

Upper and Lower Contacts

The lower contact of the Mahoenui Group is not found anywhere in the study area.

East of the Ohura Fault, the upper contact is with the Mangarara Formation, while to the west of the Ohura Fault, the upper contact is with the Mokau Group.

The contact between the Mahoenui Group and the Mangarara Formation is sharp, with an angular unconformity of ~4°.

The contact between the Mahoenui Group and the Mokau Group is conformable and gradational, and as a result it is hard to locate due to the Ohura Fault and also due to it often being covered by vegetation, especially in the Waitewhena Valley where you would expect to see a contact. Gerritsen (1994) describes the sand content of the Mahoenui Group as increasing upwards "until finally the clean medium sands of the Huhatahi (sic Bexley) are reached."

3.2.1 Taumarunui Formation

Definition

Glennie (1959, p.615) describes the Taumarunui Formation as "a monotonous succession of interbedded sandstones and mudstones...each graded unit consists essentially of a lower argillaceous sandstone which fines upwards to a siltstone and finally a mudstone."

Gerritsen (1994) mapped the sequence of alternating mudstone and sandstone cropping out at the Herlihy Bluffs (NZMS 260 S18 035518) on the Ohura-Taumarunui Road (Fig. 2.1) as Taumarunui Formation.

This usage is applied in this study for the same type of beds evident in the road cutting ~30 km north of Taumarunui on S.H. 4 (Fig. 2.2). Individual beds are typically 20-40 cm thick, although sandstone beds can be 5 cm thick in places. The ratio of sandstone to mudstone is usually 1:4. The base of the sandstone beds are sharp.

Name Derivation and Type Section

Early workers (e.g. Grange, 1927; Schofield, 1954; Glennie, 1959) described the flysch deposits in varying amounts of detail. It wasn't until Nelson and Hume (1977, p.392) that the flysch deposits were named the Taumarunui Formation, with the type section "as the cliff section exposed on the roadside immediately north of Taumarunui."

Distribution and Thickness

The Taumarunui Formation occurs predominantly in the hills north of the Ohura Fault, north of the field area. It is found further south in the field as up thrown blocks, such as along Ararimu East Rd (WP152).

Due to the fault-ridden nature of the study area, the thickness of the Taumarunui Formation is hard to determine, but at WP164 a thickness of 100 m has been measured. This is a minimum thickness due to faulting and erosion. Indeed, Topping (1978) states that 'The thickness of the Taumarunui Formation is difficult to determine because of faulting and erosion, but in thicker sequences it is at least 800 m thick.'

Lithology and Content

The Taumarunui Formation consists of blue-grey, massive, slightly calcareous mudstone and medium- to fine-grained, non- to strongly-calcareous sandstone. The sandstone beds are normally graded and occasionally exhibit horizontal laminations, and also wavy bedding, although this is on a mm size scale (Fig. 2.3).

Plant material is also found occasionally within the sandstone beds, but is usually disintegrated. Larger plant fragments exhibit a preferred north-south orientation, as do flute casts, drag marks, and ripple marks on the under surface of the sandstone beds (Glennie, 1959) (Fig. 2.4).

Age and Correlation

The Taumarunui Formation correlates with the "alternating layers of poorly fossiliferous mudstone and sandstone" of Grange (1927); the "interbedded moderately calcareous silty mudstones and medium to fine sandstones" of Schofield (1954, p.270) and Stainton and Gibson (1964), and the Taumarunui

Figure 3.1 (top-right): Taumarunui Formation exposed at Herlihy Bluff on the Ohura-Taumarunui Road (S18 033517).

Figure 3.2 (middle-right): Type-section of the Taumarunui Formation exposed on S. H. 4 north of Taumarunui (WP040).

Figure 3.3 (top-left): Normally graded, medium-to fine-grained, non- to strongly-calcareous sandstone beds and massive, slightly calcareous mudstoneof the Taumarunui Formation (WP040).

Figure 3.4 (bottom-right): Flute casts, drag marks and burrowing on the underside of the sandstone beds of the Taumarunui Formation (S18 033517).

Formation of Nelson and Hume (1977), Topping (1978), and Gerritsen (1994). The Taumarunui Formation has an Otaian age (Topping, 1978).

3.2.2 Taumatamaire Formation

Definition

Happy (1971, p.39) describes the Taumatamaire Formation as "A sequence of mudstones and calcareous mudstones in part with weakly developed bedding but generally massive, well-bedded calcareous sandstones and limestones, underlain, at least in part, unconformably, by Te Kuiti Group limestones, sandstones, or siltstones and conformably overlain by the Mokau Group ferruginous sandstone."

I define the Taumatamaire Formation as a sequence of blue-grey, slightly fossiliferous, calcareous, massive mudstones with occasional sandier lenses 30-40 cm thick.

Name Derivation and Type Section

Happy (1971) named the Taumatamaire Formation after Taumatamaire Hill (NZMS 260 R17 598832) due to the extensive cropping out of the formation on the northeastern side of the hill. The type section is the Bexley Bluffs section, which is across the valley from Taumatamaire Hill, due to its exposure of a sequence of strata from Te Kuiti Group to Mokau Group.

Nelson and Hume (1977), Topping (1978), and Gerritsen (1994) also used the term Taumatamaire Formation for the massive, calcareous, blue-grey mudstone.

Distribution and Thickness

The Taumatamaire Formation forms the lower parts of valleys and also the upper part of cliffs in some places in the northeast corner of the study area, particularly in the Waitewhena Valley area.

As stated before, the base of the Mahoenui Group is not seen in the study area. The maximum outcrop thickness of the Taumatamaire Formation in the study area is 60 m.

Lithology and Content

The Taumatamaire Formation consists of massive, blue-grey, slightly calcareous mudstone. Sandy lenses 30 – 40 cm thick occur sporadically throughout the outcrop. In outcrop the Formation has a frittered, spheroidal weathered pattern, typical of mudstones. The Awakino and Black Creek Limestone members of Happy (1971) are not found in the study area.

Age and Correlation

Topping (1978) studied the foraminifera of the Mahoenui Group in detail, and it is the most comprehensive work on the dating of Mahoenui rocks. He states that "the Taumatamaire Formation at the base of the Mahoenui Group near Taumarunui is Upper Waitakian to Otaian, but probably Otaian in age as *Globorotalia obesa, Textularia semicarinata* and *Melonis simplex* are present" (Topping, 1978, p.275).

3.3 Mokau Group

Definition

The Mokau Group in the study area consists of yellow-rusty coloured sandstone, blue-grey mudstone, conglomerate and coal seams. As a result, the Mokau Group can be hard to distinguish from the underlying Mahoenui Group and the overlying Otunui Formation, (Vonk, 1999).

The Mokau Group comprises massive, amalgamated, rusty coloured cross-bedded sandstone, overlain by coal seams and low-angle, yellow coloured, cross-bedded sandstone, in turn overlain by massive, buff-coloured sandstone with silty layers throughout.

Name Derivation and Type Section

Henderson and Ongley (1923) and Grange (1927) were the first to use the term 'Mokau' to describe sandy sediments in the King Country area. The name was derived from the Mokau River where there is extensive outcrop.

Vonk (1999) proposed that the Mokau Group be divided into four formations; Bexley Sandstone, Maryville Coal Measures, Tangarakau Formation, and Ladies Mile Mudstone. Within the study area only the first three formations are present.

Distribution and Thickness

In the study area the Mokau Group is restricted to the northwest corner, in the Waitewhena Valley area, due to the location of the Ohura Fault during deposition.

In the Waitewhena Valley the maximum thickness of the Mokau Group is 100 m, but over a distance of 20 km westwards it pinches out until distinction between the individual Mokau formations is impossible.

Age

The lower age limit of the Mokau Group can be approximated by the age of the uppermost sediments of the Mahoenui Group. Topping (1978) studied the foraminifera of Mahoenui Group strata across the King Country Basin in detail, and concluded that the uppermost Mahoenui Group is of upper Otaian-lower Altonian age for the Waitomo, Te Kuiti, Taumarunui and Mahoenui township areas. A lower Altonian age for the upper Mahoenui Group is further supported by fauna sampled near Tangitu. Rare specimens of *Globigerina trilobus trilobus* were found in the upper Mahoenui Group, while specimens of *Haeuslerella pukeuriensis* and *Globorotalia miozea* were present in the overlying Mokau Group strata.

King et al. (1993) conducted foraminiferal biostratigraphic work on the Tangarakau Formation, and recognised the three informal zones of Scott (1992) in the Ladies Mile Mudstone: *Globorotalia incognita* zone (lower Altonian); *Globorotalia zealandica* zone (middle Altonian); and *Globorotalia miozea* zone (upper Altonian). A sample collected from the Awakino Valley was given a lower Altonian age based on the presence of *Haeuslerella pukeuriensis* and *Globorotalia incognita.* King et al. (1993) note that most of the *G. miozea* is missing at this site though, which would explain the lower Altonian age. Overall, biostratigraphic ages for the Tangarakau Formation indicate a lower Altonian age.

Upper and Lower Contacts

The lower contact of the Mokau Group with the underlying Mahoenui Group is the cause of some debate. Some (Fleming, 1947; Happy, 1971) consider the contact unconformable, while others (Topping, 1978; Crosdale, 1993) suggest conformity. This is due to there being a lack of outcrop along the contact. Vonk (1999) suggests that the contact is unconformable, due to the presence of a greywacke pebble conglomerate at the base of the Bexley Sandstone at NZMS 260 S16 005248.

The upper contact of the Mokau Group is with the Mangarara Formation, and is unconformable. As with the lower contact, there is a lack of outcrop along this contact, but there is the occurrence of a greywacke conglomerate at WP131.

3.3.1 Bexley Sandstone

Definition

Vonk (1999) defines the Bexley Sandstone as comprised of 'massive, amalgamated and current-bedded sandstones,' that is weathered to an orange-brown colour in outcrop. Lisegang rings are formed from concentrations of limonite to give the sandstone pseudo-sedimentary structures.

Name Derivation and Type Section

The name "Bexley Sandstone" (Vonk, 1999) replaces the Lower Mokau Sandstone of Hay (1967) and Mokau Formation proposed by King et al. (1993).

The name is derived from 'Bexley Station' in the Awakino Gorge, where the sandstone beds have a characteristic bluff-forming outcrop.

The type section for the Bexley Sandstone is in the Mokau River, from Ohinewhero Trig eastwards to the mouth of Wade Creek (Hay, 1967).

Distribution and Thickness

In the study area the Bexley Sandstone is restricted to the northwest corner, in the Waitewhena Valley area, its deposition having been influenced by the activity of the Ohura Fault.

In the Waitewhena Valley the maximum thickness of the Bexley sandstone is 30 m, but over a distance of 20 km westwards it pinches out until distinction with other Mokau sediments is impossible.

Lithology and Content

The Bexley Sandstone is made up of massive, amalgamated, and bedded sandstone (Fig. 2.5). In outcrop the sandstone is weathered to a characteristic orange-brown rusty colour (Fig. 2.6), due to the dissolution of iron-bearing minerals, but in fresh outcrop the sandstone in light grey-buff coloured, massive, fine-grained, well sorted, and slightly argillaceous (Vonk, 1999), making it hard to distinguish from the Otunui Formation.

Age

As the Bexley Sandstone is poorly fossiliferous, biostratigraphic age control is hard to determine. Topping (1978) studied the foraminifera of the Mahoenui Group and details the upper age limits of the Mahoenui Group sediments across the North Wanganui Basin. As a result of this the lower age limit of the Bexley Sandstone can be approximated (Vonk, 1999). Topping (1978) concludes that the age of the uppermost Mahoenui Group is of upper Otaian-lower Altonian age.

The upper age limit for the Bexley Sandstone can be assessed by the age of the lowermost Ladies Mile Mudstone sediments obtained by King et al. (1993), which concludes that the Ladies Mile Mudstone has an age no younger than lower Altonian due to the presence of *Haeuslerella pukeuriensis* and *Globorotalia incognita*.

The Bexley Sandstone has an age range from upper Otaian to lower Altonian.

3.3.2 Maryville Coal Measures

Definition

The Maryville Coal Measures comprise a lower coal seam, sandstone, and then an upper coal seam. Hay (1967) subdivided the coal measures of the Mokau Group into three informal members; a lower and upper coal unit separated by massive sandstone (Fig. 2.7).

Haddock (1970) later defined these three members as; the Maryville Lower Coal Member, the Maryville Sandstone Member, and the Maryville Upper Coal Member.

I have followed Haddock (1970) in the naming of the Mokau Group, although it is stated 'Whether there is an obvious need to replace these names with names other than Maryville is debatable, and may need addressing in the future (Vonk, 1999).

Name Derivation and Type Section

Exposure of the Mokau Group in the study area is extremely poor, due to the Waitewhena Valley being covered in native forest, and the bluff-forming characteristics of the sandstone beds.

Vonk (1999) describes his type section starting in a stream in the Huhatahi Valley, which starts below Huhatahi Road, "and follows its way up to a set of prominent cliffs formed by the Tangarakau Formation sediments." Just above the road in the streambed the Maryville Lower Coal Measure is exposed and is overlain by the Maryville Sandstone Member (NZMS 260 R18 767764). Due to the poor exposure in the study area, I have decided not to include a type section of the Maryville Coal Measures.

Distribution and Thickness

In the study area the Maryville Coal Measures are restricted to the northwest corner, in the Waitewhena Valley area, due to the location of the Ohura Fault during deposition.

In the Waitewhena Valley the maximum thickness of the Maryville Coal Measures is 25 m (Fig. 2.8), but over a distance of 20 km westwards it pinches out until distinction with other Mokau sediments is impossible.

Lithology and Content

The Maryville Coal Measures in the study area consists of a lower coal seam 3-4 m thick, sandstone 20 m thick, and then an upper coal seam 2-3 m thick. These deposits would correlate to the Maryville Lower Coal Member, Maryville Sandstone Member, and Maryville Upper Coal Member respectively, of Vonk (1999).

The sandstone within the coal seams is typically massive (Hay, 1967), but some low-angle cross-bedding is evident within it. It displays the typical 'rusty' colour in weathered outcrop that characterises the Mokau Group sandstone beds.

3 3 3

Definition

The Tangarakau Formation is defined by Haddock (1970) as a series of fine-grained sandstone, shell beds, mudstone and conglomerate (Fig. 2.9) that unconformably rest upon the Maryville Coal Measures and the Bexley Sandstone.

Figure 3.5 (top-left): Bedded sandstone of the Bexley Sandstone. Note the finer beds of sand within the coarser sandstone layers (WP160).

Figure 3.6 (stop-right): Orange-brown rusty colour of the Bexley Sandstone exposed along the Waitewhena Valley Road (WP160).

Figure 3.7 (second from top): The bottom coal seam of the Maryville Coal Measures is just visible at the bottom of the out-crop. Bluff is made up of massive sandstone which separates the two coal seams (WP302).

Figure 3.8 (third from top): Looking south down the Waitewhena Valley Road. The coal seams of the Maryville Coal Measues form the flat tops of the hills (WP304).

Figure 3.9 (bottom-right): Conglomerate of the Tangarakau Formation (WP303).

Name Derivation and Type Section

The name 'Tangarakau' is derived from the Tangarakau River. The type section of Haddock (1970) for the Tangarakau Formation is the cliffs and streams at Pukemiro Trig (NZMS 260 R19 720448).

Distribution and Thickness

In the study area the Tangarakau Formation is restricted to the northwest corner, in the Waitewhena Valley area, due to the location of the Ohura Fault during deposition.

In the Waitewhena Valley the maximum thickness of the Tangarakau Formation is 30 m, but over a distance of 20 km westwards it pinches out until distinction between this and other Mokau sediments is impossible.

Lithology and Content

The Tangarakau Formation within the study area consists of massive silty sandstone beds with siltier lenses occurring throughout the unit.

The silty sandstone beds are buff in colour, while the silty lenses are blue-grey, and exhibit a conchoidal weathering pattern.

Age

Haddock (1970) gave a sandstone member within the Tangarakau Formation an Altonian age, but there were conflicting ages of microfauna and macrofauna at one locality, which do not support this age.

The upper age limit of the Tangarakau Formation can be defined by the age of the overlying Otunui Formation, which yields microfauna of Lillburnian to Tongaporutuan age (Gerritsen, 1994).

3.4 Mangarara Formation

Definition

The Mangarara Formation varies greatly throughout the field area, and consists of a yellow-brown to blue grey, fossiliferous glauconitic limestone with sandy lenses, to a conglomeratic, fossiliferous sandy limestone (Fig. 2.10).

Name Derivation and Type Section

Hay (1967) was the first to use the name 'Mangarara' to define a Mangarara Sandstone Formation within the Mohakatino Group, after Mangarara Stream in the lower Mohakatino Valley. Other workers to use this name include Happy (1971; Mangarara Sandstone Formation, Mohakatino Group) and King et al. (1993; Mangarara (Sandstone Member), Mohakatino Formation); and redefined by Wilson (1994; Mangarara Limestone Formation, Manganui Formation), Hansen (1996; Mangarara Sandstone Member, Mohakatino Formation) and Vonk (1999; Mangarara Formation).

The term 'Mangarara Formation' is used in this study. The variable lithology of the unit throughout the field area precludes the use of a descriptive lithological name such as sandstone or limestone in its formal definition (Vonk, 1999).

Distribution and Thickness

The Mangarara Formation is found from Pongahuru Road, near Taumarunui, to the Ohura Railroad in the north of the field area.

The thickness of the Mangarara Formation is between 0.4 m at the end of Pongahuru Road, to 2 m on the side of S.H. 4 north of Taumarunui (Fig. 2.11). It is usually ~1.5 m thick.

Lithology and Content

The Mangarara Formation's lithology is basically a mixture of medium-grained bioclastic remains with terrigenous material (Fig. 2.12). Bioturbation is visible at

Figure 3.10 (top-left): Mangarara Formation outcrop next to rail tracks at WP144. Person is sittung on Otunui Formation and contact is where waterfall starts.

Figure 3.11 (top-right): Mangarara Formation exposed on the side of S.H. 4 north of Taumarunui (WP139).

Figure 3.12 (middle-right): Bioturbation within the Mangarara Formation at WP144.

Figure 3.13 (bottom-right): Sample of Mangarara Formation taken from the base of the contact with the Mahoenui Group. Note the large greywacke pebbles and other terrigenous material.

railway tracks site (WP144) (Fig. 2.13), and also at Pongahuru Road end (WP305). The Mangarara Formation is also very sandy, with glauconite common throughout. At some localities (WP144 and WP152) there is a thin 20-30 cm sandy layer in the middle of the formation.

Age and Correlation

Haddock (1970) determined the age of the Mangarara Formation to be Waiauan to Tongaporutuan in age based on studies of the microfauna.

King et al. (1993) and Wilson (1994) micropaleontologically dated the Mangarara Formation, and determined an age of late Altonian to early Clifdenian. This was based on microfaunal assemblages sampled from the Awakino River mouth (R17/f8020) and Pahaoa Hill (R18/f81). Further inland at Awakau, King et al. (1993) assign a Waiauan age to the Mangarara Formation (R18/f81).

