Kora – A Study of a Miocene, Submarine Arc-Stratovolcano, North Taranaki Basin, New Zealand

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Abstract

Kora is a relict submarine arc-stratovolcano buried offshore in north Taranaki Basin, New Zealand. Kora was active on the seafloor in middle to upper bathyal water depths from the late Early Miocene to Late Miocene times. Post-eruptive burial of the volcanic edifice by Mohakatino Formation and Giant Foresets Formation sediments has preserved the edifice and its flanking volcaniclastic deposits.

Arco Petroleum New Zealand Inc. drilled the Kora feature in 1987 and 1988. Core recovered from the Kora-1A, Kora-2, and Kora-3 wells contain lithologies derived entirely from fragmented volcanic rocks, with no evidence for massive lavas or pillow lavas. Typical lithologies are interbedded tuffs, hyaloclastite tuffs, volcanic conglomerates, and tuff breccias. The framework clasts in the tuff breccias and conglomerates are porphyritic andesite lithic clasts and andesite eruptives. The lithics were derived from subvolcanic intrusions that formed prior to the main period of edifice construction between 16 Ma. and 12 Ma. The round porphyritic conglomerate framework clasts were shaped in *transit* through the volcanic conduit during volcanic eruptions. Conglomerates lack a planar clast fabric and have a polymodal matrix. They were deposited as density modified grain flows. The tuff breccias are the suspended tails of these deposits. The interbedded tuffs and sparse pebble trains are interpreted to be suspension deposits derived from primary subaqueous eruptions.

The fragmental volcaniclastic rocks erupted from Kora were formed entirely at the water-magma interface from fuel-coolant interactions, and cooling-contraction granulation. In contrast, modern volcaniclastic rocks on the southern Kermadec submarine arc-volcanoes, Rumble IV and Rumble V, commonly form from collapsing proximal pillow lava outcrops and small eruptive vents. Like Kora, epiclastic redeposition of volcaniclastic debris on Rumble IV and Rumble V include avalanche slides, debris flows, and grain flows, with little evidence for large-scale channel deposits.

Seismic facies comprising the Kora edifice were determined from seismic reflection profiles. The individual apron facies reflectors are identified. These comprise a downlapping terminal wedge that marks the downslope limit of volcaniclastic debris, or the surface along which they travelled. Long continuous, subparallel, individual apron facies reflectors typify northwestern aspects of Kora; these reflectors can be traced laterally from the crest of the edifice to the long thin terminal wedge at the toe of the edifice. The southeastern aspect consists of individual apron facies reflectors that are hummocky, discontinuous and intertwined, with short thick terminal wedges. The edifice has been subject to a sector collapse on NW slopes, where a slump scar occurs. The eastern slopes dip more steeply than the western slopes. The edifice has a conical morphology and is some 10 – 12 km in diameter.

The major element geochemical analyses from Kora have been compared to geochemical anlayses from the Coromandel, Waitakere, Rumble IV, Wairakau, Egmont, Titiraupenga, Alexandra, Kiwitahi, and Tongariro volcanic centres using discriminant function analysis. Results have identified four assemblages of volcanic centres with comparable major element geochemistry. Kora, which fits in to the Waitakere, Wairakau and Alexandra volcanic assemblage is a southward extension of the Northland volcanic "trend".

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Joshua Adams
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Chapter 2

1.0 INTRODUCTION

1.1 BACKGROUND

Kora is a Miocene submarine arc-volcano buried beneath the western margin of the Northern Graben in New Zealand's offshore Taranaki Basin (Fig. 1.1). The Kora Structure was first studied in 1988 after processing of seismic reflection data and subsequent drilling by Arco Petroleum N.Z Inc. unveiled a potential hydrocarbon reservoir. The exploration programme around the Kora Structure was abandoned by Arco after assessment of the structure revealed sub-economic quantities of marine sourced oil (Reed, 1992). A large amount of well and seismic reflection data associated with the Kora prospect are now held on open file with the New Zealand Ministry of Commerce in Wellington under prospect license PPL 38447. These data have been used in this study to model the volcaniclastic processes associated with the development of the Kora edifice, and to define a "parent arc" for the Kora volcano.

