Rapid progradation of the Pliocene-Pleistocene continental margin, northern Taranaki Basin, New Zealand, and implications

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Abstract

Progradation and aggradation of the modern continental margin in northern Taranaki Basin has resulted in the deposition of a thick and rapidly accumulated Pliocene-Pleistocene sedimentary succession. It includes the predominantly muddy Giant Foresets Formation, and the underlying sandy Mangaa Formation. Investigation of the internal attributes and depositional systems associated with the Giant Foresets Formation suggests that it would provide very little effective reservoir for hydrocarbon accumulations, although it does provide essential seal and overburden properties. While the sand-dominated Mangaa Formation could be a hydrocarbon reservoir, drilling so far has yet to reveal any significant hydrocarbon shows. Undoubtedly the most significant contribution that the Giant Foresets and Mangaa Formations have had on petroleum systems in northern Taranaki Basin is the cumulative effect that rapid and substantial accumulation has had on maturation and migration of hydrocarbons in the underlying formations.

Palinspastic restoration of a seismic reflection profile across the Northern Graben, together with isopach mapping of stratigraphic section for biostratigraphic stages, indicates that the thickest part of the Pliocene-Pleistocene succession is along the central axis of the Northern Graben. Deposition of this succession contributed substantially to subsidence within the graben, providing further accommodation for sediment accumulation. Isopach and structure contour maps also reveal the extent to which submarine volcanic massifs were exposed along the axis of the graben and the timing of movement on major faults.

Introduction

Kora-1 in northern Taranaki Basin encountered sub-commercial quantities of hydrocarbons contained in the Kora volcano (Mohakatino Formation), and several others wells (e.g.Tangaroa-1 and Turi-1) have recorded significant shows. Hence prior studies (e.g. Bergman et al. 1992, Thrasher et al. 2002) suggest that the potential exists for substantial accumulations of hydrocarbons within the Northern Graben, northern Taranaki Basin (Fig. 1), with the most prospective reservoirs considered to be deeply buried volcanic sequences of the Mohakatino Formation along the axis of the graben. In addition, Bennett et al. (1992) have argued that the overburden required for source rocks to reach expulsion maturity in this part of the basin has only been achieved during the past 5 million years, and probably the past one to two million years following final phases of deposition of the Giant Foresets Formation.

The Pliocene and Pleistocene sedimentary section encountered in northern Taranaki Basin, and in particular, the Northern Graben is extremely thick (>2000 m). It comprises the sand-dominated Mangaa Formation in the axis of the Northern Graben, and the mud- and silt-dominated Giant Foresets Formation beneath the modern shelf and slope, which has prograded across the Northern Graben and the Western Stable Platform. Although the Mangaa Formation has been the target of several exploration efforts (e.g. Forder and Sissons 1992, Murray and de Bock 1996), the Giant Foresets Formation has never held any real exploration interest for petroleum companies. However, McAlpine (2000) suggested that the extreme thickness and rapid deposition of the Giant Foresets Formation to the west of the Maui Field has both contributed to the earlier-than-expected maturation of hydrocarbons in underlying petroleum systems, and to an extent controlled the hydrocarbon migration pathways. Furthermore, the thickness and muddy lithology of the Giant Foresets Formation provides effective seal properties. For these reasons it is important to better understand the character and evolution of the Mangaa and Giant Foresets Formations as part of a basin analysis, as their accumulation and the evolution of the basin during their deposition will have had some control on the petroleum systems developed at depth in older

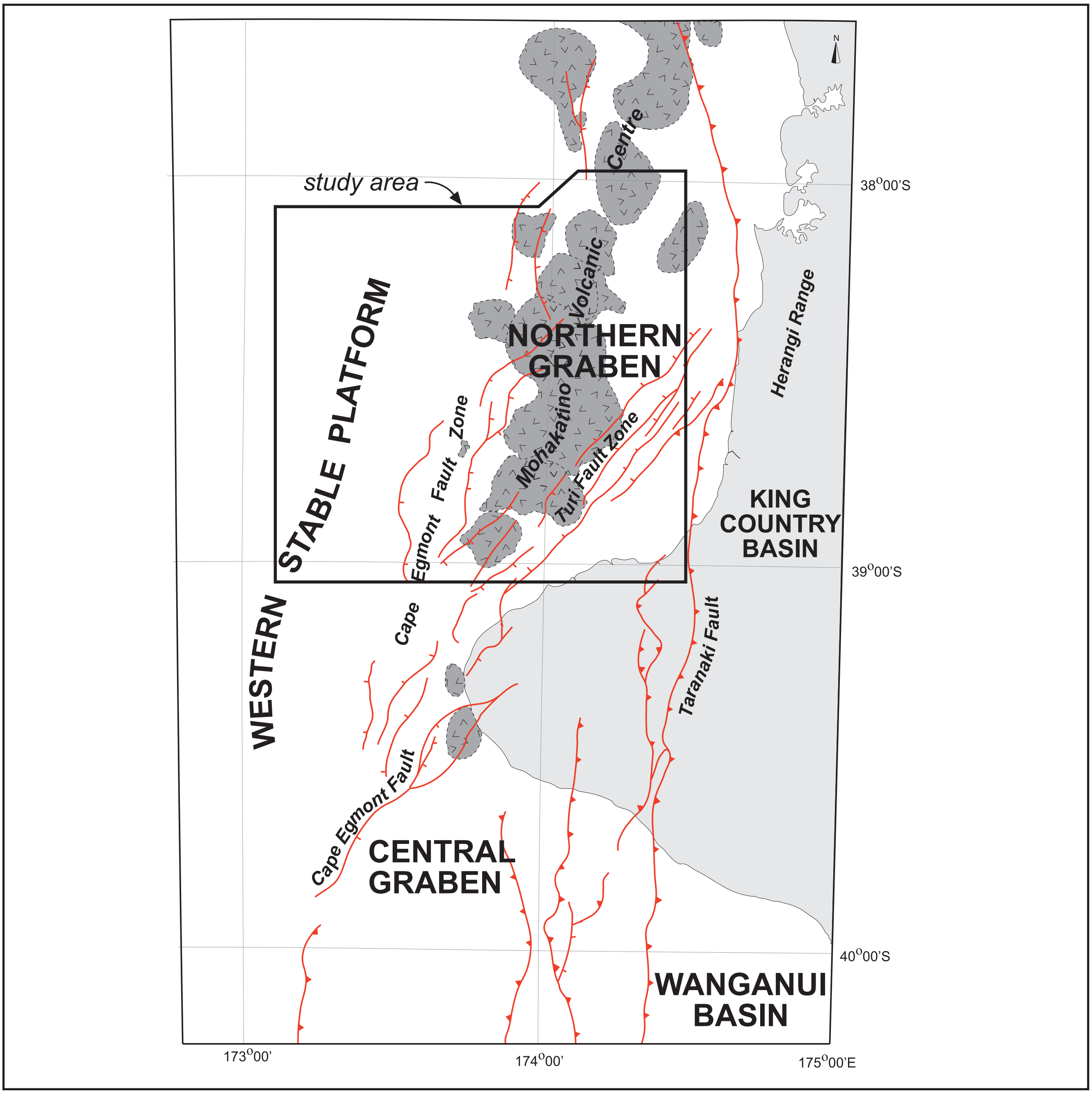


Figure 1: Structural domains and principal tectonic features, Taranaki Basin (after King et al. 1993; King and Thrasher 1996). Major volcanic centres after Thrasher et al. 2002).

formations. This paper is intended to provide a brief overview of the depositional geometry and sedimentation patterns of the Mangaa Formation and Giant Foresets Formation. This information may be useful in constraining modeling of hydrocarbon maturation and migration in northern Taranaki Basin.

Depositional geometry of the Pliocene and Pleistocene succession

More than seventy seismic units, based on distinctive internal reflector configurations, have been identified and mapped within the study area (Fig.2). These have been mapped over a seismic grid covering the study area, and isopach maps have been prepared for broad divisions based on biostratigraphic stages. The successive isopach maps illustrate broad changes in depositional patterns and geometry through time (Figs. 3a-3d). Opoitian (5.2-3.5 Ma; Fig. 3a) parts of the Giant Foresets Formation were initially limited in extent, and involved prograded into northern Taranaki Basin as a series of lobate slope fans (Soenander 1992). Concurrently, thick sandstone-dominated units (Mangaa Formation) accumulated in the Northern Graben. The prominence of volcanic massifs (Mohakatino Volcanic Centre, Fig. 1), some being exposed along the central axis of the graben into the Late Opoitian, affected the depositional patterns. During the Waipipian (3.5-2.79 Ma) to Mangapanian (2.79-2.28 Ma) (Fig. 3b), depositional patterns were affected by the structural control of continuing extension of the Northern Graben; some volcanic massifs

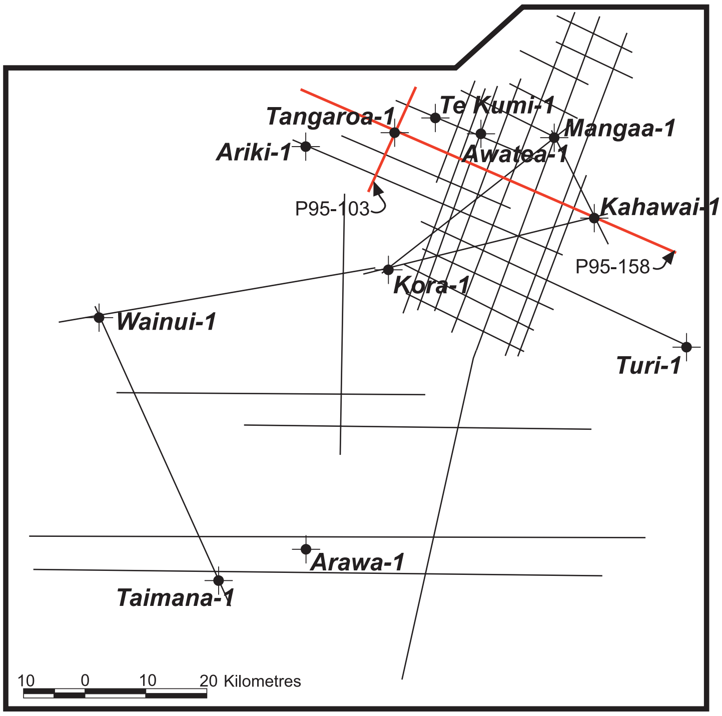


Figure 2: Location map illustrating the approximate extent of the area covered by this study, key well sections, and the seismic grid used. Seismic reflection profiles P95-158 (Fig. 4) and P95-103 (Fig. 5) are highlighted.

may have exerted some continuing paleogeographic influence upon sedimentation. By the Early Nukumaruan (2.28-1.8 Ma; Fig. 3c), a linear depositional front was developing, but with some structural control still exerted by the graben extension. By the Late Nukumaruan (1.8-0.33 Ma; Fig. 3d), deposition was strongly aligned along a SW-NE front (slope), with graben subsidence having minimal influence on sedimentation.