The macrofossil assemblage of the Mangarara Formation in the field gives an age most likely of Lillburnian-Waiauan. This is due to the abundance of *Zenatia acinaces* and *Zenatia cretacea*, and also the presence of *Spissatella* sp.

3.5 Otunui Formation

Definition

The Otunui Formation consists of blue-grey, massive, argillaceous sandstone. In the upper parts of the formation, coarser, cleaner sandstone lenses occur, along with some mudstone lenses. Localised channel deposits and conglomerate occur in several places.

The Otunui Formation overlies the Mangarara Formation, and is in turn overlain by the Mt Messenger Formation.

Name Derivation and Type Section

The Otunui Formation takes its name from the Otunui Valley where excellent exposures occur (Gerritsen, 1994). The type locality starts in a creek (NZMS 260 S18/953626), and runs to the top of the hill (S18/476298). The Otunui Formation is correlated to part of the Mokau beds and the Mohakatino beds of Henderson and Ongley (1923) and Grange (1927); the Mohakatino Formation of Glennie (1957), van der Sijp (1959) and Stainton and Gibson (1964); the Mohakatino Group (Omoao Formation) of Nelson and Hume (1977); the Mohakatino Group of Manhire and Phelps (1988); and the Otunui Formation of Gerritsen (1994) and Vonk (1999).

Distribution and Thickness

The Otunui Formation occurs throughout the field area, and is the predominant rock type east of the Ohura Fault. It is found in the valley bottoms and also on the tops of ridges, giving it a thickness of 180 m in the field area. Gerritsen (1994) claims that the maximum thickness of the Otunui Formation would be in excess of 250 m east of the Ohura Fault, but I have found no evidence for this thickness. West of the Ohura fault, it has a thickness of 30 m, but thickens to the north up to 100 m.

Lithology and Content

The Otunui Formation's dominant lithology is of fine- to medium-grained, moderately sorted argillaceous sandstone. The sandstone forms characteristic blue-grey coloured bluffs, but weathers to a yellow-brown colour (Gerritsen, 1994; Vonk, 1999) (Fig. 2.14). Sandstone beds are typically massive but can sometimes appear to have bedding present, due to subtle changes in mud content, and which result in 'cryptic' bedding when viewed from a distance (Fig. 2.15).

Previous work (Stainton and Gibson, 1964; Hay, 1967; Happy, 1971; King et al., 1993; Gerritsen, 1994; Vonk, 1999) has found the Otunui Formation to be tuffaceous, a characteristic that is diagnostic of the Otunui Formation, but this tuffaceous material is not present anywhere throughout the field area. Vonk (1999) noted that "In the Tangarakau Gorge region, the Otunui Formation tends to have a higher mud-sand ratio and does not appear to contain tuffaceous material." It seems that the amount of tuffaceous material found in the Otunui Formation tends to decrease in more inland eastern localities.

Throughout the field area, the base of the Otunui Formation is very glauconitic (Fig. 2.16) and contains a lot of fauna, with an abundance of *Zeacolpus pukeuriensis* over the first 3-5 m of the deposit (Fig. 2.17). In the lower 50 m of the sequence, the dominant lithology is medium-grained, massive, blue-grey, highly glauconitic sandstone. Higher up in the sequence re-deposited material becomes more dominant (Fig. 2.18). This material takes the form of thin (10-20 cm) coarse sandstone beds within the fine-grained sandstone (Fig. 2.19). The upper parts of the Otunui Formation are exposed in the Hapurua Valley area, where it grades quickly into fine-grained sandstone to a coarse-grained mudstone, with re-deposited beds of coarser sandstone beds up to 50 cm in thickness.

In the vicinity of Pukepoto, conglomerates and channel deposits occur. The channel deposits consist of concretions from the Otunui Formation, and weathered, iron stained pebbles of fine-grained cemented sandstone, set in a matrix of shell hash and calcareous sandstone (Vonk, 1999) (Figs. 2.20, 2.21). Conglomerate beds consist of a poorly sorted matrix of rounded pebbles and shell hash, and also have a thin (30 cm) sandstone bed in the middle. The conglomerate beds vary in thickness from 1-2 m.

AGE

Gerritsen (1994) gives the Otunui Formation an age of Mid-Upper Lilburnian to Tongaporutuan, based on micropalaeontological assessment of samples taken from the Otunui Formation.

Figure 3.14 (top-left): Typical blue-grey exposure of the Otunui Formation.

Figure 3.15 (top-right): Changes in mud content within the Otunui Formation.

Figure 3.16 (middle-right): Glauconitic base of the Otunui Formation. This is 2-3 m above the contact with the Mangarara Formation. Shell hash is also present with the glauconite.

Figure 3.17 (bottom-right): *Zeacolpus pukeuriensis* in the first 3-5 m of the Otunui Formation. This species is extremely aboundant in the base of the Otunui Formation.

From limited palaeontological work on three samples collected from the Otunui Formation, this age given by Gerritsen (1994) is most likely, although the age of the formation may be slightly older due to the presence of *Amphistegina aucklandica*, which is constrained to this time period, but due to the dominance of *Uvigerina rodleyi, Zeaflorilus parri, Rectobolivina parvula* and *Cibicides perforatus* in all of the samples, a Tongaporutuan age is most likely (Hornibrook et. al, 1989).

The Otunui Formation correlates to Grange's (1927) Mokau Group where it lies east of the Ohura Fault, and to the Mohakatino Group, to the Mohakatino Formation of Glennie (1957), van der Sijp (1959) and Stainton and Gibson (1964); to the Mohakatino Group of Hay (1967), Nelson and Hume (1977) and Manhire and Phelps (1988); and to the Otunui Formation of Gerritsen (1994) and Vonk (1999).

Upper and Lower Contacts

To the east of the Ohura Fault, the Otunui Formation overlies the Mangarara Formation, as observed at WP139, WP144 and WP152, where the Mangarara Formation usually unconformably overlies the Taumarunui Formation. Howver, in the Waitewhena Valley it overlies the Taumatamaire Mudstone, although the contact is obscured (WP291).

To the west of the Ohura Fault the Otunui Formation overlies the Mokau Group, although the contact is not visible as it is obscured by vegetation, or occurs at the tops of bluffs formed by the Mokau Group, making description impractical.

3.6 Mt Messenger Formation

Definition

The Mt Messenger Formation consists mainly of well-sorted, very fine to fine-grained thin-bedded sandstone and siltstone, with turbidite beds comprising planar

Figure 3.18 (top-left): Re-deposited beds of coarse sandstone within the finer sandstone of the upper Otunui Formation. Okahukura Saddle Road.

Figure 3.19 (top-right): Fine-grained mudstone beds within the Otunui Formation. Okahukura Saddle Road.

Figure 3.20 (middle-right): Channelised deposits within the Otunui Formation. These consists of large 20-40 cm clasts of sandstone, and are considered separate to the conglomerates found in the Otunui Formation.

Figure 3.21 (bottom-right): Channel deposit cropping out along a hill.

laminated and ripple-laminated sandstone and massive siltstone (Browne and Slatt, 2002).

Name Derivation and Type-Section

The Mount Messenger Formation was originally known as the Mount Messenger Sandstone, first proposed by Hay (1967). King (1998a, 1988b) modified the name to the Mount Messenger Formation, named after Mount Messenger on State Highway 3 in North Taranaki.

The type section was designated by Schofield (*in* Fleming, 1959) as the sequence exposed between Kawau and Whitecliffs on the North Taranaki Coast (King and Thrasher, 1996).

Distribution and Thickness

The Mt Messenger Formation is only found in one locality in the study area – along the Okahukura Saddle road where ~50 m of exposure is visible. This was previously mapped as the Mokau Group of Grange (1927); the Mohakatino beds of Henderson and Ongley (1923) and Grange (1927); the Mohakatino Formation of Glennie (1957), van der Sijp (1959) and Stainton and Gibson (1964); the Mohakatino Group of Hay (1967), Nelson and Hume (1977) and Manhire and Phelps (1988); and the Otunui Formation of Gerritsen (1994).

The Mt Messenger Formation has a thickness of 40-50 m in the study area.

Lithology and Content

The Mt Messenger's lithology consists of conglomerate, massive sandstone and mudstone, and interbedded, laminated sandstone and mudstone.

The conglomerate at the base of the Mt Messenger Formation consists of rounded to well-rounded pebbles of sandstone, greywacke, and redeposited sandstone clasts. Broken faunal material occurs near the top of the 5 m thick conglomerate, concentrated in a 30 cm thick band. Above the conglomerate is 2 m of massive, coarse-grained, yellow-brown weathered sandstone, which then grades up into massive, blue-grey mudstone, 1 m thick (Fig. 2.22).

This massive mudstone then grades into 40 m of interbedded sandstone and mudstone beds, grading up into each other (Fig. 2.23). Within these beds laminations are present, with some folding of laminations occurring (Fig. 2.24).

Age

The age of the Mount Messenger Formation has been given as late Lillburnian-early Tongaporutuan (Browne et al., 1996; King and Thrasher, 1996; Kamp, et. al, 2002).

Upper and Lower Contacts

The Mt Messenger Formation conformably overlies the Otunui Formation of massive, blue-grey sandstone, and underlies the Urenui Formation (King et. al, 1994), although this contact is not seen in the study area. As the Mt Messenger Formation conformably overlies the Otunui Formation, determining the exact boundary between the two is hard (Fig. 2.25). I infer the contact between the two to be the contact with the conglomerate and the underlying sandstone (Evans, 1941).

3.7 Ongarue Ignimbrite

Definition

The Ongarue Ignimbrite is a crystal rich, pumice absent, densely welded ignimbrite, which ranges in colour from a grey-white to a lilac colour (Cartwright, in prep.).

Figure 3.22 (top-left): Massive, coarse-grained sandstone of the Mount Messenger Formation grading into coarse-grained mudstone.

Figure 3.23 (top-right): Interbedded sandstone and mudstone beds of the Mount Messenger Formation.

Figure 3.24 (middle-right): Laminations within the beds of the interbedded sandstone and mudstone beds.

Figure 3.25 (bottom-right): Redeposited beds in the upper Otunui Formation/ Mount Messenger Formation. Determining the exact position of the boundary between these two Formations is difficult.

Name Derivation and Type-Section

The Ongarue Ignimbrite is given its name due to the location it was first found at near the settlement of Ongarue, 25 km north of Taumarunui, off State Highway 4. The type section is located at NZMS 260 S18 204724, where it forms 20-30 m high cliffs at the top of the low-lying farmland.

Distribution and Thickness

The Ongarue Ignimbrite is found in only two locations in the study area: It is found capping Features Pukepoto and Okaihae. Previous mapping by Hay (1967) considered the unit to be Ongatiti Ignimbrite.

Lithology and Content

The crystal component of the Ongarue Ignimbrite makes up ~25% of the composition. Phenocrysts include quartz, plagioclase and hornblende. It displays a reversely welded appearance in outcrop.

Age

The age of the Ongarue Ignimbrite is controlled by the ages on the under- and overlying deposits. The age of the underlying Ngaroma Ignimbrite is given as 1.55 ± 0.05 Ma (Houghton et al., 1995), and the age of the overlying Ongatiti Ignimbrite is given as 1.21 ± 0.04 Ma (Houghton et al., 1995).

Upper and Lower Contacts

Within the study area the Ongarue Ignimbrite unconformably overlies the Otunui Formation. Further east of the study area, it is underlain by the Ngaroma Ignimbrite and overlain by the Ongatiti Ignimbrite (Cartwright, in prep.).

CHAPTER 4: FACIES ASSOCIATION

4.1 INTRODUCTION

Traditional lithofacies analysis has been applied to the sedimentary units mapped within the study area (e.g. Walker, 1992) as an approach to help establish the depositional paleoenvironments. Seven facies have been identified in the study area. These have been sub-divided into 14 sub-facies (Table 3.1). Studying the various sub-facies helps to understand the depositional paleoenvironment and mechanism of deposition of the sediments. This information can then be used in basin reconstruction and basin history.

4.2 MAHOENUI GROUP

4.2.1 ALTERNATING SANDSTONE AND MUDSTONE (MS1)

The alternating sandstone and mudstone lithofacies consists of a repetitive alternation of sandstone and mudstone beds (flysch beds). The thickness of these beds varies throughout the study area. At the type section (road cutting by S.H.4) the sandstone beds are 10-20 cm thick, while the mudstone beds are 10-40 cm thick. There do not seem to be significant changes within the field area. The sand to mud ratio is typically 1:4.

The mudstone beds are massive while the sandstone beds occasionally exhibit horizontal or wavy laminations and are commonly normally graded. In most outcrops the sandstone beds appear to be massive, but this appearance is most probably due to weathering. The

Table 4.1: Summary of facies and sub-facies in field area.

Facies Association	Code	Description of Lithofacies	Depositional Environment	Mechanism of Emplacement	Unit
Conglomerate	Co1	Cobble-peble sized clasts. Well-rounded clasts of greywacke and sandstone < 5 cm in diameter,in a matrix of sandstone	Shoreface/Inner shelf	Slumping or debris flow	Ot
	Co2	Concretionary conglomerate. Well rounded clast of concretions and greywacke pebbles	Shoreface/Inner shelf	Redeposition during ravinement	Mg
Sandstone	Sa1	Fine- to medium-grained massive sandstone. Yellow-brown in fresh outcrop but blue-grey when weathered	Inner shelf to mid shelf	Suspension sedimentation and low energy turbidity currents	Ot
	Sa2	Cross-bedded sandstone. Low angle (<10), and is only visible when standing away from the outcrop	Dune, shoreface	Wave action on beach	Bx, MMs, Tk
	Sa3	Planar-bedded, fine- to medium-grained sandstone	Inner shelf	Deposited with slump material. Part of the lower flow regime/end of deposition	MMs
	Sa4	Massive, blue-grey, markedly glauconitic fine-grained sandstone	Outer shelf - upper slope	Suspension sedimentation at a slow rate. High biogenic productivity	Ot
	Sa5	Amalgamated sandstone. A series of alternating fine- to medium-grained sand-stone beds. Up to 50 cm thick	Inner shelf, storm dominated	Suspension and traction emplacement	Tk
	Sa6	Cryptically bedded sandstone. Alternating beds of fine- and coarse-grained sandstone	Outer shelf to upper slope	Cohesive and cohesionless debris flows	Ot
Mudstone	M1	Massive, blue-grey mudstone. Spheriodal weathering patterns	Slope to bathyal	Hemipelagic settling	Tae
	M2	Massive, glauconitic blue-grey mudstone	Slope to bathyal	Pelagic settling. Low rate of sedimentation	Mg
Limestone	L1	Shelly pebbly limestone	Shore face/Inner shelf	Redeposition during ravinement	Mg
Alternating sandstone and mudstone	SM1	Alternating sandstone and mudstone beds. Repetitive. Flysch deposits	Slope to bathyal	Turbidites	Tm
Channel deposits	Cd1	Concretionary, iron-stained pebbles of fine cemented sandstone, set in a matrix of calcareous sandstone	Outer shelf to slope	Slumping	Ot
Coal	C1	Sub-bituminous coal seams	Estuarine/Swamp/Flood Plains	Plant growth and inundation	MCM

mudstone and underlying sandstone beds are clearly associated as the later grades normally into the former; they represent a single sedimentological event. The contacts between particular mudstone beds and overlying sandstone beds are invariably sharp and micro erosional (Figs. 4.1, 4.2). The base of the mudstone beds also exhibit burrowing, tool marks, and flute casts (Fig. 4.3).

This lithofacies is widely distributed throughout the study area, with it being the predominant lithofacies north of the Ohura Fault in the top half of the study area. It also occurs at the base of fault-bounded inliers throughout the rest of the study area (Fig. 4.4).

These alternating deposits of sandstone and mudstone are commonly referred to as flysch. Glennie (1959) mapped these deposits from Taumarunui to Te Kuiti, and inferred that they were distributed in a fan-shaped pattern, with the apex near Te Kuiti and the toe just south of Taumarunui. The flysch deposits probably represent deposition in a submarine fan environment (Fig. 4.5).

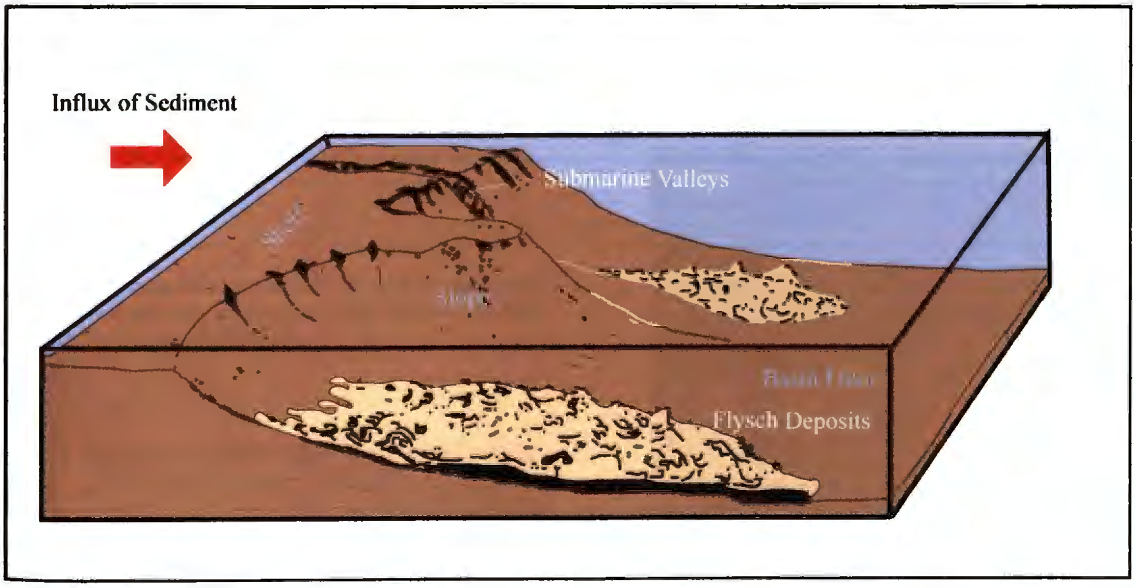


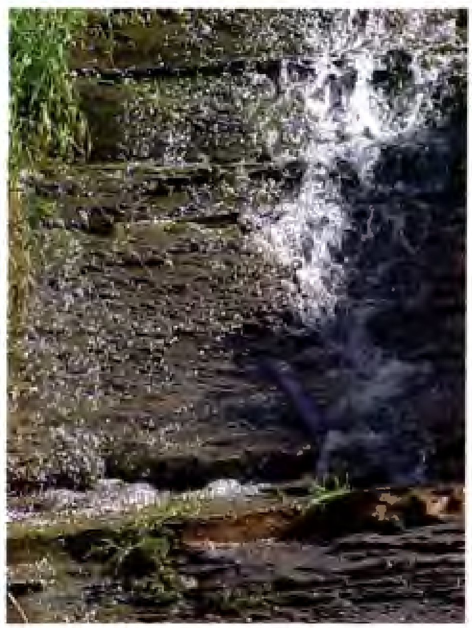
Figure 4.5 : Diagram of environment of emplacement of flysch deposits. Material from the shelf or upper slope flows down the slope and is deposited on the basin floor. A single flow event is represented by a sandstone bed and the overlying mudstone bed (Adapted from Hamblin and Christiansen, 1995).