Major element geochemical analyses from eruptive rocks at Kora have been compared with published major element analyses from 9 North Island Miocene to Recent volcanic centres using discriminant function analysis to determine the likely parent arc for the Kora Volcanic Centre. The size and extent of the Kora volcaniclastic depositional units flanking the volcanic edifice has been defined through interpretation of seismic reflection profiles, while the transport mechanisms have been inferred from analyses of the textural fabric observed in the cores. These data have been combined with previously published data, including radiometric dating, XRD analyses, and geophysical well logs (Arco Petroleum N.Z Inc., 1988a; 1988b; 1988c; and Bergman *et al.,* 1992) to develop a model of the Kora Structure. This model has been "tested" by comparing it with published observations of volcaniclastic processes associated with modern submarine arc volcanoes in the Tonga-Kermadec arc (Gamble *et al.,* 1993; Wright, 1993a,1993b,1996) and in the Izu-Ogasawara arc (Dietz, 1954; Fiske *et al.,* 1998).

There has been limited research in the field of submarine arc volcanism and the associated volcaniclastic processes and deposits. This is largely because of the practical limitations that restrict the study of modern analogues in deep submarine environments. The large amount of well and seismic data associated with Kora, and

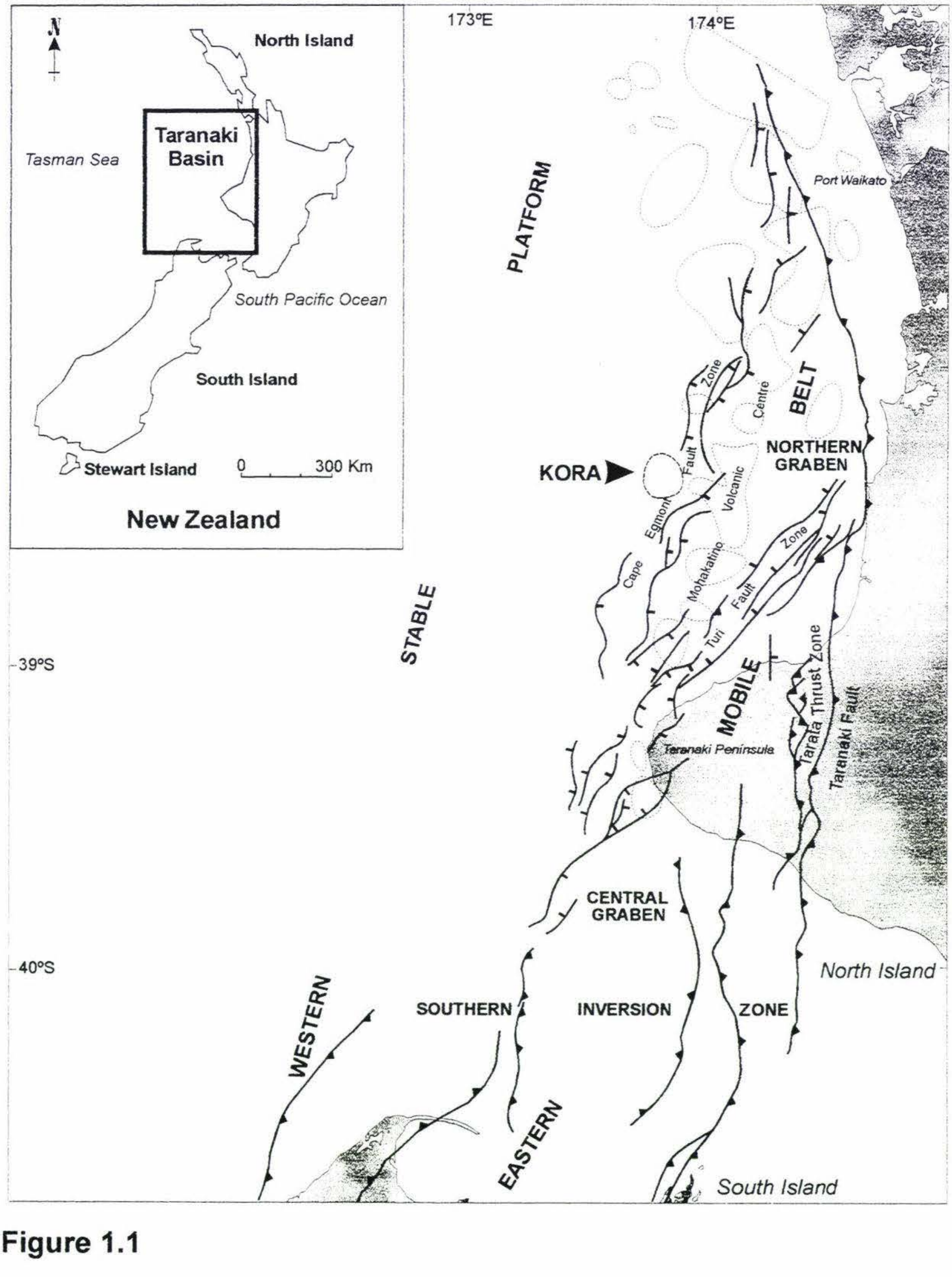


Figure 1.1

Location map showing Kora and the main structural features of the Taranaki Basin (After King and Thrasher, 1997) the preserved nature of the Kora edifice, provide a good example of a submarine arc-volcano. Consequently results from this research will contribute new information to the global database for submarine arc-volcanism, as well as contributing to the record of Late Cenozoic volcanism in New Zealand.

