Annual Conference of the Geoscience Society of New Zealand

Field Trip 4
Hawke's Bay Monocline and Forearc Basin
Tuesday 27th November 2018


Photo from Darkys Spur Road (Tangoio Block) west to the crest of Maungaharuru Range, all part of the Hawke's Bay Monocline within the Hawke's Bay Forearc Basin (photo: Betty-Ann Kamp).

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Part A: Schedule of field trip sites (stops) with associated notes and figs 1–10;

Part B: Geological context of the Hawke's Bay Monocline and Forearc Basin (text with figs 11–14)

Part A

STOP 1. Whirinaki Bluff, Tangoio (NZMS 260: 2846961/6198520)

Fig. 1: Stratigraphic column No. 79

Fig. 2: Nukumaruan generalised stratigraphy

Fig. 3: Stratigraphic nomenclature for Hawke's Bay Forearc Basin

Fig. 4: Integrated biostratigraphy and chronology

Table 1: Facies Summary

Examine a good exposure of the Tangoio Limestone Mb and the Te Ngaru Mudstone Mb of the late Pliocene Petane Formation (Haywick, 1990; Bland, 2006; Bland and Kamp, 2014). The Tangoio Limestone Mb has two parts: a lower cross-bedded sandy limestone with disarticulated *Tawera*; and an overlying weakly bedded and highly fossiliferous shelly medium to coarse-grained limestone with *Eumarcia*. *Ostrea* and intact valves become common in the upper part of this unit. An abrupt contact lies between the upper limestone and the overlying Te Ngaru Mudstone Mb. The lower part of the mudstone comprises a dispersed shellbed with articulated *Ostrea* and *Zeacolpus vittattus* with some *Dosinia* sp and bryozoans. The overlying mudstone comprises sparsely fossiliferous massive siltstone. This facies typically contains *Pratulum*, *Neilo*, *Ostrea*, *Tawero-Patro* and *Talochlamys* (Haywick and Henderson, 1991; Bland et al., 2013).

A sequence boundary is inferred to lie between the two limestone units at about 2 m above the beach deposits. Up close to the outcrop it is difficult to puts one's finger on this contact—stand back and it is evident from differences in bedding type and degree of cementation. The lower limestone is interpreted as a regressive systems tract (RST), whereas the upper one is interpreted as a transgressive systems tract (TST). The matrix-supported shellbed in the lower part of the mudstone unit is interpreted as a downlap shellbed, reflecting rapid water depth increase to mid to outer-shelf environments, associated with initially low terrigenous sediment input as a muddy wedge starts to downlap across the TST.

STOP 2. Café at Pohokura Road (Coffee and toilet stop)

STOP 3. Darkys Spur Road section, Tangoio Block (NZMS 260: 2840702/6210500)

Fig. 5: Stratigraphic column No. 46

Examine a well-exposed 36 m-thick section of the uppermost part of the Aropaoanui Mudstone Mb and the Darkys Spur Mb of the late Pliocene Petane Formation on Darky's Spur Road, western face of the Tangoio Block. The Aropaoanui Mudstone Mb is a massive, bioturbated, slightly fossiliferous (*Talochlamys gemmulata*, *Pelicaria convexa*, *Panopea zelandica*, *Austrofusus*, *Dosinia lambata*, *Atrina pectinata zelandica*, *Modiolaca*, *Zenatia acinaces*, *Bassina yetei* and *Penion sulcatus*) inner-shelf sandy siltstone that transitions into shoreface Darkys Spur Mb via a 3 m-thick interbedded interval of thin- to thick-bedded sandstone within background sandy siltstone facies. Darkys Spur Mb comprises very well sorted, slightly micaceous laminated fine sandstone that passes upward into broadly cross-bedded fine sandstone with abundant fossiliferous shelly lenses containing *Dosinia anus*, *Rexithaerus spenceris*, *Tellinota edgari*, *Perinidea garimardi* and *Austromegbalnus dacor*us. Shoreface sandstone facies transition via small pebble lenses into trough cross-bedded pebble conglomerate that passes upward into low-angle stratified conglomerate named Tararere Conglomerate Bed. This conglomerate facies is inferred to be a beach or barrier deposit not unlike Whirinaki Beach (Stop 1). The conglomerate facies are overlain by 6 m of non-marine siltstone (containing a channelized conglomerate bed) and sandstone beds, including thin tephra and lignite. This 6 m interval is inferred to represent fluvial deposits.

The succession described thus far is interpreted as the upper (regressive) part of a sequence (cyclothem), including the late Highstand Systems Tract (HST) represented by the Aropaoanui Mudstone Mb, followed upwards by the RST (Darkys Spur Mb) to 31 m in Fig. 2. The facies transition from inner-shelf sandy siltstone to shoreface fine sandstone is well-displayed and -exposed. This section is unusual in the context of late Pliocene cyclothems in the forearc basin by including non-marine fluvial facies above shoreface facies. This indicates that the lowstand shoreline passed through this succession and lay to the east (probably east of Devils Elbow section on the Napier–Wairoa State Highway).

At 31 m in the section (Fig. 2) non-fossiliferous siltstone is separated from an overlying sandy shellbed (with disarticulated *Maorimactra ordinaria*, *Panopea zelandica* and *Nucula nitidula*) by a sharp surface. This surface is inferred to be a wave-cut sequence boundary (ravinement surface) and the shellbed is interpreted as an onlap shellbed. This shellbed is overlain by 3–4 m of very well exposed and accessible fossiliferous fine sandstone with a diverse shoreface to inner-shelf macrofaunal assemblage, including *Fellaster zelandiae*, *Zethalia zelandica*, *Struthiolaria frazeri* and *in situ Panopea zelandica*. The beds above the sequence boundary are interpreted as TST deposits. This expression of a TST is unusual in the context of the late Pliocene forearc basin cyclothems in being relatively thick (4 m versus typically 1–2 m) and composed of essentially uncemented fossiliferous fine sandstone versus differentially cemented fossiliferous limestone.

STOP 4. Whakamarino Formation, confluence of Mohaka and Te Hoe rivers (NZMS 260: 2840049/6235605)

Fig. 6: Stratigraphic column No. 1

From Stop 3 we drive via Pohokura Road (making one view stop along the way) and Waitere Station to this site. In doing so, we cross the middle to lower part of the forearc basin succession, appreciating its thickness and consistent south easterly dip. At this site we view (at a distance across Mohaka River) a 10 m-thick section of the early Miocene (late Otaian–Altonian) Whakamarino Formation. Cutten (1994) nominated this site as the type section of Whakamarino Formation. This formation comprises massive to weakly bedded siltstone with interbedded turbidites up to about 0.5 m thick. The beds dip west, opposite to the regional dip, related to deformation along Te Kooti Fault and within the core of Pohokura Anticline, as mapped by Cutten (1994). Within part of the Te Hoe River catchment, Whakamarino Formation unconformably overlies Wanstead Formation. In parts of the Te Hoe River and Mohaka River area, Whakamarino Formation (Eocene) is conformably overlain by Clifdenian–Lillburnian Pomako Formation, and nearby is unconformably overlain by Tongaporutuan Waitere Formation. To the west, Whakamarino Formation is in fault contact with basement across Mohaka Fault. Whakamarino Formation is up to 750 m thick along the Te Hoe River section, thinning to 350 m south of Mohaka River in the vicinity of Stop 4.

Whakamarino Formation is strikingly similar in appearance (facies) to the Otaian Mahoenui Group in the southern part of King Country Basin. These two units both accumulated in bathyal paleoenvironments either side of the Pleistocene Taupō Volcanic Zone. The most eastern Mahoenui Group exposures are only 110 km due west of this stop. This is an opportunity, with reference to the 1:1,000,000 geological map, to comment upon early Miocene paleogeography.

STOP 5. Waitere Formation (Te Ipuohape Sandstone Member), Waitere Station, Pohokura Road (NZMS 260: 2838400/6233700)

Fig. 7: Tologa Group stratigraphy

We will park near the hairpin corner on Pohokura Road and walk through the upper part of the Te Ipuohape Sandstone Member of Waitere Formation, which forms a spectacular bluff of about 300 m thickness.

Te Ipuohape Sandstone Mb is the lowermost of three members in Waitere Formation. It rests unconformably upon Clifdenian–Lillburnian Pomako Formation and upon Whakamarino Formation in Pohokura Anticline. South of Waitere Station Te Ipuohape Sandstone Mb rests unconformably on basement. Hence the start of accumulation of this member represents the end of a local phase of uplift and erosion and the start of subsidence and infilling of a new basin, which we identify as the Hawke's Bay Forearc Basin.

At this site and elsewhere along strike of the basin margin, Te Ipuohape Sandstone Mb comprises pale yellow-brown, massive or weakly bedded fine, slightly micaceous sandstone (Cutten, 1994). A honeycomb weathering pattern on the sandstone, where broken away, suggests thin bedding is obscured by surface weathering. This unit largely lacks macrofossils. Poorly preserved, low diversity foraminiferal assemblages near the base of the unit contain *Bolivinita pohana*; *Globoquadrina dehiscens* occurs higher within the sandstone (Scott et al.,1990), indicating that accumulation started during the early Tongaporutuan. Given its stratigraphic position immediately above an erosional unconformity, the sandstone member probably accumulated overall as a transgressive sandstone in an inner-shelf depositional environment. This is supported by the significant southward overstepping by this unit onto basement, well beyond the point of onlap of Pomako Formation.

As we walk up through part of the thick sandstone unit, can we find evidence for breaking it up into packages bounded by master surfaces that could represent a succession of sequences that possibly reflect changes in relative sea level?

STOP 6. Waitere Formation, Auroa Alternating Member, Waitere Station, Pohokura Road (NZMS 260: 2838600/6233200)

This site is at the first road cutting along Pohokura Road south of Waitere Woolshed. The top of Te Ipuohape Sandstone Mb is only metres below the woolshed. The outcrop at this site occurs within the lowermost part of Auroa Alternating Member (Cutten, 1994) and only a few metres stratigraphically above the top of the Te Ipuohape Sandstone Mb. The lithology comprises interbedded massive siltstone and thin sandstone considered here to be redeposited mass-flow deposits. Planktonic foraminifera examined by George Scott, as reported by Cutten (1994), indicate oceanic water and middle bathyal water depths. These features suggest sedimentation on a continental slope. If so, there was substantial subsidence and increase in water depth and paleoenvironment between the end of accumulation of Te Ipuohape Sandstone Mb and the start of Auroa Alternating Member. The substantial and rapid tectonic subsidence implied would have been accompanied by flooding of the basin margin, which probably terminated for a period the supply of sediment to this part of the basin until the depositional systems adjusted and progradation was renewed. In this type of scenario, bathyal redeposited facies within hemipelagic mudstone can be anticipated immediately above inner-shelf sandstone beds (Te Ipuohape Sandstone Mb).

Rakaita Siltstone Member (Waitere Formation) and Mokonui Sandstone

As we travel back along Pohokura Road to Pohokura Saddle (STOP 7), we pass upwards through Rakaita Siltstone Member. Road cuttings expose blue-grey, weathering to yellow-brown, finely laminated to massive siltstone, which is bioturbated and non-calcareous. In this part of the basin this siltstone member is about 1000 m thick, dips southeast and has a late Tongaporutuan to Kapitean age based on foraminifera (Cutten, 1994). Thin rhyolitic tephra occur within this member.

This thick siltstone unit is interpreted as representing rapid accumulation on a continental slope, possibly as offlapping migrating clinoforms, into the western flank of the forearc basin during the late Miocene. At about two-thirds up into the Rakaita Siltstone Mb, there is a transition zone where many metre-thick sandstone beds with sharp bases and tops are interbedded within the siltstone facies. These are interpreted as storm-emplaced traction deposits reworking parts of the shore-connected sand wedge onto the shelf, probably during lowstand sea-level conditions. Further up the section there is a rapid and conformable transition from Rakaita Siltstone Mb into Mokonui Sandstone. Mokonui Sandstone comprises a very well sorted largely non-fossiliferous fine sandstone. It is about 300 m thick in the vicinity of Pohokura Road but thickens up to about 1000 m in the Mohaka River section to the north. From foraminiferal content, it is considered to have accumulated during the late Kapitean and early Opoitian.

Mokonui Sandstone is interpreted here as having accumulated as an inner-shelf to shoreface environment. It represents the upper (inner-shelf to shoreface) part of a very thick progradational succession that includes Auroa Alternating Mb and Rakaita Siltstone Mb, which represent the slope and outer-shelf components of the progradational system. In this context, in the Waitere and Mokonui formations we have observed a complete 4^{th} order sequence. The lower transgressive component comprises Te Ipuohape Sandstone Mb, the downlap surface is the contact between it and Auroa Alternating Member, and this is overlain by bottomsets (Auroa Alternating Mb), slopesets in Rakaita Siltstone Mb and topsets in the upper part of Rakaita Siltstone Mb and Mokonui Formation.