Figure 4.2 (top-left): Sharp contact between a sandstone bed and an underlying mudstone bed (flysch deposits). A sandstone bed and an overlying mudstone bed represents a single event (WP040)..

Figure 4.3 (top-right): Close-up of the sharp contact between sandstone and mudstone beds of the Taumarunui Formation (WP040).

Figure 4.4 (middle-right): The base of a sandstone bed showing burrowing, drag marks, and also flute casts (S18 033517).

Figure 4.5 (bottom-right): Taumarunui Formation flysch deposits. Hammer is resting on a sandstone bed. The sand/mud ratio here is 1:4 (S18 115655).



The structures exhibited by the sandstone beds (the horizontal or wavy laminations), are a result of the energy of the turbidity current that caused their deposition. As the turbidity current moves down a slope the energy of the flow decreases from the upper flow regime to the lower flow regime. The horizontal laminations occur when the current is in its upper flow regime, and when the energy of the flow drops into the lower flow regime wavy or ripple cross-laminations form (Walker, 1978).

Paleoenvironmental work indicates that this lithofacies was probably deposited in bathyal water depths (Topping, 1978).

This facies is restricted to the Taumarunui Formation.

4.2.2 Massive Mudstone (m1)

This lithofacies is composed of massive blue-grey mudstone. No bedding or structures are apparent. In outcrop the mudstone has a frittered spheroidal weathering pattern. Trace fossils and other fossils are seldom evident, although some burrowing has been observed.

Bed thickness varies from 1 m to 30 m.

The fine-grained characteristic of the deposit implies an environment of low energy. The apparent lack of structure and trace fossils within the mud makes it hard to place the mud in a depth environment.

The Taumatamaire Formation was deposited in conditions varying from neritic to abyssal, and Topping (1978) suggested that it represents facies G of Walker and Mutti (1973); that is basin floor outer neritic-upper bathal muds.

4.3 Mokau Group

4.3.1 Massive Sandstone (SA1)

This facies consists of fine- to medium-grained sandstone. It is usually a yellow-brown colour in fresh outcrop, but turns a blue-grey colour when weathered. There are no sedimentary structures evident in either fresh outcrop or weathered outcrop. This unit is up to 250 m thick.

In the Tangarakau Formation the massive sandstone facies makes up the majority of the deposit. The Tangarakau Formation consists of fine- to medium-grained sandstone. It was most probably deposited in back-barrier environments and reflect deposition in tidal channels and intertidal mudflats (Vonk, 1999).

4.3.2 Cross-Bedded Sandstone (SA2)

The cross bedding in the sandstone is low angle (<10°) (Fig. 4.6), and is only visible when standing a few metres from the outcrop – any closer than this and it is not (Fig. 4.7). Within the Mokau Group this facies occurs in the Bexley Sandstone.

According to Boggs (1995), cross-ripples form by the migration of ripples and dunes, either above the water by wind, or beneath the water by wave action. This migration of dunes or ripples leads to the formation of dipping laminae, due to avalanching or suspension settling on the lee side of these bedforms. If the sediment is too coarse to be transported in suspension, avalanching of sediment down the lee slope of the ripple will cause formation of laminae that are steep, and which make contact with the horizontal suspension deposited laminae. This facies was most likely deposited in a shoreface-to foreshore environment (Vonk, 1999).

4.3.3 Amalgamated Sandstone (SA5)

This facies consists of alternating fine- and very fine-grained sandstone beds, up to 1 m thick, stacked on top of one another. The boundary between the top of a particular very fine-grained sandstone bed and the overlying fine-grained sandstone bed is sharp, and is quite evident from a distance. Within the beds, horizontal parallel laminations are present. This facies occurs in the Tangarakau Formation.

This facies was most likely deposited in an inner shelf to mid shelf environment. Parallel lamination develops under low velocity wave motions and unidirectional currents under fair weather conditions. Amalgamation surfaces are a response to marine transgression and an increase in shelf accommodation (Vonk, 1999).

4.3.4 Coal (C1)

The coal lithofacies is of sub-bituminous B (ASTM) rank. It is hard, brown-black to black, brittle, and breaks with a conchoidal fracture (Fig. 4.8). The coal seams are 0.5 to 3 m thick, and consist of alternating dull and moderately bright bands, each a few millimetres thick.

The coal seams crop out in the Waitewhena and Hapurua valleys, and are part of the Maryville Coal Measures of the Mokau Group. In the Waitewhena Valley two seams occur, each varying from 0.5 to 3 m in thickness, and separated by 30 m of medium-grained, well sorted sandstone, in places fining into fine-grained sandstone, with planar to low-angle cross-bedding.

The coal represents a terrestrial or near-shore deposit. The presence of framboidal pyrite indicates the coal formed soon before marshes were transgressed by marine to brackish water environments (Horne et al., 1978). It is most likely that the coals were deposited at or close to sea level.

4.4 Mangarara Formation

4.4.1 Glauconitic Mudstone (M2)

Fine-grained mudstone with sand-sized grains of glauconite. The matrix is a hard, carbonate-cemented, grey, moderately bioturbated mudstone. Fauna are not very well preserved in the deposit, and harder concretionary layers are sometimes present (Fig. 4.9).

The abundance of glauconite (Fig. 4.10) indicates a low rate of sedimentation with oxidising-reducing sea floor conditions. Biogenic activity was also high.

Figure 4.6 (top-left): Cross-bedded sandstone (Sa2) of the Bexley Sandstone. Cross-bedding is low angle, and was most likely formed by the migration of ripples in a near-shore environment. (WP160).

Figure 4.7 (top-right): Close-up of cross-bedding (Sa2) in the Mokau Group Bexley Sandstone. Bedding is hard to see when close to outcrop. (WP160).

Figure 4.8 (bottom-right): Coal (C1) from the Maryville Coal Measures. This is the lower seam of the Measures. The next seam is separated by 30-50 m of massive sandstone. (WP303).

4.4.2 Concretionary Conglomerate (Co2)

A cobble conglomerate that is clast-supported with concretions and greywacke pebbles. Clasts are well rounded (Fig. 4.11), and some concretions can be up to 30 cm in diameter. Algal nodules are also present. The conglomerate varies in thickness from 50 cm to 1.5 m.

The clasts within the conglomerate were probably deposited during a marine transgression, and accumulated during the ravinement of the underlying sediment in a shore face/inner shelf environment.

4.4.3 Shelly Pebbly Limestone (L1)

Coarse-grained, light yellow to brown in colour, glauconitic, shelly, pebbly limestone. Pebble layers 10 – 20 cm thick contain dark-grey, well-rounded pebbles <2 cm in diameter, supported in a matrix of medium-grained sandstone and shell fragments (Fig. 4.12). The faunal material is dominated by bivalves (Fig. 4.13) and bryozoans (Hayton et al., 1995). Large siliciclastic fragments are common throughout.

The abundance of bivalves and bryozoans indicates an near shore environment, as they are common on high-energy open shelves around New Zealand (Nelson et al., 1982; Hayton et al., 1995). The presence of large rock fragments and pebbles suggests a high-energy environment, up to 50 m water depth with a hard or sandy substrate (Hayton et al., 1995).

4.5 Otunui Formation

4.5.1 Massive Sandstone (Sa1)

This facies consists of muddy fine- to medium-grained sandstone. It is usually a blue-grey colour in fresh outcrop, but turns a yellow-brown colour when weathered (Fig. 4.14). There are no sedimentary structures evident in either fresh outcrop or weathered outcrop. This unit is up to 250 m thick.

Figure 4.9 (top-left): Harder concretionary layer within the Mangarara Formation. Faunal remains are not usually preserved within this facies. (WP139).

Figure 4.10 (top-right): Glauconitic mudstone (M2) of the Mangarara Formation. This represents a low rate of sedimentation on the sea floor. (TE005)

Figure 4.11 (2nd from top): Well-rounded clasts in a concretionary conglomerate (CO2). Algal nodules are also present (TE007).

Figure 4.12 (3rd from top): Shell fragments of a shelly pebbly limestone (L1). (WP144).

Figure 4.13 (bottom-right): Bivalves within a shelly pebbly limestone (L1). (WP144).

In the Otunui Formation this massive sandstone facies makes up the majority of the deposit. The sandstone of the Otunui Formation is finer-grained than the Mokau Group sandstone beds and reflect a more distal provenance.

The Otunui Formation was probably deposited in an outer shelf to upper slope setting, in 200-600 m water depth. This is suggested by the microfaunal content (Gerritsen, 1994) and involved hemipelagic suspension sedimentation (e.g. Cook et al., 1982).

4.5.2 CONGLOMERATE (Co1)

This lithofacies consists of cemented sediment of pebbles of sandstone, greywacke granules and shell fragments, in a matrix of sandstone (Fig. 4.15). The pebbles are well rounded and do not exhibit grading or imbrication. There is a wide range of clast sizes in the conglomerate (granule to pebble sized clasts). The thickness of the lithofacies ranges between 2 and 4 m thick.

The conglomerate deposit in the Otahu Valley within the Otunui Formation is 2-3 m thick, with greywacke and sandstone pebbles 2- 5 cm in diameter. These pebbles are also very rounded. Concretions are present throughout the conglomerate, with a 10 cm diameter clast found at this site. Mudstone layers up to 15 cm thick can occur within conglomerate beds. The underlying contact with the Otunui Formation is sharp, with massive grey sandstone fining into mudstone at the contact. The conglomerate has a dip of 20° to the north at WP136.

The conglomerate on Okahukura Saddle Rd (WP045) is up to 2 m thick, and consists of a mix of pebbles, shell hash and mudstone, all poorly sorted, and which is supported by a matrix of medium sandstone. Sometimes there are whole shell fossils that have been preserved. The pebbles exhibit no grading or imbrication. Lenses of mud and shell material occur throughout the conglomerate, but these have no orientation and no order to their occurrence.

The conglomerate in the Otahu Valley crops out sporadically over 2 km of the valley, and can also be traced in the next valley over (S18 995685). Due to the 20° dip of the conglomerate to the north, it is not seen at any other locations.

The conglomerate on Okahukura Saddle Rd is only found in one place and crops out over an area 2 m high by 5 m wide in the road cutting.

The conglomerate facies are considered to represent upperslope channel fill units.

4.5.3 Glauconitic Sandstone (SA4)

This facies consists of massive, medium-grained sandstone that is typically blue-grey in colour. It is markedly glauconitic (Fig. 4.16) and also fossiliferous, being abundant in *Zeacolpus pukeuriensis* (Fig. 4.17). This facies occurs at the base of the Otunui Formation, typically in the first 5 m above the contact with the underlying Mangarara Formation.

This facies was most likely deposited in an outer shelf environment. On microfaunal evidence, Otunui Formation sediments overlying the glauconitic sandstone indicate sedimentation in 400 – 600 m water depth (Gerritsen, 1994). The abundance of glauconite indicates a slow sedimentation rate with oxidising-reducing sea floor conditions with high biogenic productivity.

4.5.4 Cryptic bedded Sandstone (SA6)

This facies consists of coarse- and fine-grained sandstone beds ~ 30 cm in thickness. These sandstone beds are massive, well sorted, and blue-grey in colour. Associated mudstone beds are well cemented and bioturbated. The basal contacts of the sandstone beds are sharp and individual beds are devoid of bioturbation. Within the sandstone and mudstone beds a very slight upwards decrease in grain size is present. This results in outcrops having a bedded appearance from a distance, but when close to the outcrop the deposit has a massive appearance (Fig. 4.18).

Figure 4.14 (top-left): Typical blue-grey, massive to bedded sandstone (Sa1) of the Otunui Formation. There are no sedimentary structures evident in either fresh or weathered outcrop. WP066.

Figure 4.15 (top-right): Cemented sediment of pebbles of sandstone, greywacke, and shell fragments, set in a matrix of sandstone. There is a wide range of clastsizes in the conglomerate (Co1) (TE006).

Figure 4.16 (2nd from top): Glauconitic sandstone (Sa4) consisting of massive, blue-grey, fossiliferous sandstone, that is very glauconitic. WP064

Figure 4.17 (3rd from top): *Zeacolpus pukeuriensis* in a glauconitic sandstone (Sa4). This species is especially abundant in the uppermost 5 m of the Otunui Formation. WP064.

Figure 4.18 (bottom-right): Cryptic bedded sandstone (Sa6) of the Otunui Formation. Beds can be seen easily from a distance, but close to the outcrop it appears massive. WP127.

The cryptically bedded sandstones were deposited in an outer shelf to upper slope submarine canyon channel system: massive structureless sands can be classified as sandy debris flows which represent a continuous spectrum of depositional processes between cohesive and cohesionless debris flows (Shanmugam, 1996). They are inferred to have been deposited in 400-600 m water depth, possibly as part of an upper submarine-fan setting, such as an upper fan canyon (Lowe, 1982; Shanmugam, 1996).

4.5.5 Channel Deposits (Cd1)

The channel deposits within the Otunui Formation consist of poorly sorted concretions of Otunui Formation sandstone, pebbles of fine-grained cemented sandstone, which are weathered and iron stained, set in a matrix of calcareous sandstone. The channel deposits are considered to be separate from the conglomerates, as the average grain-size for the channel deposits is a lot coarser – on average clast size is 20 –25 cm, compared to the 2 – 10 cm clasts in the conglomerates. The channel deposits also display a distinct lack of faunal material compared to the conglomerates.

These channel sediments were most likely deposited in an outer shelf to upper slope environment, as a result of slumping of shelf deposits. They are mass emplaced and were probably associated with one-off events, such as slumping or storm events.

4.6 Mount Messenger Formation.

4.6.1 Amalgamated Sandstone (Sa5)

This facies consists of alternating fine- and very fine-grained sandstone beds, up to 1 m thick, stacked on top of one another (Fig. 4.20). The boundary between the top of the very fine-grained sandstone and the fine-grained sandstone is sharp, and is quite recognisable from a distance (Fig. 4.21).

Within the beds, horizontal laminations are present due to internal shearing within the sandy debris flow deposits. In some instances the laminations are folded, which most likely indicates syn-sedimentary deformation associated with dewatering of the beds.

4.6.2 Planar-Bedded Sandstone (Sa3)

This facies consists of thickly laminated to very thinly bedded, medium- to fine-grained sandstone. The bedding is parallel and essentially horizontal – it sometimes may be wavy but there is only relief of 1 cm at the most (Fig. 4.22). It varies in colour from blue-grey to yellow-brown.

This planar bedding probably forms from the deposition of material under rapidly flowing currents (upper flow regime).

Figure 4.19 (top-left): Cross-bedded sandstone (Sa2) of the Mount Messenger Formation. Cross-bedding is low angle and only visible when standing away from the outcrop. (WP130).

Figure 4.20 (top-right): Fine- and very fine-grained sandstone beds of the amalgamated sandstone facies (Sa5). The boundary between the top of the very fine-grained and the fine-grained sandstone is sharp and recognisable from a distance. (WP131).

Figure 4.21 (middle-right): Evident boundary between the fine-grained and very fine-grained sandstone beds of amalgamated sandstone. (WP131).

Figure 4.22 (bottom-right): Planar-bedded sandstone (Sa3). Bedding is parallel to wavy. (WP130).

CHAPTER 5: BASIN DEVELOPMENT

5.1 INTRODUCTION

The stratigraphy and sedimentology of the Miocene Mahoenui Group, Mokau Group, Mangarara Formation, Otunui Formation and Mount Messenger Formation have been described and discussed in the previous chapters. This chapter aims to relate the controls of sea-level change, tectonism and sediment supply on the stratigraphic and structural development of the field area and the wider King Country Basin during the Otaian to Tongarorutuan stages (Early to Late Miocene).

The Neogene sedimentary succession within the King Country Basin is similar to that in Taranaki and Wanganui Basins, and consequently the geological history of the three basins have similarities. The successions in the King Country and Wanganui Basins contain four 2nd order megasequences that principally have a tectonic origin (Kamp et al., 2002). This definition of megasequences provides a useful basis to consider the sequence stratigraphy at a lower order in the King Country Basin.

5.2 Sequence Stratigraphic Interpretation

A sequence stratigraphic model was developed by the Exxon Production Research Company, led by Peter Vail, as a means of interpreting the geological development and origin of sedimentary sequences. The principles of sequence stratigraphy are described in a number of key papers (e.g. Vail, 1987; Van Wagoner et al., 1987, 1988, 1990; Posamentier et al., 1988; Posamentier and Vail, 1988).

Sequence stratigraphy applied to outcrop uses facies analysis to develop the occurrence of linked depositional systems (systems tracts) within a chronostratigraphic framework bounded by flooding surfaces (Swift et al., 1991). The depositional sequence forms the basic unit in the Vail (1987) sequence stratigraphic model, which is defined as "a conformable succession of genetically related strata bounded above or below by unconformities or their correlative conformities" (Mitchum, 1977). The sequences of Vail (1987) consist of a variety of subunits, which include facies and linked depositional systems (systems tracts), all organised in order of increasing magnitude. A systems tract is a linkage of contemporaneous depositional systems, while a depositional system is a three-dimensional assemblage of facies (Van Wagoner, 1987, 1988, 1990; Swift et al., 1991). The sequence stratigraphic model of Vail (1987) includes four systems tracts: lowstand (LST), highstand (HST), transgressive (TST) and shelf margin tracts.

The Mahoenui Group sediments represent in overall terms a megasequence containing elements of onlap and transgression (TST), highstand development (HST) and lowstand development (LST). The Mokau Group sediments are ascribed to a megasequence, which may also be able to be divided into sequences and systems tracts. The Mangarara Formation represents a TST, and is followed by the Otunui Formation as a HST. The Mount Messenger Formation accumulated as a result of major basin subsidence and probably contains multiple sequences.

5.3 King Country Basin Megasequences

As mentioned before, the King Country Basin contains four 2nd order megasequences – the early-Early Miocene (Otaian Stage) Mahoenui Group megasequence and the late-Early Miocene (Altonian Stage) Mokau Group megasequence, which both correspond to the lower part of the Manganui Formation in the Taranaki Basin. These are overlain by the middle-Late Miocene Whangamomona Group megasequence and the latest Miocene-Pleistocene Rangitikei megasequence, both of which can be traced through all three basins. The base of each megasequence is marked by sediments deposited during marine flooding (Kamp et al., 2002).

5.3.1 Otaian Stage.

The Mahoenui Group megasequence corresponds to rapid subsidence of the King Country Basin in a compressional setting (Kamp et al., 2002). Large volumes of sediment were deposited at bathyal depths by redeposition (mass emplacement) and hemipelagic settling. This is evident in the study area by a gradational contact between the flysch dominated Taumarunui Formation, and the massive mudstones of the underlying Taumatamaire Formation. This contact probably marks a transition from shelf to slope (about mid-bathyal depth) where a submarine fan started to accumulate.

The Taumarunui Formation was probably deposited during the Otaian as several basin floor fan and lobe systems. The Taumarunui Formation is encompassed by the mudstones of the Taumatamaire Formation, a unit that is considered to be relatively continuous and which signifies a general shallowing throughout the entire basin (Fig. 5.1; Fig. 5.2).

