STRUCTURAL CONTROL OF THE RESERVOIR ROCKS AT THE NGAWHA GEOTHERMAL FIELD, NORTHLAND, NEW ZEALAND

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ABSTRACT

The low porosity (< 4%) of the Waipapa Greywacke reservoir rock, and the comparative abundance of youthful faults and lineaments on the Ngawha geothermal anomaly, indicates that fracture zone permeability should be the drilling target. However, the reservoir is blinded by c.500 m of low bulk permeability allochthonous cap-rock that has inadequate outcrops for structural studies. Notwithstanding, the physiography has been partly controlled by fault crush zones which appear as lineaments on Landsat and aerial photographs. Within the northland region, Ngawha lies at a nodal intersection of major northwest, east-northeast, northeast and meridional faults, and is locally covered by a network of predominantly northeast and northwest, often curved, fractures. The late Cenozoic volcanic and hot spring alignments follow the northeast trends, and a sigmoidal graben-like structure follows the general northwest trend of the Ngawha Basin except for a central northeast section on the line of the main Ngawha springs. A dextral rotational torsional stress system is one possible cause of the local fracture pattern, and could have been the result of interacting major east-northeast and meridional faults with respectively, left and right lateral strike-slip components in a northeast-southwest principal horizontal stress system.

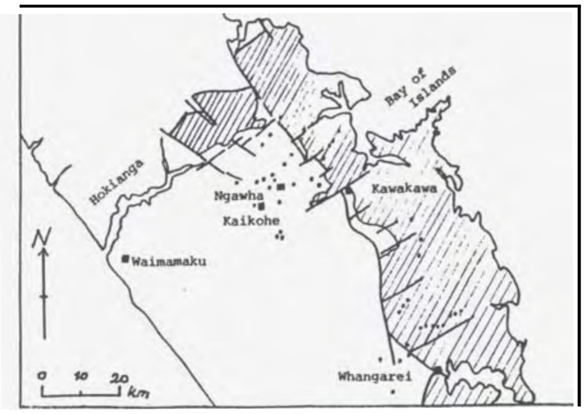

Figure 1. Locality map with Ngawha in relation to eruption centres of Bay of Islands Volcanic Zone (dots), Waipapa Greywacke (hachured Cretaceo-Tertiary cover (blank) and main boundary faults to Waipapa Group.

GEOLOGICAL SETTING

Ngawha Geothermal Field (Fig. 1) is set within the late Cenozoic Bay of Islands Volcanic Zone (Kear et al. 1961) which although predominantly basaltic, includes minor peralkaline rhyolite and calc-alkaline andesite (Bell and Clarke 1909; Ferrar 1925; Brothers 1963; Skinner 1966; Mulheim 1973; Bowen 1974; Smith et al. 1977; Heming 1979. Volcanism began at least 1.33 m.y. B.P. (Stipp and Thompson 1971) and continued until perhaps 1500 y. B.P. (Wellman 1962). Alignment of discrete eruption centres, multiple vents, rifts and hot springs, and the movement of eruption foci with time, is predominantly along northeast and northwest trends (Fleming 1945; Kear et al. 1961; Kear 1964), whereas the common fault alignment in the Permian to Jurassic Waipapa Greywacke rocks east and north of Ngawha are northwest. to north-northwest and east-northeast (Ferrar 1925; Kear and Hay 1961). The latter trend persists across the Ngawha area as major fault and volcanic centre alignments (Skinner 1966) and both trends are characteristic of faults cutting pre-Miocene rocks south and southeast of Ngawha (Hay 1960). However, faults cutting early Miocene Otaua Group and many cutting Oligocene Motatau Group are more northeasterly aligned (Hay 1960).