STOP 7. Titiokura Formation, Pohokura Road (NZMS 260: 2838700/6227300)

Fig. 8: Titiokura Formation geological map

Fig. 9. Simplified columns for Titiokura Formation

Fig. 10: Stratigraphic column No. 9

Titiokura Formation comprises a mixed carbonate–siliciclastic succession, cyclothemic in places, which accumulated during the late Opoitian and Waipipian above Mokonui Formation along the western margin of the forearc basin (Bland et al., 2004). Much has been made of an unconformity between Mokonui and Titiokura formations, but here it is merely considered to be a sequence boundary originating from wave and channel cut erosion of unconsolidated underlying sand (Mokonui Formation) during a relative change in sea-level during a 41,000 kyr orbitally-paced cycle of sea-level change.

Fig. 8 shows the distribution of five members within Titiokura Formation along the crest of Maungaharuru Range and its eastern flank. Fig. 9 helps to explain the map distribution of Titiokura Formation. Along the crest of Te Waka Range (south of State Highway 5) and the Maungaharuru Range (Ahuateatua and Taraponui trigs), Titiokura Formation comprises a 50–60 m thick limestone, which holds up the crest of the range. At this site (Stop 7, Pohokura Saddle), the formation widens out substantially and five members have been mapped (Graafhuis, 2001), each comprising a sequence. This map distribution of members represents increasing accommodation at a point northwards along the basin margin during the late Opoitian.

Fig. 10 shows stratigraphic columns for Naumai and Te Rangi members of Titiokura Formation east of Pohokura Saddle. Each member is considered to represent accumulation during a 41,000 kyr sea-level cycle. The base of each sequence is marked by a sharp erosional surface, being a sequence boundary. This is followed by a TST comprised of clast-supported conglomerate beds containing siltstone and sandstone clasts with a calcareous cross-bedded sandstone matrix. The base of Te Rangi Member includes in the upper part of the TST a cross-bedded sandy limestone bed about 1 m thick. The successive TSTs are overlain by 53 m (Naumai Mb) and 62 m (Te Rangi Mb), respectively, of carbonate–siliciclastic sandstone. There is variable development of concretions, mud drapes, channel-fill conglomerate, shelly lens and pods, trough cross-bedding on small to large scales and water escape deformation structures. These features are indicative of rapid sedimentation. The copious supply of sand throughout highstand to regressive conditions has resulted in a different sequence architecture for these cyclothems to that typically observed in Pliocene and Pleistocene sequences in Hawke's Bay and Whanganui basins (Naish and Kamp, 1997). There was evidently not much water depth increase during the HST as a result of the copious flux of sediment being delivered to the basin margin during that period.

STOP 8: Café at Pohokura Road (toilet stop if necessary)

Figures 1–10 for Part A of this Field Trip Guide now follow:

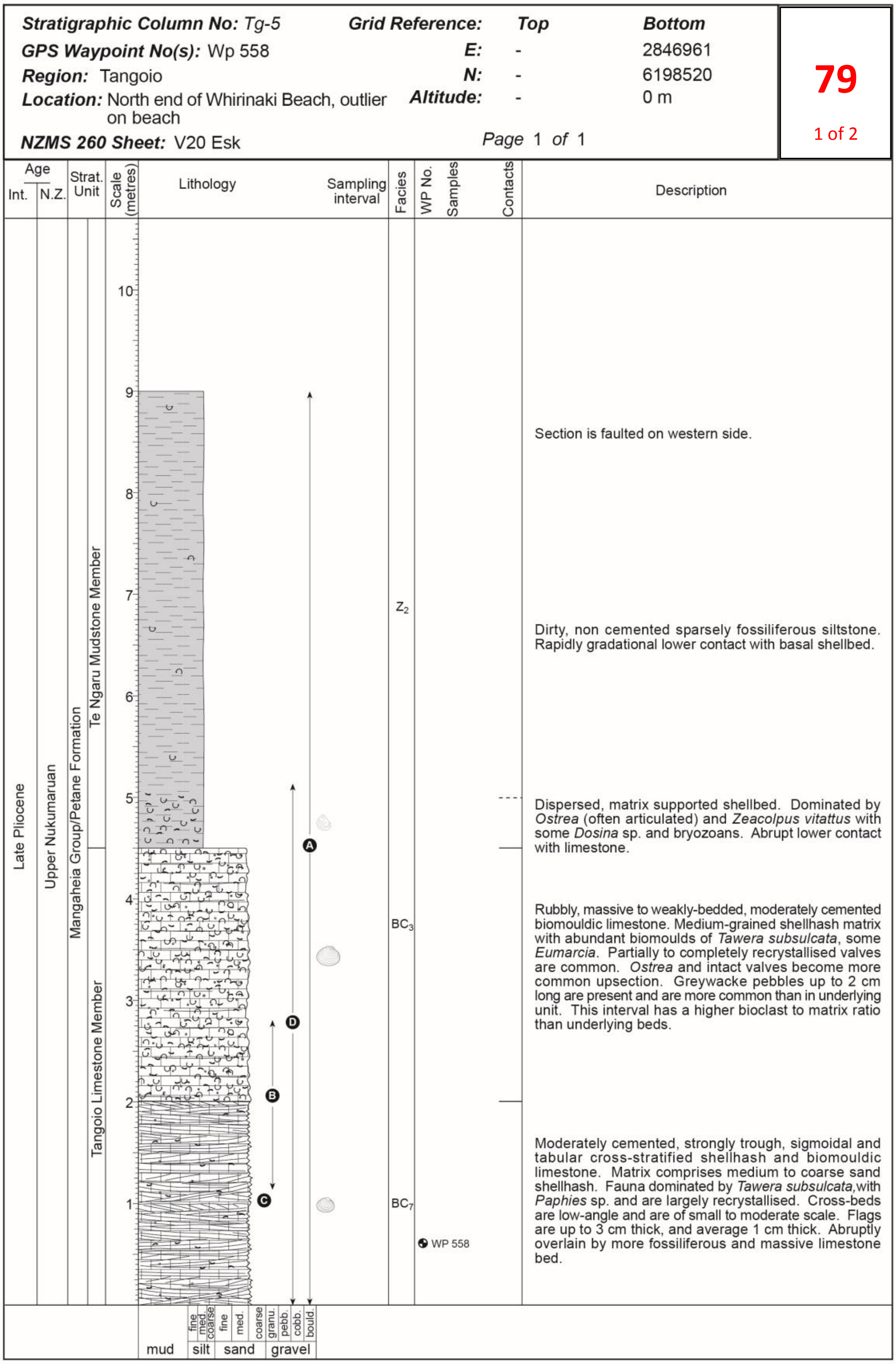

Fig. 1: Whirinaki Beach section stratigraphic column No. 79 (1 of 2) (Kamp et al., 2007).

Fig 1: Stratigraphic column No. 79 (2 of 2)—photos (Kamp et al., 2007).

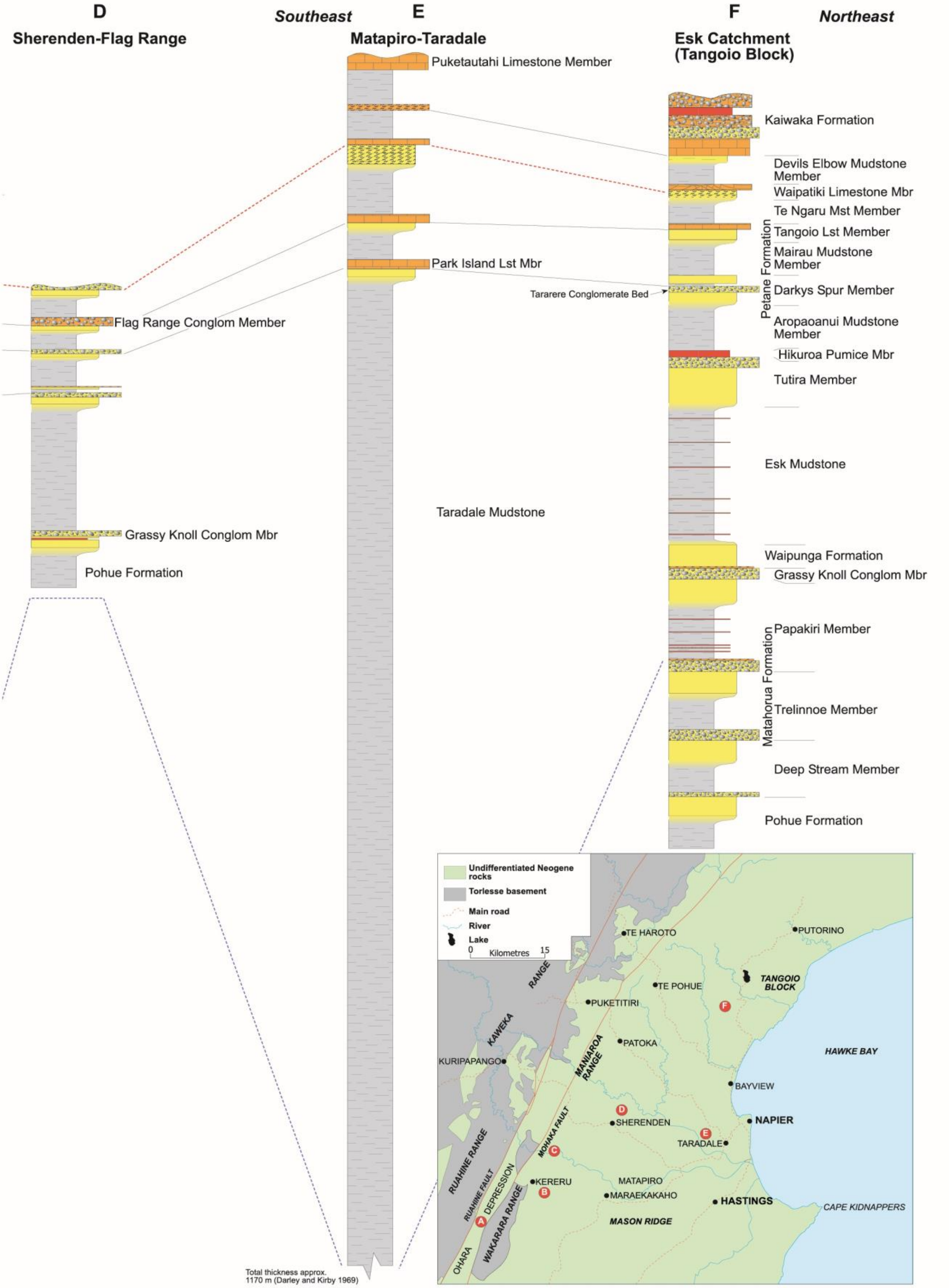

Fig. 2: Nukumaruan generalised stratigraphy (Bland and Kamp, 2014).

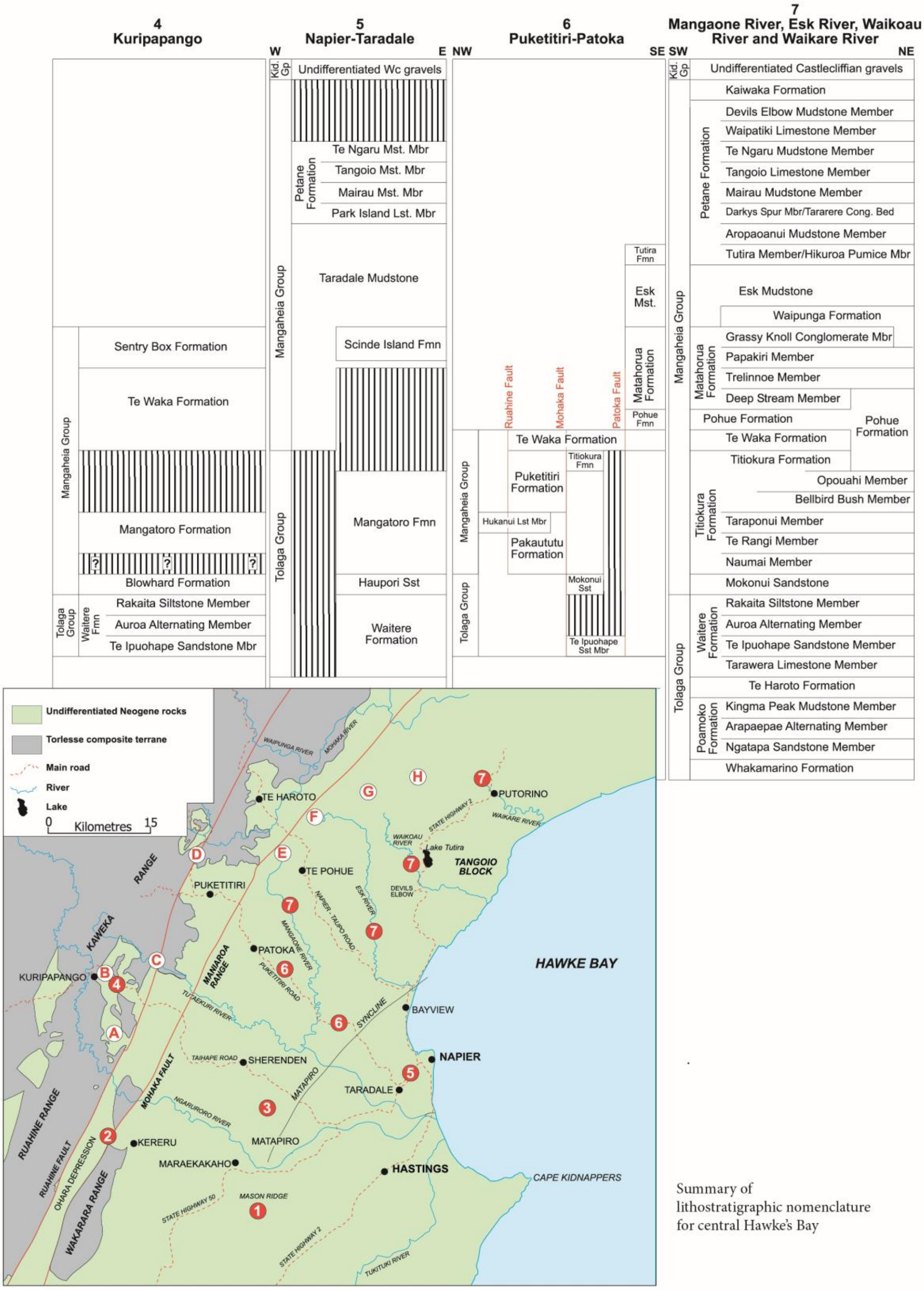

Fig. 3: Stratigraphic nomenclature for Hawke's Bay Forearc Basin (Bland and Kamp, 2014).

Integrated Biostratigraphy and Chronology summary

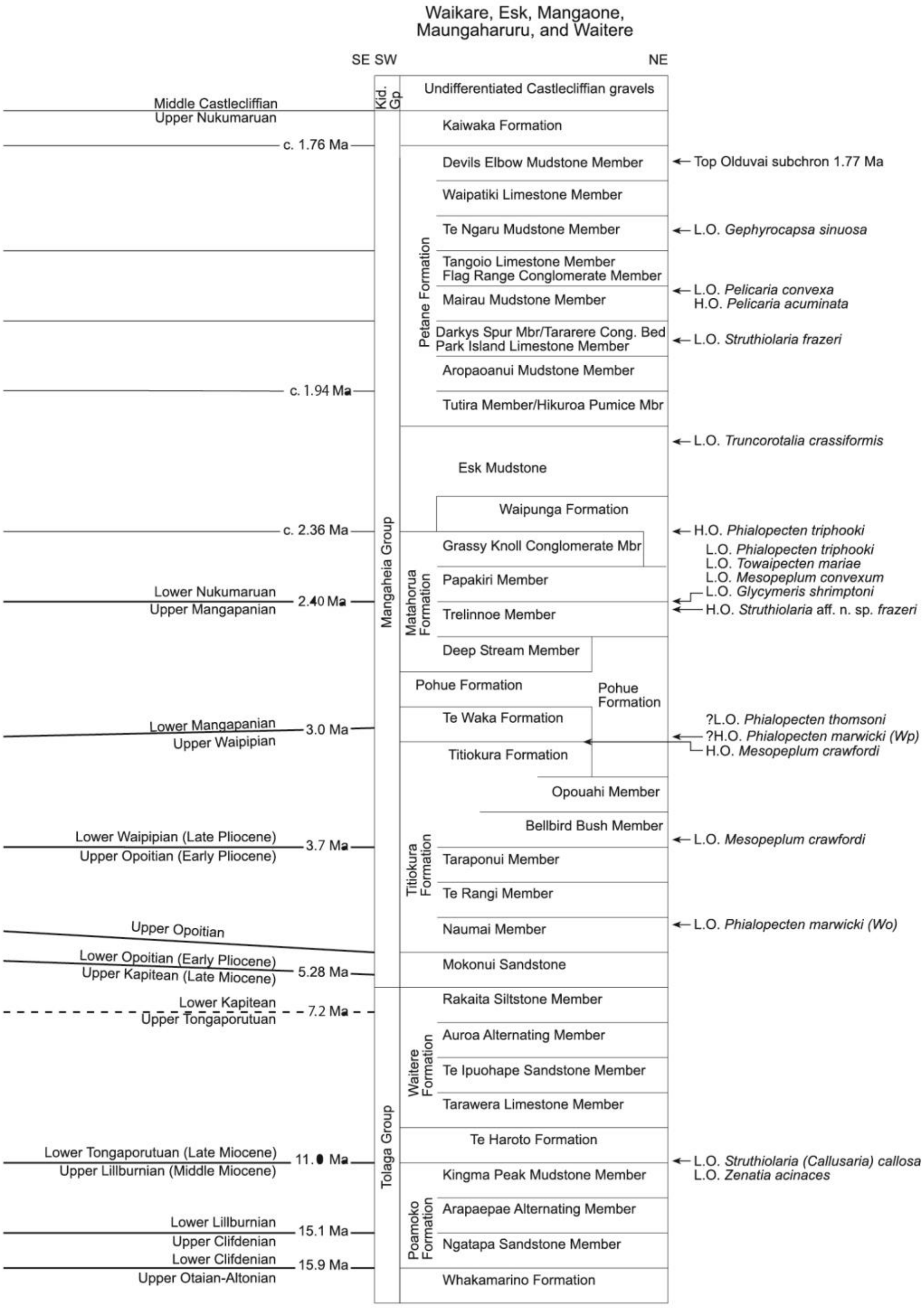

Fig. 4: Integrated biostratigraphy and chronology for the Neogene succession in the Hawke’s Bay Forearc Basin (Bland and Kamp, 2014).

Table 1: Facies summary for late Neogene sediments, Hawke's Bay (Bland and Kamp, 2014).

	Lithofacies	Description	Inferred environment of deposition	Typical faunal associations
Sandstone		**Siliciclastic-dominated**		
S_1	Massive sandstone (C)	Massive, non cemented non fossiliferous slightly micaceous very well-sorted fine to medium sandstone.	Shoreface to nearshore	None
S_2	Massive to cross-stratified sandstone (C)	Massive to cross-stratified non cemented very well-sorted fine to medium sandstone.	Shoreface to inner shelf	None
S_3	Massive to cross-stratified fossiliferous sandstone (C)	Massive to cross-stratified non cemented very well-sorted moderately to highly fossiliferous fine to medium sandstone. Macrofossils commonly concentrated into densely-fossiliferous lenses.	Shoreface to inner shelf	*Dosinia, Zethalia, Fellaster*
S_4	Silty sandstone (C)	Non cemented non to sparsely fossiliferous massive to laminated well-sorted fine sandstone to silty sandstone.	Lower-inner to middle shelf	*Atrina, Maorimactra, Dosinia (Kereia), Patro*
S_5	Calcareous sandstone (S)	Non to well cemented non to sparsely fossiliferous slightly to moderately calcareous fine sandstone with prominent concretions and cemented horizons. May contain a noticeable bioclastic content.	Lower-inner to middle shelf	*Atrina*
S_6	Interbedded sandstone-siltstone (S)	Non to well cemented non to sparsely fossiliferous fine sandstone to sandy siltstone with common concretionary horizons and prominent sandstone and silstone interbeds.	Inner shelf	*Dosinia (Kereia), Atrina*
S_7	Sandstone with siltstone stringers (UC)	Non to well cemented fine sandstone to sandy siltstone with common mudstone stringers. Beds are faintly to strongly laminated.	Marginal-marine to sheltered nearshore	*Austrovenus, Patro*
S_8	Ripple and flaser-bedded sandstone (R)	Non to slightly fossiliferous ripple, flaser- and cross-bedded fine to medium sandstone with common interbeds and detached lenses of siltstone.	Estuarine	*Austrovenus*
S_9	Pebbly sandstone (S)	Non cemented, non to moderately fossiliferous massive to cross-stratified to laminated sandstone with common to abundant greywacke pebbles and conglomerate lenses.	Shoreface to nearshore	*Dosinia, Zethalia*
S_{10}	Concretionary sandstone (S)	Non to slightly cemented non- to sparsely-fossiliferous moderately to strongly laminated and cross-stratified fine to medium sandstone with common to abundant concretionary horizons.	Nearshore to inner shelf	*Atrina*
S_{11}	Sandstone with fossiliferous concretions (S)	Slightly to well cemented fine to medium sandstone with moderately to highly fossiliferous, moderately to well cemented concretionary bodies up to 1 m thick.	Nearshore to inner shelf	*Struthiolaria (Callusaria), Zeacolpus*
S_{12}	Laminated to convolutedly-bedded sandstone (R)	Strongly laminated to cross-stratified to convolutedly-bedded fine to medium sandstone bodies in a series of stacked packages up to 0.5 m thick. Contains common to abundant tephric sediments.	Inner shelf	Null
Siltstone				
Z_1	Massive siltstone (A)	Non fossiliferous, massive to weakly laminated non to slightly cemented siltstone. May contain concretions up to 1 m across.	Outer shelf to bathyal	None
Z_2	Fossiliferous siltstone (A)	Slightly to moderately fossiliferous, massive to laminated non cemented firm bioturbated siltstone.	Middle to outer shelf	*Pratulum, Neilo, Ostrea, Tawera-Patro, Talochlamys, Tegulorhynchia-Talochlamys*
Z_3	Fossiliferous sandy siltstone	Slightly to moderately fossiliferous massive to laminated bioturbated siltstone.	Lower-inner to middle shelf	*Atrina, Patro, Dosinia (Kereia), Stiracolpus-Talochlamys, Tawera-Patro*
Z_4	Siltstone with sandstone interbeds (UC)	Non to moderately fossiliferous, fine-grained siltstone with sandstone interbeds and stringers. Ripple and flaser-bedded units are common.	Estuarine	*Austrovenus*
Z_5	Pebbly siltstone (C)	Non cemented, slightly to moderately fossiliferous, slightly to moderately pebbly siltstone to sandy siltstone.	Inner to middle shelf	*Stiracolpus-Talochlamys, Ostrea, Neilo*
Z_6	Siltstone-sandstone couplets	Slightly to strongly laminated planar-bedded non cemented, fine to large-scale alternating fine siltstone/sandstone couplets.	Upper bathyal	None
Z_7	Channelised siltstone-sandstone couplets (S)	Strongly-laminated non cemented alternating fine-grained siltstone-sandstone couplets in large packages with sharp, highly erosional and channelised bases.	Upper bathyal	None
Z_8	Siltstone with tephra beds (S)	Non to slightly fossiliferous non cemented sandy siltstone to siltstone with prominent discrete tephra beds.	Middle to outer shelf	*Pratulum, Atrina, Talochlamys*
Z_9	Alternating siltstone-sandstone (C)	Alternating beds of non to slightly fossiliferous non cemented sandy siltstone interbedded with fine-grained well sorted non fossiliferous sandstone.	Inner to upper-middle shelf	*Dosinia (Kereia), Atrina*
Z_{10}	Siltstone with plant remains (R)	Non cemented fine grained grey brown laminated siltstone with some to abundant plant remains	Non- to marginal-marine	None
Z_{11}	Muddy shellbed (C)	Non to weakly cemented, massive siltstone to silty sandstone, matrix-dominated bed containing a concentration of molluscan macrofauna. May be noticeably pebbly in places. Inferred to occur above downlap surfaces.	Middle to outershelf	*Ostrea, Ostrea*-glycymerid