In the north of the basin, these newly formed shelves accumulated sandy sediments, which provided a source for the sandy sediments of the Taumarunui Formation. In the

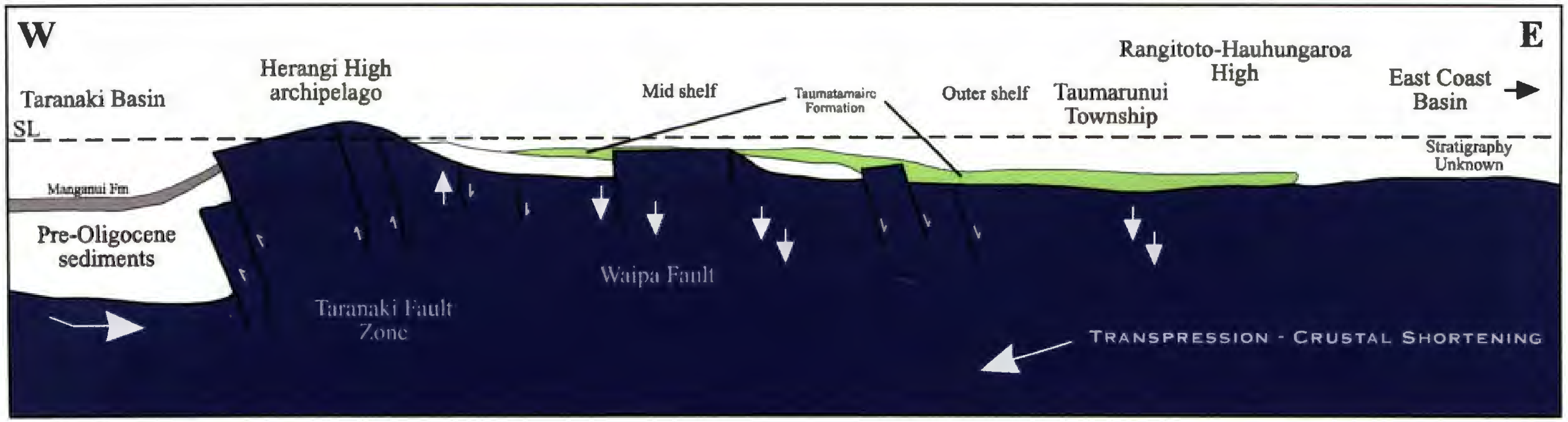


Figure 5.1: Schematic diagram of the structural architecture of the King Country Basin during the earliest Miocene (Otaian Stage).Transpression and basin over-thrusting were occuring, resulting in large scale and relatively rapid subsidence in the King Country Basin and uplift/erosion of the Herangi - Patea -Tongaporutu High (Nelson et al., 1994). This uplifted generated large amounts of terrigenous sediment and saw the deposition of Mahoenui Group sediments (at this stage Taumatamaire Formation)in the King Country Basin. The highest rate of sedimentation is thought to have been occurring in the eastern part of the King Country Basin as the Taumatamaire Formation is thickest in this part. (Adapted from Vonk, 1999).

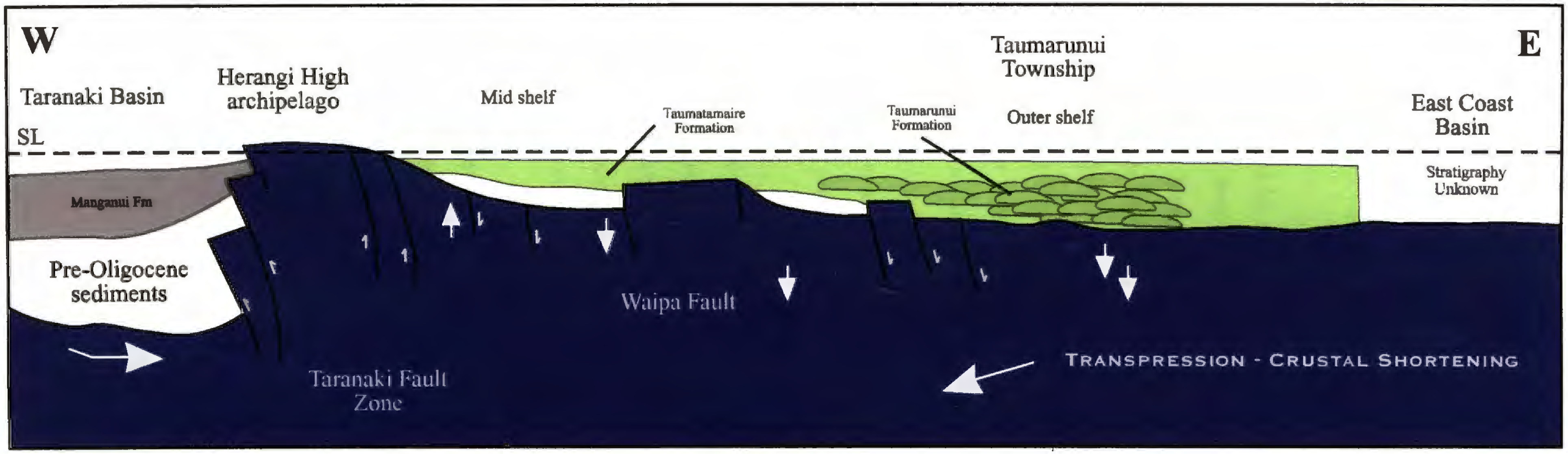


Figure 5.2: Schematic diagram of the structural architecture of the North Wanganui Basin during the early Miocene (Otaian - lowermost Altonian, 22-18.5 Ma). The Taumarunui Formation was being deposited in outer shelf water depths and comprises several basin floor fan and lobe systems stacked on one another. The Taumarunui Formation overlies the Taumatamaire Formation, and is relatively continuous and represents a general shallowing throughout the entire basin. (Adapted from Vonk, 1999).

central part of the basin the Taumarunui Formation was probably associated with fan distributary channels.

5.3.2 Lower Altonian Stage

This period was characterised by a change from tectonic subsidence to tectonic uplift in the basin. Previously this tectonic subsidence created the accommodation for the Mahoenui Group sediments. Basement blocks were uplifted along reverse faults due to this change in tectonics. This period also marks the inception of the Ohura Fault, which divided the King Country Basin into the Whangamomona Block in the west and the Taumarunui Block in the east (Fig. 5.3). At this point in time movement along the Ohura Fault resulted in uplift of the Taumarunui Block. As the environment of the Mahoenui Group changed from that of a bathyal setting to one of subaerial exposure it is expected that shelfal sediments would have been deposited. However, there is no evidence in the basin stratigraphy for a shelfal succession. This succession, if it accumulated, must have been eroded during the uplift phase prior to deposition of the Mokau Group.

The uplift that caused the predicted "Mahoenui" shelfal deposits to be eroded continued throughout the Altonian, causing the Mahoenui Group sediments that were part of the Taumarunui Block to be subaerially exposed and eroded. This is evident in the stratigraphy of the King Country Basin as an unconformity between the Taumarunui Formation (flysch) and the overlying Mangarara Formation.

The distribution of sedimentation during Mokau Group times was controlled by the Ohura Fault. The Ohura Fault would have formed the eastern boundary of sedimentation, and a shoreline would have been developed close to the trace of this structure. Subsidence of the Whangamomona Block, possibly along with an increase in global eustatic sea-level (Haq et al., 1987), generated an increase in relative sea level. This resulted in transgression across the Whangamomona Block and the Patea-Tongaporutu High, shown by the deposition of the Bexley Sandstone. This unit was not deposited on the eastern side of the Ohura Fault as the Taumarunui Block had been tectonically uplifted and was above sea-level. This transgression resulted in an unconformity between the Mahoenui Group and the Bexley Sandstone. The transgression continued and resulted in the deposition of the massive and amalgamated sandstone beds of the Bexley Sandstone (Mokau Group), and also caused the migration of the transgressive depositional systems eastwards against the Patea-Tongaporutu High. This is shown by the progressive overlap westwards of the Bexley Sandstone against basement (Vonk, 1999) (Fig. 5.4).

5.3.3 Early-Mid Altonian Stage

Subsidence of the Whangamomona Block continued during the early-Mid Altonian, although the rate of sediment supply is the same as the rate of subsidence in eastern areas of the King Country Basin. The Taumarunui Block still formed a shoreline to the east, and the uplifted Mahoenui Group sediments were eroded and topographic features were created. The Ohura Fault was still active, and movement along this fault created relative uplift of the block adjacent to the fault, with the amount of throw decreasing to the west (Crosdale, 1993). Coal deposition occurred in the eastern part of the Whangamomona Block, due to the presence of back-barrier systems, which migrated west over time (Fig. 5.5). McQuillan (1977) considered that the Patea-Tongaporutu High, which is in the position of the western depositional margin, was emergent during Mokau Group deposition. This view is supported by the deposition of the Bexley Sandstone, but Crosdale (1993) proposed that the western depositional margin around the Maryville Coal Measures was formed by barrier systems and tidal channels during accumulation of the Maryville Coal Measures. This theory is supported by the stratigraphy of the field area, where two coal seams are separated by the Maryville Sandstone Member. The Maryville Sandstone Member represents inner shelf/shoreface environments, and the coal seams represent back-barrier environments. Braided river channels formed adjacent to these back-barrier coal basins, and resulted in the deposition of conglomerates in the Tangarakau Formation. According to Stainton and Gibson (1965), the source of the conglomerates was the Waipapa Terrane, based on the composition of the clasts (greywacke containing chert, vein quartz and prehnite).

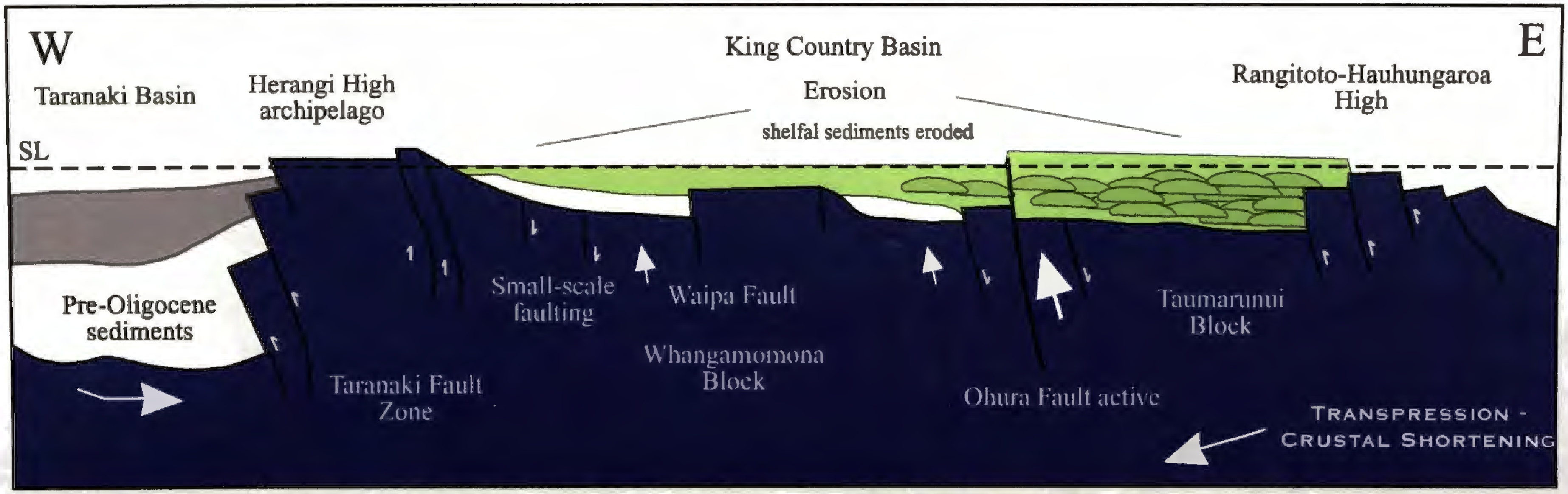


Figure 5.3: Schematic diagram of the structural architecture of the King Country Basin during the mid-early Miocene (lowermost Altonian, 18.5 Ma). This was a period of tectonic uplift in the King Country Basin. Uplift caused the basement blocks to become more defined along thrust faults. This stage probably marked the inception of the Ohura Fault, creating the Taumarunui Block in the east and the Whangamomona Block in the west. (Adapted from Vonk, 1999).

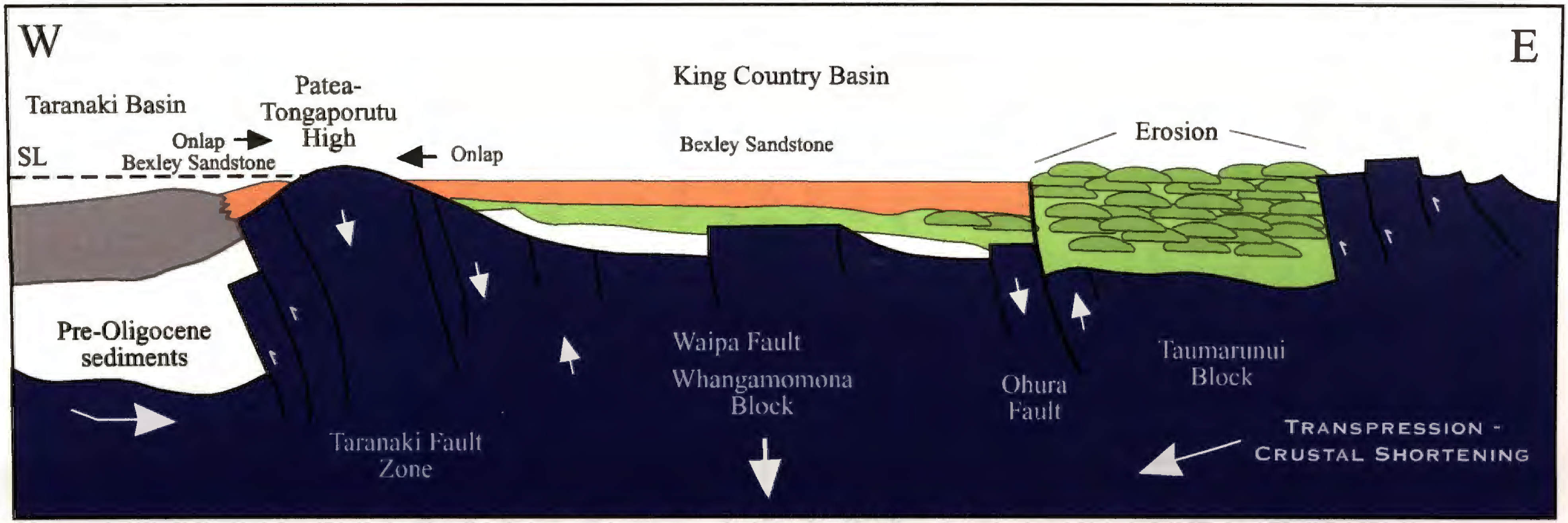


Figure 5.4: Schematic diagram of the structure of the King Country Basin during the late Early Miocene (Altonian). Mahoenui Group sediments are uplifted on the Taumarunui Block and exposed. The Ohura Fault forms the eastern boundary for Mokau Group sedimentation. On the Whangamomona Block a transgression causes the deposition of the massive and amalgamated sandstonebeds of the Bexley Sandstone. (Adapted from Vonk, 1999).

5.3.4 Mid-Late Altonian Stage

The Whangamomona Block continued to subside during the Mid-Late Altonian due to sediment loading and crustal shortening, and this created accommodation for the deposition of Tangarakau Formation in the east of the King Country Basin, and the stratigraphic equivalent, the Ladies Mile Mudstone, in eastern Taranaki Basin. The rate of sediment supply to the Whangamomona Block was equal to the rate of subsidence, which prevented the deep water mudstones of the Ladies Mile Mudstone being deposited in the King Country Basin.

The deposition of the Maryville Coal Measures ended as a result of a marine transgression across the whole of the King Country Basin. This resulted in the deposition of the Peneta Sandstone Member (Tangarakau Formation) of Vonk (1999). In the south-eastern part of the basin a second phase of coal deposition occurred, with the Mangapapa Coal Measures being deposited (Vonk, 1999). Simultaneously with the deposition of these coal measures was the deposition of the Tonga Conglomerate Member (Vonk, 1999) in braided river channels and alluvial fans, which were located close to the shoreline formed by the Taumarunui Formation. A rapid marine transgression halted the deposition of the coal measures, and resulted in the deposition of the Peneta Sandstone Member and the Waingarara Sandstone Member, both of the Tangarakau Formation (Mokau Group) (Vonk, 1999) (Fig. 5.6). This deposition marks the change from back-barrier environments (Mangapapa Coal Measures), to nearshore intertidal and offshore subtidal environments (Peneta Sandstone Member), to storm-dominated shelf settings (Waingarara Sandstone). This transgression is also supported by the eustatic sea-level curve of Haq et al. (1987), where a small but rapid increase in eustatic sea level began ~ 17.5 m.y. B.P.

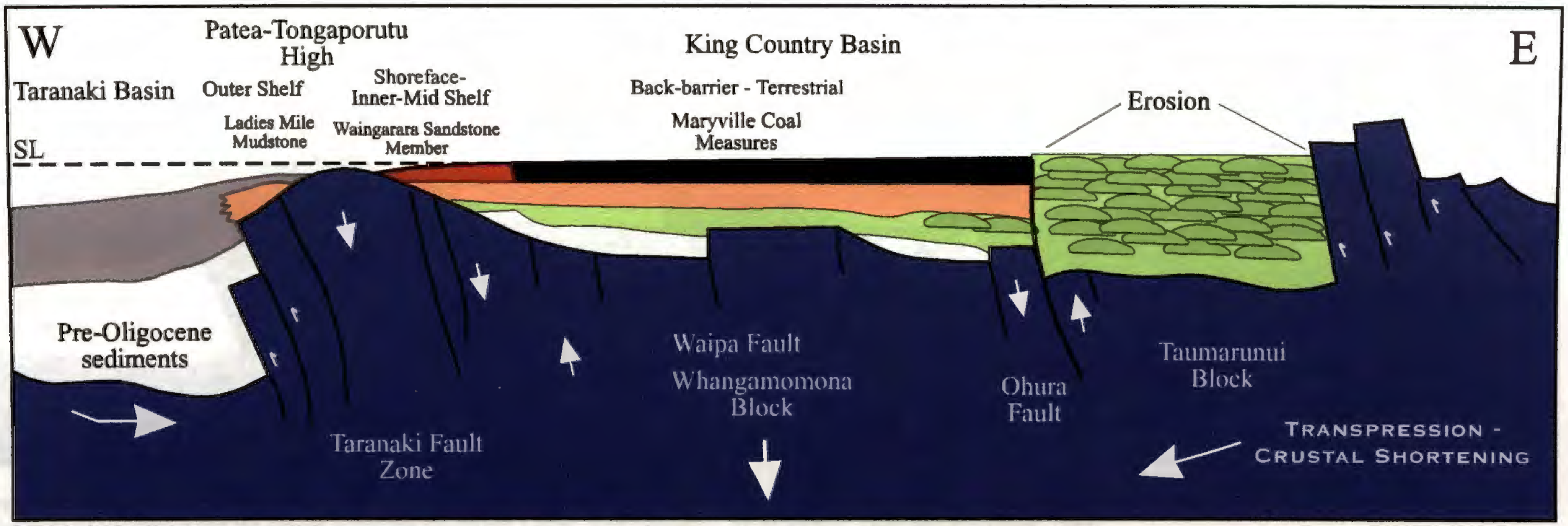


Figure 5.5: Schematic diagram of the structural architecture of the King Country Basin for the early-Middle Altonian. The Whangamomona Block continues to subside and the Taumarunui Block still forms a shoreline to the east with the Mahoenui Group sediments eroding and forming topographic relief. Coal deposition occurred in the Whangamomona Block in back-barrier systems that were migrating westward. (Adapted from Vonk, 1999).