Ngawha also lies within an extensive area of Cretaceo-Tertiary rocks to the west of their overlap onto Permian-Jurassic Waipapa Group of greywacke and argillite that forms the local and regional basement (Fig. 1). The Cretaceo-Tertiary rocks, sometimes known as the Northland Allochthon (Ballance and Spörli 1979) and referred to in the past as Onerahi Chaos breccia (Bowen and Skinner 1972), thicken westwards from c500 m at Ngawha (Bowen and Skinner 1972) to greater than 3356 m at Waimamaku (Hornibrook et al. 1976). At Ngawha, most if not all these rocks are allochthonous but at Waimamaku only the sequence above 2865 m is so interpreted. The source, direction and distance of emplacement of the allochthonous rocks is the subject of much speculation (Brothers 1974), ranging from hundreds of km (Ballance and Spörli 1979) to almost zero (J. C. Schofield, pers. corn. 1980). Certainly emplacement of the allochthon preceded the early Miocene volcanism and sedimentation of Otaua, Parengarenga and Waitemata Groups (Hornibrook et al. 1976; Ballance and Spörli 1979), and near Ngawha, may also have preceded deposition of argillaceous limestone of Motatau Group (Oligocene) since the limestone is common all about the Ngawha region, yet unlike the Waimamaku sequence, has not been intersected by the Ngawha drillholes.

Within the geothermal context, these Cretaceo-Tertiary rocks form a well-nigh impermeable cap-rock to the system since they consist of sheets of siliceous and calcareous clayey sediments separated by at least two major clay-rich melange zones of tectonic breccia. Fault and fracture permeable zones tend to be self-sealing because of the clays and calcite mobility, so that the total discharge of the surface springs is but a few litres/second (Ellis and Mahon 1966).

The various lithologies within the underlying Waipapa Group also have low porosities (maximum 4%). As these rocks are the reservoir to the geothermal system, the obviously variable, but in the case of drillholes Ng4 and Ng5, very high fluid transmissivity must be due to a superimposed joint/shear fracture permeability. The geologist's aim is to locate such permeable zones.

TECTONIC SETTING

Because of the age difference between the emplacement of the reservoir rocks, the cap-rock, and the late Cenozoic volcanism and hot spring activity, it should be possible to separate those structures inherited from the pre-Cretaceous and Cretaceo-Tertiary allochthonous rocks from those initiated in the late Cenozoic during the evolution of the Bay of Islands Volcanic Zone. To the south and southeast of Ngawha, and at Kawakawa, the complexity and extent of faulting, involving as it does the Oligocene rocks, is well documented (Hay 1960; Kear and Hay 1961), but apart from the few faults on the maps of Ferrar (1925; 1934), little is known of the regional fault pattern. The late Cretaceous and early Tertiary rocks weather deeply and erode easily leaving few outcrops suitable for structural interpretation, but fault crush zones influence the drainage and physiography of the terrain and show up as well developed lineations on both Landsat and conventional aerial photographs. Major regional lineations were determined from Landsat colour photo 30180-21314, produced by PEL (DSIR) at 1:500,000 from bands 1, 2 and 4 by positive edge enhancement. In order to be as objective as possible, lineations were plotted on transparent overlays and combined as a map of the most obvious lineations (Fig. 2) which were then compared with the known geology.

Four general trends are apparent: northwest, e.g. the well defined faulted western margin of Waipapa Group; east-northeast, e.g. the cross faults of Waipapa Group; meridional in the Cretaceo-Tertiary rocks south of Ngawha; and northeast in the Oligocene to Quaternary rocks. These trends lie in four broad zones of faulting which converge on Ngawha as a structural node. The most prominent lineations observed are undoubtedly the Kawakawa Fault, in existence prior to the late Eocene but with post Eocene throw of at least 200 m (Ferrar 1925), and its western analogue, here named the Waimamaku Fault which stretches east-northeast from the Hokianga Harbour mouth through Otaua-Punakitere to meet western branches of the Kawakawa Fault to the south of Ngawha; this Waimamaku-Kawakawa fault zone must count as a major Cenozoic feature in the geological history of North Auckland.

From the north, faults parallel to the strongly deformed Umawera Fault zone strike southeast through Putahi Rhyolite into Ngawha, and from the south, a broad zone of complex faulting directed towards Ngawha includes several near meridional faults, namely the Otaua, the Awakino-Tangowahine-Awarua and the Mangatoa-Kaikou-Waiopiko-Pokapu Faults and their trace correlatives (Ferrar 1925; 1934; Hay 1960; Thompson 1961). All appear to be cut off by or to merge with the Waimamaku-Kawakawa Fault zone via northeast trending segments of which the continuation of the Awakino-Awarua Fault system passes close to Ngawha Springs. This system appears to have a right lateral strike-slip component since there is offset and apparent sigmoidal drag across the Tangowahine Anticline of Hay (1960).

Grindley (1979) speculated that such a meridional right lateral strike-slip fault deep beneath Ngawha may have controlled magma rise (resulting in the elongate heat-flow pattern), and produced subsidiary northeast trending tensional fractures and thus a permeability in the Waipapa Group basement. From the alignment of volcanic rifts, multiple vents, centres, discrete groups of centres, pit craters and springs (Fig. 3), a northeasterly fracture pattern must have certainly played an important role in the development of the reservoir at Ngawha (fig. 1 - Fleming 1945; Kear 1964). Indeed, the siting of exploration drillholes by the geologists has used this as a working hypothesis to find permeable zones. There is further confirmation of this trend from structural contours drawn on the top of the Waipapa Greywacke beneath Ngawha (Fig. 4) using drillhole intersections (1st order data) and resistivity soundings (2nd order data), the latter with an estimated error of about 10%. The result is a northeast trending basin crossed by a northwest trending ridge on which drillholes Ng2, 4 and 9 are sited. There is good coincidence with the alignment of hot and cold springs (Fleming 1945) and a fault mapped by Hay (1960) near Ng7. Of course, without more refined data, there is little chance of recognising displacements of less than about 30 m, or of identifying individual fracture zones of permeability.

The frequency distribution of such fracture zones at Ngawha may be remarkably high. Grindley (1980) prepared a fault/lineation map from conventional aerial photographs on which surprisingly few lineations could be recognised to the south of Ngawha, suggesting that the Ngawha block has indeed been the locus of more intense tectonism than surrounding regions (Fig. 5). Some lineations show physiographic displacement and are undoubtedly faults; others are of more obscure origin but are presumed to be secondary faults and joints. The majority of lineations are straight or gently curved sections of streams channelled along narrow crush zones; a minority offset spurs and ridges and thus have moved relatively recently. Because few displacements are recognisable, all are presumed to be noraml (tensional) faults although minor strike-slip cannot be ruled out.

The lineation pattern has some interesting features. The east-northeast trending Mangamutu, Waiparere and Kawakawa Faults enter the Ngawha area from the east and splay out into several diverging strands. What may be their continuation into the Waimamaku Fault, trend away to the west-southwest. The Ngawha basin and the hills to the west are dominated by a northwesterly, somewhat curved fracture pattern parallel to the northern and southern sections of the basin. These sections are offset by a 2 km northeast trending central section along the line of the main zone of thermal activity. A small graben-like structure appears to continue the Ngawha basin to the southeast to meet. the western strands of the Kawakawa Fault system. A less distinct, wider graben may extend northwest from Ngawha through Putahi - Te Pua; the western boundary fault is quite distinct on the aerial photos and may be the continuation, although with opposite downthrow, of the Umawera Fault zone.

Figure 2. Major lineamnets of probable faults in central Northland observed on Landsat photo 30180-21314; hachured area is Waipapa Greywacke. Identified faults are shown with dentate pattern as follows: U-Umawera, Wo-Waihou, T-Turntable Hill, P-Puketona, K-Kawakawa, Po-Pokapu, Or-Otai+Ramarama, Pu-Puketitoi, Ko-Kaikou, Wp-Waiopiko, M-Mangatoa, A-Awakino, Tw-Tangowahine structure, Aw-Awarua, Mk- Mangakahia, Kh-Kaihu, Ot-Otaua, W-Waimamaku, O-Otao.

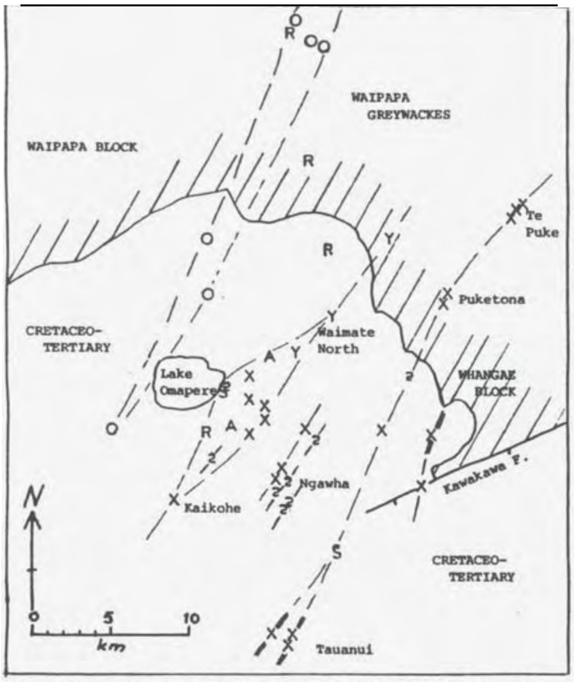

Figure 3. Northeast trend of eruption centres of older (O) and younger (Y) Horeke Basalts, Taheke Basalts (X), Quaternary andesites (A) and rhyolites (R), sinters (S), hot and cold springs (♨) and rift craters (✐).

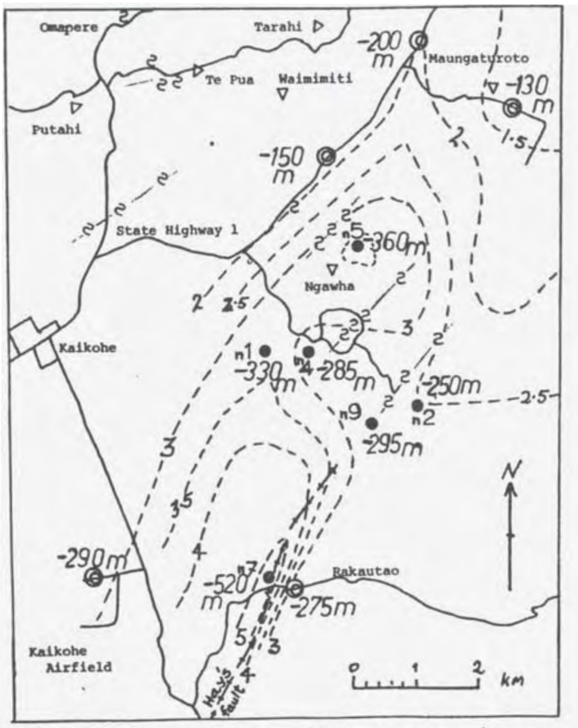

Figure 4. 100 m negative structural contours on top of Waipapa Greywacke at Ngawha and relation to Hay's fault (1960), drillholes (● - n5) resistivity soundings (◎), volcanic centres (▽), and springs (♨); depths in metres and contours are below mean sea level datum.

STRUCTURAL SYNTHESIS AND CONCLUSION

Earlier in this paper, Ngawha was described as the nodal intersection of several major structural lineations of which the meridional Awarua-Awakino Fault system had apparent right lateral strike slip. This is appropriate to the late Cenozoic northeasterly principal horizontal stress previously determined for the Auckland-Northland region (Wellman 1954; Wodzicki and Weissburg 1970; Skinner 1967; 1976; Kear 1964; Schofield 1978; Waterhouse 1978), and thus east-northeasterly faults could have a left lateral strike-slip component. Because of the nodal position of Ngawha, a torsional stress system could have developed locally by the interference of the various faults to yield dextral rotation of the Ngawha block, distortion of the original northwest trending Ngawha basin or graben into a sigmoidal shape, and the production of tensional fissures parallel to the strongly extended northeast section of the basin through Ngawha Springs (Grindley 1980).

Thus the drillhole siting philosophy has been amended to explore the western fault zone between Ng4 and Ng9 and the graben like structure extending northwest and southeast of Ngawha Springs, as well as continuing to explore northeasterly trending spring/fracture zones throughout the Ngawha Basin.

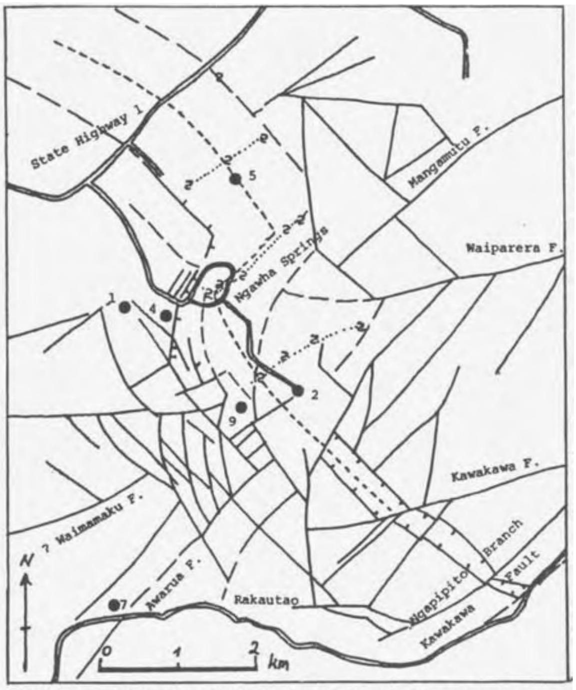

Figure 5. Lineaments and faults in the Ngawha area recognised from conventional aerial photographs; short dashed line is axis of Ngawha Basin 'graben'; drillholes (●); springs (♨) alignment dotted. After Grindley (1980).

REFERENCES

Ballance, P. F., and Spörli, K. B., 1979, The Northland Allochthon. Jl. Royal Society N.Z. v. 9 (2), p 259-275.

Bell, J.M., and Clarke, E. de C, 1909, Geology of the Whangarei Subdivision, Hokianga Division. N.Z. Geol. Surv. Bull. 8.

Bowen, F. E. 1974, The Parahaki volcanics and their associated clays. N.Z. DSIR Bulletin 215.

Bowen, F. E., and Skinner, D. N. B. 1972, Geological interpretation of Ngawha'deep drillhole, Kaikohe, Northland (N15) N.Z. N.Z. Jl. Geology and Geophysics v. 15, p 129-139.

Brothers, R. N. 1965, &Thompson B. N., and Kermode, L.O. (editors) Kaikohe/Ngawha. N.Z. Volcanology, Northland, Coromandel, Auckland. N.Z. DSIR Information Series 49.

Brothers, R. N. 1974, Kaikoura orogeny in Northland, New Zealand. NZ Jl. Geology and Geophysics, v 17, p 1-18.

Ellis, A. J., and Mahon, W. A. J., 1966, Geochemistry of the Ngawha hydrothermal area. N.Z. Jl. Science v. 9, 440-456

Ferrar, H. T. 1925, The geology of the Whangarei-Bay of Islands Subdivision. N.Z. Geol. Surv. Bull. 27.

Ferrar, H. T. 1934, The geology of the Dargaville-Rodney Sub-division. N.Z. Geol. Surv. Bull 34.

Fleming, C. A. 1945, Hydrothermal activity at Ngawha, North Auckland. N.Z. Jl. Science and Technology v. B26, p255-276.

Grindley, G. W. 1979, Geothermal drilling at Broadlands and Ngawha, comparisons and contrasts. Proceedings N.Z. Geothermal workshop 1979 pt 1, p72-78. University of Auckland.

Grindley, G. W. 1980, Geological Structure of Ngawha geothermal field. Report to Geothermal co-ordinator June 1980.

Hay, R. F. 1960, The Geology of Mangakahia Subdivision. N.Z. Geol. Surv. Bull. 61.

Heming, R. F. 1979. A magmatic heat source for the Ngawha geothermal field. Proceedings 1st N.Z. Geothermal workshop 1979 pt 1 p.30-43.

Hornibrook, N. de B., Edwards, A. R., Mildenhall, D. C., Webb, P. N. and Wilson, G. J. 1976, Major displacements in Northland, New Zealand; micropaleontology and stratigraphy of Waimamaku 1 and 2 wells. N.Z. Jl. Geology and Geophysics v. 19 (2) p.233-264.

Kear, D. 1964, Volcanic alignments in Northland west of New Zealands Central Volcanic Zone. N.Z. Jl. Geology and Geophysics, v 7 (1) p. 24-44.

Kear, D. and Hay, R. F. 1961. Geological Map of N.Z. 1:250,000 Sheet 1 North Cape. N.Z. DSIR Wellington.

Kear, D., Waterhouse, B.C. and Swindale, L. D. 1961, Bauxite deposits in Northland. N.Z. DSIR. Information Series, 32.

Mulheim, M. M., 1973, Volcanic geology of the Kaikohe area, Northland, N.Z. Unpublished M.Sc. Thesis, University of Auckland.

Schofield, J. C. 1978, Geological map of N.Z. 1:63,360 Sheet N48 Mangatawhiri, N.Z. DSIR.

Skinner, D. N. B. 1966, Geology of Ngawha in Kear D. (compiler), