Late Neogene Structural Development of Eastern Raukumara Peninsula: Implications for Oil Exploration

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Abstract

The orientation and style of structures in Cretaceous-Pliocene rocks north of Gisborne are difficult to explain in terms of conventional convergent margin structures, ie foreland or seaward directed thrusts, or strike-slip faults. Instead outcrop mapping and interpretation of seismic reflection profiles indicate that late-Miocene to Recent deformation within Neogene rocks was dominated by trenchward extension associated with gravitational sliding and diapirism.

The thick (up to 5 km) mudstone dominated Neogene rocks of eastern Raukumara Peninsula are broken up by a series of large scale normal faults with a variety of strikes and dips. In places these faults merge with decollement surfaces which are most commonly gently inclined towards the trench. Detachments accommodate dip-slip displacements, at places exceeding 2 km, and occur within Eocene smectitic claystones characterised by high fluid pressures. The high fluid content in the claystones gives rise to gravitational instability and produces both reactive and active diapirism.

Thin-skinned anticlines form in association with diapirism and may be displaced by late-stage normal faults. These faults allow dewatering of the overpressured claystones and contribute to venting of fluids and gases at the surface. Such venting will eventually render the diapirs passive.

Gravitational structures are most obvious in the Raukumara area but are also known to occur further south. These structures are expected to be present throughout the East Coast North Island in one form or another where clay-rich rocks with high fluid content occur. This paper aims to raise awareness of the need for correct structural interpretation for hydrocarbon exploration in view of the structural complexity of the East Coast, the range of structural styles previously invoked in the area, and the limited subsurface data available. The gravity sliding - diapirism model outlined predicts trap geometries different from other models and is currently being tested as a play concept in the East Coast.

Introduction

New Zealand's East Coast (North Island) region lies on a well defined obliquely-convergent plate margin. The margin contains a thick uplifted Neogene clastic forearc sequence (locally exceeding 5 km), in places complexly deformed. While subduction-accretion occurs along the southern part, typified by landward dipping imbricate structures such as in Hawkes' Bay (Pettinga 1982); the northern part (Raukumara Peninsula) is undergoing tectonic erosion (Katz and Wood 1980) in which large submarine landslides are a feature (Lewis et al 1997).

A correct understanding of structural style is critical for successful oil exploration in the complex East Coast; especially as many previous efforts have failed to understand structure. Several, often conflicting, structural models have been proposed in the northern area (eg Cutten 1992, Haskell 1994, Phizackerly 1962, Stoneley 1962, Ridd 1964) but, because of limited data, it has often been difficult to test these hypotheses. High quality seismic information is extremely limited onshore while detailed surface mapping is patchy. In order to gain a better understanding of the structural style, this paper will discuss evidence from the Gisborne-Te Puia area (Figure 1) which has been relatively well studied through surface mapping (eg Mazengarb et al 1991) and in which a recent seismic line was acquired. Field observations crucial to elucidating the structural style are listed below. These are in turn compared with structures described in the international literature.

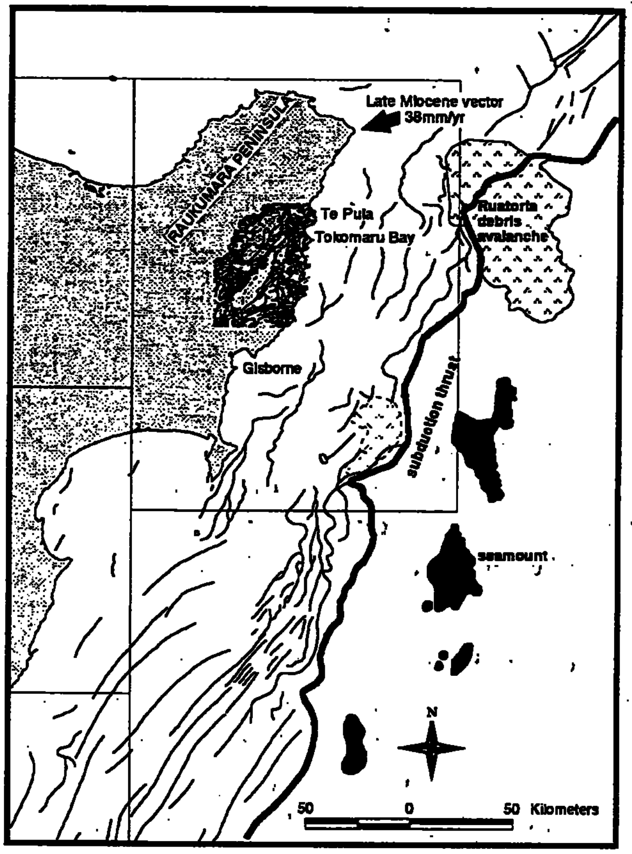

Figure 1. Location of area discussed between Gisborne and Te Puia, and showing plate boundary structure to the east. The Raukumara Peninsula is an uplifted forearc along which SE tilting of Neogene strata has occurred on the eastern flank. Offshore structure (adapted from Collot et al 1996, Lewis et al 1997, Field and Uruski et al in prep) includes two very large landslides (one of which is named the Ruatoria debris avalanche). The late-Miocene Pacific plate vector is also shown to demonstrate the obliquity to Neogene structures in the study area. Rectangles show 1:250 000 map boundaries (QMAP project) of which the Raukumara geology is currently being compiled by the author.

Observations of Significance to Structural Style

- The Neogene stratigraphy of the area between Te Puia and Gisborne consists of, a thick (>5 km) mudstone dominated clastic marine sequence (see Mazengarb et al 1991). In contrast, the underlying Late Cretaceous to Eocene sequence is much thinner and includes shale and smectitic claystone (ibid). The Neogene contains at least two angular unconformity surfaces, late-Miocene (Tonga-porutuan) and latest-Miocene to Pliocene (Kapitean-Opoitian), which help to constrain deformation events. In some instances latest-Miocene to Pliocene hanging-wall sequences display significant thinning toward major normal faults, indicating the presence of a pre-existing topographic high.
- Folds are common in Neogene rocks but orientation is variable, although a NE alignment is dominant. Few if any folds can be simply related to the late Miocene plate convergence vector (calculated by G Rait, pers comm 1998), as many are in fact nearly parallel to it. Strongly contrasting fold orientations can be present in adjacent fault blocks. Some folds are parallel to adjacent faults (see below), but perpendicular relationships have also been observed. Synclines are generally open structures while anticlines are tight and commonly faulted.
- Faults are also common features, and most are clearly normal faults. The strike orientation of faults are variable, but dominant downthrow direction is in the SE quadrant. Throws exceeding 2 km are known and some structures have "unusually" low dips for normal faults (c 300). Some normal faults have at least two phases of movement. No strike-slip faults have been proven (although Ridd 1964, Phizackerly 1962 and Thornley 1996 among others have invoked such structures), while faults with proven reverse motion are exceedingly rare and have minor displacements (<1 m).
- Inliers of Late-Cretaceous and Early Tertiary rocks, containing Eocene smectitic claystone, occur sporadically within the area. The inliers are either associated with faults or in the cores of Neogene anticlines. Neogene strata are commonly steeply upturned in the vicinity of these inliers and as well there is an increased incidence of calcite veining.
- Gas and oil seeps, hot and cold saline springs, and mud volcanoes are commonly associated with fault lines and in areas of outcropping pre-Neogene rocks (eg Ridd 1970). Smectitic-melange extrusions have been witnessed in the last century and high fluid pressures have been encountered in drillholes. Diapir-like structures have been interpreted in offshore seismic lines by Katz and Wood (1980).

A Preferred Model

The orientation and form of structures in the northern area are difficult to explain in terms of typical convergent margin structures, ie imbricate landward (foreland) or seaward directed thrusts, or of transcurrent faulting, as there is a virtual lack of obvious reverse or strike-slip faults. Instead, an extensional environment is favoured because of the widespread evidence of multidirectional normal faulting and folding. The open syncline- tight anticline structural style is typical of thin-skinned tectonics underlain by diapiric material; a process in which diapiric flow of the smectitic units occurs into the hinges of anticlines, oversteepening the limbs. There are indications in outcrop that excessive pore pressure development in the smectite and shale sequence has enabled this unit to act as the detachment surface for the overlying

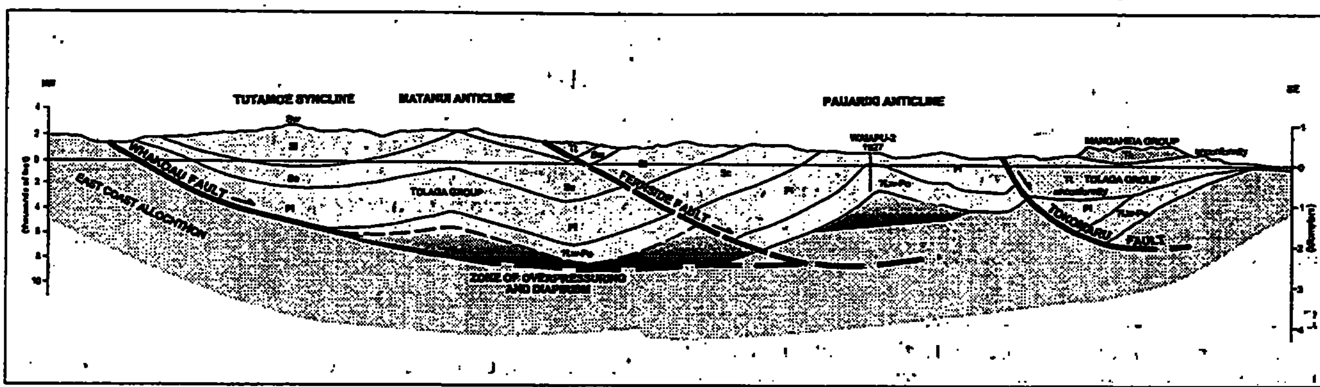

Figure 2. Tokomaru cross-section showing the predicted subsurface structure. The line is a revision of a cross-section in Mazengarb et al 1991 and extended to the coast. Both reactive- and anticlinal diapirs are invoked in this model involving a detachment beneath the Neogene Tolaga Group. Eocene smectitic mudstones within the East Coast Allochthon are forming the diapiric material. Standard New Zealand Timescale abbreviations are used. Lw, Po, Pl = early-Miocene; Sc, Sl, Sw = mid-Miocene; Tt, Tk = late-Miocene.

Neogene sequence. It is considered that the Neogene strata has partially detached and slid in a SE direction under the influence of gravity in response to late-Miocene uplift and seaward tilting of the forearc. During the process of sliding the major anticlines and synclines would have formed.

During sliding, the Neogene block has broken into smaller parts as normal faults have propagated through the sequence connecting with the decollement. Based on geometrical relationships it is probable that the development of the normal faults was accompanied by "shale" diapirism. The unusual geometry of the foot- and hanging-walls in the vicinity of these faults (footwalls are commonly steeply upturned; Figure 2) can be most readily explained in terms of reactive diapirism (eg Vendeville and Jackson 1992), in which a diapir forms as a reaction to the unloading effect of the normal fault. In cases where both the hanging and footwalls are upturned it can be further surmised that the unloading effect of the normal fault reached a point where the upward force of the diapir exceeded the vertical load and drove itself upwards, no longer requiring normal fault movement (active diapirism, ibid). Active diapirism is stopped if pressures are reduced sufficiently, this can be achieved if the seal over the diapir is breached thus venting the fluids at the free surface. The release of fluids, gases and solids is referred to as passive diapirism (ibid), of which there are many examples in the study area.

The timing of deformation (ie gravity sliding and diapirism) in this study area is constrained by angular unconformities to have commenced in Tongaporutuan times and continues to the present day. The thinning of latest-Miocene to Pliocene hanging-wall sequences towards major normal faults is unusual compared with many examples worldwide where the opposite occurs. However it can be explained in terms of sedimentation (onlap) against a preexisting high created by an active-diapir (one that followed a reactive type diapir, or an anticlinal

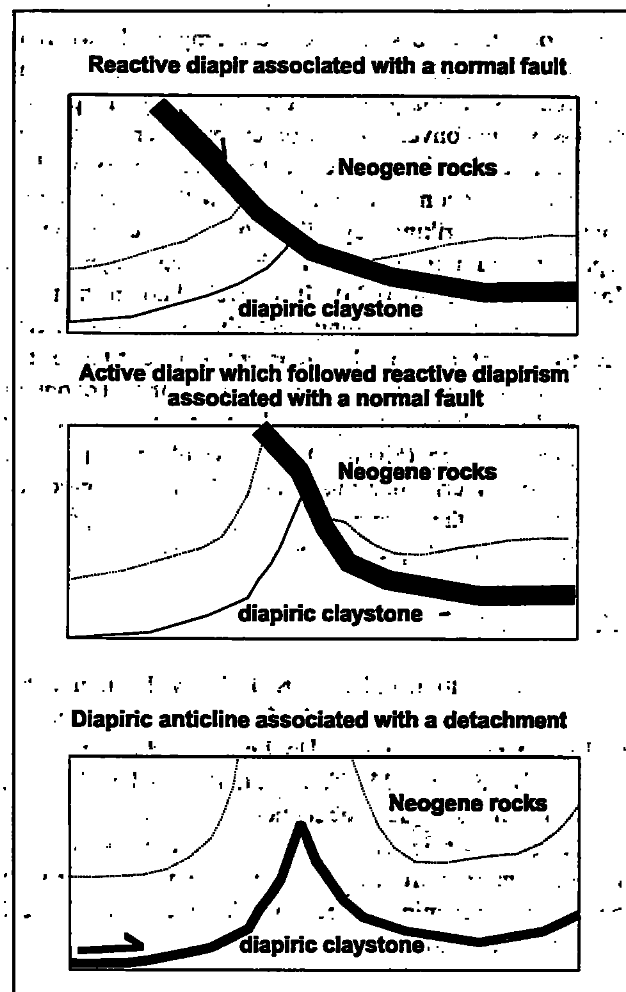

Figure 3. Schematic examples of three types of diapiric structures envisaged in the study area.

diapir). The model then requires a subsequent phase of post Pliocene normal faulting which may be accompanied by further reactive diapirism.

Conclusion and Implications for Oil Exploration

The model presented explains many of the features of the "unusual" structures in the northern part of the East Coast margin. Although the processes of diapirism and gravity sliding have been proposed previously by several workers in this area eg Stoneley (1962, 1960), none have combined the processes in the way outlined in this paper.

Extensional structures are most obvious in the Raukumara area but are also known to occur further south in Hawke Bay (A Nicol pers comm 1998). These structures are expected to be present throughout the East Coast North Island in one form or another where clay-rich rocks with high fluid content occur. In other areas where gravitational structures were not formed, compressional diapirism and detachment folding may still have strongly influenced the structural style.

I have not come across documented examples elsewhere in the world of thin skinned extension and diapirism in convergent plate margins; most examples are in passive margins, while convergent margin examples are associated with compressional structures in the accretionary wedge. However, the geometric similarities with other diapiric provinces are striking regardless of tectonic setting or diapiric medium (evaporite or 'shale') (eg Niger Delta, Morley and Guerin 1996). It is well known that the processes of gravity sliding and diapirism can create attractive structures for oil entrapment. A recent test of the model by the IndoPacific consortium, the Tokomaru seismic line, shows strong similarity to the previously drawn cross-section (Figure 2). In view of these points I would strongly urge that this structural style is considered in other parts of the margin, as it may prove to be a powerful predictive tool for interpreting subsurface structure.

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