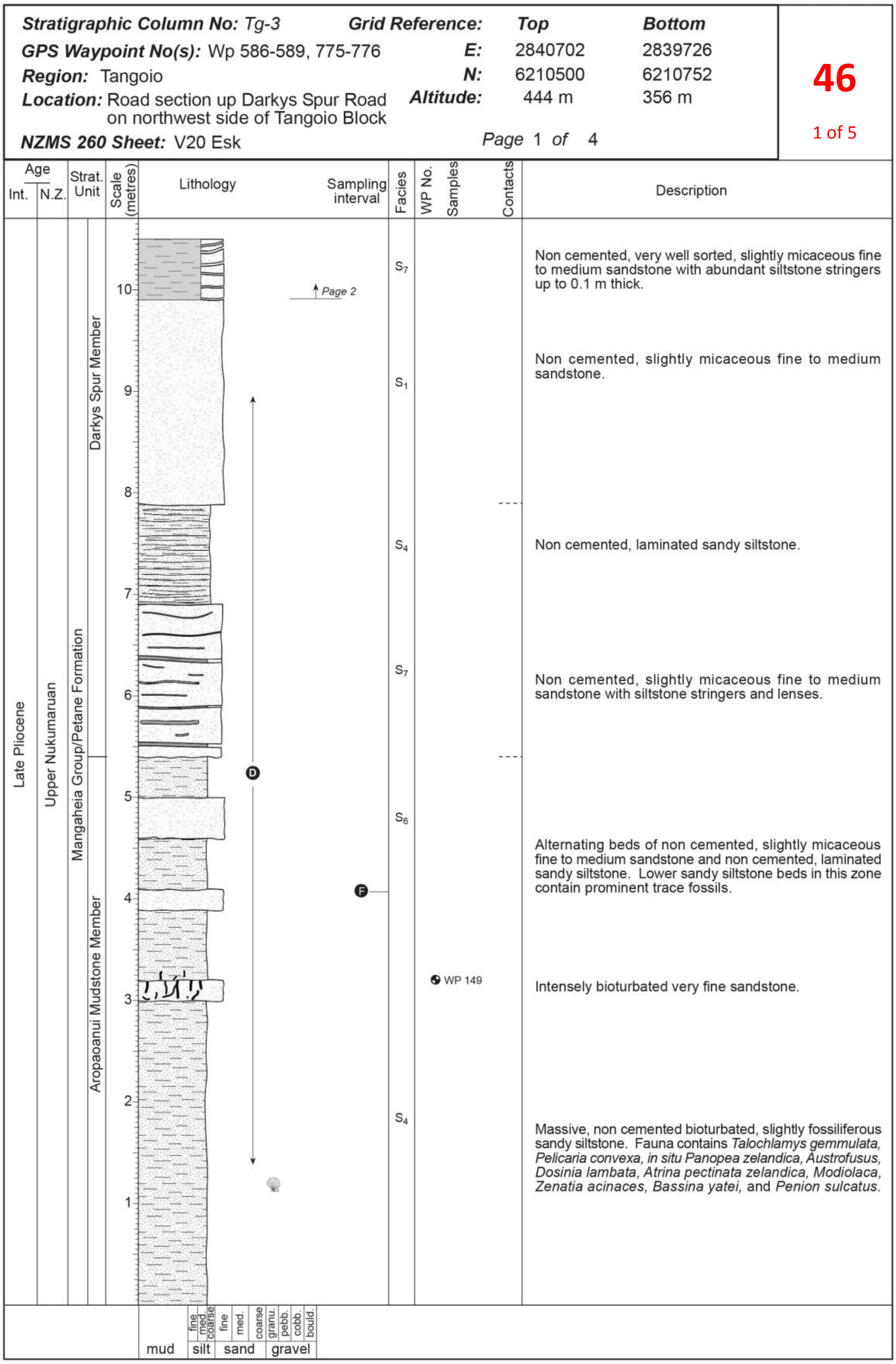

Fig. 5: Stratigraphic column No. 46 (1 of 5) (Kamp et al., 2007).

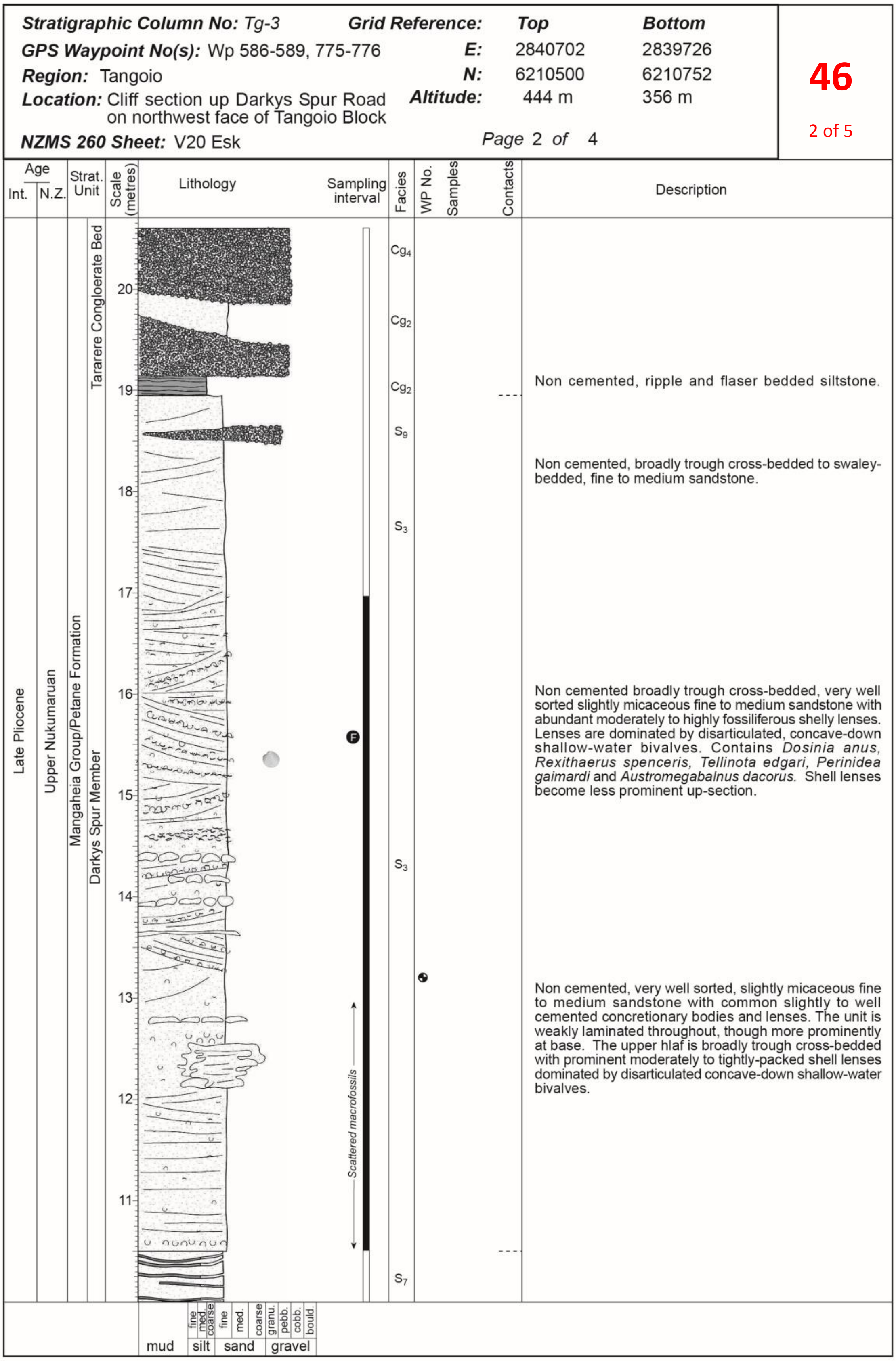

Fig. 5: Stratigraphic column No. 46 (2 of 5).

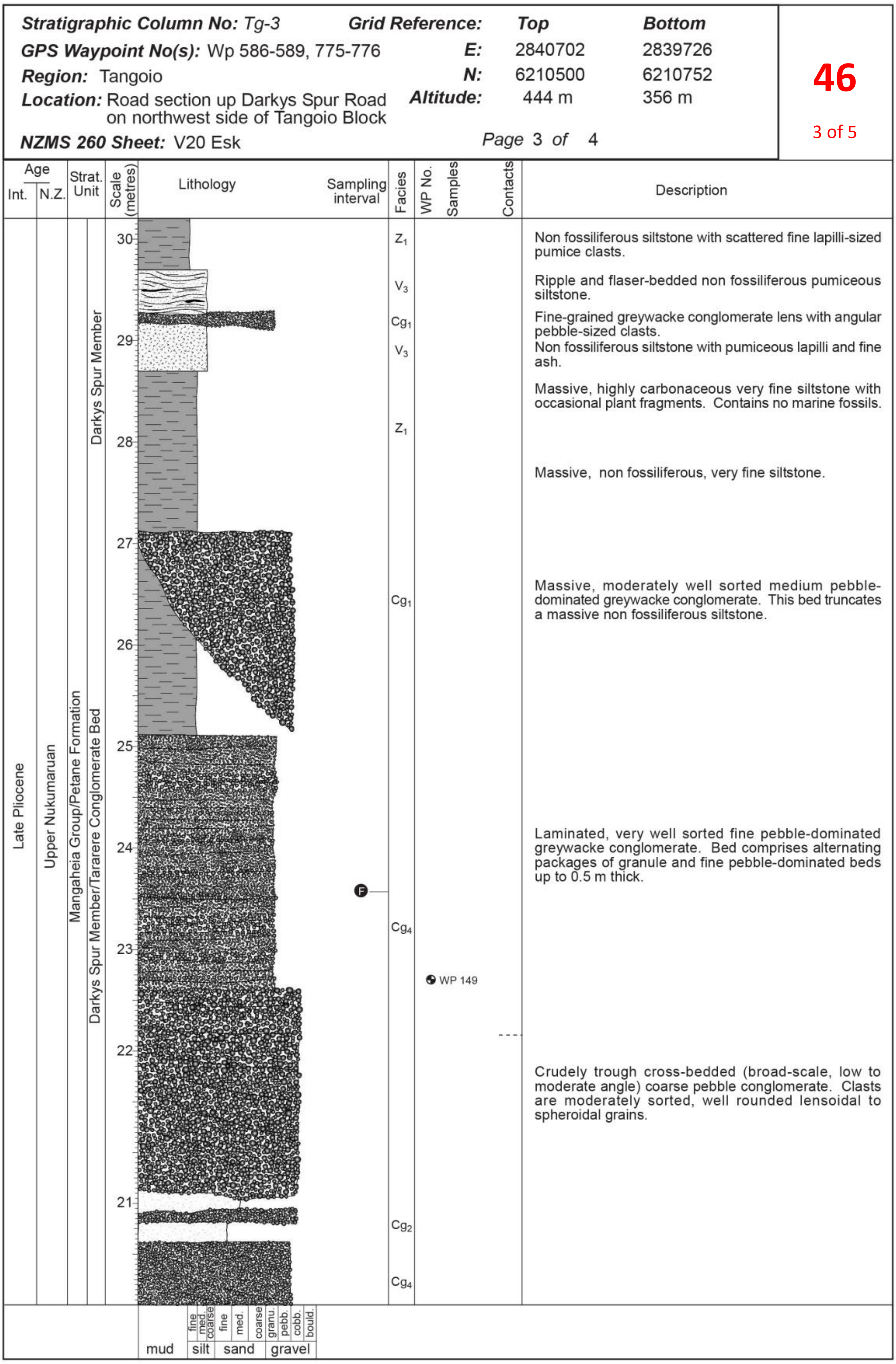

Fig. 5: Stratigraphic column No. 46 (3 of 5).

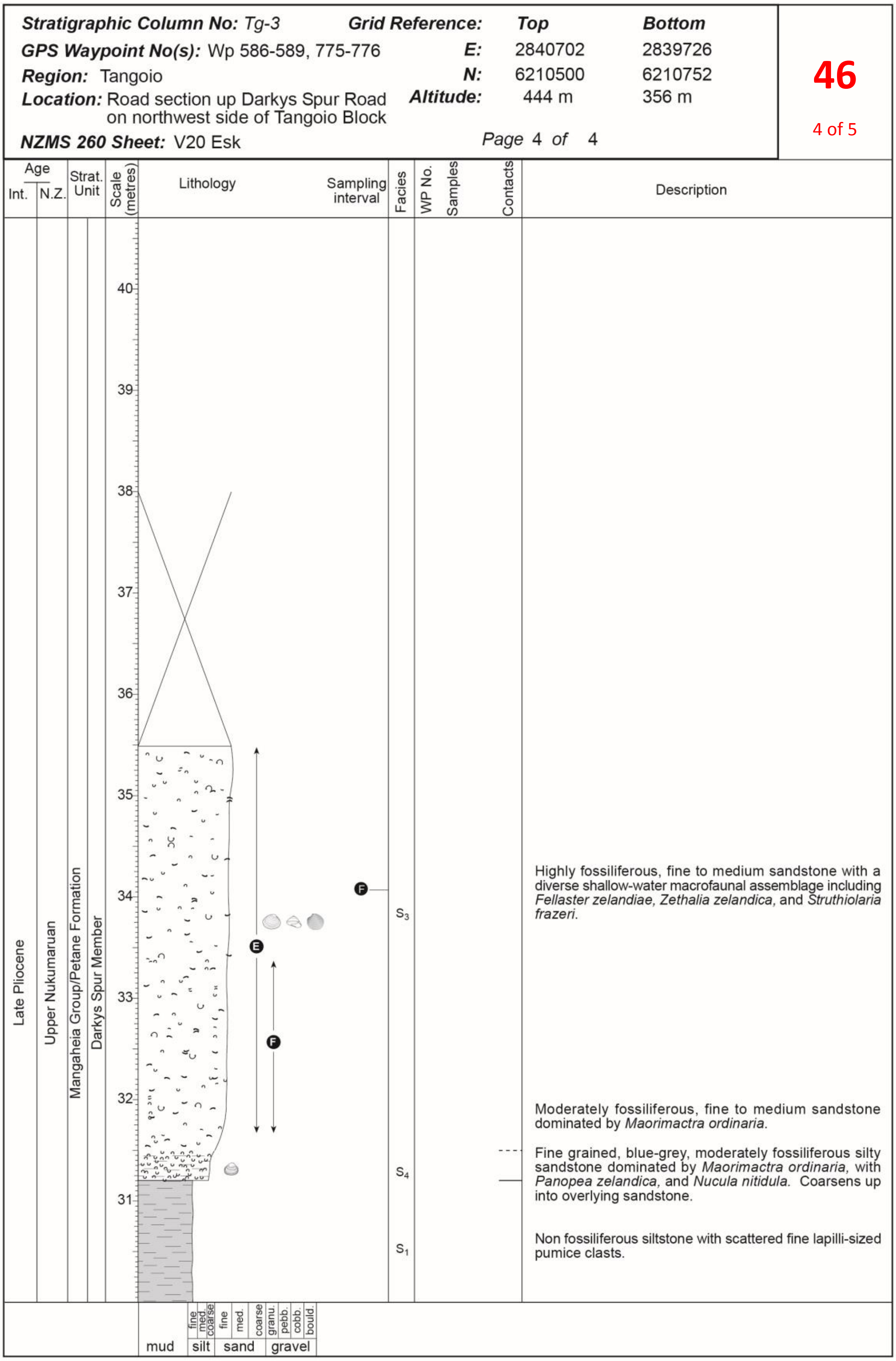

Fig. 5: Stratigraphic column No. 46 (4 of 5).

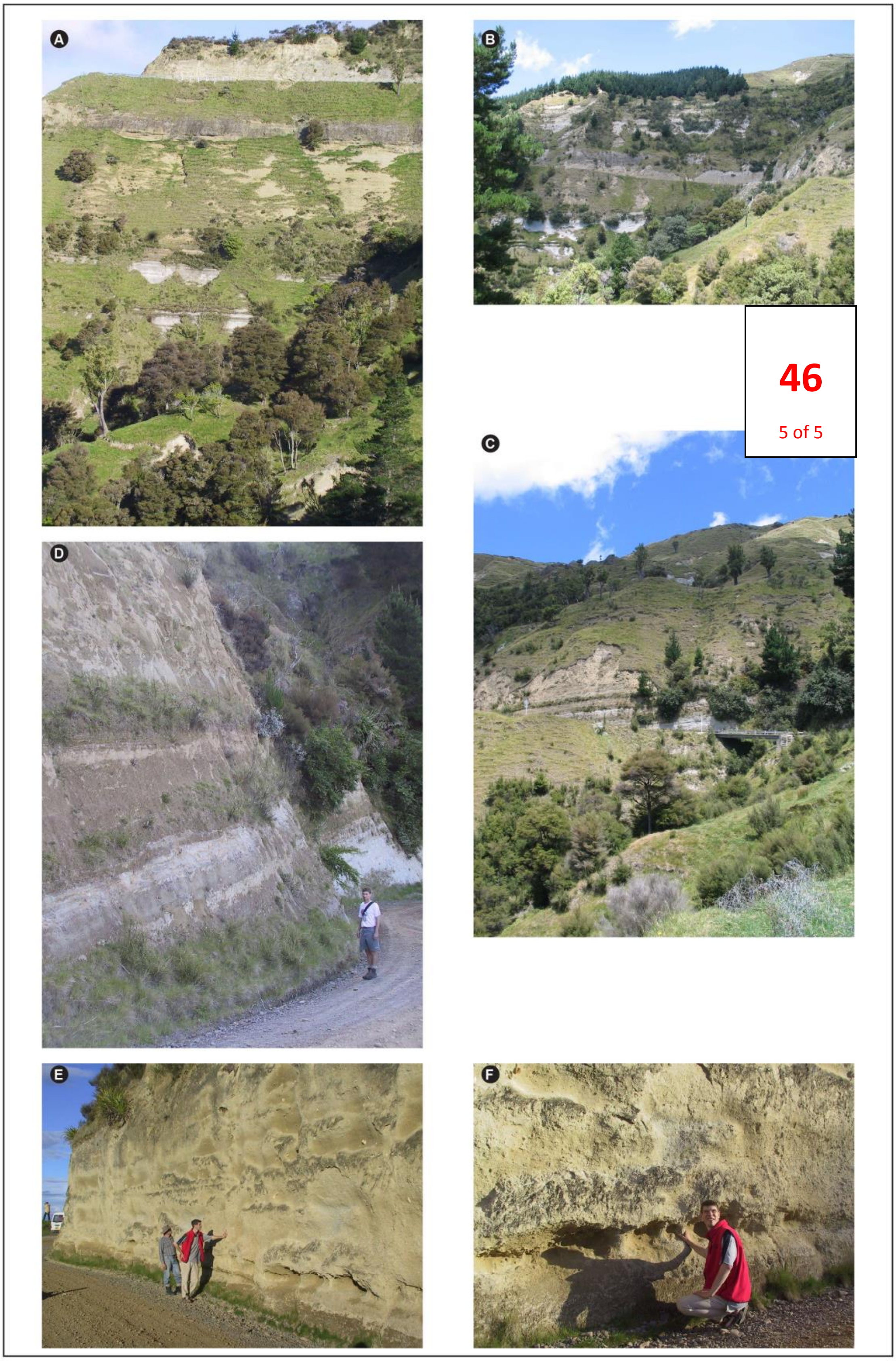

Fig. 5: Stratigraphic column No. 46 (5 of 5)—photos.

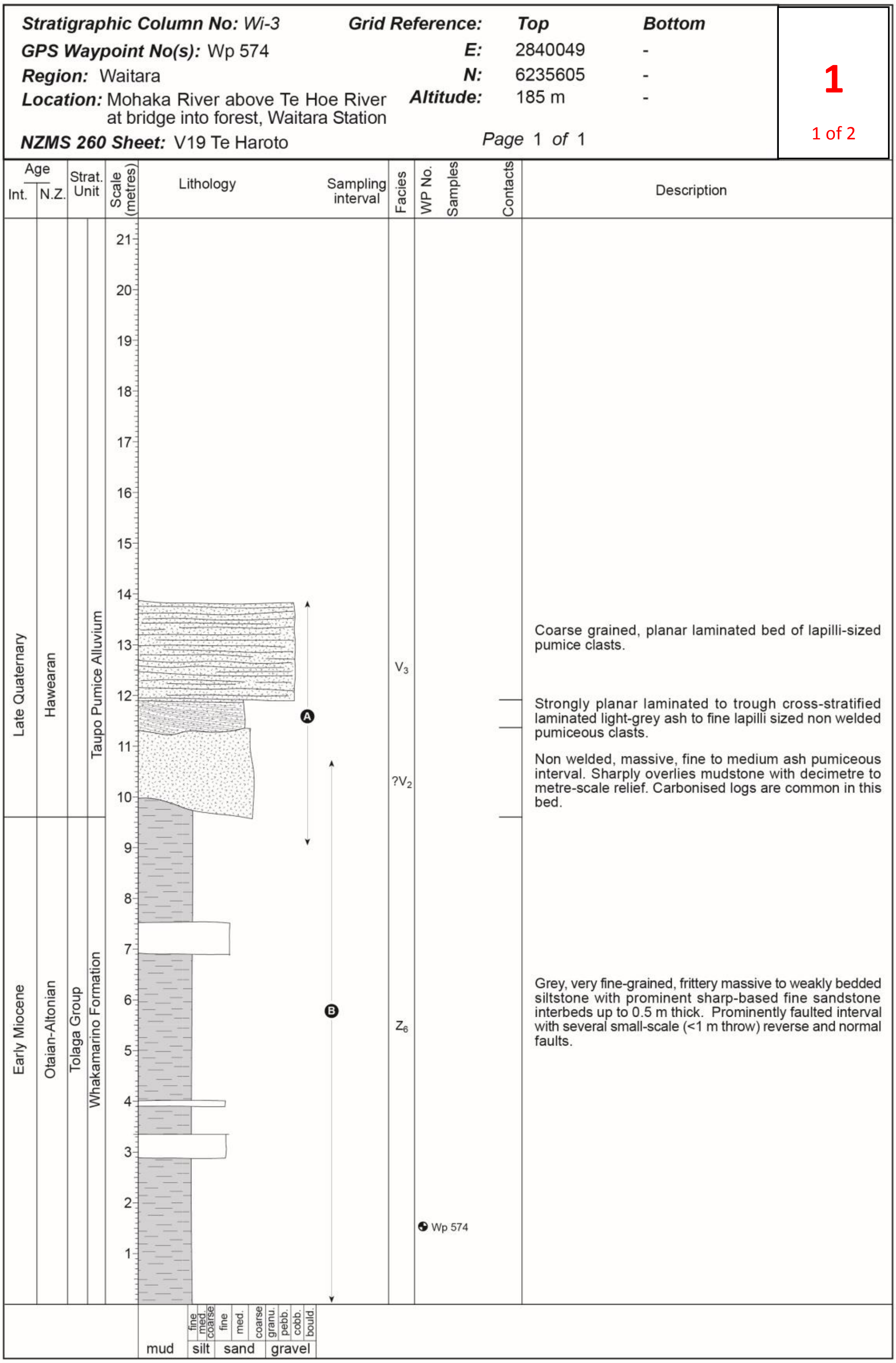

Fig. 6: Stratigraphic column No. 1 (1 of 2) (Kamp et al., 2007).

Fig. 6: Stratigraphic column No. 1 (2 of 2)—photos.

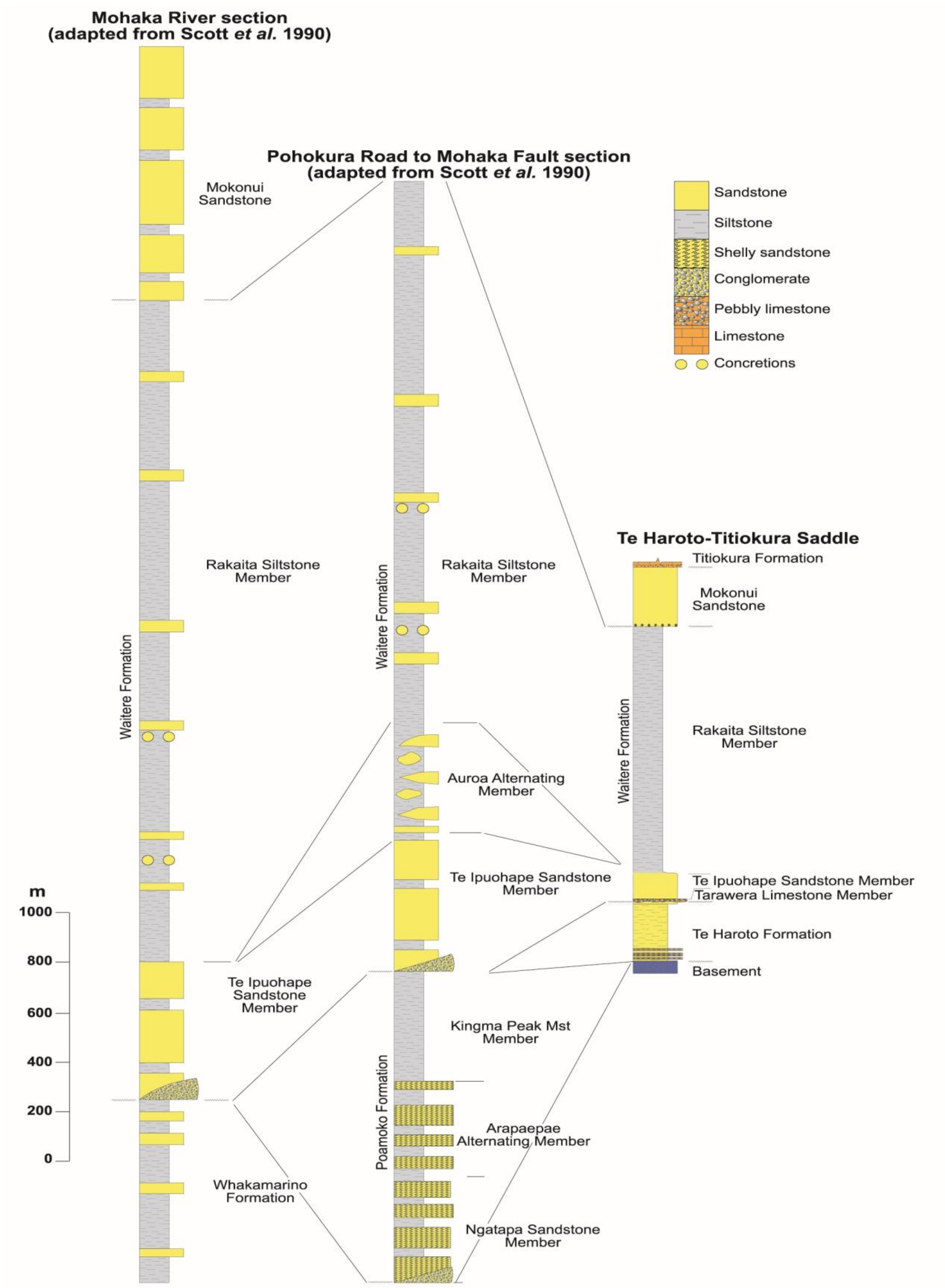

Fig. 7: Schematic stratigraphic columns illustrating the general stratigraphy of Tolaga Group rocks in the study area. Beds range in age from Otaian (early Miocene, Whakamarino Formation) to early Opoitian (early Pliocene, Mokonui Sandstone). Not how not all formations occur in all areas. The Waitere Formation and Mokonui Sandstone are the most widespread formations in the Tolaga Group (Bland and Kamp, 2014).

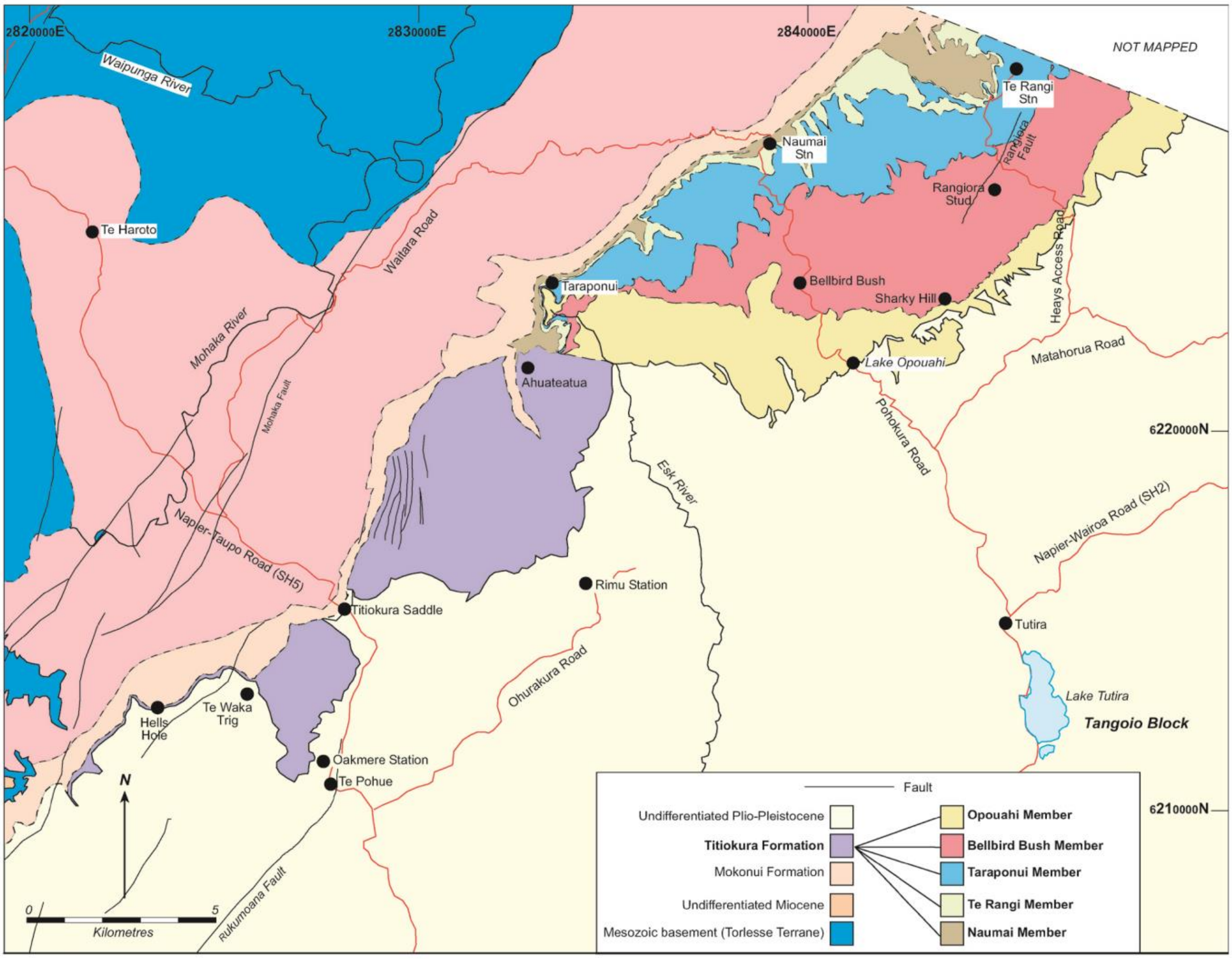

Fig. 8: Simplified geological map of part of the Hawke's Bay Monocline showing in particular the distribution of the Titiokura Formation and its constituent members (Bland, 2006).

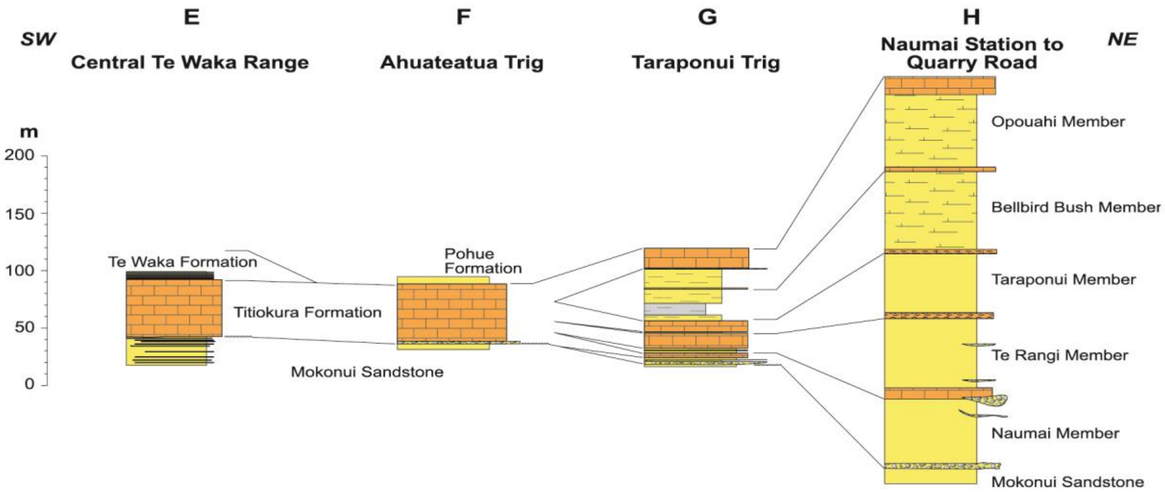

Fig. 9: Simplified stratigraphy of the Titiokura Formation and its constituent members along the crest of Te Waka Range and Maungapuru Range (Bland and Kamp, 2014).

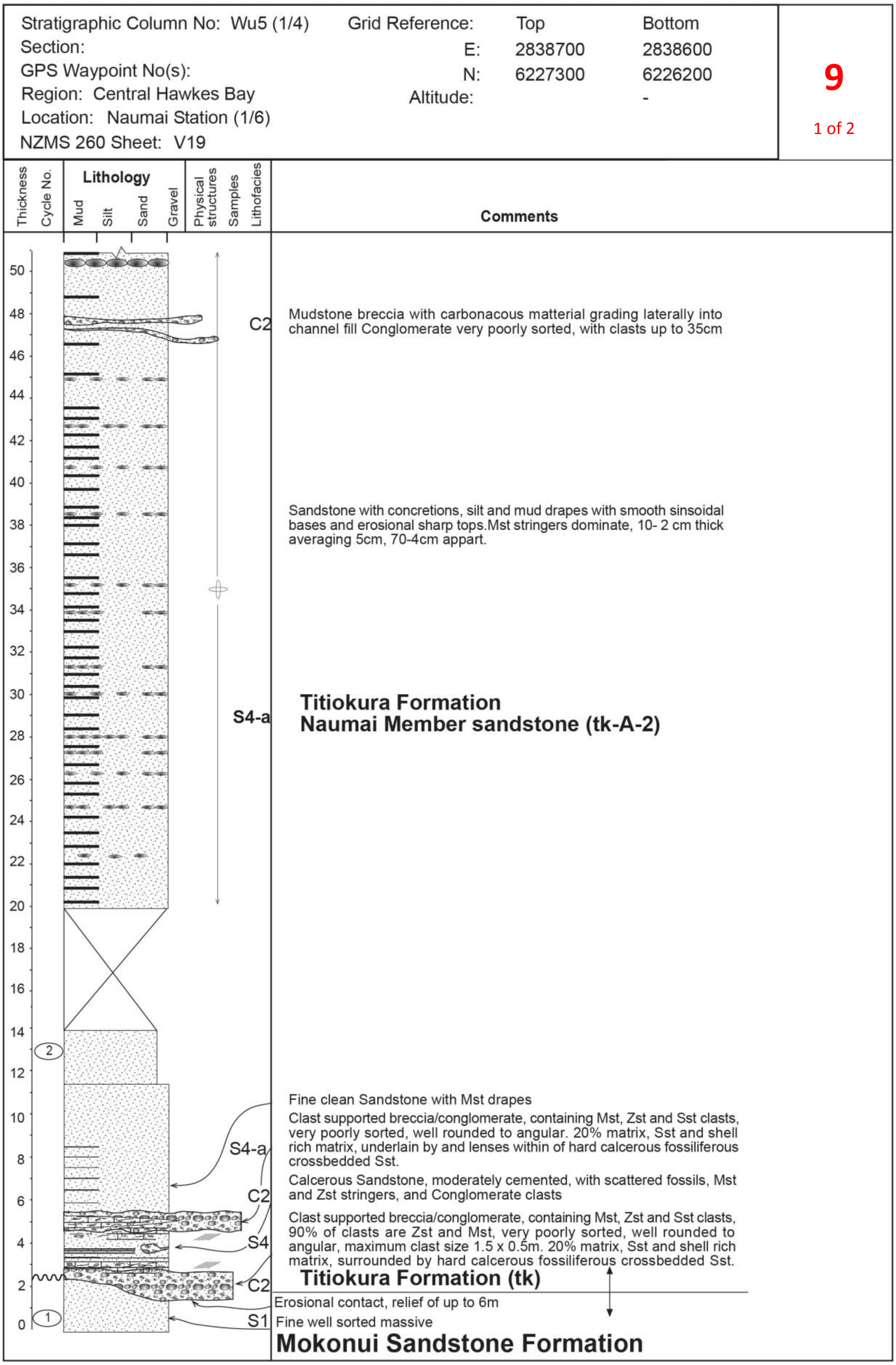

Fig. 10: Stratigraphic column No. 9 (1 of 2) (Kamp et al., 2007).

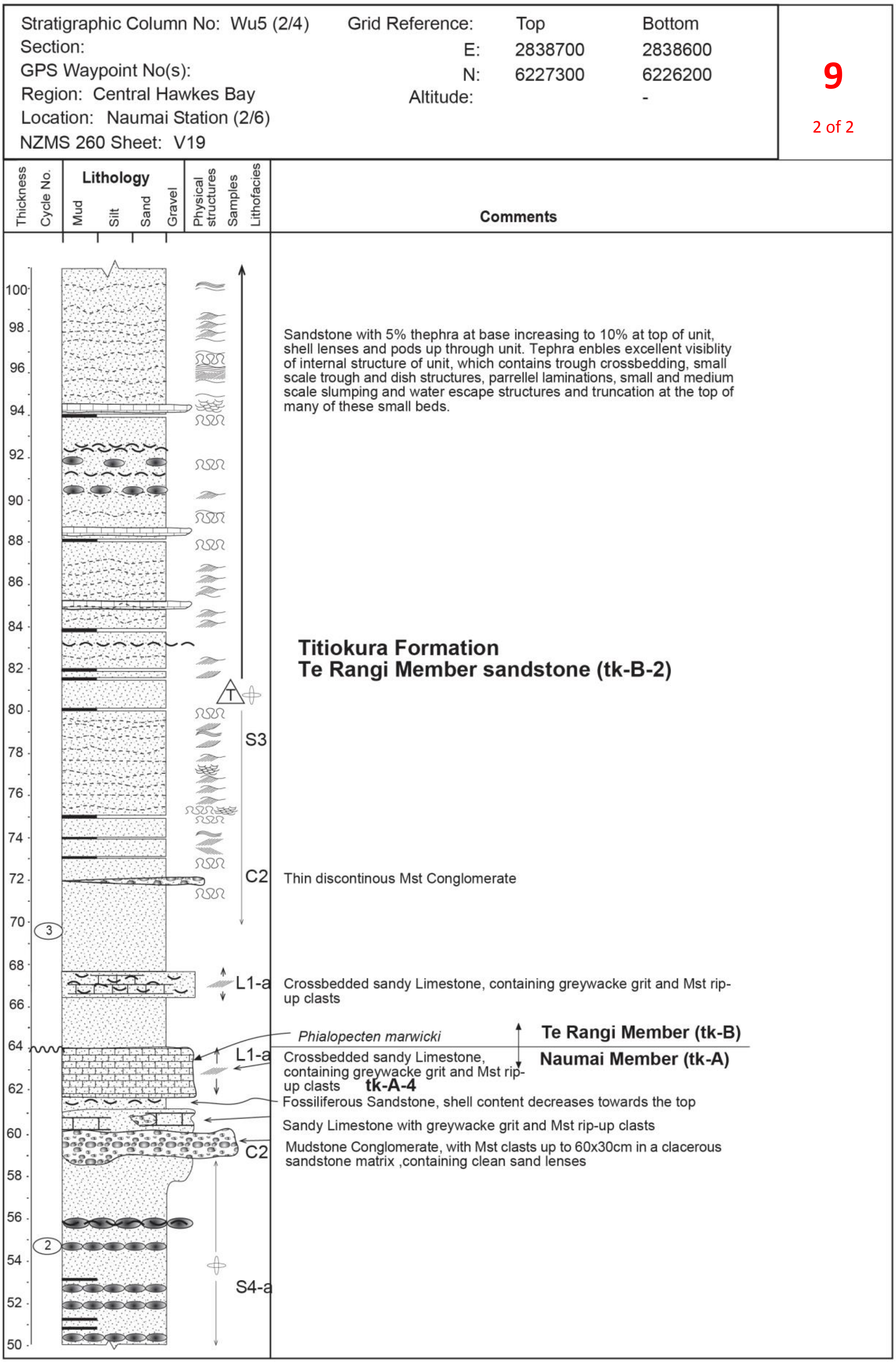

Fig. 10: Stratigraphic column No. 9 (2 of 2).

