

# GRAVITY EXPRESSION OF THE PATEA-TONGAPORUTU HIGH AND SUBSEQUENT MODEL FOR THE TARANAKI BASIN MARGIN

C Mills  
New Zealand Oil and Gas Ltd

The Patea-Tongaporutu High, western North Island of New Zealand, is delineated and the associated uplift and erosion of the Taranaki and Wanganui Basins are estimated on the basis of gravity, borehole and geological data.

The regional gravity component used was derived from the gravitational effects of a large scale 3-dimensional lithospheric model proposed by Siern. After residual field modelling, selection of this regional component enables the entire Bouguer Anomaly to be explained in terms of geologic structure.

Two-dimensional modelling of the residual anomaly defined the structure of the Patea-Tongaporutu High. The High shallows and undergoes an eastward, step-like migration relative to  $174^{\circ} 30'$  to the north. Both the eastern (Strathmore Fault) and western (Taranaki Fault Zone) margins of the High are modelled as medium angle ( $45^{\circ}$ ) reverse faults.

Basement for the Patea-Tongaporutu High and Wanganui Basin was modelled at the standard density of  $2.67 \text{ Mg/m}^3$  for Mesozoic greywacke. Beneath Taranaki Basin it was necessary to model denser ( $2.72$  to  $2.75 \text{ Mg/m}^3$ ) basement; this has been interpreted as corresponding to a Northwest Nelson type plutonic and metamorphic basement.

Within the area, evolution of the Patea-Tongaporutu High started with Cretaceous to Late Oligocene extension. Following this, until the Late Miocene, the area underwent a compressive phase that increased in magnitude to the north. This event caused the Taranaki Fault Zone to rotate to its present reverse style, the Strathmore Fault to develop as a back thrust feature, and the Patea-Tongaporutu High to thrust westward over the suture between Northwest Nelson and Torlesse type basement lithologies.

## INTRODUCTION

The Patea-Tongaporutu High is a narrow, north-south trending basement structure separating the Taranaki and Wanganui Basins in the North Island of New Zealand (Fig. 1). It is bounded in the east and west respectively by the Strathmore Fault and the Taranaki Fault Zone. Acheson (1939) first demonstrated the gravity expression of the High. Subsequent gravity studies (e.g., Hunt, 1980), have concentrated on the basins on either side. This study focuses on the Patea-Tongaporutu High.

## OBSERVATIONS

Some 1180 new gravity observations were made using a La Coste Romberg gravity meter (Victoria University of Wellington meter G 519). The observations were measured relative to the New Zealand Primary Gravity Network and were reduced and catalogued using the New Zealand Department of Industrial Research (DSIR) computer network. Station elevations were either surveyed (46%) or barometrically levelled (54%). The 1180 new observations were combined with 1146 existing observations in the DSIR catalogue for the study.

Errors in Bouguer anomalies at surveyed locations are of the order of  $0.40 \mu\text{N/kg}$  in easy to rolling country and  $1.2 \mu\text{N/kg}$  in the most rugged terrain. At barometrically levelled sites errors are between  $8.8 \mu\text{N/kg}$  and  $9.6 \mu\text{N/kg}$ . Errors are primarily dependent on the accuracy of station height determination, however, in regions with steep topography the terrain correction estimation becomes an increasingly significant source of error.

## REGIONAL GRAVITY

The gravity field as measured at the earth's surface is composed of short and long wavelength components which may originate from a wide range of depths. Long wavelength features may result either from sharp lateral density variations at depth or from more gradual variations near the surface. Short wavelength features however must result from shallow lateral density variations. To facilitate gravity interpretation the long wavelength component is frequently subtracted as a first step. The separation of the long wavelength (regional) field may be somewhat arbitrary but this approach is a means of focusing the data on those shallow features which gravity interpretation can realistically address.