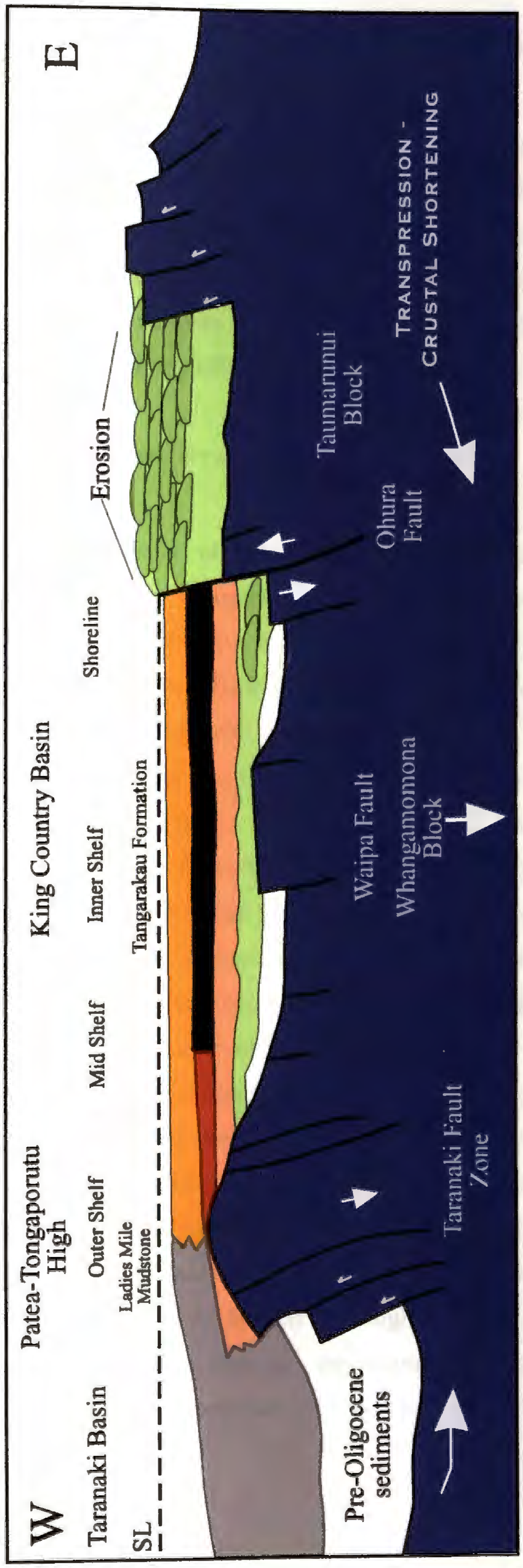


Figure 5.6: Schematic diagram of the structural architecture of the King Country Basin for the Mid-Late Altonian. Subsidence continues in the Whangamomona Block and the Tangarakau Formation and the deeper water age equivalent Ladies Mile Mudstone are deposited. (Adapted from Vonk, 1999).

5.3.5 Latest Altonian-Earliest Clifdenian Stage

In this period there was a basin-wide regression that exposed the sediments of the King Country Basin. This regression was most likely caused by the effects of tectonic uplift and a large global sea level fall of ~ 80 m near the Altonian – Clifdenian boundary (16.3 Ma) (Haq et al., 1987). This regression caused both the Taumarunui Block and the Whangamomona Block to be eroded, resulting in erosion of any topography associated with the Ohura Fault scarp (Fig. 5.7).

5.3.6 Clifdenian Stage

The Clifdenian is a period of mixed carbonate-siliciclastic deposition across parts of the basin, which formed the Mangarara Formation (Vonk, 1999). On the Whangamomona Block the Mangarara Formation unconformably and irregularly overlies the Ladies Mile Mudstone and Tangarakau Formation sediments, while on the Taumarunui Block the same type of contact occurs with the underlying Mahoenui Group (Fig. 5.8). This contact is a Type-1 sequence boundary. The deposition of carbonate-siliciclastic sediments is associated with a transgressive phase, and represents a marine inundation of the basin after subaerial exposure. According to Vonk (1999), it is likely that eustacy and tectonics during the Clifdenian – Waiauan Stages have produced more than one of these carbonate-dominated transgressive sequences, all of which exhibit an unconformity with the underlying sediment. This theory is supported by the stratigraphy of the Mangarara Formation on the Taumarunui Block – it has an extremely variable lithology, there being no real pattern to the facies distribution. Also, on the Taumarunui Block the base of the Mangarara Formation commonly contains a thin greywacke conglomerate with some fragmented faunal remains, the most likely source of which would be the erosion of conglomerates from the Tangarakau Formation. This is also compatible with the idea of multiple transgressions across the two blocks. Another possible source for the conglomerate clasts could be the Herangi High immediately to the east, but this is not likely, as the greywacke pebbles are extremely well rounded, not particularly volcaniclastic, and it is accepted that they must have either travelled a great distance or

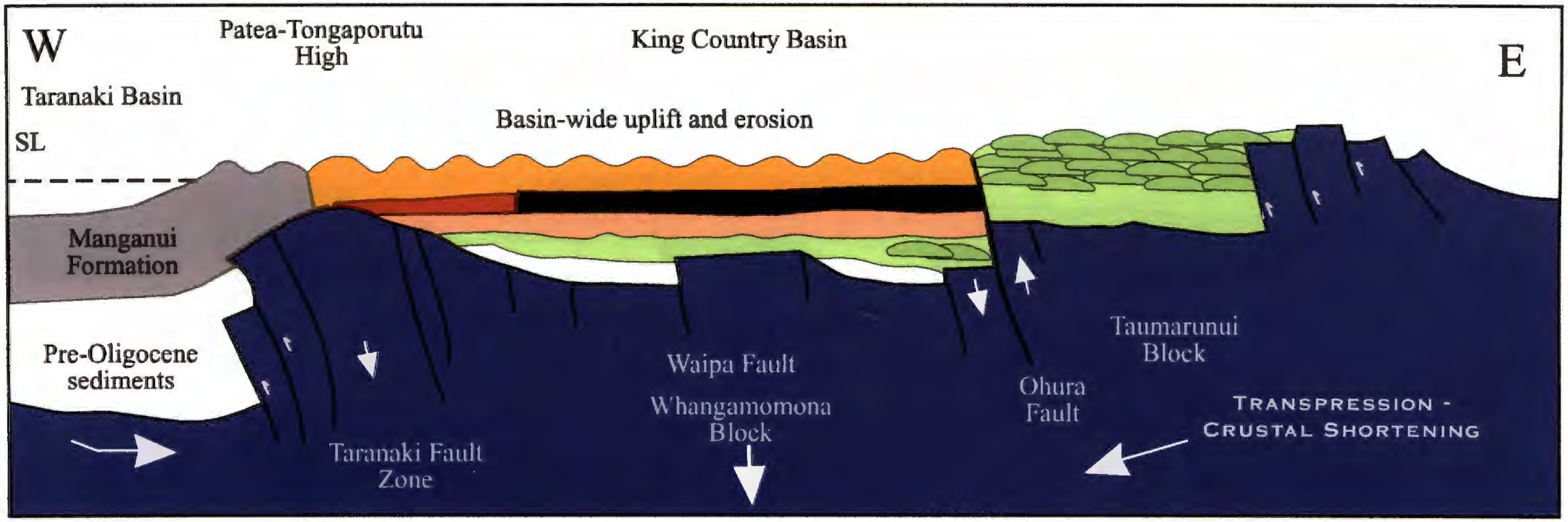


Figure 5.7: Schematic diagram of the structural architecture of the King Country Basin for the latest Altonian-earliest Clifdenian. Basinwide regression occurs due to tectonic uplift and global sea level fall resulting in the subaerial exposure of the entire King Country Basin. (Adapted from Vonk, 1999).

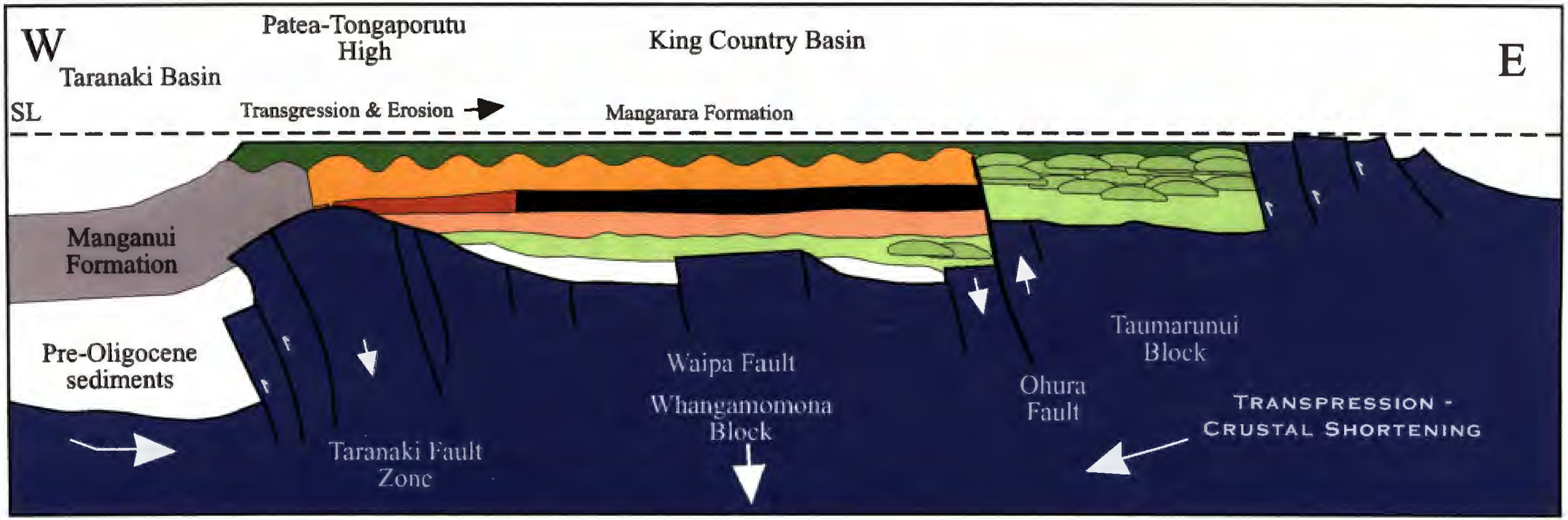


Figure 5.8: Schematic diagram of the structural architecture of the King Country Basin for the Clifdenian. Transgression occurs resulting in the deposition of the Mangarara Formation on to Mokau Group on the Whangamomona Block, and on to Mahoenui Group on the Taumarunui Block. Due to the unconformable nature of this resulting contact, there is a variable distribution of the Mangarara Formation across the King Country Basin. (Adapted from Vonk, 1999).

have been suitably reworked. This reason effectively excludes the Herangi High as a source for the greywacke pebbles due to its close proximity to the Taumarunui Block. The patchy distribution of the Mangarara Formation in the King Country Basin is caused by the variable erosion of the upper part of the underlying sediment, producing not only a patchy distribution, but also a variable lithology throughout the entire King Country Basin at this level.

The occurrence of multiple transgressive phases is also supported by ages gained for the Mangarara Formation. Based on microfaunal evidence the age of the Mangarara Formation is variable – cf. Clifdenian-Awakino River mouth, Awakino area; Waiauan – Awakau area; Tirua Point, Waikawau; Waiauan to Tongaporutuan – Tangarakau Gorge (Haddock, 1970; Nodder et al., 1990; King et al., 1993).

5.3.7 Lillburnian-Tongaporutuan Stage

The stratigraphy of the King Country Basin records a rapid deepening after the deposition of the Mangarara Formation. The environment of deposition changed from one of near-shore to that of inner-shelf to mid-shelf. Sedimentation changed to that of fine-grained, massive sandstone of the Otunui Formation (Fig. 5.9). This rapid change indicates that there was significant tectonic subsidence during this period, most likely related to lithospheric downwarp (Stern et al., 1993) associated with the compressive plate boundary interactions in eastern North Island at the time. The age range of the Otunui Formation, based on microfossil assemblages, is Lillburnian to Tongaporutuan (15.0-10 Ma), and was deposited in 400-600 m of water (Gerritsen, 1994). The age equivalent of the Otunui Formation is the Mohakatino Formation exposed on the Taranaki Coast. The Mount Messenger Formation represents deposition into the deeper Taranaki Basin at the time, however parts of the King Country Basin would have been deep enough for these sediments to have been deposited, as shown by the stratigraphy of the area. The Mount Messenger and Mohakatino sediments represent sedimentation in a basin floor/slope depositional system (King et al., 1993; Wilson, 1994; Hansen, 1996).

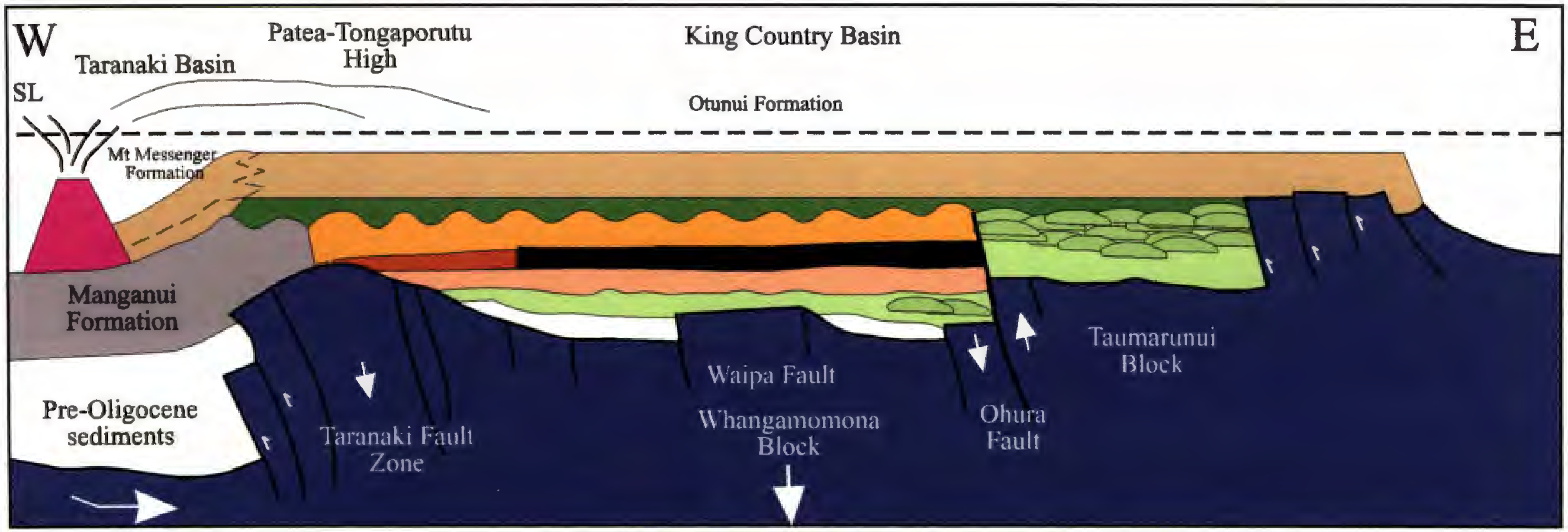


Figure 5.9: Schematic diagram of the structural architecture of the King Country Basin for the Lillburnian to Tongaporutuan. Sediments record a rapid deepening of the King Country Basin and sedimentation is marked by the deposition of predominantly fine-grained massive sandstone of the Otunui Formation. The Otunui Formation is age equivalent to the Mohakatino Formation in the Taranaki Basin. Otunui Formation sediments are tuffaceous in the western parts of the King Country Basin due to volcanism in the Taranaki Basin. (Adapted from Vonk, 1999).

Chapter 6: Summary and Conclusions

6.1 Geological Mapping and GIS

The geological map included in this thesis (Appendix 2) covers the western half of Topographic Map Sheet S18 and will potentially make up part of the Waikato Sheet of the GNS QMAP geological mapping programme. The geologic map was created using ArcInfo 8 and was drawn at a scale of 1:50 000. An advantage of using GIS in this project is that data, such as aerial photographs, topography, and especially geological data, can be organised into layers and stored in a geodatabase that allows for better data access for other people or organisations that may wish to use these data.

6.2 Lithostratigraphy

The study area contains a 400 m-thick sedimentary succession of mainly Miocene aged sediments, comprising the Mahoenui Group (containing the Taumarunui and Taumatamaire Formations), the Mokau Group (containing the Bexley Sandstone, Maryville Coal Measures and Tangarakau Formation), and the Mangarara, Otunui and Mount Messenger Formations.

The Taumarunui Formation of the Mahoenui Group contains alternating beds of sandstone and mudstone (flysch deposits). The Taumatamaire Formation is made up of massive mudstone. The Bexley Sandstone comprises massive, amalgamated and bedded sandstone, and its light grey in colour making it hard to distinguish from the Otunui Formation. The Maryville Coal Measures consist of two 3-4 m-thick sub-bituminous coal seams separated by 20 m of typically massive sandstone, although some low-angle cross-bedding is evident within it. The Tangarakau Formation within the study are consists of massive silty sandstone beds with siltier lenses occurring throughout the unit, and these exhibit a conchoidal weathering pattern. The Mangarara Formation varies greatly throughout the field area, and consists of a yellow-brown to blue-grey, fossiliferous glauconitic limestone with sandy lenses, to a conglomeratic, fossiliferous sandy limestone. The Otunui Formation contains blue-grey, massive, argillaceous sandstone. In the upper parts of the formation, coarse, clean sandstone lenses occur. Localised channel deposits and conglomerate occur in several places as well. The Mt Messenger Formation consists of redeposited and channelised conglomerate, massive sandstone and mudstone beds, and interbedded, laminated sandstone and mudstone beds. Overlying this sedimentary succession is the Ongarue Ignimbrite (Cartwright, in prep.), a crystal rich, pumice absent, densely welded ignimbrite that only occurs in a couple of localities in the study area.

6.3 Lithofacies Association

Seven facies have been identified in the study area, and these have been sub-divided into 14 sub-facies, with each facies representing different depositional environments. The facies have been described, and probable environment of deposition inferred, for each stratigraphic unit. The Mahoenui Group is comprised of two sub-facies; alternating sandstone and mudstone facies (Ms1) and massive mudstone facies (M1). The alternating sandstone and mudstone facies (flysch deposits) is restricted to the Taumarunui Formation, and the massive mudstone facies is restricted to the Taumatamaire Formation.

The Mokau Group contains four sub-facies: massive sandstone facies (Sa1), cross-bedded sandstone facies (Sa2), amalgamated sandstone facies (Sa5) and coal facies (C1). The massive sandstone facies makes up the majority of the Tangarakau Formation, and was probably deposited in back-barrier environments. The cross-bedded facies occurs in the Bexley Sandstone, and was most likely deposited in a shoreface-to foreshore environment. The amalgamated sandstone facies occurs in the Tangarakau Formation and represents deposition in an inner shelf to mid shelf environment as a response to marine transgression and an increase in accommodation on a shelf.

The Mangarara Formation contains three sub-facies: concretionary conglomerate facies (Co2), shelly pebbly limestone facies (L1) and glauconitic mudstone facies (M2). The concretionary conglomerate facies was probably deposited during a marine transgression, and accumulated during the ravinement of the underlying sediment in a shore face/inner shelf environment. The shelly pebbly limestone facies exhibits an abundance of bivalves and bryozoans, and as well as large rock fragments and pebbles, indicates a nearshore, high-energy environment. The abundance of glauconite in the glauconitic mudstone facies indicates a low rate of sedimentation with oxidising-reducing sea floor conditions.

The Otunui Formation comprises five sub-facies: massive sandstone facies (Sa1), conglomerate facies (Co1), glauconitic sandstone (Sa4), cryptic bedded sandstone (Sa6) and channel deposit facies (Cd1). The massive sandstone facies was probably deposited in an outer shelf to upper slope setting in 200-600 m water depth by hemipelagic suspension sedimentation. The conglomerate facies are considered to represent upper slope channel fill units. The glauconitic sandstone facies was most likely deposited in an outer shelf environment, as the abundance of glauconite indicates a slow sedimentation rate with oxidising-reducing sea floor conditions. The cryptic bedded sandstone facies represent sedimentation in an outer shelf to upper slope submarine canyon channel system, and are inferred to be deposited in 400-600 m water depth, possibly as part of an upper-submarine-fan setting. The channel deposit facies were most likely deposited in an outer shelf to upper slope environment as a result of slumping of shelf deposits during one-off events, such as storm events.

The Mt Messenger Formation contains two sub-facies: amalgamated sandstone facies (Sa5) and planar-bedded sandstone facies (Sa3). The amalgamated sandstone facies contains folded near-horizontal laminations, indicating syn-sedimentary deformation associated with the dewatering of beds. The planar-bedded sandstone facies represents deposition of material under rapidly flowing currents (upper flow regime).

6.4 Basin Development

The Miocene sedimentation of the King Country Basin has been controlled fundamentally by tectonic movements. The Basin is divided by the Ohura Fault into the Whangamomona Block in the west, and the Taumarunui Block in the east. The Ohura Fault has exhibited reversal in its sense of displacement from reverse (late Early-Miocene) to normal (Quaternary) producing large vertical displacements. The history of basin development and sedimentation throughout the Early and Middle Miocene has been summarised in nine schematic diagrams (Figs. 5.1 to 5.9).

The King Country Basin developed in response to transpression and crustal shortening related to the inception of the modern plate boundary system through New Zealand. The sedimentary succession of the Mahoenui Group, Mokau Group, Mangarara Formation, Otunui Formation and Mt Messenger Formation developed in response to the effects of tectonics and changes in relative sea level.

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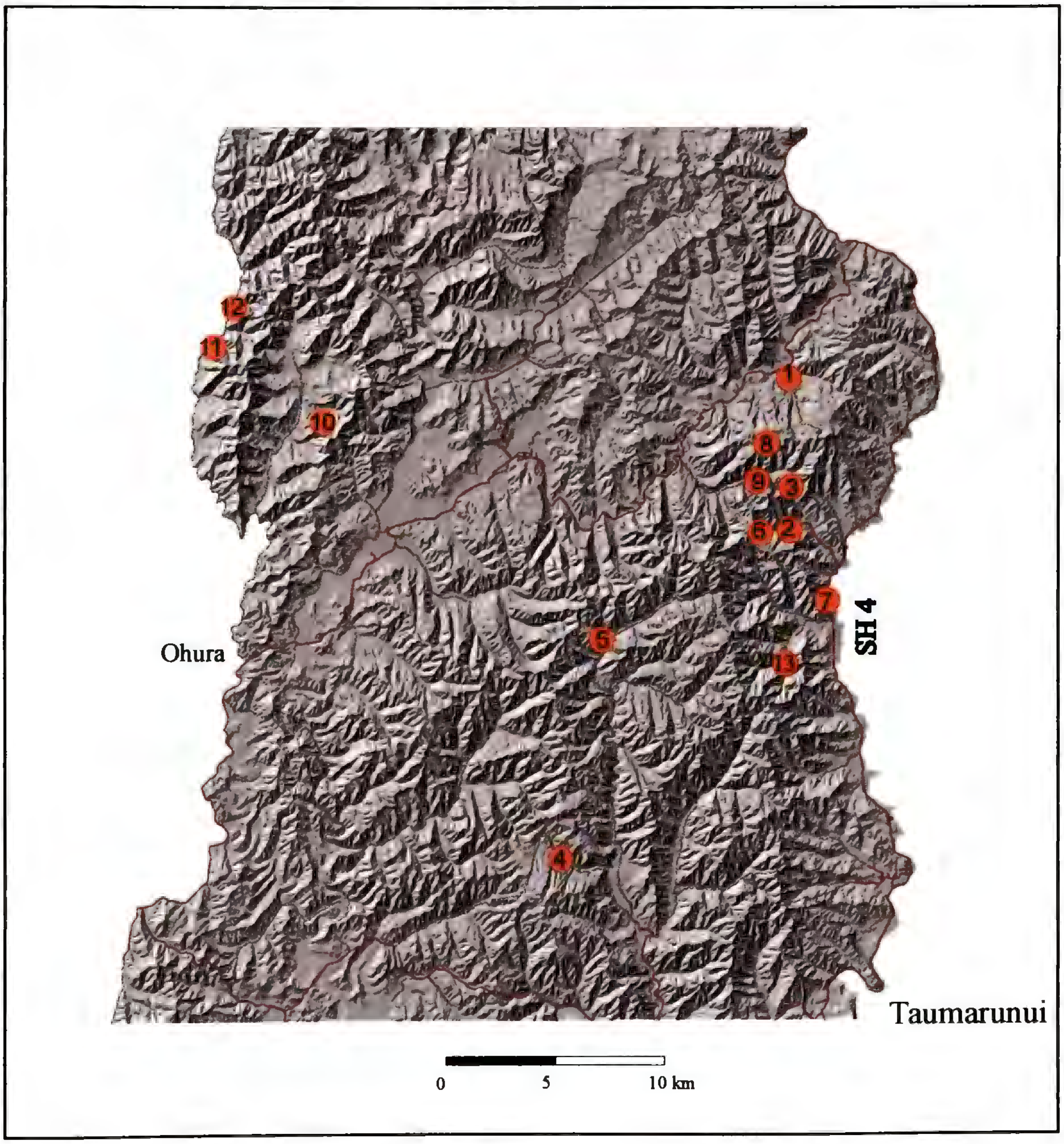
LOCATION OF STRATIGRAPHIC COLUMNS



APPENDIX A

Stratigraphic Column

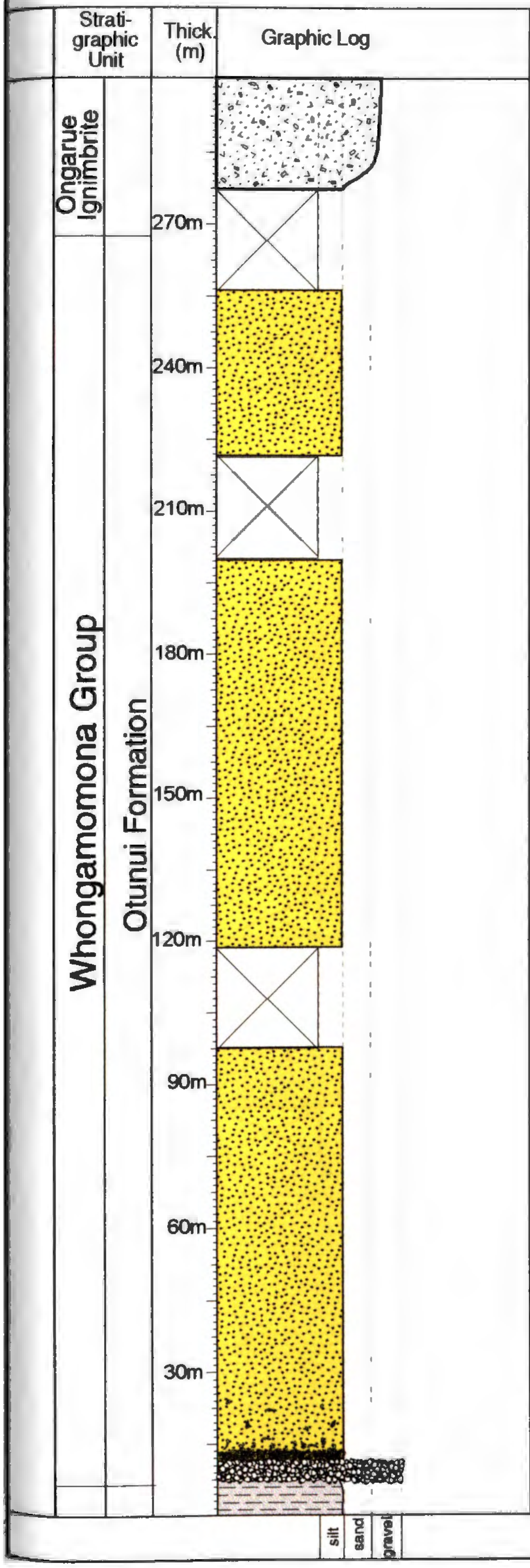
Date: 06 February 2002

Name: T. Evans

Stratigraphic Column No: 1

Region: King Country Basin

Location: S003. Start in valley off S.H. 4 1.5 km north of Kura Road.
Follow stream up valley to top of Pukepoto.



Description and notes

Crystal rich ignimbrite, with 25% crystals. Quartz, feldspar and hornblende present. Very lithic rich, but pumice poor. Extremely weathered.

Massive blue-grey sandstone.

Sandstone very fossiliferous at base.

Conglomerate with pebbles of greywacke. No faunal remains.

Sandy mudstone, light brown in colour.

Lithology, hardness & cementation, colour, weathering, bedding, sedimentary structures, texture (grain size, sorting, shape, roundness), fossils, ichnofossils, mineralogy, preliniminary assessment of environment of deposition.

Stratigraphic Column

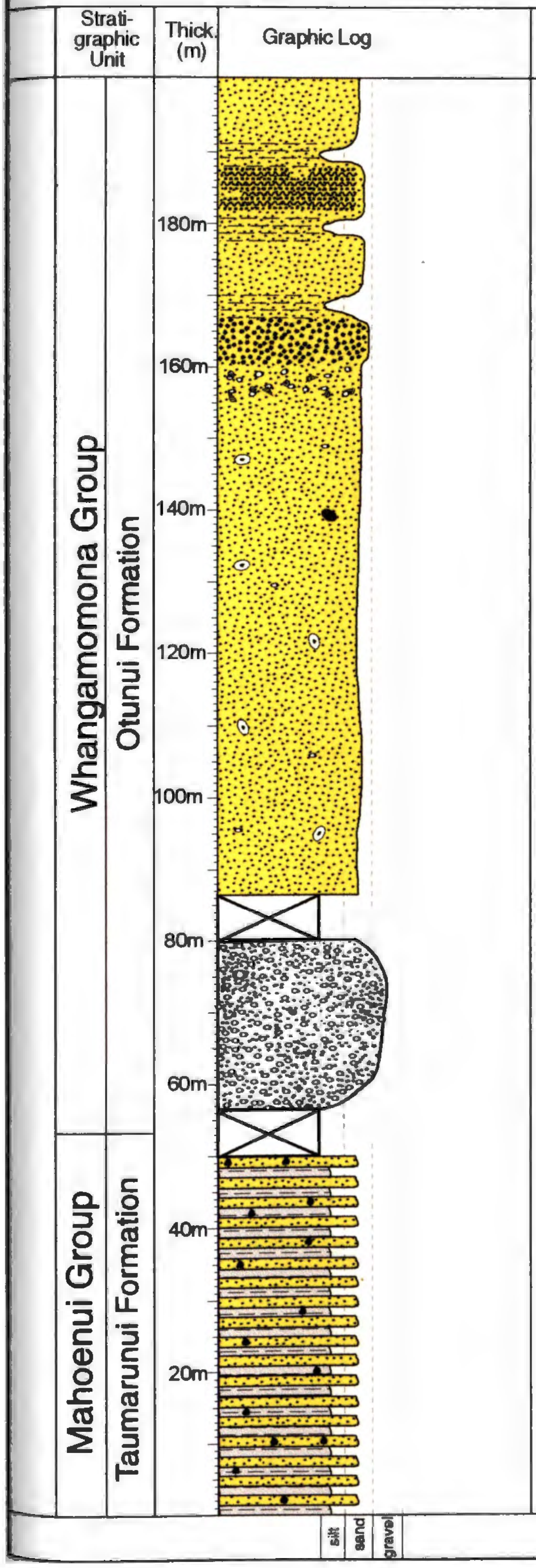
Date: 12 December 2001

Name: T. Evans

Stratigraphic Column No: 2

Region: King Country Basin

Location: WP041. Start on the first tight bend of the Okahukura Saddle Road. Continue up the road and stream to the top of the hill.



Description and notes

Folding in sandstone - evidence of faulting during deposition. Folds run out within the outcrop.
Thin layers of mudstone within sandstone layers. Sandstone layers are laminated.

Coarse sandstone layer at base. Also hyper concentrated sand flows at contact.

Conglomerate with some shell material. Made up of greywacke pebbles.

Grey massive sandstone. Concretions and greywacke pebbles throughout outcrop.

Alluvium deposits with rounded pebbles of Mahoenui.

Flysch deposits. Indurated at stream level (grey colour), but weathered further up (yellow-brown colour).
Carbonised material within sediment, as well as plant fossils.

Lithology, hardness & cementation, colour, weathering, bedding, sedimentary structures, texture (grain size, sorting, shape, roundness), fossils, ichnofossils, mineralogy, preliminary assessment of environment of deposition.

Stratigraphic Column

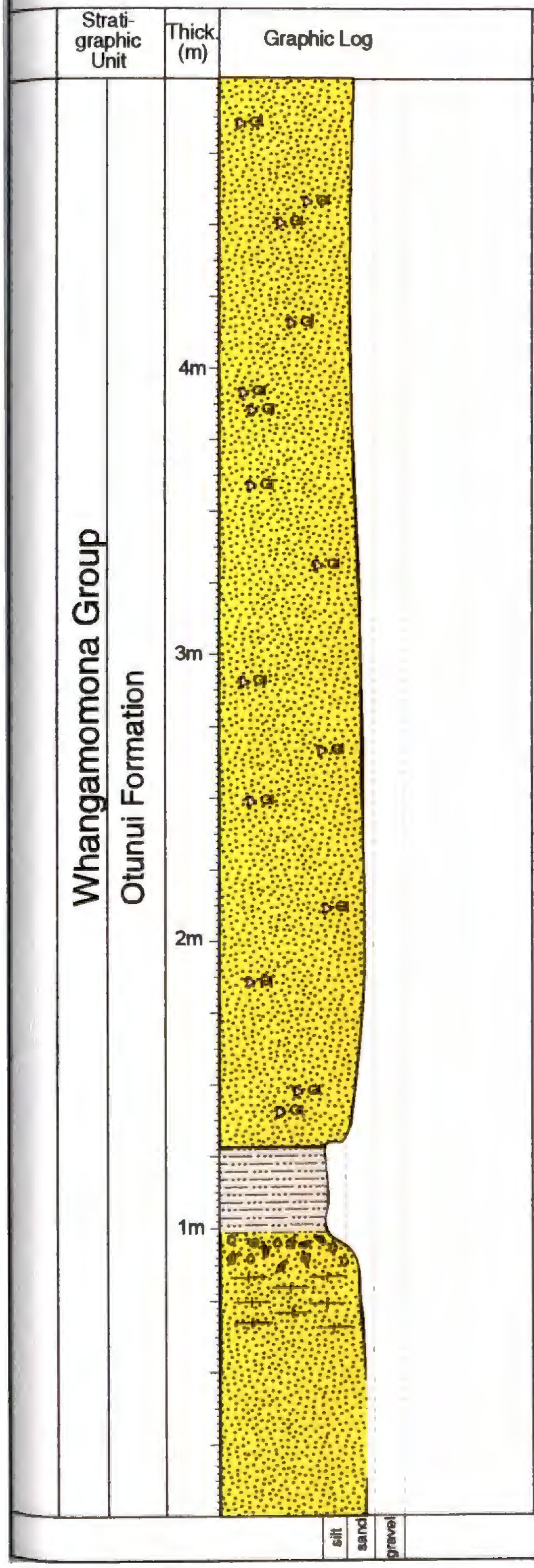
Name: T. Evans

Date: 12 December 2001

Stratigraphic Column No: 3

Region: King Country Basin

Location: WP044. Okahukura Saddle Rd.



Description and notes

Grey sandstone - massive. Extremely weatherd in parts.

Glauconitic rich pockets ~ 5cm wide.

Grey mudstone. Layer is extremely frittery.

Massive sandstone - yellow-brown in colour at base but grades into a more indurated grey sandstone at the top. Fossiliferous at top with coral remains.

Lithology, hardness & cementation, colour, weathering, bedding, sedimentary structures, texture (grain size, sorting, shape, roundness), fossils, ichnofossils, mineralogy, preliminary assessment of environment of deposition.

Stratigraphic Column

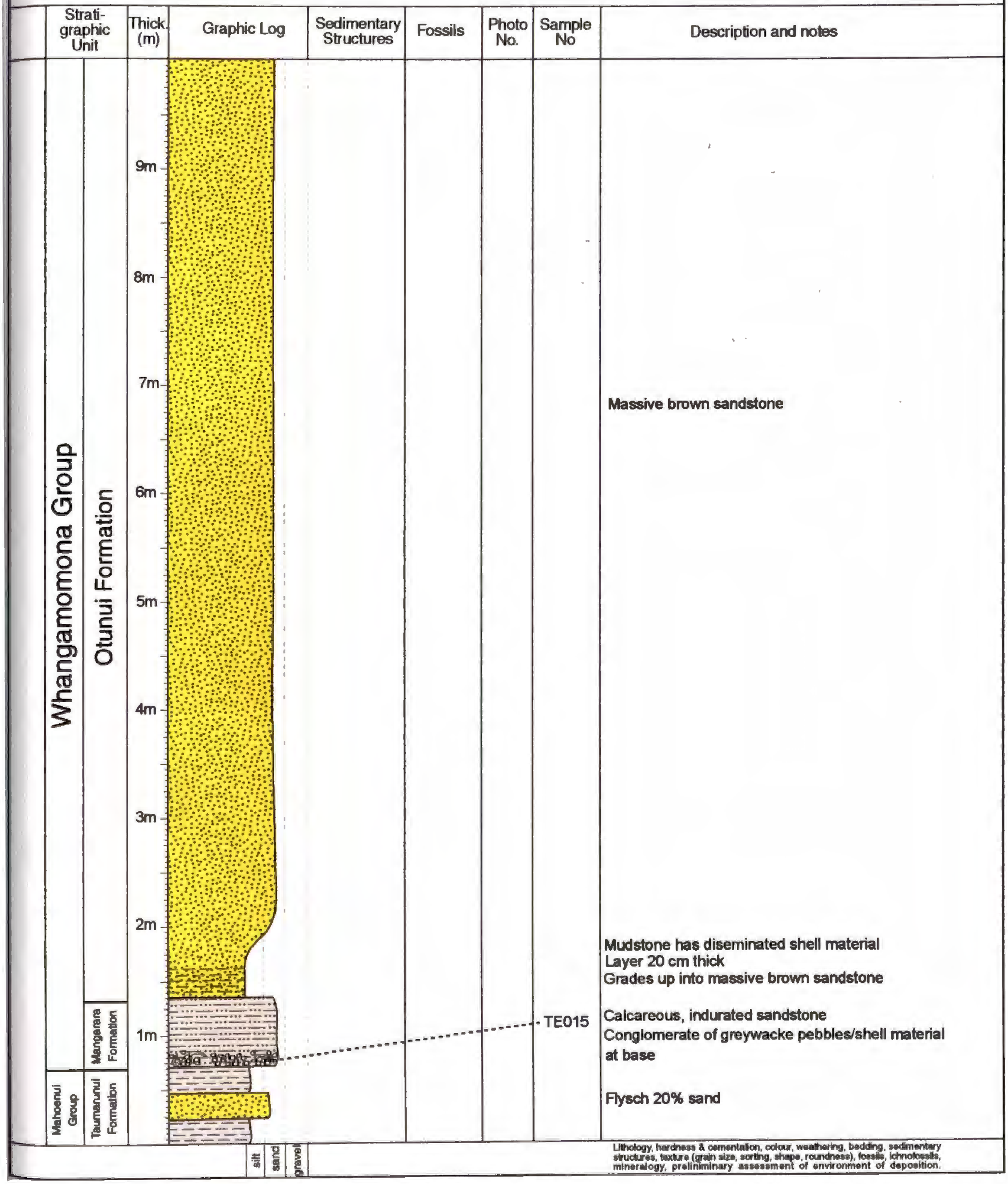
Name: T. Evans

Date: 4 February 2002

Stratigraphic Column No: 4

Region: King Country Basin

Location: WP158. Kururau Road



Stratigraphic Column

Date: 25 February 2002

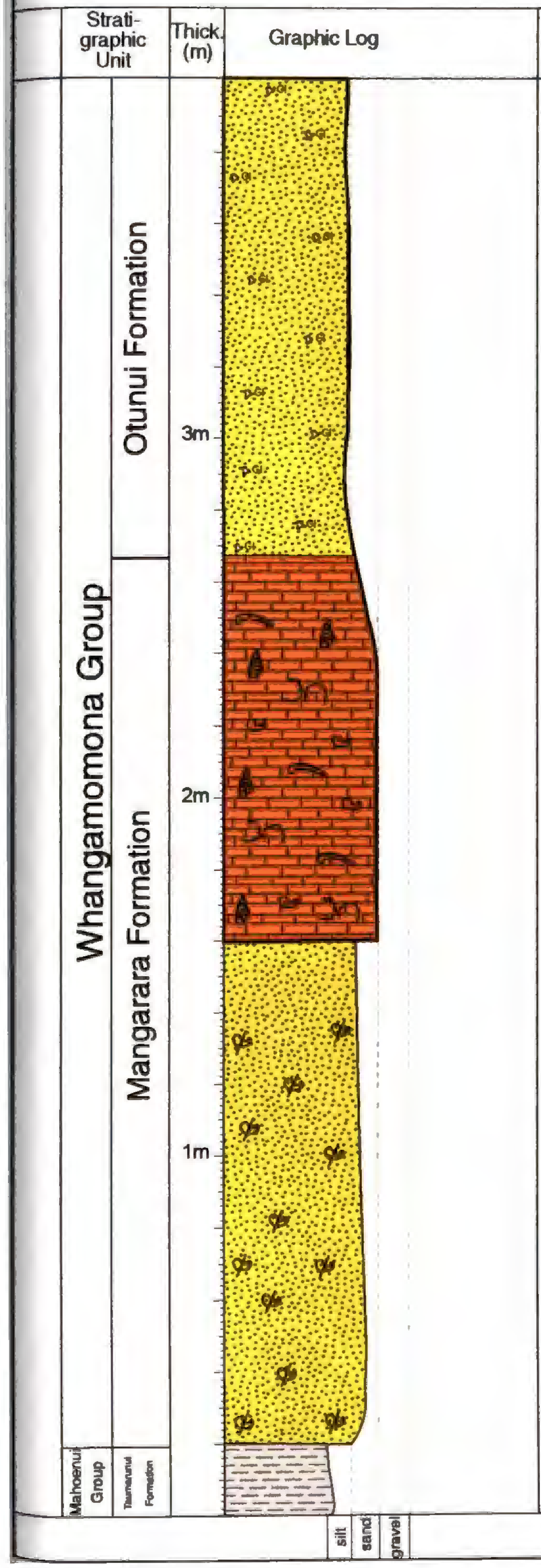
Name: T. Evans

Stratigraphic Column No: 5

Region: King Country Basin

Location: WP152. Ararimu East Road. Walk around behind woolshed, and outcrop is in stream to the right.

Description and notes



Massive grey sandstone
Fossiliferous at base
Glauconitic

Limestone which grades into a grey sandstone
Large fossils (4-5 cm)

Fine sandstone layer between limestone and coarser sandstone beneath.

Calcareous sandstone
No fossils, just broken shell material

Siltstone (part of Mahoenui flysch)
Layer has 20 % sand

Lithology, hardness & cementation, colour, weathering, bedding, sedimentary structures, texture (grain size, sorting, shape, roundness), fossils, ichnofossils, mineralogy, preliminiary assessment of environment of deposition.

Stratigraphic Column

Date: 14 February 2002

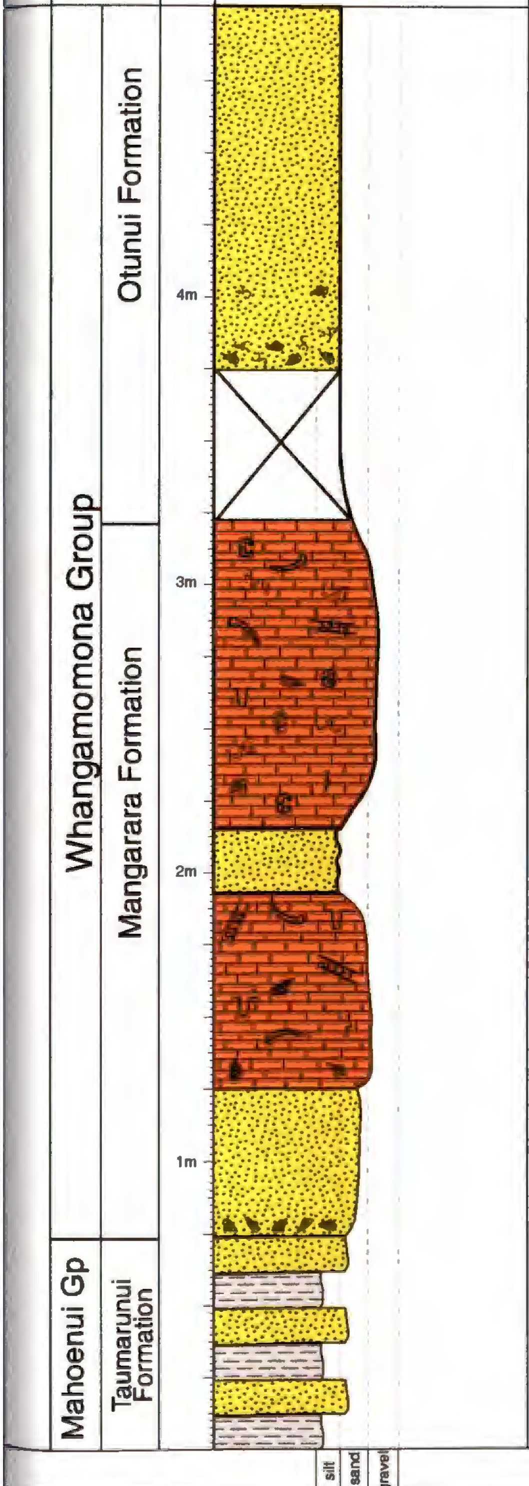
Name: T.Evans

Stratigraphic Column No: 6

Region: King Country Basin

Location: WP144. Go up Okahukura Saddle Road from S.H. 4 and stop when you come to the first wool shed on the left. Cross the paddock and walk down the railway lines until the tunnel.

Stratigraphic Unit	Thick. (m)	Graphic Log	Description and notes



Massive sandstone, blue-grey in colour.
Some gastropods/bivalves close to base (although contact is covered by vegetation), but these are very small and become sparser the further up the outcrop you go.

Thin sandy layer within the limestone.

Base of limestone is perfectly flat. There are no pebbles present,

but a few small (~1 cm) gastropods are present.

Basal coarse sandstone of limestone. No fauna visible.

Lithology, hardness & cementation, colour, weathering, bedding, sedimentary structures, texture (grain size, sorting, shape, roundness), fossils, ichnofossils, mineralogy, preliniminary assessment of environment of deposition.

Stratigraphic Column

Name: T. Evans

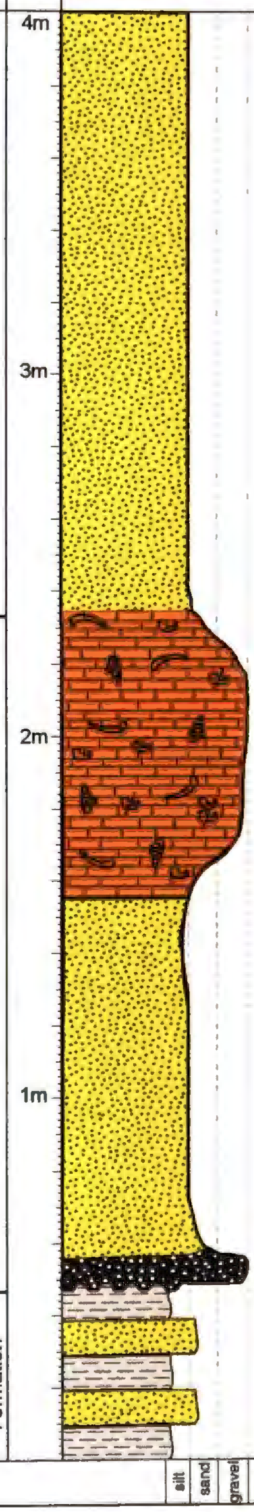
Date: 12 February 2002

Stratigraphic Column No: 7

Region: King Country Basin

Location: WP139. Rest area on S.H. 4 ~15 km north of Taumarunui.
Road cutting usually overgrown, and base of Mangarara
Formation is just above the height of the road.

Strati-graphic Unit		Thick. (m)	Graphic Log	Description and notes
Whangamomona Group	Otunui Formatioin			Massive, blue-grey sandstone. Extremely weathered inplaces resulting in an orange-brown appearance.
	Mangarara Formation			Limestone consisting of broken up shell hash material.
				Massive, calcareous, blue-grey sandstone
				Conglomerate at base of Otunui Formation. Unconformity between flysch and overlying conglomerate. Consists of greywacke pebbles, well-rounded, 2-8 cm in diameter.
Mahoenui Gp	Taumarunui Formation			Flysch 25% sand



Lithology, hardness & cementation, colour, weathering, bedding, sedimentary structures, texture (grain size, sorting, shape, roundness), fossils, ichnofossils, mineralogy, preliminary assessment of environment of deposition.

Stratigraphic Column

Date: 13 February 2002

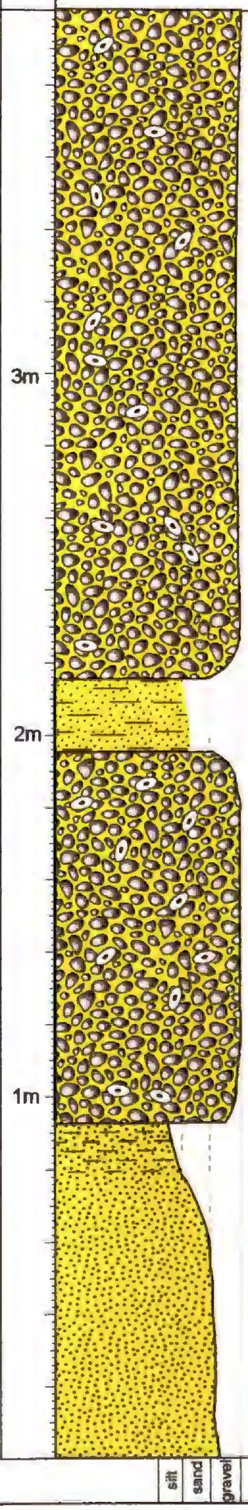
Name: T. Evans

Stratigraphic Column No: 8

Region: King Country Basin

Location: WP136. Otahu Valley. Walk down into valley off Okahukura Saddle Road. Cross stream and walk up track.

Strati-graphic Unit		Thick. (m)	Graphic Log	Description and notes
Whangamomona Group	Otunui Formation			Conglomerate - pebbles made from sandstone (which is extrememly weathered, possibly iron stained, and concretions. Pebbles range in size from 2 cm to 10 cm in diameter. Pebbles are very rounded, although there are some angular clasts included.
		3m		Typical Otunui concretions found in conglomerate.
		2m		Thin sandy mudstone layer within the conglomerate.
				Conglomerate - pebbles made from sandstone (which is extrememly weathered, possibly iron stained, and concretions. Pebbles range in size from 2 cm to 10 cm in diameter. Pebbles are very rounded, although there are some angular clasts included.
		1m		
				Massive, grey sandstone, which almost fines into mud - sized sediment at the top.
			silt / sand / gravel	Lithology, hardness & cementation, colour, weathering, bedding, sedimentary structures, texture (grain size, sorting, shape, roundness), fossils, ichnofossils, mineralogy, preliminary assessment of environment of deposition.



Stratigraphic Column

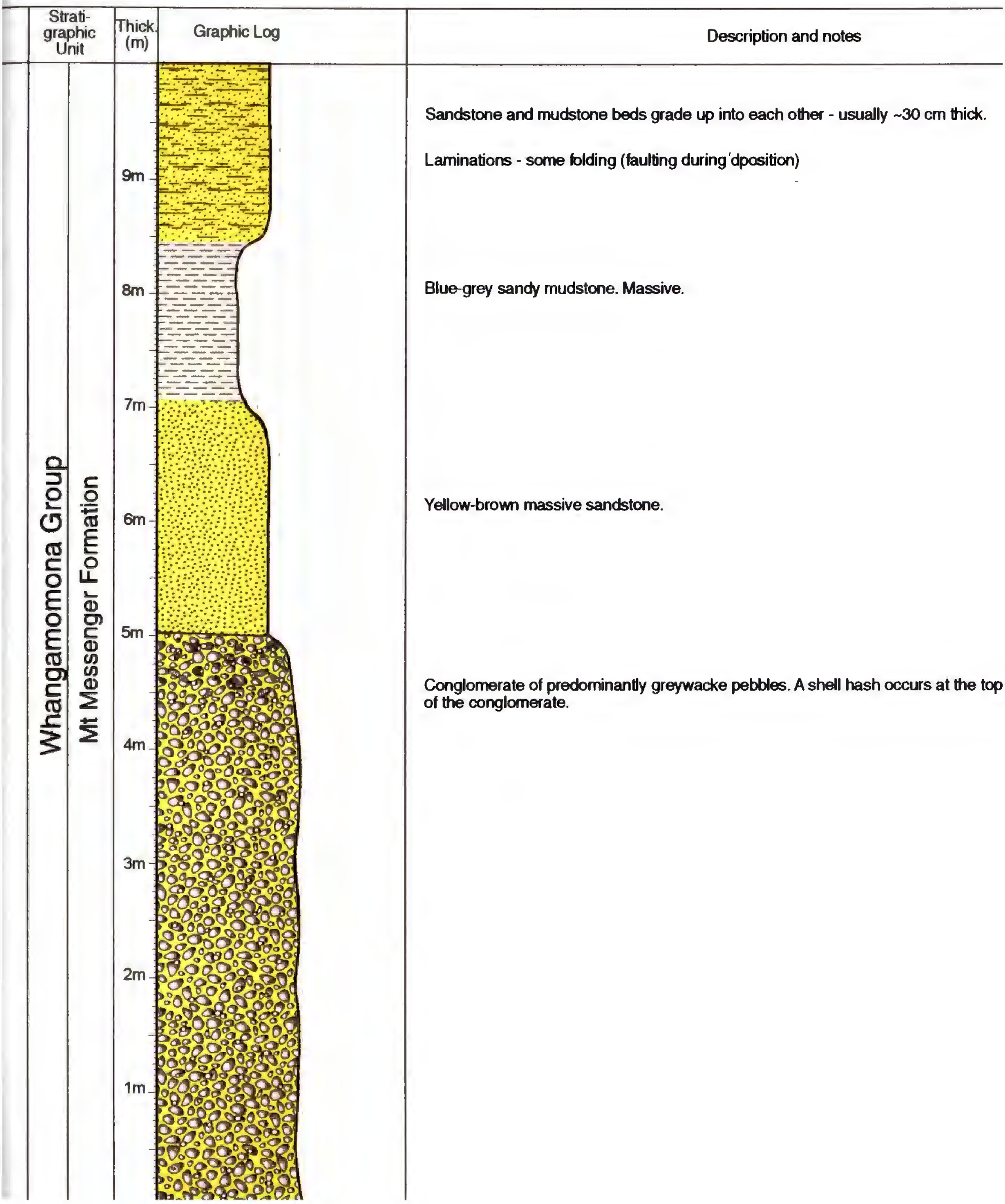
Date: 12 February 2002

Name: T. Evans

Stratigraphic Column No: 9

Region: King Country Basin

Location: WP045. Okahukura Saddle Road.



Stratigraphic Column

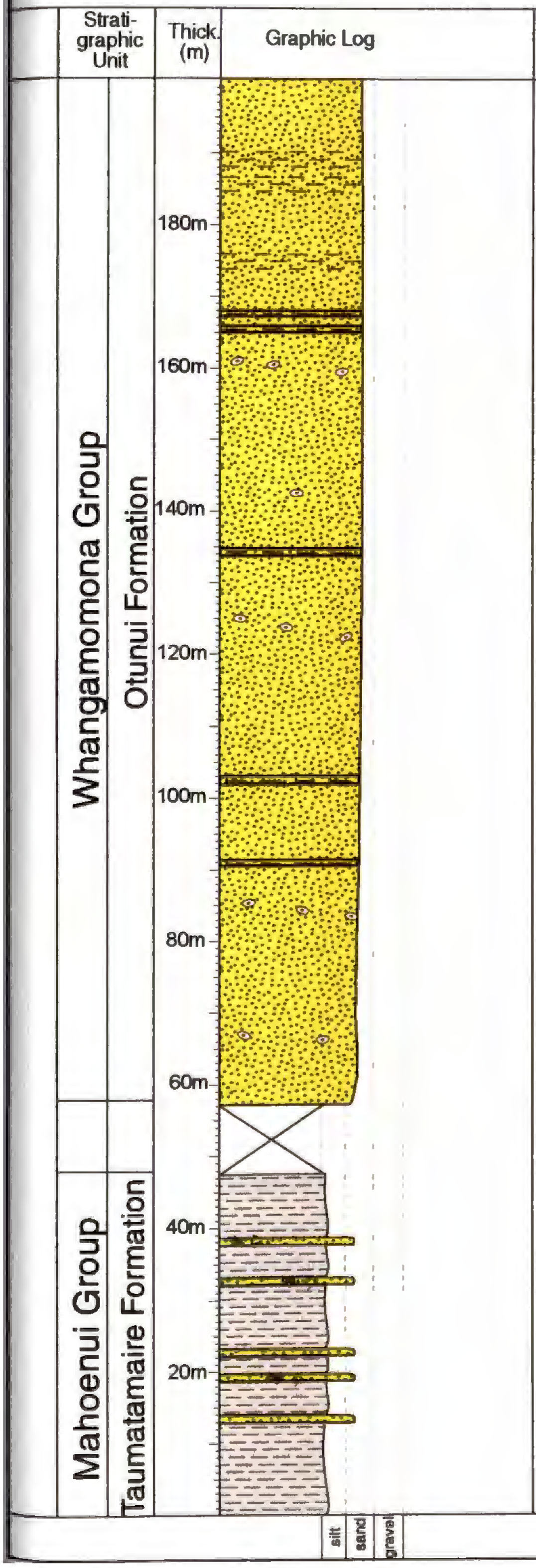
Date: 06 August 2002

Name: T. Evans

Stratigraphic Column No: 10

Region: Hapurua Valley

Location: WP291. Eastern side of Hapurua Valley Road. Follow valley/stream up to the top of feature 390.



Description and notes

Sandstone fines upwards. Becomes muddier the further up the section you go.

Outcrop consists of massive, blue grey sandstone. Concretions present throughout the outcrop. Indurated calcareous sandstone layers 30 - 50 cm thick occur throughout the outcrop, and are probably redeposited.

Hidden contact between Taumatamaire sltst and Otunui Formation. Mokau Group sdst and overlying Mangara formation would be here. They are exposed on the other side of the valley, outside of the field area.

Massive grey mudstone, interbedded with sandstone layers 30 - 50 cm thick. These sandstone beds are extremely carbonaceous, with plant remains and leaves up to 15 cm in length.

Lithology, hardness & cementation, colour, weathering, bedding, sedimentary structures, texture (grain size, sorting, shape, roundness), fossils, ichnofossils, mineralogy, preliminary assessment of environment of deposition.

Stratigraphic Column

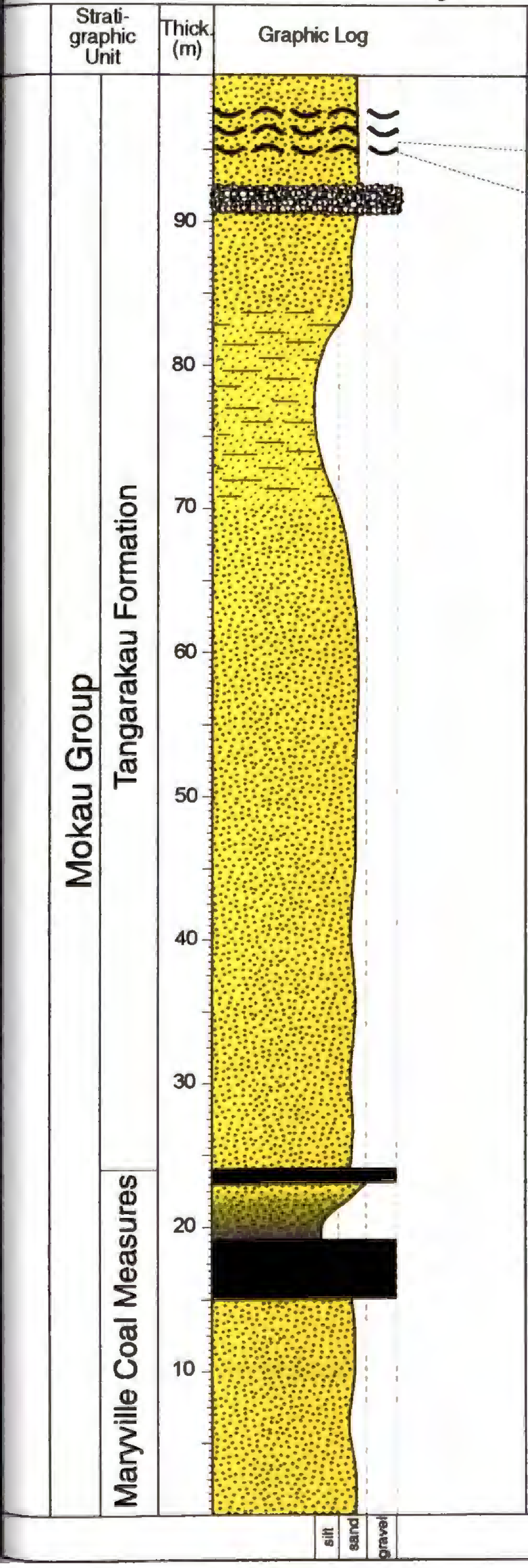
Date: 21 August 2002

Name: T. Evans

Stratigraphic Column No: 11

Region: Waitewhena Valley

Location: WP301. Western side of Waitewhena Valley Road. From abandoned Coal Mine follow farm track north until it branches, take bottom one until you come to stream, column goes up stream until you hit the track again.



Description and notes

~15 cm thick indurated sandstone beds. Fossiliferous at top. Calcareous. Fauna is highly fragmented and contains many unidentified bivalves.

Blue-grey, medium-grained sandstone.

Fine-grained, orange-brown sandstone.

Medium-grained, orange-brown, fluffy sandstone that grades up into silt, then sandy again.

60 cm thick sub-bituminous coal seam.

Mudstone grades up into fluffy sandstone.

4 m thick sub-bituminous coal seam.

Orange-brown sandstone.
Decimetred bedding.

Lithology, hardness & cementation, colour, weathering, bedding, sedimentary structures, texture (grain size, sorting, shape, roundness), fossils, ichnofossils, mineralogy, preliminary assessment of environment of deposition.

Stratigraphic Column

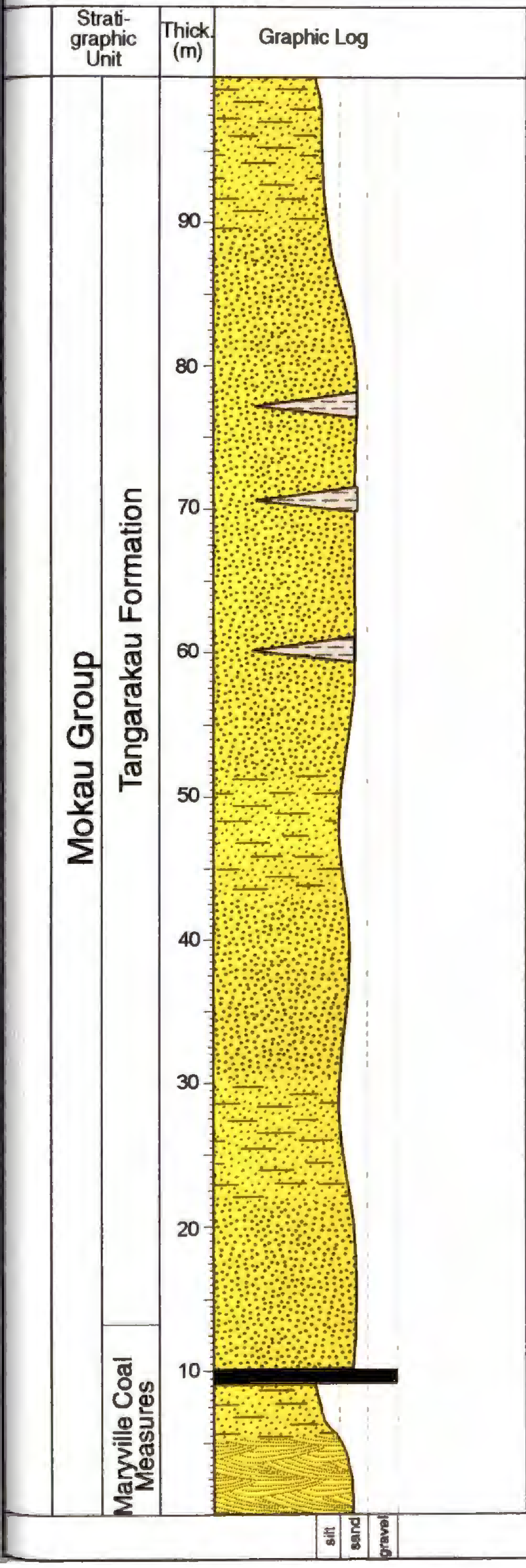
Date: 21 August 2002

Name: T. Evans

Stratigraphic Column No: 12

Region: Waitewhena Valley

Location: WP304. Western side of Waitewhena Valley Road. From the start of Column 11 head down stream to the road, and then log back up the stream until you came to where you started.



Description and notes

Grades up into an orange-brown, muddy sandstone.

Massive, orange-brown medium-grained sandstone with muddy lenses.

Massive, orange-brown muddy sandstone.

Massive, orange-brown medium-grained sandstone.

Massive, orange-brown muddy sandstone.

Massive, orange-brown medium-grained sandstone.

1 m thick sub-bituminous coal seam.

Medium-grained, blue-grey sandstone, well sorted, planar bedded with low-angle cross-bedding. Fines into a muddy sandstone.

Lithology, hardness & cementation, colour, weathering, bedding, sedimentary structures, texture (grain size, sorting, shape, roundness), fossils, ichnofossils, mineralogy, preliminary assessment of environment of deposition.

Stratigraphic Column

Date: 26 November 1992

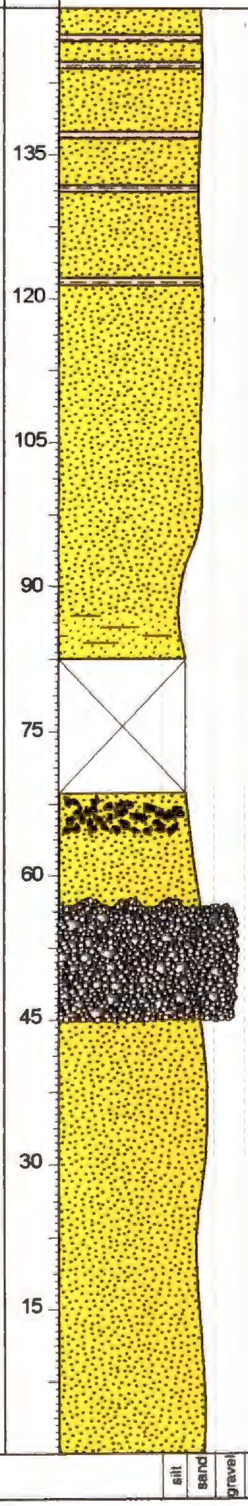
Name: S. Gerritsen

Stratigraphic Column No: SGC18

Region: Taumarunui

Location: Go to end of Mahuri Rd, off Opotiki Rd, until the track crosses a bridge. Keep on left side of the valley. The column starts under a totara by the stream, goes up the stream to a waterfall, then cuts back up the hill to the top.

Strati-graphic Unit	Thick. (m)	Graphic Log	Description and notes
Whangamomona Group; Otunui Formation			



Blue-grey, weathered, massive sandstone with thin (10-20 cm thick) calcareous mudstone beds.

Yellow-brown, weathered, indurated sandstone.

Chaotic mix of blue-grey weathered sandstone with mm-cm scale bedding.

Weathered, blue-grey, massive, calcareous, fossiliferous sandstone.

10 m thick shelly conglomerate.

Blue grey, weathered, indurated, massive calcareous sandstone. Occasional yellow-brown fine sandstone lenses 10 cm thick.

Lithology, hardness & cementation, colour, weathering, bedding, sedimentary structures, texture (grain size, sorting, shape, roundness), fossils, ichnofossils, mineralogy, preliminiary assessment of environment of deposition.

APPENDIX B

Waypoint Location Data

Waypoint Number	Eastings	Northings	Altitude (m)	Strike/Dip
26	2691398	6275734	260	
27	2694261	6278146	349	
28	2696407	6267203	205	
29	2698480	6267887	200	042/010NW
30	2702793	6269484	579	
31	2701537	6271669	220	
32	2701607	6272367	240	180/009W
40	2704675	6267230	220	034/11NW
41	2701677	6266546	212	
42	2701547	6266701	246	
43	2701351	6266717	260	
44	2701468	6266756	285	
45	2701579	6267623	365	
59	2710100	6265635	768	
62	2695189	6276723	395	
63	2696308	6275909	247	
64	2691251	6276302	212	
65	2691191	6276655	211	
66	2691078	6277188	413	
67	2690986	6277077	418	
100	2700539	6278569	415	
101	2700061	6278069	333	062/003N
102	2699593	6278015	368	140/004W
103	2700529	6278202	310	
104	2701917	6277307	282	060/004W
105	2702464	6276533	343	
106	2704609	6275898	332	
107	2702414	6273477	231	
108	2701650	6272301	225	
125	2702793	6269351	548	
126	2701069	6271760	213	
127	2698701	6267723	205	
128	2699249	6267790	222	
129	2700288	6268111	269	
130	2701104	6267843	318	
131	2701553	6267629	373	
132	2702771	6264047	204	
133	2703160	6261725	180	
134	2701836	6268381	232	
135	2702059	6268650	319	
136	2701617	6268415	332	
137	2701393	6268537	319	
138	2701495	6268538	352	
139	2702967	6264677	177	020/004N
140	2702940	6263777	140	100/007SW
141	2702925	6263703	177	
142	2705286	6255688	142	
143	2705022	6256554	185	
144	2700957	6266442	247	
145	2701419	6266542	320	
146	2701451	6266389	298	
147	2700565	6266383	365	
148	2699275	6268358	280	
149	2699833	6265660	412	
150	2697159	6264847	528	

151	2696888	6264579	538	
152	2694951	6262225	314	
153	2701445	6267072	346	
154	2697334	6263915	360	010/002SE
155	2694926	6261606	300	040/004WNW
156	2695732	6261149	283	110/010N
157	2695621	6258274	219	
158	2701302	6254713	443	020/014NW
159	2690603	6275629	186	
160	2682749	6266272	168	086/009NW
291	2685197	6269325	221	
292	2685264	6269304	237	048/004NW
293	2685597	6269003	279	
294	2685444	6268775	419	
295	2681290	6251935	273	
296	2681984	6251935	262	
297	2689571	6253311	144	
298	2701590	6254284	386	
299	2703239	6261377	372	
300	2682260	6273392	195	
301	2681933	6272879	183	
302	2681419	6273952	282	
303	2680946	6274286	288	
304	2681777	6273622	308	
305	2681978	6277817	215	

APPENDIX C

Fossil Record Data

Sample Number: TE001

Name: *Dosinian (Raina) bensoni*

Identifier: Marwick (1927).

Age: Altonian-Waiauan

Unit/Lithology: Mangarara Formation

Abundance: Sparse

Condition: Poor

Column/Waypoint No: WP041

Sample Number: TE002

Name: *Zeacolpus pukeuriensis*

Identifier: Marwick (1934)

Age: Altonian-Lillburnian

Unit/Lithology: Otunui Formation

Abundance: Abundant

Condition: Good

Column/Waypoint No: WP066, WP065, WP067, WP144, WP152, WP156

Sample Number: TE003

Name: *Spissatella* sp. (undet. sp.)

Identifier: Finlay (1926)

Age: Kaiatan-Tongaporutuan

Unit/Lithology: Mangarara Formation

Abundance: Sparse

Condition: Poor

Column/Waypoint No: WP155

Sample Number: TE004

Name: *Tellinota cf. edgari*

Identifier: Iredale (1915)

Age: Whaingaroan-Recent

Unit/Lithology: Mangarara Formation

Abundance: Sparse

Condition: Poor

Column/Waypoint No: WP152

Sample Number: TE005

Name: Limopsis sp. (undet. sp.)

Identifier: Sassi (1827)

Age: Wangaloan-Castlecliffian

Unit/Lithology: Mangarara Formation

Abundance: Sparse

Condition: Poor

Column/Waypoint No: WP152

Sample Number: TE006

Name: *Dosinia (Raina) bensoni*

Identifier: Marwick (1927)

Age: Altonian-Waiauan

Unit/Lithology: Otunui Formation

Abundance: Sparse

Condition: Poor

Column/Waypoint No: WP157

Sample Number: TE007

Name: *Cirsotrema sp.* (undet. sp.)

Identifier: Morch (1852)

Age: Bortonian-Recent

Unit/Lithology: Otunui Formation

Abundance: Sparse

Condition: Moderate

Column/Waypoint No: WP147

ample Number: TE008

Iame: *Bartrumia tenuiplicata*

dentifier: Marwick (1934)

ge: Otaian-Tongaporutuan

Jnit/Lithology: Otunui Formation

bundance: Moderately abundant

Condition: Moderate

Column/Waypoint No: WP158

Sample Number: TE009

Name: *Eumarcia (Atamarcia) thomsoni*

Identifier: Iredale (1925)

Age: Altonian-Haweran

Unit/Lithology: Otunui Formation

Abundance: Sparse

Condition: Poor

Column/Waypoint No: WP150, WP151

Sample Number: TE010

Name: *Austrofuses (Neocola) demissus*

Identifier: Kobelt (1879)

Age: Bortonian-Waipipian

Unit/Lithology: Otunui Formation

Abundance: Sparse

Condition: Poor

Column/Waypoint No: WP157

Sample Number: TE008

Name: *Bartrumia tenuiplicata*

Identifier: Marwick (1934)

Age: Otaian-Tongaporutuan

Unit/Lithology: Otunui Formation

Abundance: Moderately abundant

Condition: Moderate

Column/Waypoint No: WP158

Sample Number: TE009

Name: *Eumarcia (Atamarcia) thomsoni*

Identifier: Iredale (1925)

Age: Altonian-Haweran

Unit/Lithology: Otunui Formation

Abundance: Sparse

Condition: Poor

Column/Waypoint No: WP150, WP151

Sample Number: TE010

Name: *Austrofuses (Neocola) demissus*

Identifier: Kobelt (1879)

Age: Bortonian-Waipipian

Unit/Lithology: Otunui Formation

Abundance: Sparse

Condition: Poor

Column/Waypoint No: WP157