PART B

Geological context of the Hawke's Bay Monocline and Forearc Basin (text with figs 11–14)

Introduction

Hawke's Bay is a province in eastern North Island, New Zealand. The marine embayment is named Hawke Bay. Both lie within the Hikurangi margin, which is an ocean–continent subduction zone at the northern end of the New Zealand sector of the Australia–Pacific plate boundary zone (Fig. 11). Much of Hawke's Bay and the provinces to the north (Poverty Bay) and south (Wairarapa), are underlain by sedimentary successions of Neogene age that accumulated in a forearc position, either within the principal forearc basin, or accretionary slope basins above an accretionary wedge Lee et al. (2011) (Fig. 12). The forearc basin is best developed on land in Hawke's Bay between Wairoa and Dannevirke. South of Cape Kidnappers, Pliocene and Pleistocene strata that accumulated in the forearc basin dip northwest, having been uplifted since the late Pliocene by continuing deformation within the inboard part of the accretionary wedge (Caron et al., 2004a), whereas to the west, strata of the same age dip southeast off elevated Jurassic basement (e.g., Ruahine Range; Caron et al., 2004a; 2012). The name Hawke's Bay Monocline is attributed to the late Neogene sedimentary succession that dips southeast between Wairoa in the north and the Ngauroro River in central Hawke's Bay. It is likely that during the early and middle Miocene the basin had a NW–SE orientation rather than the present NE–SW structural grain (Kamp and Xu, 2002). The modern structural orientation of the forearc basin probably dates from the late Miocene (Tongaporutuan).

A succession of post-graduate research projects on the stratigraphy and structure of the forearc basin in Hawke's Bay have been completed by students at Waikato and Auckland universities over the past 40 years, following the 1971 publication of a Geological Survey bulletin by Kingma (1971). In his PhD thesis work, Kyle Bland (Bland 2006), mapped the central part of the forearc basin producing a series of new 1:50,000 scale geological maps, drawing upon previous maps where they existed. Subsurface information from exploration drill holes was also incorporated in that study. This work has been published in a series of New Zealand Petroleum and Minerals petroleum reports, available from its website (Bland and Kamp, 2014; Kamp and Bland, 2014). Stratigraphic columns drawn for central parts of the forearc basin by the succession of University of Waikato students have been compiled into a separate PR volume (Kamp et al., 2007).

Structural overview

The forearc basin is bounded to the east by the inboard part of an uplifted and semi-emergent accretionary wedge and on its western side by an elevated fault-bounded frontal ridge underlain by indurated Mesozoic basement (Field and Uruski, 1997; Lee et al., 2011) (Fig. 12).

The frontal basement ridge is marked on its eastern side by a zone of dip-slip and dextral oblique-slip faults collectively known as the North Island Shear Belt (NISB). The more major faults in this zone include the Ruahine and Mohaka faults, which align with the Wellington Fault to the south. A feature of the structure of the western margin of the forearc basin is the more easterly regional strike of the basin fill than the strike of the oblique-slip fault system, meaning that the faults truncate progressively younger parts of the succession southward and to a substantially greater degree (Fig. 12). Most of this deformation and associated uplift of the frontal ridge occurred during the Pleistocene, involving late Pliocene marine strata. On the eastern margin of the basin, the accretionary wedge developed during the late Miocene–Pleistocene (Pettinga, 1982), building that margin and enabling it to slowly migrate to the northwest, shown by offlap of successive Waipipian–Nukumaruan limestone sheets (Kamp et al., 1988; Caron, 2002).

Hawke's Bay Monocline: Cross-section A-A' (Fig. 13)

A north–south cross-section (Fig. 13) shows a strongly developed monoclonal fold striking NE–SW and dipping to the southeast, involving the late Miocene–early Pleistocene fill of the Hawke's Bay Forearc Basin. Early and middle Miocene formations occur beneath Tongaporutuan (late Miocene) beds in the vicinity of the confluence of the Te Hoe and Mohaka rivers and they show variable degrees of deformation (Cutten, 1994). The choice of the cross-section line (Fig. 14) avoids that structural complexity. The late Miocene–early Pleistocene succession is broadly conformable, but the dip decreases up-section from about 10° to a few degrees. This is indicative of syn-sedimentary tilting near the western basin margin, most of this occurring since the late Opoitian. Dips steepen locally across the Rangiora Fault. Within the Tangoio Block, the dips in shelf marine beds are only a few degrees SE, indicating that the contemporary highstand shoreline must have lain east of Maungaharuru Range during the late Pliocene.

Faults

The distribution of faults within and marginal to the forearc basin are shown in red in Fig. 14 where they are regarded as active faults. For a detailed description of each of these faults (and folds) readers are referred to Kamp and Bland (2014). Within the axial range, the main faults (Wellington, Ruahine, Mohaka and Whakatane) (Fig. 14) are oblique-slip faults, have active traces, strike for 400–500 km in a NNE–SSW direction (030°) (Beanland and Haines, 1998) and represent seismic hazard for the region.

The Ruahine Fault and Mohaka Fault are the most significant faults in the map area in terms of lateral continuity and offset, and along parts of them they mark a geological boundary at the surface between basement and Neogene cover strata. The generally straight trace of Ruahine Fault indicates that it has a steeply dipping fault plane (Browne, 1981; Beanland, 1995). The vertical offset on these faults is probably less than the strike-slip displacement, although the cumulative amount of the horizontal component of offset is difficult to measure (Erdman and Kelsey, 1992; Kelsey et al., 1993) and is probably less than 10 km based on stratigraphy of units either side of the Ruahine and Mohaka faults (Kamp and Bland, 2014). For the Ruahine Fault the ratio of horizontal to vertical offset is estimated at 2.1:1 and for Mohaka Fault in the Ohara Depression it ranges between >1:1 to 8:1 (Erdman and Kelsey 1992).

Rangiora Fault (Fig. 14) lies within the Hawke's Bay Monocline. It is a 14 km-long structure located about 40 km north of Napier and 13 km east of Mohaka Fault. A 5 km-long late Quaternary trace occurs along the central section of this fault at Rangiora Station near Waikare River. This fault was mapped by Grindley (1960), Cutten et al. (1998), Francis (1991) and Graafhuis (2001). The fault strikes 030°, oblique to the strike (055°) of the late Pliocene beds it displaces. The linear trace of the fault changes in the sense of vertical offset along the fault suggesting that the fault plane has a steep but variable dip (Cutten et al., 1998). Total vertical offset on the fault is unknown, but is likely to be less than a few tens of metres (Cutten et al., 1998; Graafhuis, 2001). At the northern end of the fault trace at Waikare River, Cutten (1994) reported a series of river terraces to be dextrally offset with progressive displacements of 5–15 m. Cutten et al. (1998) inferred three events each involving 4 to 6 m right lateral displacement, with one event occurring between 3,300 and 1,900 years ago and two during the last 1,900 years. Rangiora Fault is inferred to have had an average late Holocene slip rate of 4.5 mm/yr (Cutten et al., 1998), comparable to that of Mohaka and Ruahine faults.

Sedimentary fill of the basin

The sedimentary fill exposed in the Hawke's Bay Monocline comprises a late Miocene to early Pleistocene (~10–1.7 Ma) asymmetric 4th order sequence of about 2500 m thickness (Fig. 13). Early Miocene Whakamarino Formation and middle Miocene (Pomako Formation) are regarded here as part of a forearc basin that probably had a different architecture and structural orientation to the present forearc basin (Kamp and Xu, 2002). Early Tongaporutuan sandstone beds (Waitere Formation, Te Ipuohape Sandstone Member) about 300 m thick, onlap a surface cut across Whakamarino and Pomako formations, as well as basement. The Te Ipuohape Sandstone Mb is overlain by a thick (2000 m) progradational succession that represents the migration of a continental slope and shelf wedge (upper Waitere Formation and Mokonui Formation). Farther north in the Wairoa area, the basin probably contains a late Neogene fill of up to 5 km thickness (Field and Uruski, 1997). As noted above, the basin fill is progressively truncated to the south by the Mohaka and Ruahine faults (Fig. 12).

Neogene sediments onlap basement progressively to the south along the western basin margin (Bland and Kamp, 2014). The southern limit of onlap of early Tongaporutuan (late Miocene) sediments occurs in the vicinity of the Napier–Taupo Highway. The youngest and most southern beds onlapping basement are of Nukumaruan (late Pliocene) age and do so in the vicinity of Ohara Depression adjacent to the northern Ruahine Range. This southward onlap onto basement indicates the direction of forearc basin subsidence and development (Kamp 1999).

In general, the basin contains a mixed carbonate–siliciclastic succession, although the lower parts of the basin fill are virtually exclusively siliciclastic, except for the Tarawera Limestone Member in Waitere Formation, which is a TST shellbed associated with an early phase of basin subsidence and marine onlap (Bland and Kamp, 2014). Large volumes of terrigenous sediment in the Hawke's Bay Monocline are tied-up in the Tongaporutuan–Kapitean progradational shelf–slope wedge described above. Carbonate sediments first appear in any volume in the Titiokura Formation of late Opoitian and early Waipipian age. Five sequences in Titiokura Formation at Pohokura Saddle and the area to the north are regarded as 41,000-year cyclothems, albeit that they are thick and sandstone-dominated (Bland et al., 2004) and hence architecturally different from the classic Whanganui Basin shelf sequences (Naish and Kamp, 1997).

About 1000 m stratigraphic thickness of shelf sediments accumulated in the forearc basin and are involved in the Hawke's Bay Monocline from the base of Titiokura Formation to the top of the Petane Formation. The details of the stratigraphic nomenclature of the various units mapped in Central Hawke's Bay within this succession are detailed in Figs 2 and 3. The Waipipian and Mangapanian units stratigraphically above Titiokura Formation are siliciclastic, including four cyclothems containing conglomerate facies as regressive systems tracts. Limestone beds, probably better described as shellbeds, reappear in the upper part of the Pliocene and earliest Pleistocene succession (Petane Formation; Haywick, 1990; Haywick et al., 1991; Bland and Kamp, 2014). This could be due to a decreasing influx of siliciclastic sediment to axial parts of the forearc basin.

Chronology

Dating of the forearc basin fill has necessarily appealed to an established biostratigraphy for the basin based on foraminiferal and macrofossil datums (Scott et al., 1990; Beu, 1995). For mapping and correlation of Pliocene units across central parts of the basin, often involving beds having different facies, we have necessarily focused upon key datums. A key stratigraphic marker is the first occurrence of *Phialopecten triphooki*, a pectinid associated with the base of the Nukumaruan Stage (late Pliocene) at ~2.4 Ma. In Ohara Depression and the Kuripapango area, early Nukumaruan rocks contain *Zygochlamys delicatula* (Browne, 1981; Beu et al., 1981), which is a cold-water scallop that has traditionally been used to define the base of the Nukumaruan in Whanganui Basin (Fleming, 1953). Other important age diagnostic species identified include the bivalves *Sectipecten* *wollastoni* (Kapitean), *Phialopecten marwicki* (Opoitian–Waipipian), *Mesopeplum crawfordi (*Opoitian–Waipipian), *Phialopecten thomsoni* (Mangapanian) and *Sectipecten mariae* (base Nukumaruan), and the gastropods *Struthiolaria dolorosea* (Opoitian) and *Pelicaria convexa* (Nukumaruan) (Beu, 1995).

One paleomagnetic datum, the top of the Olduvai Subchron (1.77 Ma) has been identified in the Devils Elbow Mudstone Member of Petane Formation by Kamp and Turner (unpublished).

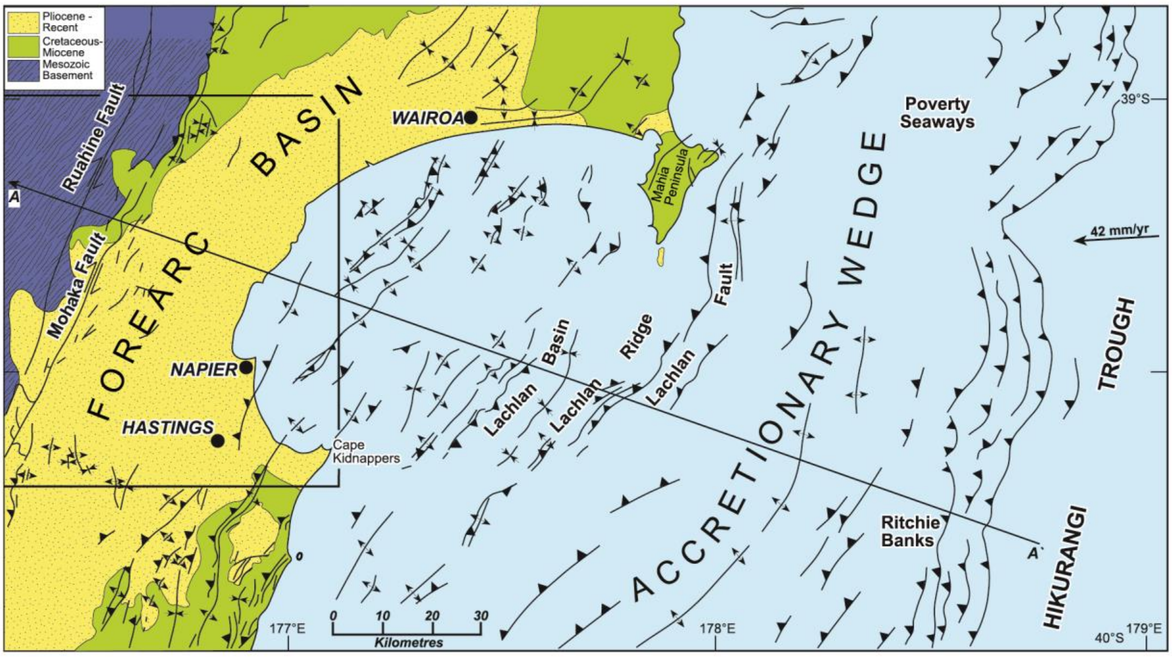

Fig. 11: Structural setting of the Hawke's Bay Forearc Basin from Bland and Kamp (2014), with structure offshore adapted from Barnes et al. (2002).

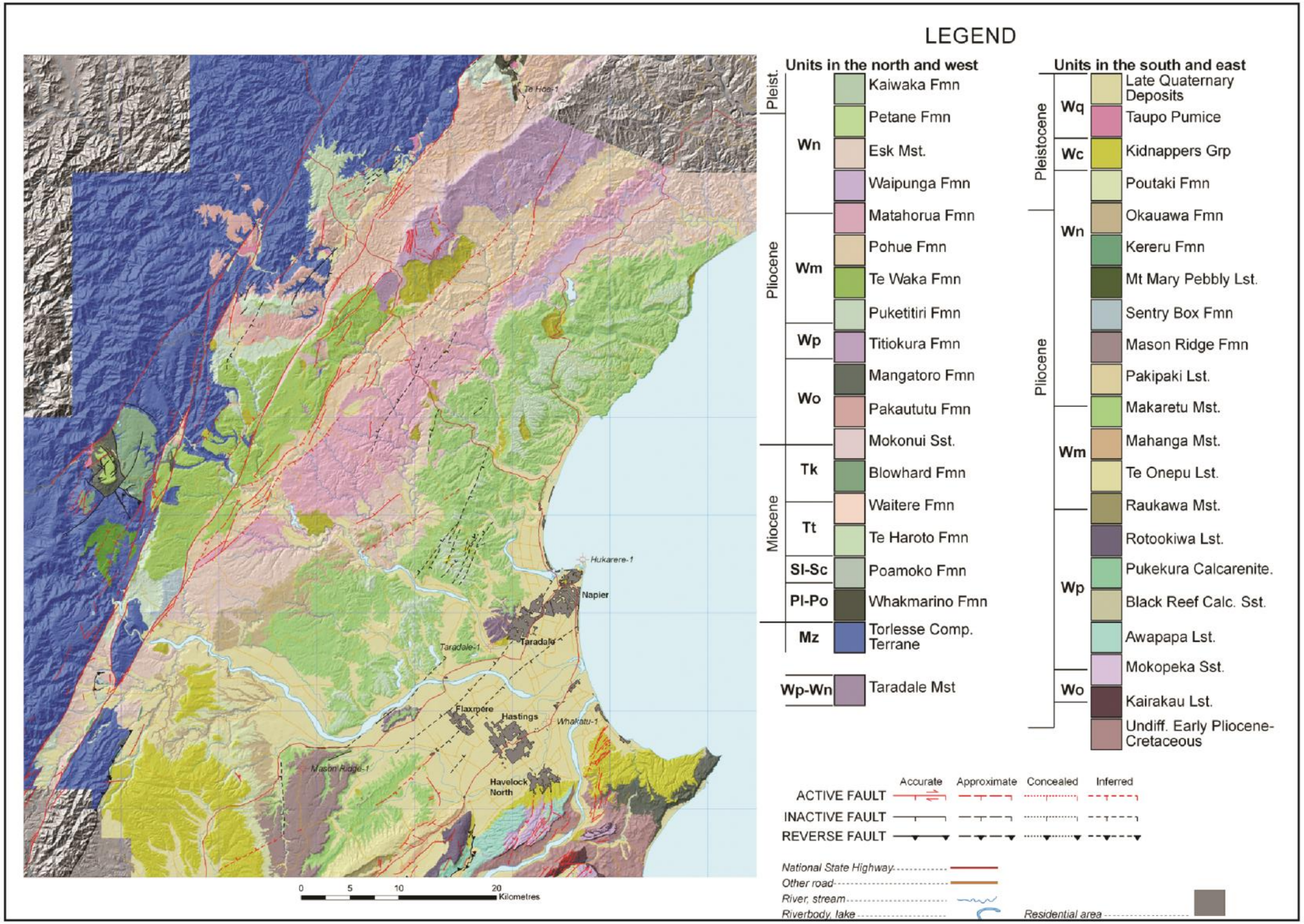

Fig. 12: Geological map of central Hawke's Bay (Bland, 2006).

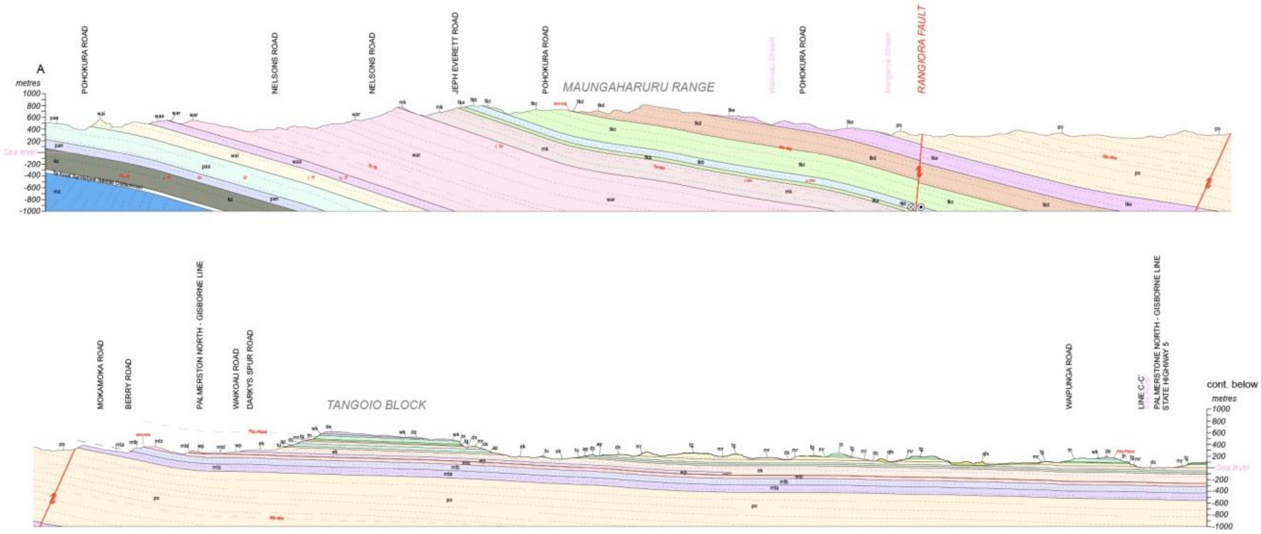

Fig. 13: Geological cross-section of the Hawke's Bay Monocline, north of Napier (Kamp and Bland, 2014).

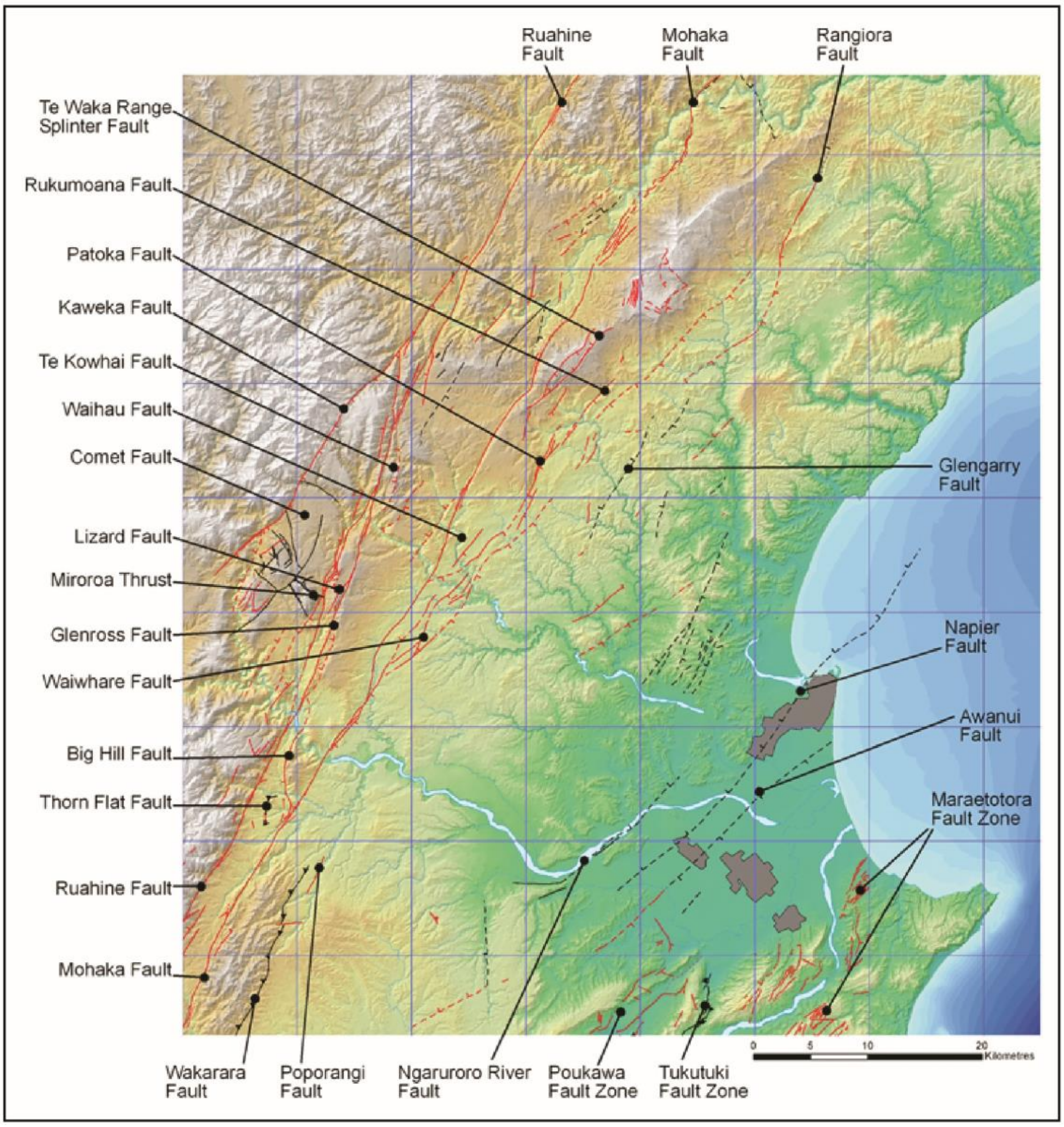

Fig. 14: Location and names of faults in Central Hawke's Bay (Kamp and Bland, 2014).

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