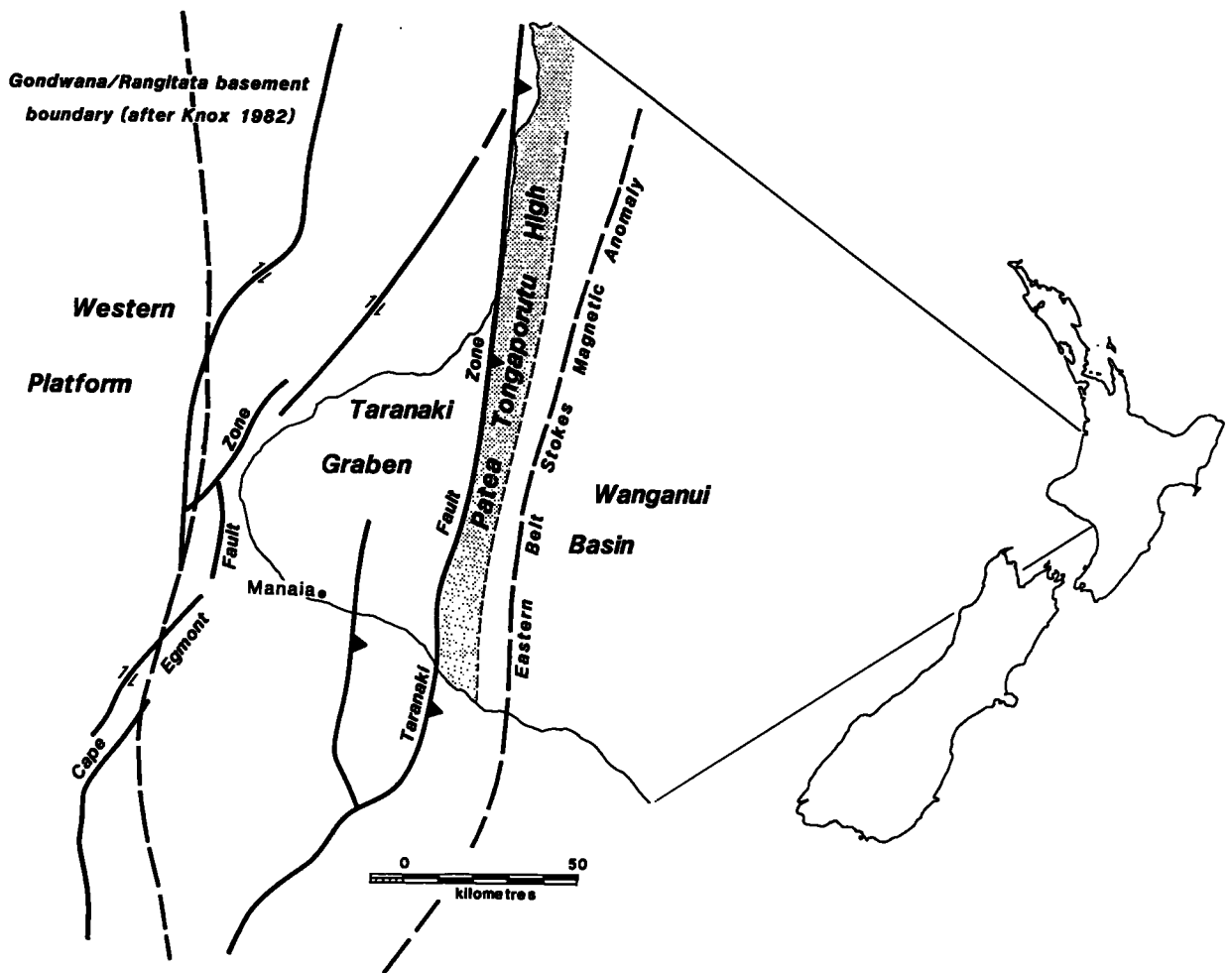


Fig. 1: Locality diagram and major structural elements map.

In this study the regional gravity used is the calculated gravitational effect of a large scale lithospheric model of the North Island (Fig 2). The particular features of this model, as proposed by Stern (1982, 1988) are:

- (a) A boundary running from Egmont through Ruapehu to White Island which divides thin crust with low density mantle in the north from normal crust and mantle in the south.
- (b) A region of very thin crust designated the Central Volcanic Region extending from Ruapehu to the Bay of Plenty.

The residual field was computed by subtracting Stern's regional from the Bouguer anomalies and is shown contoured in Fig 3.

### RESIDUAL GRAVITY

In Taranaki the residual gravity is generally conceived of as deriving from the mass deficit where less dense Tertiary rocks overlie Mesozoic basement. The residual anomaly will reflect basement topography and will be everywhere negative. Stern's regional gives a residual anomaly which clearly does not derive solely from basement topography as can be seen by the fact that residuals over the northern part of the Patea-Tongaporutu High are positive where the

shallow Tertiary cover would indicate small negative residuals.

It is also found that residuals in the Taranaki Basin are not as negative as expected. Basement intersected in the Patea-Tongaporutu High has a density of  $2.67 \text{ Mg/m}^3$ . Downhole density curves in deep oil wells in the Taranaki Basin to the west of the High indicate densities in the Tertiary section ranging from approximately 2.20 to  $2.67 \text{ Mg/m}^3$ . The resulting mass deficit relative to  $2.67 \text{ Mg/m}^3$  basement would give rise to residual anomalies of up to  $-540 \mu\text{N/kg}$ . The largest mapped residual in the Basin is  $-240 \mu\text{N/kg}$ . Thus there would appear to be denser material underlying the Tertiary rocks in the Taranaki Basin than the  $2.67 \text{ Mg/m}^3$  material in the Patea-Tongaporutu High. This is not inconsistent with the regional geology.

Paleozoic igneous and metamorphic rocks as found in outcrop in Northwest Nelson make up basement in several offshore wells in West Taranaki and may also underlie the onshore Taranaki Basin where wells have not reached basement. The density of these rocks at outcrop is  $2.80 \text{ Mg/m}^3$ , significantly greater than the of  $2.67 \text{ Mg/m}^3$  of the basement which underlies the Patea-Tongaporutu High. If Nelson type basement underlies the Taranaki Basin this can account for the smaller residuals observed there.

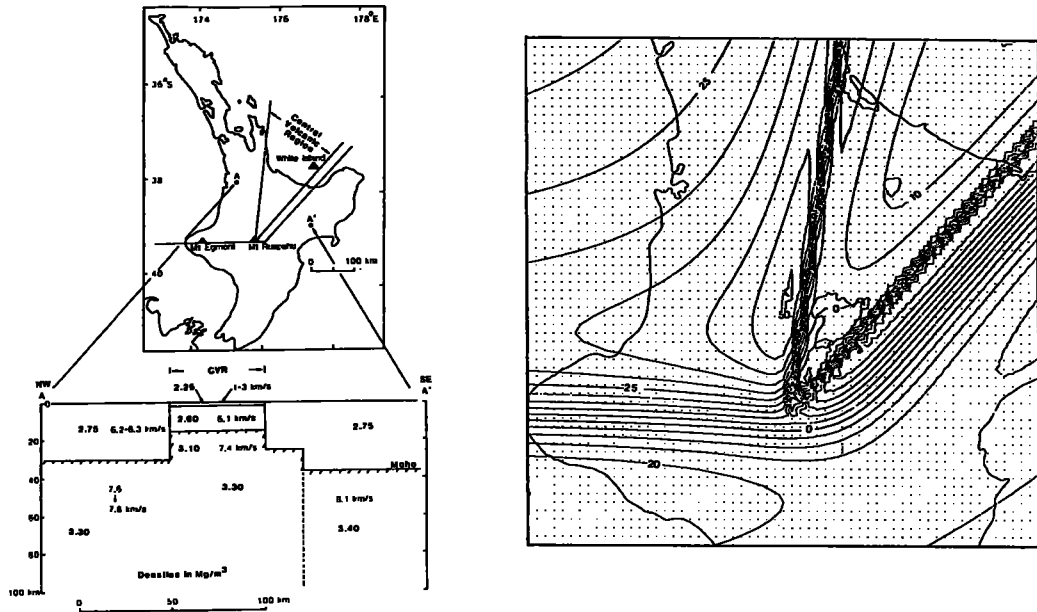


Fig. 2a: 3-dimensional lithosphere model used for gravity regional estimation (after Stern, 1982). 2b: Central North Island regional gravity field resulting from model lithosphere. Crinkled contours are a result of computer contouring. Dots represent calculation points.

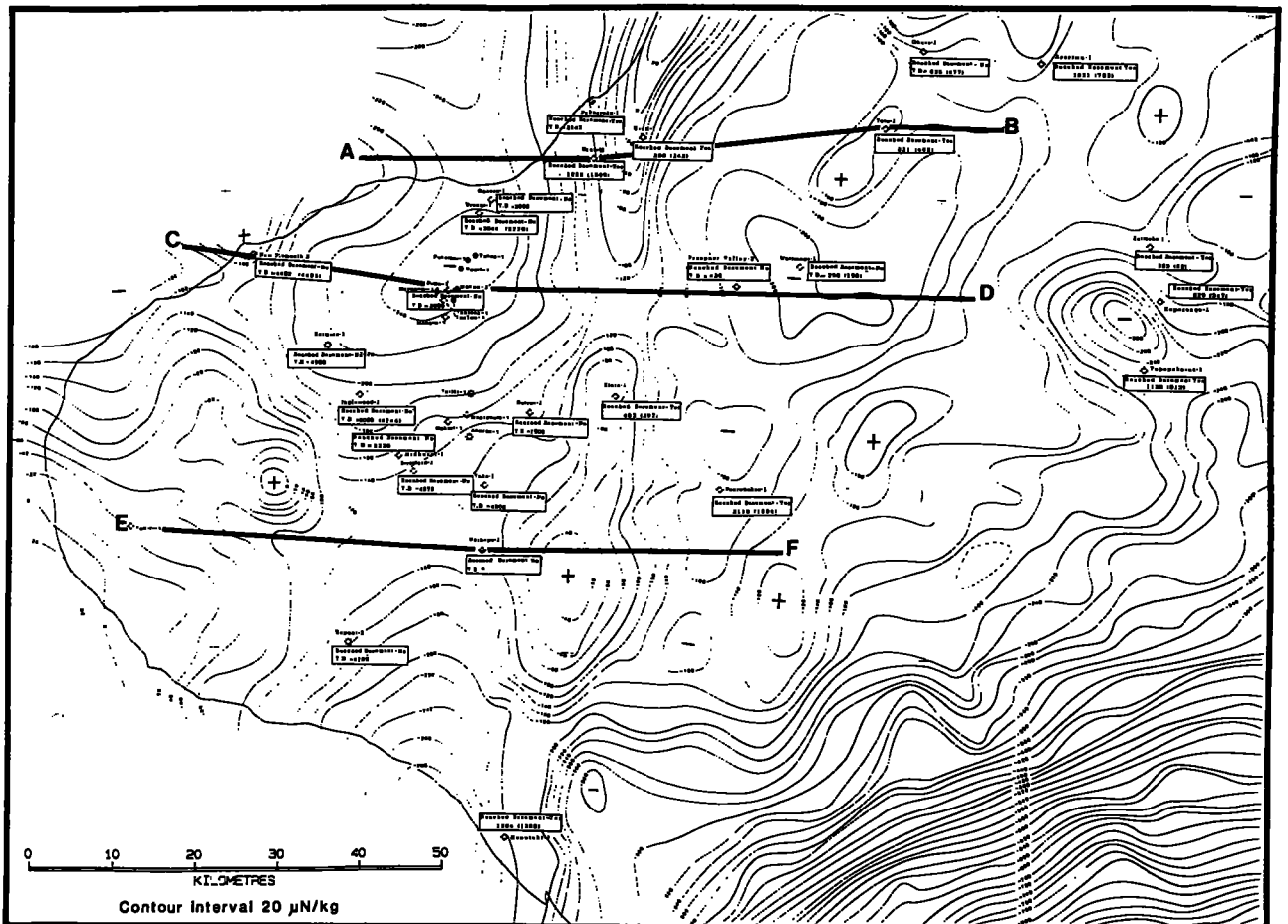


Fig. 3: Contours on residual Bouguer anomalies.

## MODELLING

Quantitative interpretation of residual anomalies was performed by 2D forward modelling on 3 east-west profiles. Having removed the regional field, the residual field represents the near surface lateral variations in density. Preliminary models of the near surface density structure were constructed using existing petroleum exploration data. Repeat sections as encountered in the McKee-1 exploration well, and also observed in seismic interpretations (Knox, 1982) indicate that the Taranaki Fault Zone is a zone of reverse faulting. Fault style along the eastern side of the Patea-Tongaporutu High (the Strathmore Fault) is less well known but is also assumed to be reverse.

The Taranaki Fault Zone was modelled as five 45° thrust slices. Although the sensitivity of the gravity data is insufficient to accurately model the lower thrusts, in the absence of independent control these have been modelled at the same angle as the shallower thrusts. The density profile in the Tertiary sequence west of the Patea-Tongaporutu High was taken from petroleum wells. None of the wells is deeper than 4500 m or reach basement. It was therefore necessary to extrapolate borehole density data below the

base of the boreholes. Densities were extrapolated down to 6000 m where the density approaches 2.67 Mg/m<sup>3</sup>.

### Profile A-B

Profile A-B (Fig. 4), extends some 90 km from the Te Kiri-1 well through Waihapa-4 and into the Wanganui Basin. The Tertiary rock densities within Taranaki Basin are constrained by data from the wells Te Kiri-1, Kapuni-8 and Waihapa-1 and have been modelled by a series of horizontal slabs subdivided into segments having different densities. This configuration represents the lateral densities gradient caused by progressive uplift of the Tertiary towards the Patea-Tongaporutu High. Basement west of the Patea-Tongaporutu High is modelled with a density of +0.08 Mg/m<sup>3</sup>.

The western end of Profile A-B crosses the flank of the Egmont volcano. It has been unnecessary to introduce any anomalous mass to achieve a gravity fit in this area and it is therefore concluded that the Egmont volcanism is thin skinned with only a localized feeder system.

### Profile C-D

Profile C-D (Fig. 5) extends some 70 km from the New Plymouth-2 well eastwards through McKee-1, across a saddle

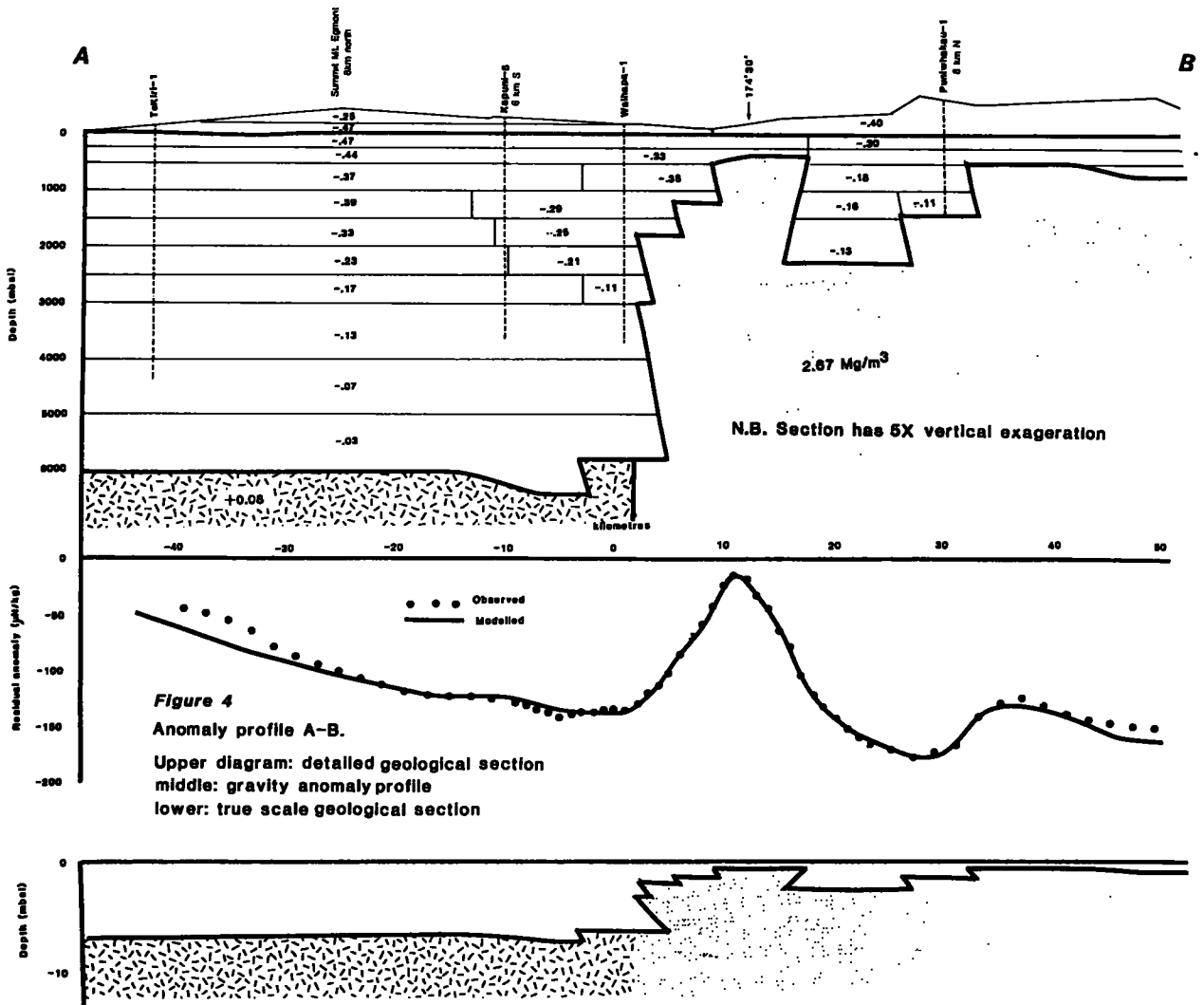


Fig. 4: Anomaly profile A-B. Upper diagram: detailed geological section. Middle diagram: gravity anomaly profile. Lower diagram: true scale geological section.

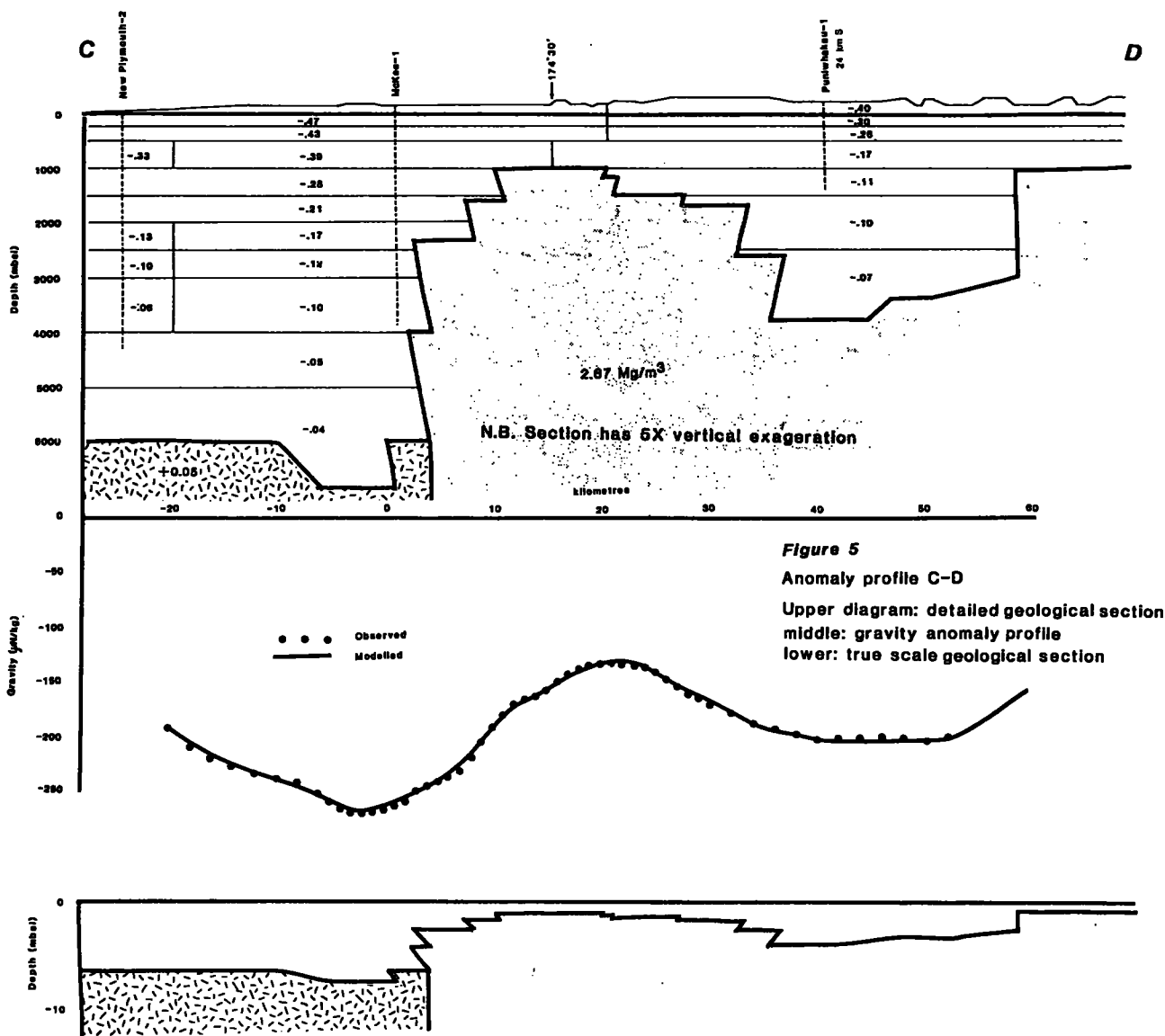


Figure 5

Anomaly profile C-D

Upper diagram: detailed geological section  
 middle: gravity anomaly profile  
 lower: true scale geological section