1.2 GEOLOGICAL SETTING – TARANAKI BASIN

Taranaki Basin is presently New Zealand's primary oil and gas producing region. This Cretaceous and Tertiary sedimentary basin constitutes an offshore and onshore area of some 100 000 km^2 (King, 1994), and embraces most of the western margin of the North Island of New Zealand. The basin is bounded in the east by the Taranaki Fault, and extends west to where Neogene sediments prograde on to the Challenger Plateau. The southern limits of Taranaki Basin are thought to merge with the basin and range province of Northwest Nelson, while the northern part of Taranaki Basin is contiguous with the offshore Northland Basin (King, 1994), however, a latitude of 37°S is designated the boundary between these two sedimentary basins (Isaac *et al.*, 1994).

1.2.1 Structural Components

Taranaki Basin is subdivided in to two structural provinces; the Western Stable Platform, and the Eastern Mobile Belt (Fig. 1.1). The easternmost part of the Western Stable Platform occurs where Neogene depositional sediments prograde on to the regionally subsiding sea floor (King and Thrasher, 1997), while the Eastern Mobile Belt consists of a northern sector consisting of the Northern Graben and Central Graben, and a southern sector which includes the Southern Inversion Zone and Tarata Thrust Zone (King, 1994). The boundary between the Eastern Mobile Belt and the Western Stable Platform is defined by the eastern limit of plate boundary deformation on the overriding Australian plate (King, 1994).

1.2.2 Stratigraphy and Geological History

Taranaki Basin contains up to 9 km of Cretaceous and Tertiary sedimentary fill (Palmer, 1985). The stratigraphy is presented in Fig. 1.2. The Cretaceous - Cenozoic geological history of Taranaki Basin is well documented in a number of papers, for example King and Thrasher (1992; 1997), King (1994), Stern and Holt (1994), and