Palinspastic reconstruction

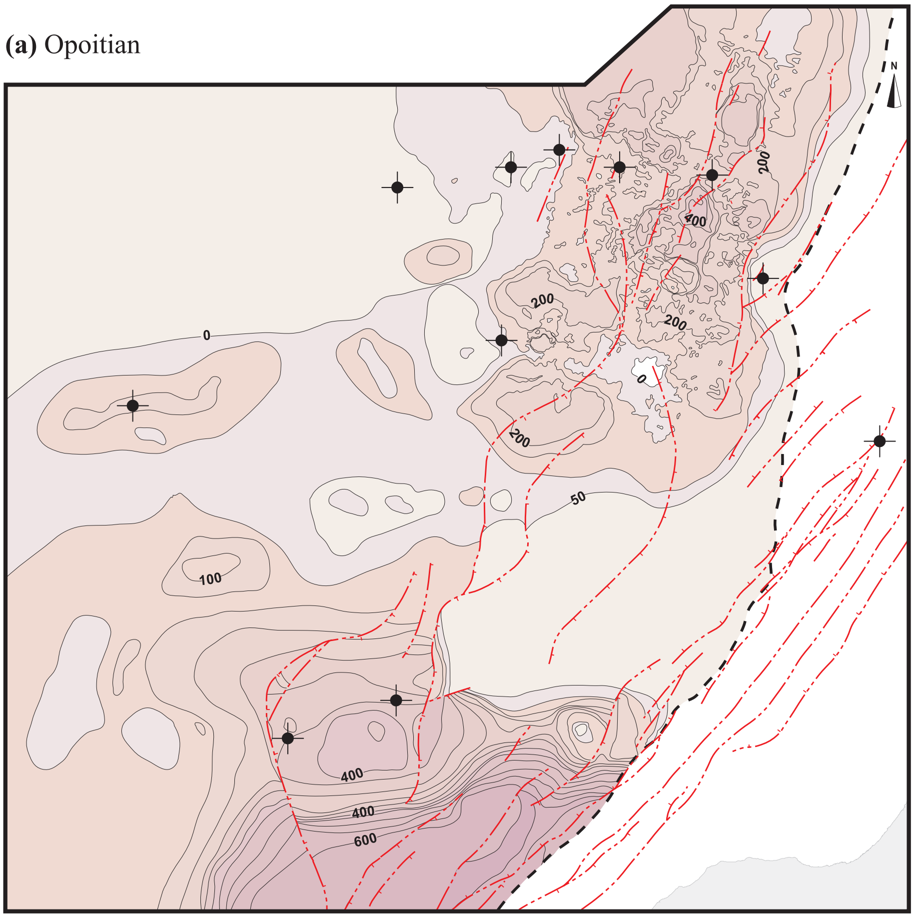
A two-dimensional excel-based backstripping programme was used to undertake backstripping and decompaction of the post-Miocene section of seismic reflection line P95-158 (see Fig.2 for transect location). Input parameters for the palinspastic restoration of this section included paleo-bathymetry, established from foraminiferal analysis of intersecting wells Tangaroa-1 and Kahawai-1, lithology (combined porosity and compaction coefficient values), and the thickness of each interpreted seismic unit encountered on the profile. All depths in TWT for seismic units were converted to depths in metres, and lithologies were established from wireline and lithological data. Figure 4 displays some of the steps in backstripping and decompaction that sequentially restored the palinspastic position of depositional surfaces at intervals through the Late Opoitian to Recent. The palinspastic restoration shows asymmetrical development of the Northern Graben, which began to form in the Late Miocene as a result of extensional tectonics (King and Thrasher 1996), and the control this graben extension exerted on patterns of sediment distribution in northern Taranaki Basin. The thickest succession occurs on the eastern margin of the graben. By the mid to Late Opoitian the graben was becoming a focus for sediment deposition (Mangaa Formation) relative to the Western Stable Platform. Subsidence in the graben was initially greater than the rate of sedimentation, which increased water depths. Deepening of the graben continued into the Waipipian. By the end of the Waipipian the rate of sediment accumulation was greater than the rate of subsidence, and seismic units infilled, and then spilled over the graben on to the Western Stable Platform. Subsidence of the graben continued during the Nukumaruan, with the asymmetry of the graben possibly enhanced by the progradation of foreset strata. Geohistory plots for individual wells (Awatea-1 and Mangaa-1) suggest that 300-500 m of subsidence can be attributed to the loading effect of the foreset strata.

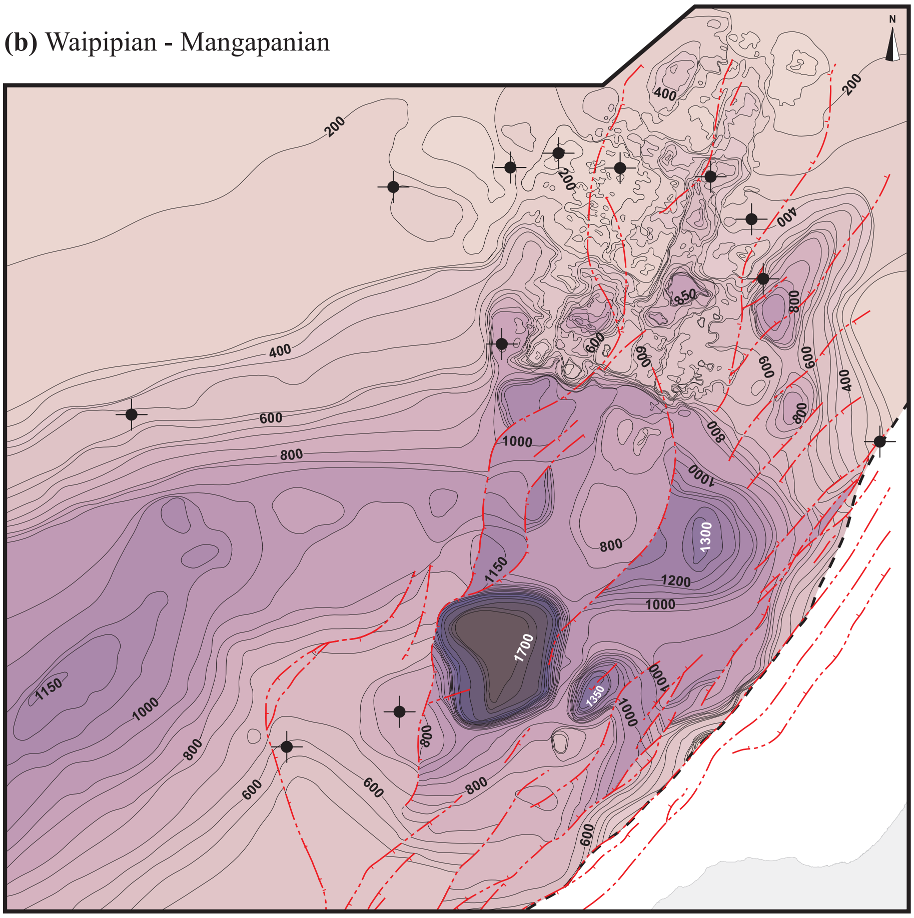
Internal characteristics of the Giant Foresets Formation

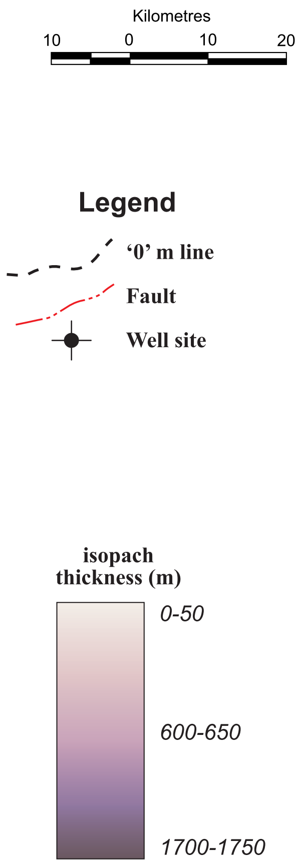
Mapping of the internal seismic characteristics of the Giant Foresets Formation has resulted in the identification of distinct architectural elements. Each of these architectural elements can be discussed in terms of the depositional systems they represent, and thus their appropriate ordering within a conventional (Vail-type) sequence stratigraphic framework (e.g. Posamentier et al. 1988). While a full description and interpretation of these features will appear in other papers, the major architectural elements are summarised in Fig.4 (seismic reflection profile P95-103; see Fig.2 for transect location). The sequences illustrated on Fig. 4 comprise several readily identifiable architectural elements, the most common of which are basin floor (lower slope) fans and channel-levee complexes. Basin floor and lower slope fan facies are concordant with channel-levee complexes of the middle slope. These latter architectural elements are relatively extensive, forming stacked complexes of channels and levees separated by subparallel reflectors of overbank deposits. Sequence boundaries are delineated by bright, high amplitude reflectors, occasional onlap, erosional truncation, and where basin floor fans are present, by downlap. Most reflectors are concordant from shelf to slope.

Sequences within the Giant Foresets Formation display an abundance of architectural elements interpreted to have been dominantly formed during lowering and low relative sea level (i.e. fans and channel-levee complexes). Only the occasional sequence includes a thin set of reflectors downlapping on to fans and channel-levee complexes that may be interpreted as lowstand wedge deposits. This diverges from the typical Vail-type model, which shows a very thick lowstand wedge relative to basin floor and channel-levee components, which may be attributed to a lack of exposure of the shelf break during relative sea level lowstands. The dominance and volume of muddy sediment delivered to northern Taranaki Basin, and the asymmetrical nature of sequences, is reflected in the stratigraphic expression of the lowstand depositional units (architectural elements) that accumulated basinward of the shelf break, with a lack of large sand-dominated fan lobes, few deeply incised channels, and numerous channel-levee complexes. While there may be some potential for stratigraphic traps associated with some lower slope to basin floor fans, these

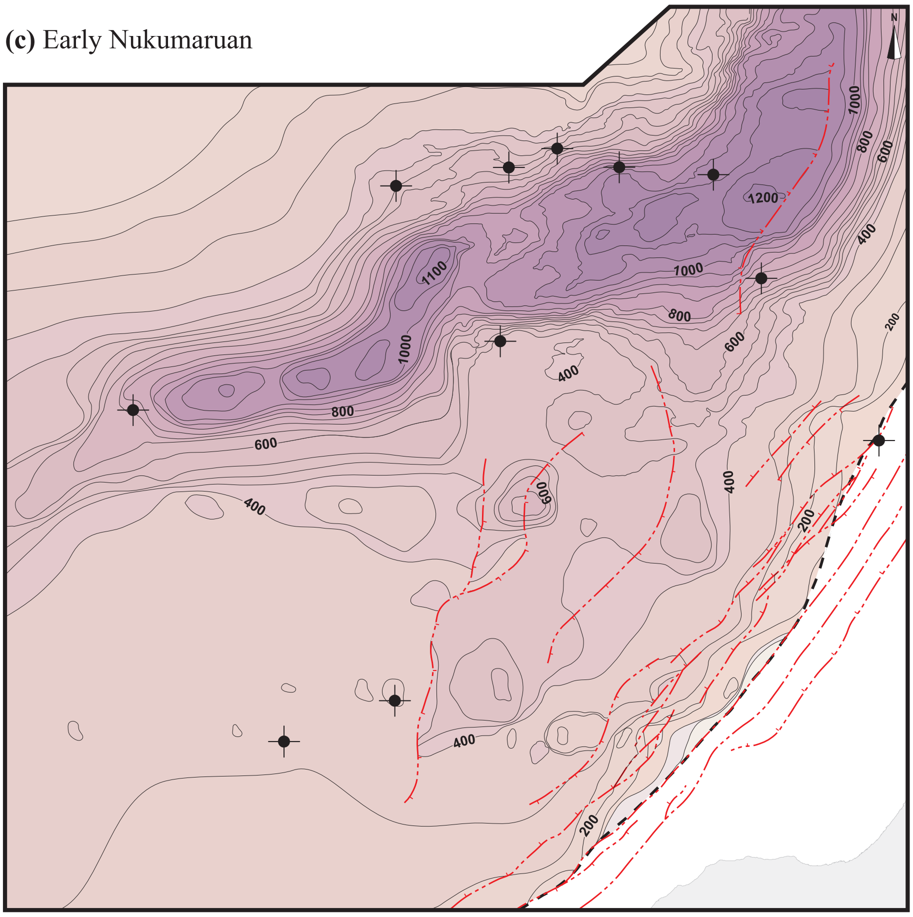
Figure 3: Distribution and depositional patterns of the Pliocene to Recent sedimentary succession (a, Opoitian Stage; b, Waipipian-Mangapanian Stages combined; c, Early Nukumaruan Stage; d, Late Nukumaruan Stage to Recent), across northern Taranaki Basin. Isopach thicknesses in metres at 50 m intervals. ‘0’ m line is point at which sediment is no longer present as a result of post-depositional erosion. See text for discussion, but note how the depositional patterns become focused along the continental slope through time as the Northern Graben undergoes less extension and it becomes infilled.



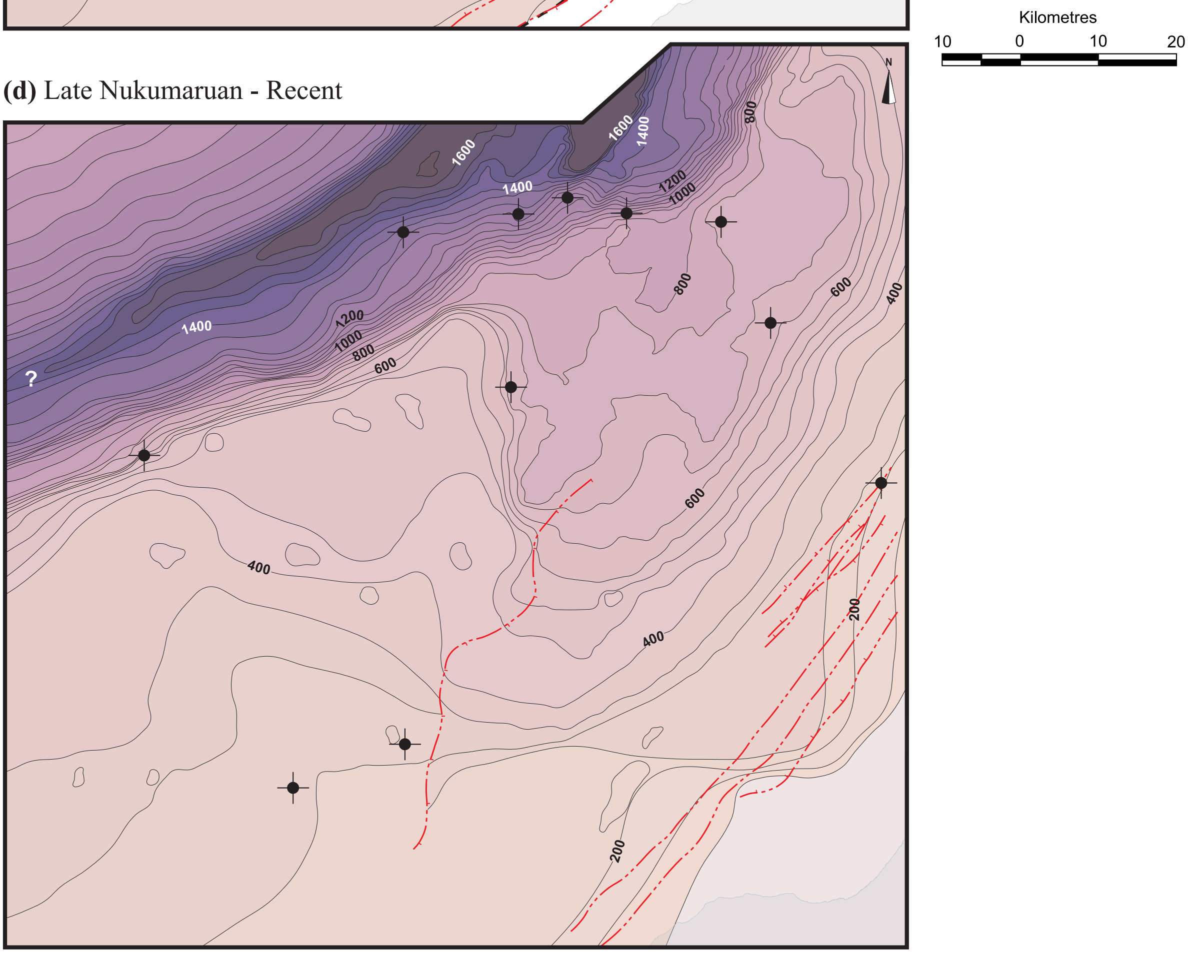




(c) Early Nukumaruan



(d) Late Nukumaruan - Recent



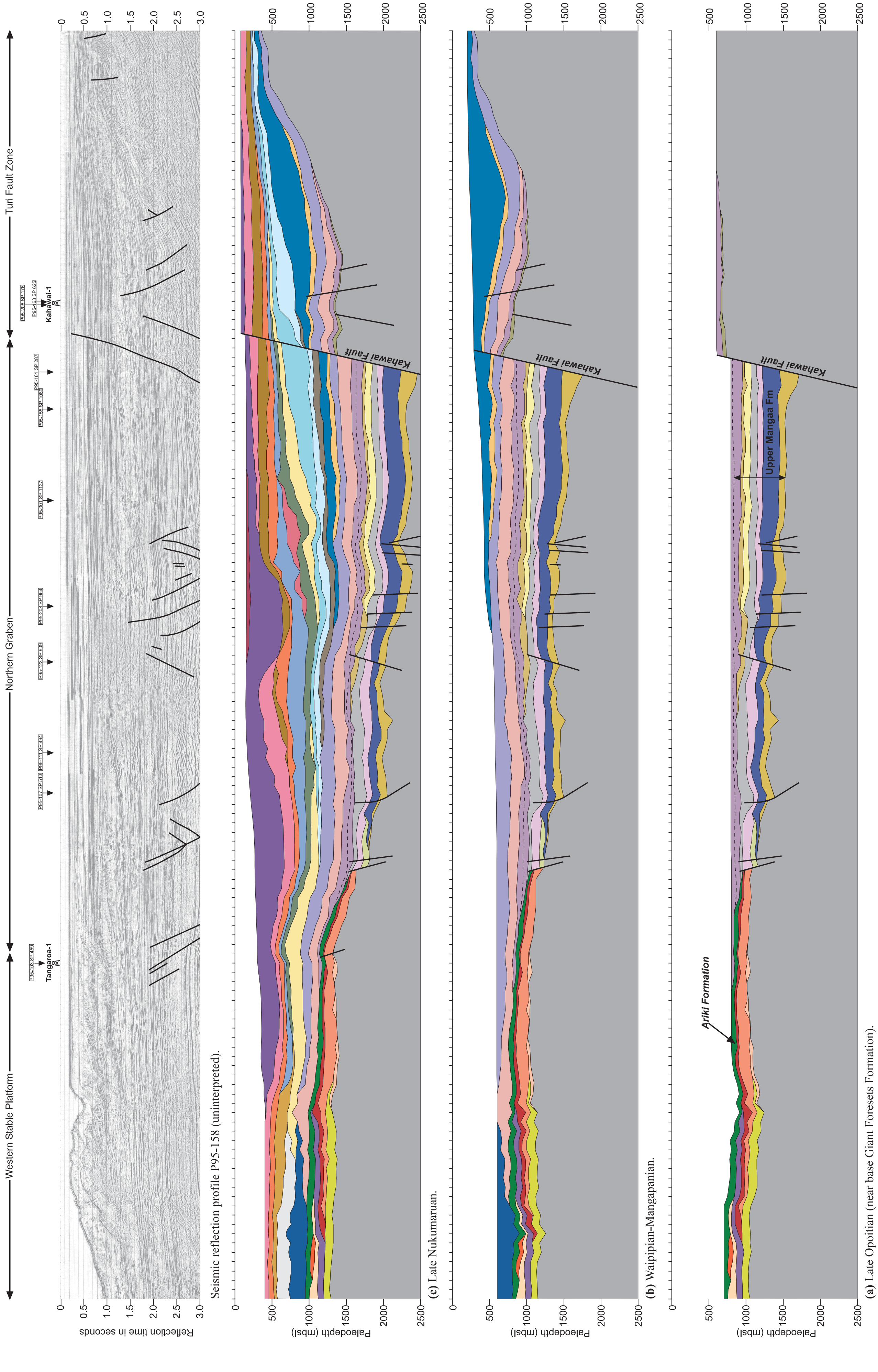

Western Stable Platform
Northern Graben
Turi Fault Zone
Tangaroa-1
Kahawai-1
Reflection time in seconds
Seismic reflection profile P95-158 (uninterpreted).
Paleodepth (mbsl)
Kahawai Fault
(c) Late Nukumaruan.
(b) Waipipian-Mangapanian.
Upper Mangaa Fm
Ariki Formation
(a) Late Opoitian (near base Giant Foresets Formation).

Figure 4

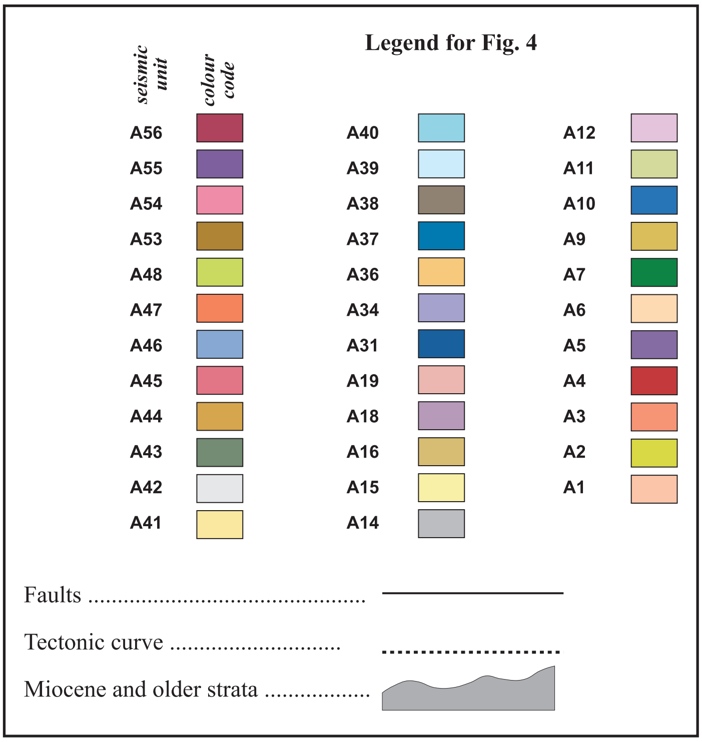


Figure 4: Seismic sequence interpretation and palinspastic restoration of the Giant Foresets Formation in the Northern Graben. The upper panel is an uninterpreted (except for faults) representation of line P95-158 (see Fig. 2 for location), showing the modern shelf out to the top of the slope and the underlying sedimentary succession. The three underlying panels show successive backstripped and decompacted palinspastic restorations of the Northern Graben. See text for discussion. Note the assymetrical development of the graben.

have relatively small spatial extent, and tend to be comparatively muddy, with little communication between successive units. Channels, channel-levee, and overbank deposits provide more effective communication between units, but while they have a higher sand content, are still relatively muddy in nature. Unfortunately, no single well intersects an entire slope to basin floor succession, and no work assessing the permeability and porosity properties of these units has been undertaken. However, a basic understanding of these characteristics suggests that there is little effective reservoir within the Giant Foresets Formation.

Implications for Hydrocarbon Prospectivity

The post-Miocene Mangaa and Giant Foresets Formations in the Northern Graben are important for providing overburden and seal properties for hydrocarbon maturation and containment. More specifically, the rapid deposition of the Pliocene-Pleistocene succession has driven regional maturation and migration alone depositional fronts coinciding with progradation of the continental slope, although modeling within the Northern Graben needs to be undertaken to understand the regional dynamics (fluid flow, thermal regimes) associated with the succession. Mapping out the depositional geometry of the Giant Foresets Formation in particular provides an essential basis for such modeling.

References

Bennett, C., Gregg, R. and King, P.R. 1992. Petroleum geology of the Taranaki Basin, with emphasis on the north-eastern quadrant. Petroleum Exploration in New Zealand News, 32*:* 15-25.

Bergman, S.C., Talbot, J. and Thompson, P.R. 1992. The Kora Miocene submarine andesite stratovolcano hydrocarbon reservoir, Northern Taranaki Basin, New Zealand. 1991 New Zealand Oil Exploration Conference Proceedings, vol. 1: 178-206.

Forder, S.P. and Sissons, B.A. 1992. The Moki C Sands: an example of Mio-Pliocene bathyal fans in the North Taranaki Graben. 1991 New Zealand Oil Exploration Conference Proceedings vol. 1: 155-167.

King, P.R. and Thrasher, G.P. 1996. Cretaceous-Cenozoic geology and petroleum systems of the Taranaki Basin, New Zealand. Institute of Geological and Nuclear Sciences monograph 13. 243 p. 6 enclosures. Institute of Geological & Nuclear Sciences Ltd., Lower Hutt.

McAlpine, A. 2000. Basin modelling of oil plays northwest of Maui: results, constraints and calibrations. 2000 New Zealand Petroleum Conference Proceedings.

Murray, D. and de Bock, J.F. 1996. Awatea-1 well completion Report. PEP 38457. Ministry of Commerce, New Zealand. Unpublished Petroleum Report 2262.

Posamentier, H.W. and Vail, P.R. 1988. Eustatic controls on clastic deposition II – sequence and systems tract models. *In* Cheryl, K. Wilgus, Hastings, B.S., Kendall, C.G.St.C., Posamentier, H.W., Ross, C.A. and van Wagoner, J.C. (eds). Sea level changes: an integrated approach. Society of Economic Paleontologists and Mineralogists Special Publication no. 42: 125-154.

Reed, J.D. 1992. Exploration geochemistry of the Taranaki Basin with emphasis on Kora. 1991 New Zealand Oil Exploration Conference Proceedings: 364-372. Ministry of Commerce, Wellington.

Soenander, H.B. 1992: Seismic stratigraphy of the Giant Foreset Formation, offshore North Taranaki–Western Platform. 1991 New Zealand Oil Exploration Conference Proceedings vol. 1: 207-233.

Thrasher, G.P., Leitner, B. and Hart, A.W. 2002: Petroleum system of the Northern Taranaki Graben. *In* 2002 New Zealand Petroleum Conference Proceedings: 1-6. Ministry of Economic Development, Wellington.

Acknowledgements

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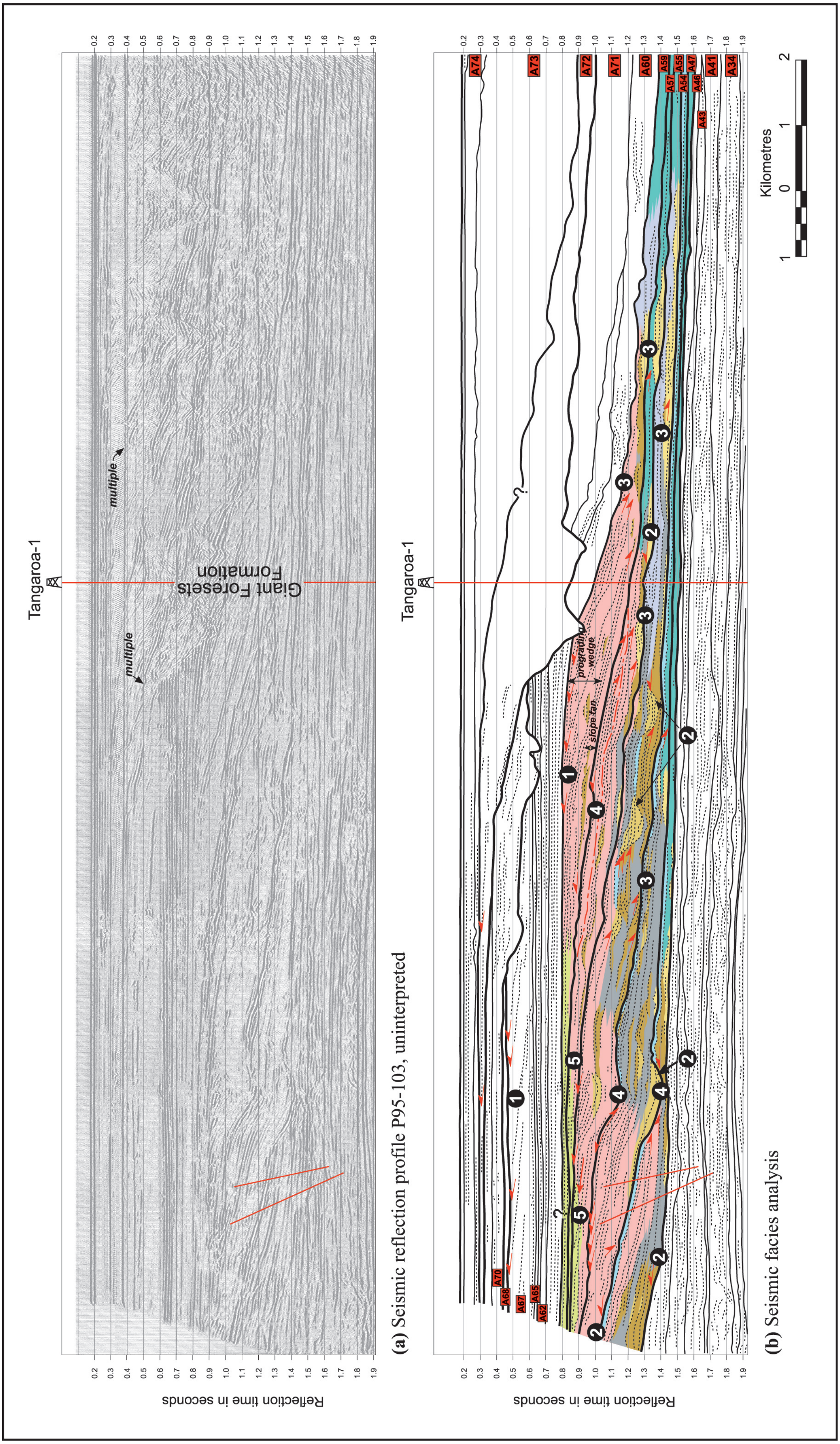
Figure 5



(a) Seismic reflection profile P95-103, uninterpreted

(b) Seismic facies analysis

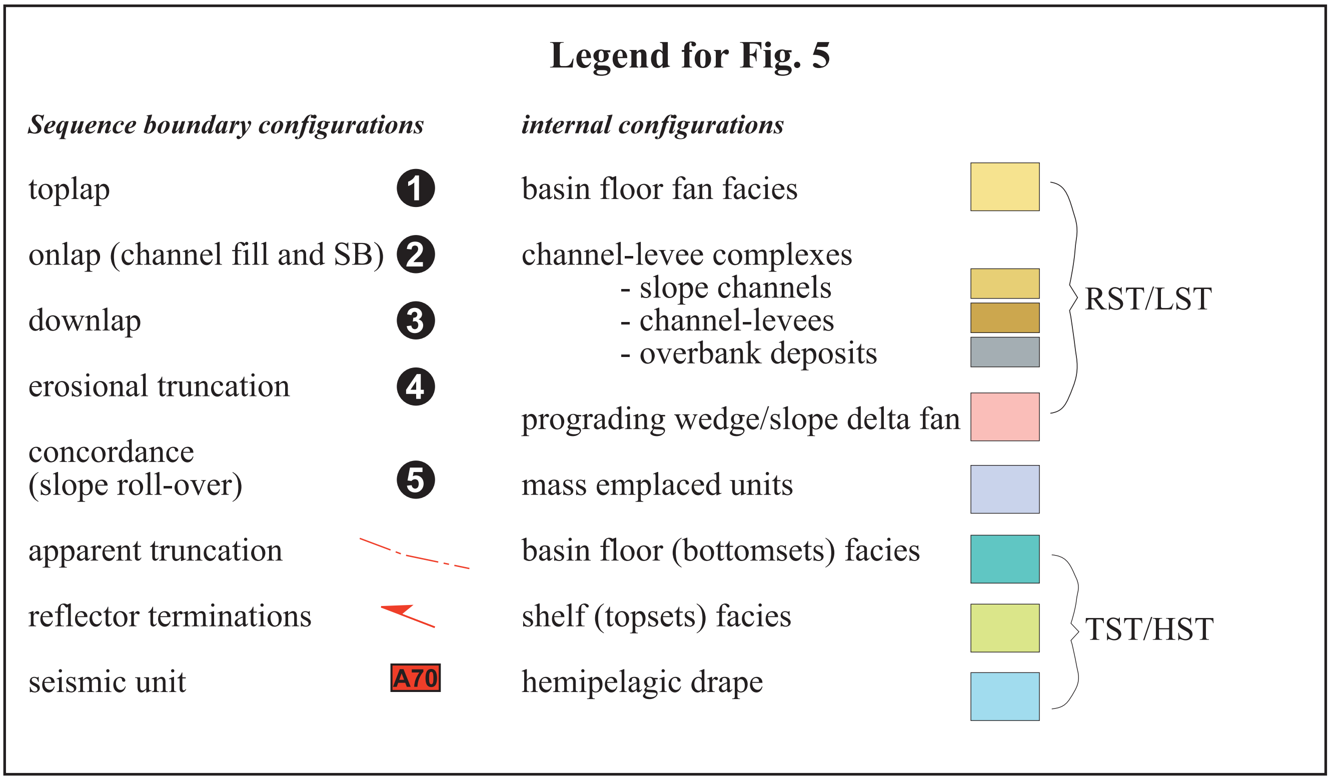


Figure 5: Sequence stratigraphic interpretation of line P95-103. Basin floor/slope fan facies (lowstand fans) are typically composed of a mixed mud-sand lithology. Low relief gull-wing geometries of channel-levee complexes coupled with acoustically transparent patterns characterise the slopes.

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