Fig. 5: Anomaly profile C-D. Upper diagram: detailed geological section. Middle diagram: gravity anomaly profile. Lower diagram: true scale geological section.

in the Patea-Tongaporutu High to a residual low in the North Wanganui Basin (Fig 3).

Due to inadequate well control west of the Patea-Tongaporutu High no attempt was made to model lateral density variations in the Tertiary section. At New Plymouth-2 at the western end of the profile densities are somewhat greater than in other wells in the Taranaki Basin. This is probably due to the proximity of the Paratutu intrusives. Higher densities have been included in the model in the west and these fit the measured residuals. Taranaki Basement was modelled with a  $+0.05 \text{ Mg/m}^3$  density contrast on this profile.

#### Profile E-F

Profile E-F (Fig. 6) extends 70 km east from an offshore position through Uruti-2 and Tatu-1 into the North Wanganui Basin (Fig 3). Densities in the Taranaki Basin Tertiary Section were constrained by the McKee-1 and Urenui-1 wells. Taranaki Basin basement density for this profile is  $0.05 \text{ Mg/m}^3$ .

The results from the three profiles have been combined in a perspective diagram (Fig 7).

#### EVOLUTION OF THE PATEA-TONGAPORUTU HIGH

During the late Cretaceous to late Paleocene (77-55 Ma) the New Zealand continental mass rifted away from Australia/Antarctica, and the opening of the Tasman Sea occurred. Spreading initially produced rapid subsidence of basement grabens. As the Tasman spreading centre became increasingly removed from Taranaki during the Eocene, and spreading finally ceased at 55 Ma, thermal equilibrium was approached and subsidence rates waned. Faulting during this period had a north-south trend approximately parallel to the strike of basement rocks.

Fault movements ceased during the Eocene and in the Oligocene the widespread deposition of the Tikorangi Limestone marked a period of tectonic quiescence. The Patea-Tongaporutu High remained emergent until the late Oligocene when deposition of the Mahoenui Formation first

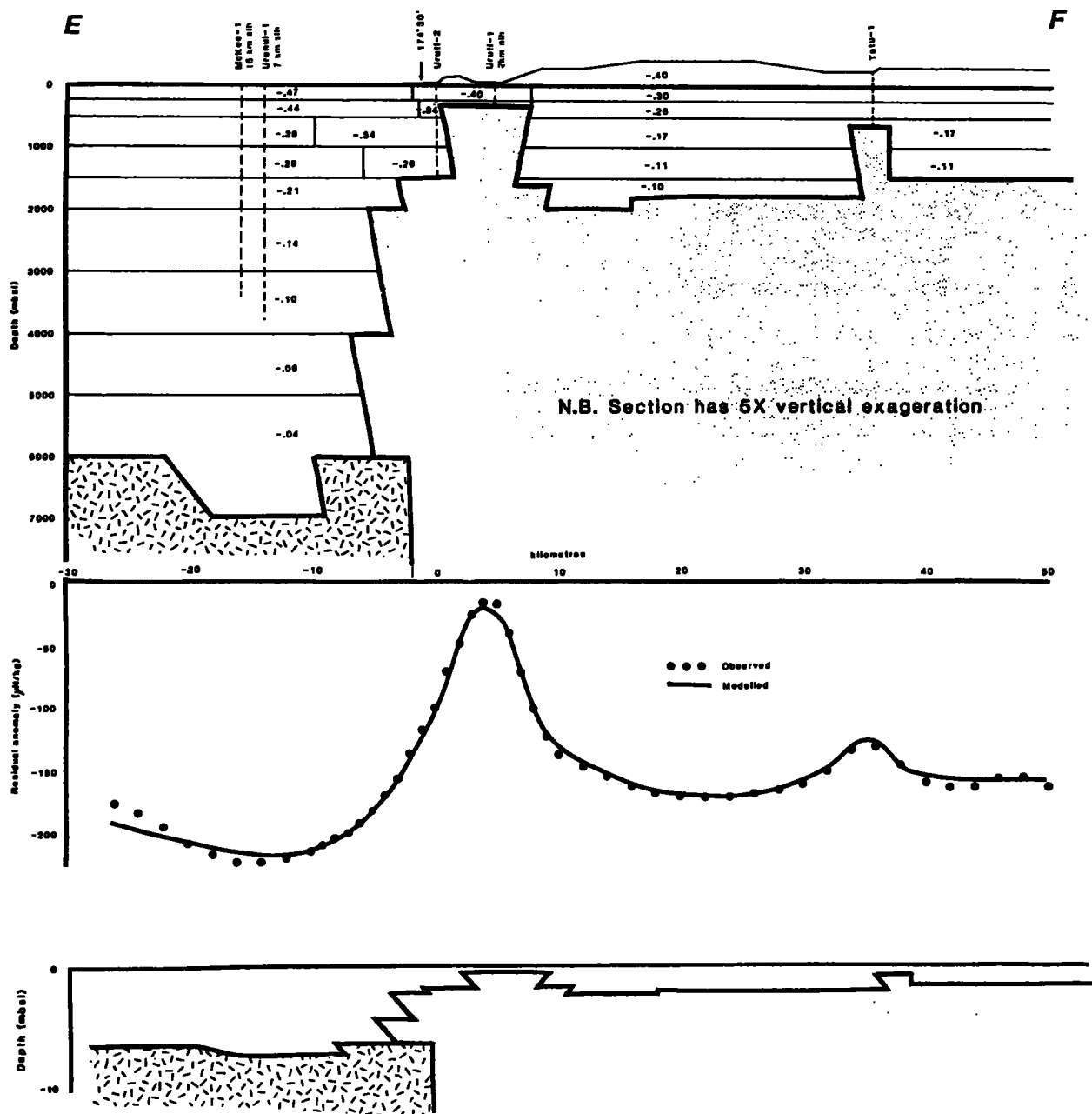


Fig. 6: Anomaly profile E-F. Upper diagram: detailed geological section. Middle diagram: gravity anomaly profile. Lower diagram: true scale geological section.

occurred through saddles in the High linking the basins on either side. The transgression continued in a southward direction through the Miocene and early Pliocene.