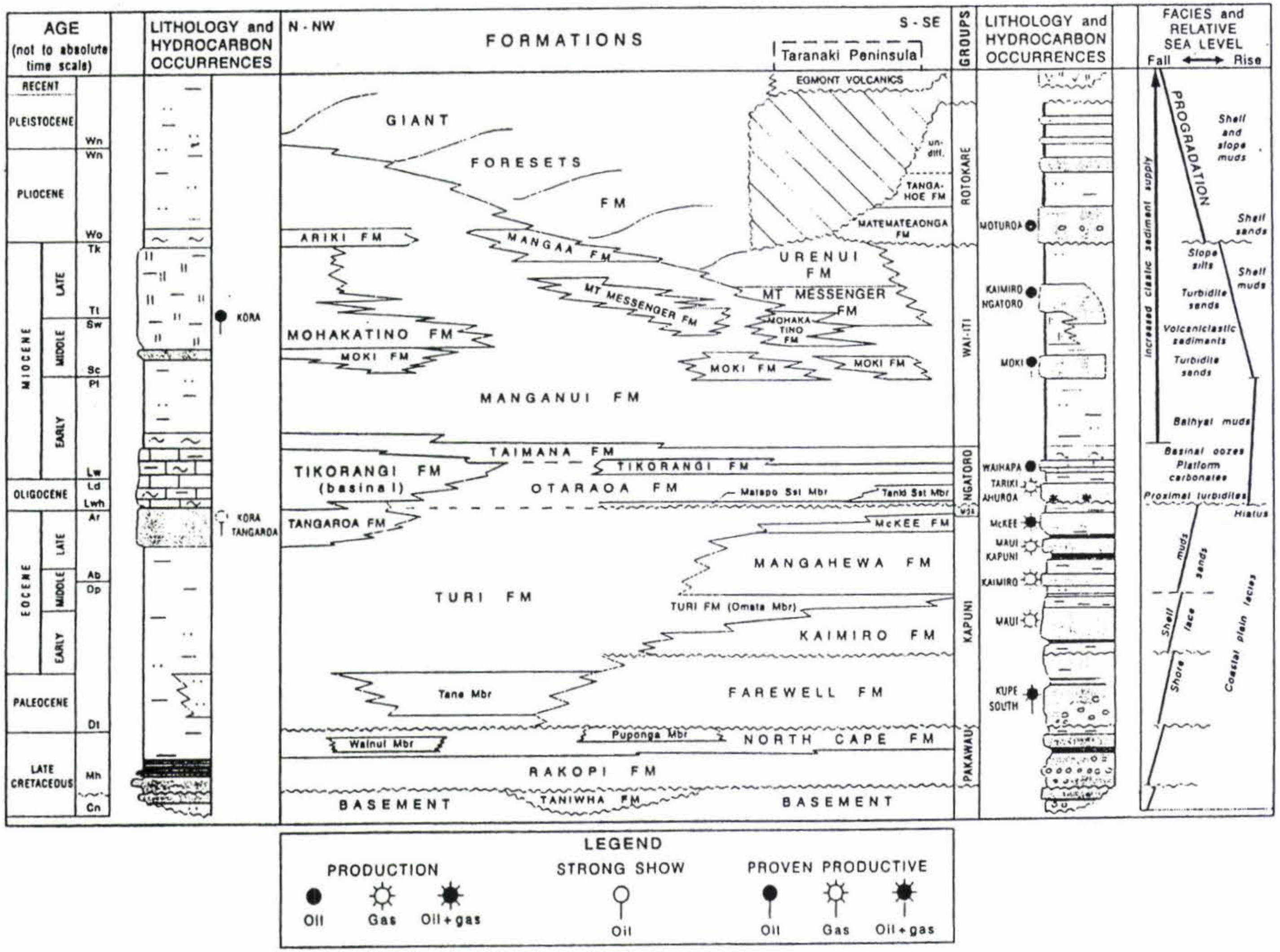


Figure 1.2

Cretaceous-Cenozoic stratigraphic framework for Taranaki Basin (from King and Thrasher, 1997)

Palmer and Andrews (1993). Most authors recognize four intervals that have played a key role in the geological development of Taranaki Basin.

1. From 80 Ma to 53 Ma the Tasman Sea opened in response to extension along the eastern margin of Gondwanaland.
2. The Late Cretaceous and Paleocene Taranaki Basin was largely emergent and sedimentation included deposition of coal measures and coastal plains deposits (Palmer, 1985).
3. From the Eocene Taranaki Basin gradually submerged, and by Early Oligocene a passive margin had developed in association with subduction along the Australian/Pacific plate boundary northeast of New Zealand. (King and Thrasher, 1997).
4. The final period of basin development occurred from Oligocene to Recent when convergent tectonics related to the present day Australian/Pacific plate boundary caused deformation of the basin fill as it is seen today (King and Thrasher, 1997).

1.2.3 Miocene Volcanism in the Taranaki Basin – The Mohakatino Volcanic Centre

Within the stratigraphic framework outlined above, Kora is one of 25 recognized Miocene intra-arc stratovolcano complexes buried in the Northern Taranaki Basin (Bergman *et al.*, 1992). These stratovolcano complexes were originally identified from magnetic anomalies (Hatherton, 1968) and collectively form the Mohakatino Volcanic Centre. The volcanic centres form a NE-SW trending lineament along the axis of the Northern Graben (King and Thrasher, 1997) between Cape Egmont in the south and Port Waikato farther north. Here the Mohakatino volcanics converge on the NW-SE trending western belt of the Early Miocene Northland Arc. The Northern Graben is mostly a post-Mohakatino feature which formed predominantly during the Plio-Pleistocene in response to fault activity along the west bounding Cape Egmont Fault Zone and the east bounding Turi Fault Zone (King and Thrasher, 1997). The Kora Structure is buried within the western rim of the Northern Graben in the Cape Egmont Fault Zone and is one of the most westerly volcanoes within the Mohakatino Volcanic Centre.

The onset of volcanism in the Mohakatino centre began in the late Early Miocene with intra-basement intrusion, followed by extrusive submarine volcanic eruptions which peaked between 14 and 11 Ma (King and Thrasher, 1997). This phase of volcanism coincided with pronounced tectonism associated with the developing Australian/Pacific plate boundary and migration of the instantaneous pole of rotation away from New Zealand between 21 Ma and 10 Ma (Walcott, 1987). For example, convergent plate motion first became evident between 23 Ma and 20 Ma when basement rocks were overthrust in a westerly direction along the Taranaki Fault (King and Thrasher, 1997). Mohakatino volcanism finally ceased at approximately 7-8 Ma (e.g. Bergman *et al.,* 1992), although some of the buried volcanics adjacent to the Egmont Peninsula may be younger (King and Thrasher, 1997).

1.3 KORA VOLCANIC CENTRE

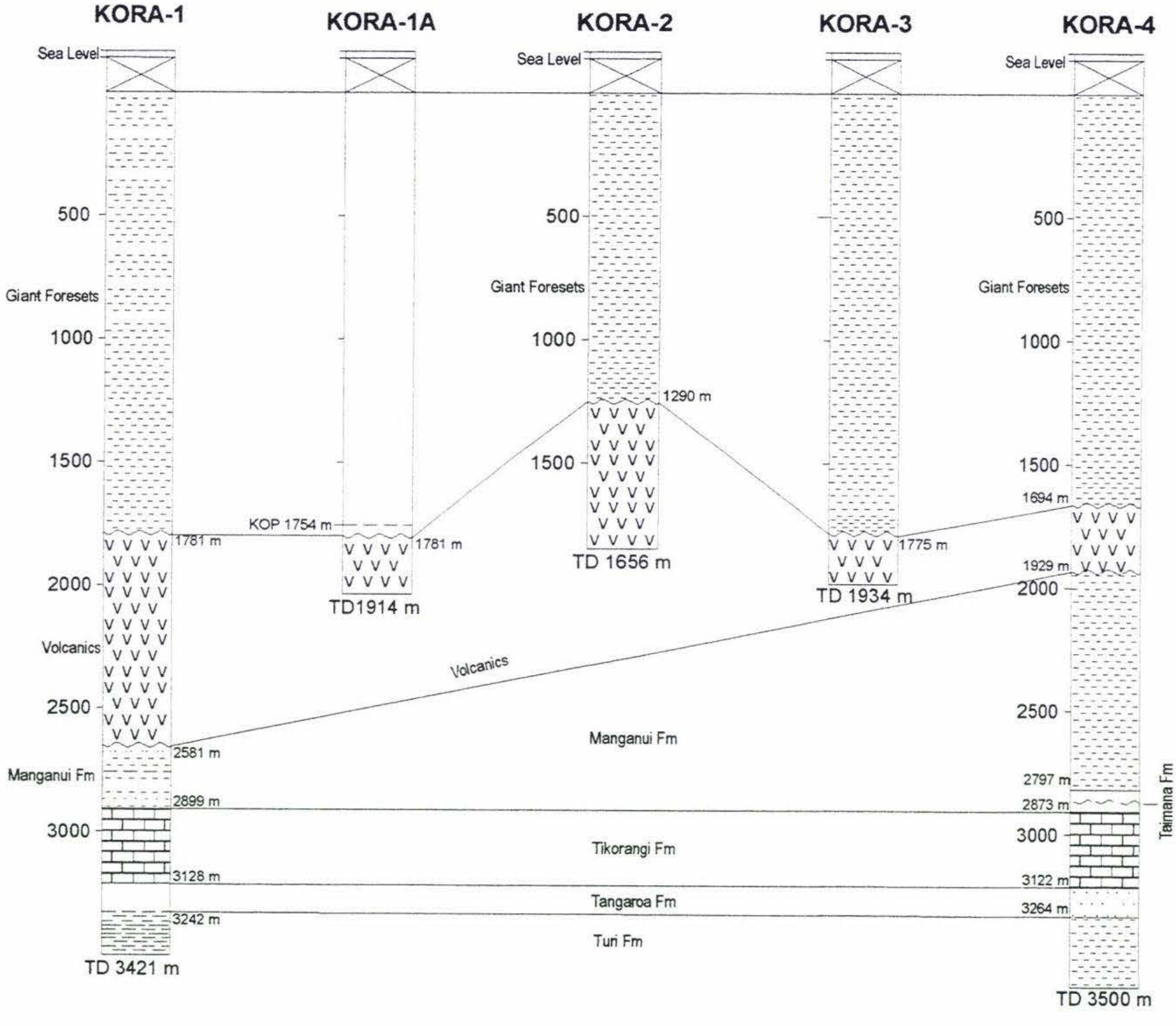
1.3.1 Distribution of Exploration Wells and Drilling Results

In 1988, Arco Petroleum NZ Inc. commenced a hydrocarbon exploration programme in which 5 wells (Kora-1, Kora-1A, Kora-2, Kora-3 and Kora-4) were drilled in to the Kora volcanic edifice (Fig. 1.3). Extensive core and electric log data were collected. The general drilling results and stratigraphy for each well are described below and summarised in Fig. 1.3. A more detailed description of the lithologies encountered in the Kora wells is covered in Chapter 2.

Kora-1 drilled the southeastern flank of the volcanic edifice. The top 1631.6 m of this well "along hole (AH)" consists of Plio-Pleistocene Giant Foresets Formation - a succession of siltstones and mudstones deposited as the shelf-break migrated westward and northward (Beggs, 1990; King and Thrasher, 1997). Underlying the Giant Foresets Formation, Miocene volcanics occur between 1781 m bkb and 2581 m bkb, and beneath these volcanics the well intersected 320 m of Early Miocene, Manganui Formation 'deep-water' mudstones (King and Thrasher, 1997). The Manganui Formation is underlain by Tikorangi Formation between 2899 m bkb and 3128 m bkb. These sediments are highly calcareous outer-shelf and upper-slope carbonates that were deposited during the Late Oligocene and Early Miocene (King and Thrasher, 1997). Beneath the Tikorangi Formation from 3128 m bkb to 3242 m bkb, deep marine sandstones comprising the Tangaroa Formation occur. This formation contains deep marine sandstones that were emplaced during the Late

Figure 1.3

Composite stratigraphic columns for Kora wells (adapted from McManamon, 1993)



Eocene and Early Oligocene as debris flows, liquified flows and turbidity currents (King and Thrasher, 1997). From the base of the Tangaroa Formation to 3421 m bkb (total well depth) Turi Formation sediments form the final metres of the Kora-1 well. This formation contains shelf and bathyal calcareous marine mudstones that were deposited from the Paleocene to late Eocene (King and Thrasher, 1997).

Kora-1A was a deviated well, drilled from a window in Kora-1 between 1754 m bkb and 1761.5 m bkb. This well was drilled entirely within the volcanics between 1781 m bkb and 1914 m bkb (McManamon, 1993). Kora-2 location is 2.5 km NNW of Kora-1 and that well drilled to a total depth of 1656 m bkb. Giant Foresets Formation account for the uppermost 1130 m and terminate directly above the volcanics at a depth of 1290 m bkb. The well terminated within the volcanic interval (McManamon, 1993). Kora-3, located 1 km NNW of Kora-1, drilled to a total depth and terminated at 1934 m bkb within the volcanics. The upper 1622.5 m of Kora-3 comprises of Giant Foresets Formation while the top of the volcanics occurs at 1775 m bkb (McManamon, 1993).

Kora-4 is located 4.5 km WSW of Kora-1 and drilled to a total depth of 3500 m bkb. The upper 1500 m comprises Giant Foresets Formation, with the volcanics spanning the interval between 1694 m bkb and 1929 m bkb. Directly beneath the volcanics, the Manganui Formation extends to a depth of 2797 m bkb, and below Manganui Formation, is 76 m AH of early Miocene marl, Taimana Formation. This formation represents a depositional hiatus which occurred in the Early Miocene as clastic sedimentation slowed. The Taimana Formation is underlain by Tikorangi Formation to a depth of 3122 m bkb and below this, Tangaroa Formation occurs until 3264 m bkb. Kora-4 reached a total well depth of 3500 m bkb within the Turi Formation.

1.3.2 Previous Studies

Analyses of the lithological and well data were summarised in a single comprehensive paper published by Bergman *et al.,* (1992). Other than the unpublished well reports this has been the only significant paper dealing specifically with the volcaniclastics at Kora. Other workers who have investigated Kora include McManamon (1993) who published a brief summary of the drilling results and petroleum geology of the Kora prospect, Reed (1992) who has studied the geochemistry of the oil from Kora, and Hayward and Strong (1988) who reported on the foraminiferal faunas in Kora-1. Since this initial work no other research referring specifically to Kora has been published. The work by Bergman *et al.*, (1992) provides an excellent summary of the "stratigraphy, volcanic facies, petrology, geochemistry, age and evolution" of Kora and its encompassing volcaniclastic sediments. The main points from this paper relevant to this study are detailed below.

The volcanic rocks erupted from Kora are subduction-related arc-andesites derived from depleted mantle based on major and trace element geochemistry. The absolute ages of the volcanic rocks vary between 20 Ma and 8 Ma with the earliest ages (*between 20 Ma and 19 Ma*) corresponding to a pre-eruptive intrusive event. The inception of eruptive volcanism began some time between 15 Ma and 17 Ma and the volcanism ended as late as 8 Ma (Bergman *et al.*, 1992).

The biostratigraphic and palaeoecological evidence (Hayward and Strong, 1988), indicates that the volcaniclastics drilled by the Kora wells were deposited under fully marine conditions. Further evidence to support this interpretation is the lack of vesiculated volcanic clasts in the lithologies cored from Kora. The top of the volcanic interval contains benthonic foraminifera indicative of upper bathyal water depths (i.e. Hayward, 1986; Hornibrook *et al.*, 1989; in Bergman *et al.*, 1992). Likewise, benthonic foraminifera within the overlying Giant Foresets Formation sediments and samples from deeper within the volcanics also indicate middle and uppermost bathyal water depths.

Some 40 seismic profiles were acquired across the Kora feature (Bergman, pers comm). These show that the Kora edifice has up to 1000 m of relief with 8°-15° slopes and a basal diameter of some 10 km. The lithologies cored from Kora include "bioturbated, calcite-cemented tuffs; tuffs, lapilli tuffs, hyaloclastite tuffs, lapillistones and tuff breccias; volcanic sandstones and reworked tuffs; and volcanic conglomerates and breccias" (Bergman *et al.*, 1992).

The mineralogy and petrography indicates that the lithologies are predominantly andesitic (Bergman *et al.*, 1992). The primary minerals are plagioclase (andesine –

labradorite), hornblende, clinopyroxene (augite), quartz, and Fe-Ti oxides (titanomagnetite and ilmenite). Many of the lithologies have altered to clays that were derived from glass as well as plagioclase and hornblende. For example smectite (after glass, plagioclase, and hornblende), quartz (after plagioclase and hornblende), zeolites (after glass, plagioclase and hornblende), illite (after glass and plagioclase), analcite, corrensite, biotite, pyrite, calcite, and hematite are the prevalent alteration phases (Bergman *et al.,* 1992).

The work of Bergman *et al.,* (1992) and the other industry related studies present a comprehensive, broad range of analyses from Kora. These have characterised the Kora Structure from a hydrocarbon reservoir perspective. The objective of this study is to place Kora within its volcanological setting.