The Alpine Fault propagated through New Zealand 23 Ma ago at the end of the Oligocene (Stock and Molnar, 1987). This was accompanied by oblique compression in Taranaki which resulted in the reversal of existing normal faults, to create high angle reverse faults and over thrusts.

It was inferred from the gravity work reported above that the Taranaki Basin is underlain by rocks correlative with Northwest Nelson basement. These rocks are part of the Paleozoic foreland of the Gondwana continent. The Patea-Tongaporutu

High and the Wanganui Basin are underlain by rocks of the Murihiku Super Group which accreted onto Gondwana during the Mesozoic. The Taranaki Fault Zone is the suture zone between these two terranes and was a zone of weakness separating rocks of different mechanical properties. In the early tensional tectonic phase the denser northwest Nelson rocks on the western side of the Taranaki Fault Zone subsided relative to the Murihiku rocks forming the proto Patea-Tongaporutu High. In the following compressive phase the lighter, less rigid Murihiku rocks were thrust over the Northwest Nelson terrane.

The following set of schematic diagrams (Figs. 8a-f) illustrate the evolution of the Patea-Tongaporutu High.

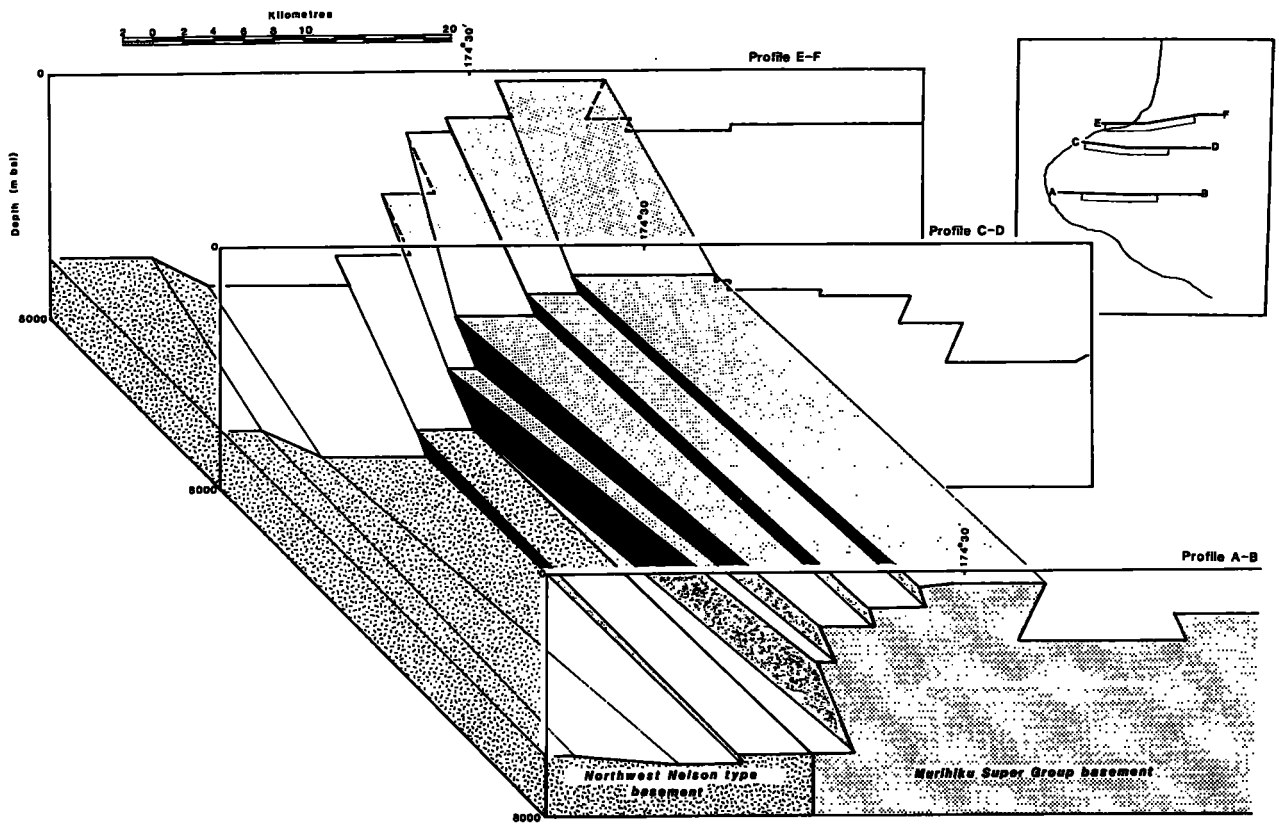
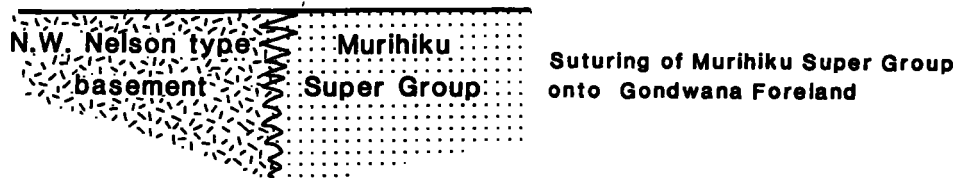


Fig. 7: Three-dimensional structure of the Patea-Tongaporutu High from linear interpolation between correlatable points on portions of the three residual anomaly modelled profiles. N.B. 2X vertical exaggeration.

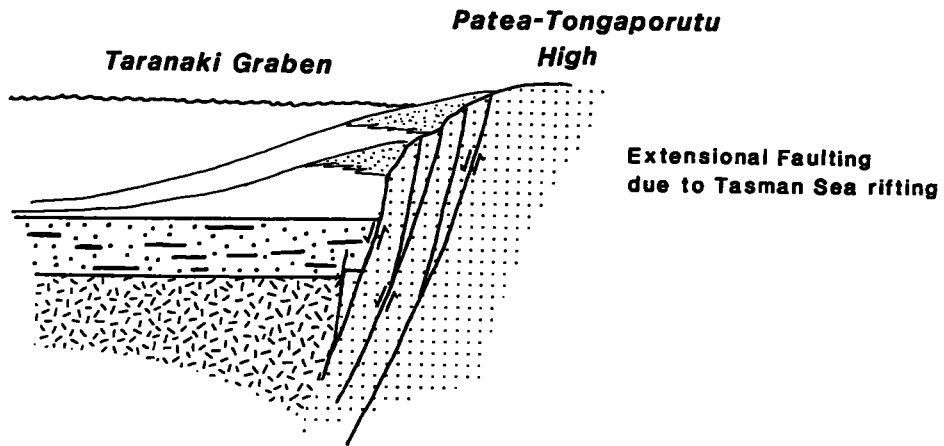
### Pre-Cretaceous



During the Mesozoic Murihiku Super Group rocks in the proto Wanganui Basin were sutured onto a Gondwana foreland of North West Nelson metamorphic and igneous rocks.

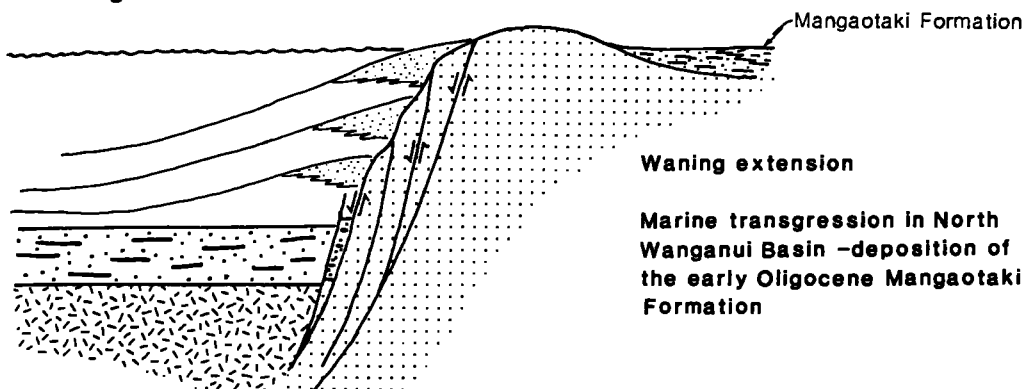
Figs. 8a-f: Evolution of the Patea-Tongaporutu High.

Paleocene



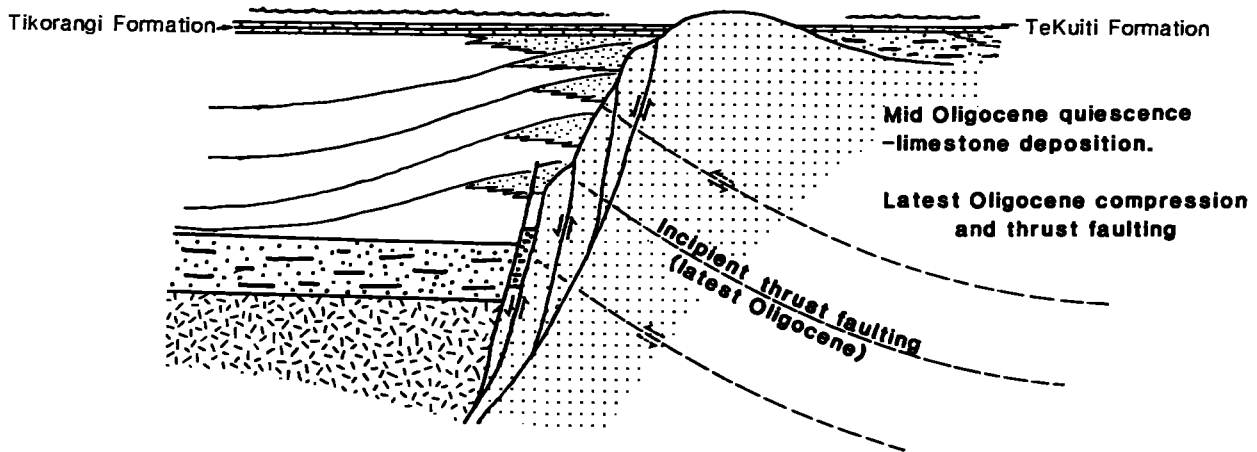
Tasman Sea seafloor spreading commenced in the late Cretaceous and continued until the late Paleocene (77-55 Ma). Basement grabens and depressions formed within the Taranaki region due to crustal attenuation and/or rift margin cooling. The suture between Murihiku and Northwest Nelson basement terranes was a zone of weakness along which faulting preferentially occurred. Subsidence of the Taranaki Basin (Northwest Nelson type basement) was initiated leaving the Murihiku basement to the east as the proto Patea-Tongaporutu High.

Eocene to Mid Oligocene

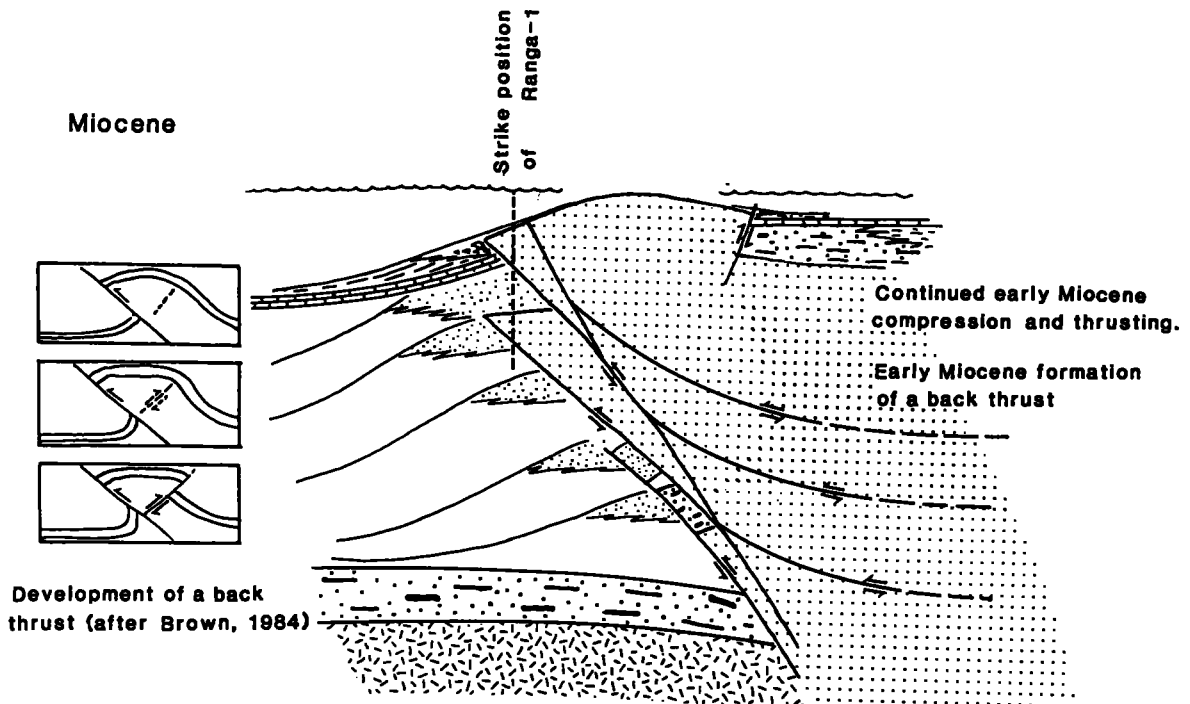


The rate of tectonism and regional subsidence in Taranaki decreased. An early Oligocene, south directed, marine transgression brought sedimentation east and west of the Patea-Tongaporutu High. The Patea-Tongaporutu High remained emergent.

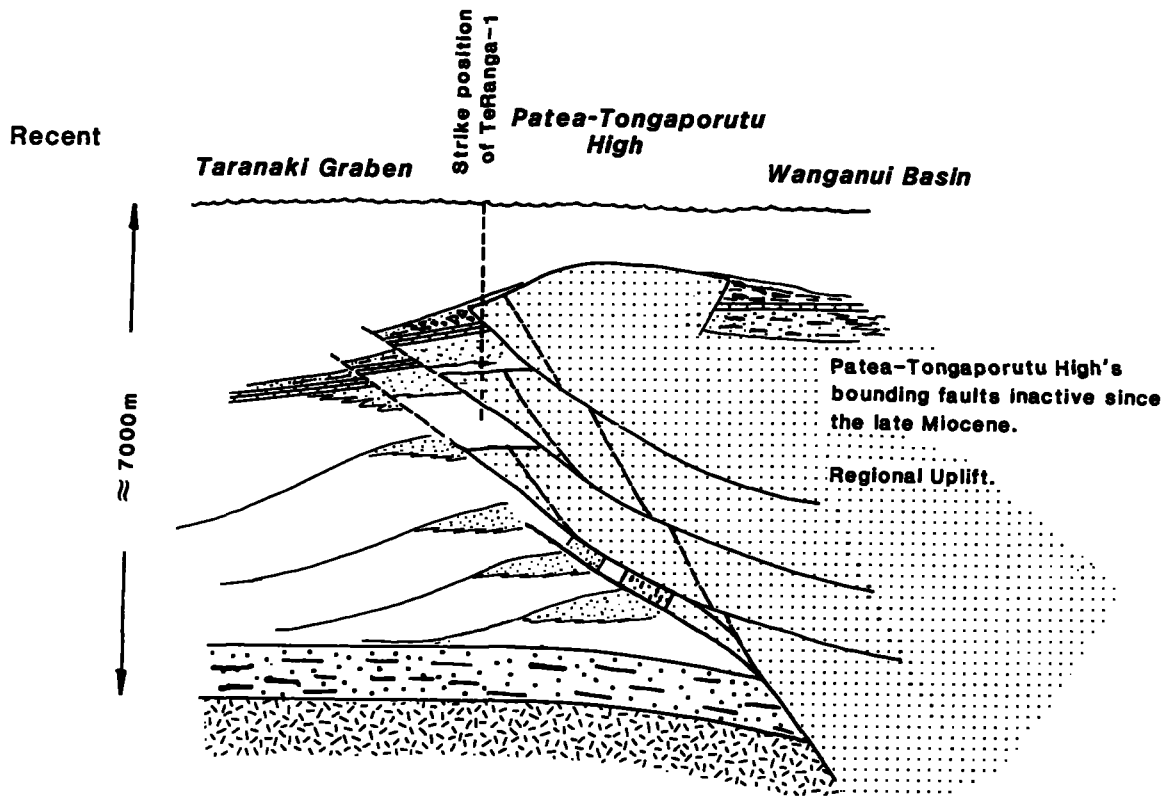
## mid to late Oligocene



Limestone deposition throughout the region indicates low clastic input and tectonic quiescence. Fault reversal and basement thrusting commenced along the Taranaki Fault Zone during deposition of the late Oligocene/early Miocene Mahoenui Formation. The age of thrusting broadly coincides with the propagation of the Alpine Fault plate boundary through New Zealand. Mahoenui Formation sediments are deposited over the High in the north and through saddles further south.



Continued westward thrusting of the Patea-Tongaporutu High and accelerated subsidence of Taranaki Graben. Development of a backthrust along the eastern side of the High (see inset diagram). North Wanganui Basin margin moves south in response to continued subsidence/marine transgression. Burial of the Patea-Tongaporutu High north of latitude 39 deg 30' is complete with deposition of the late Miocene Urenui Formation.



Tilting of the Wanganui basin about a hinge line at 39 deg 30' gives subsidence in the south while the north is uplifted.

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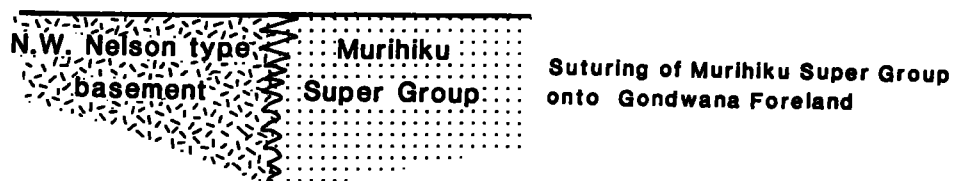
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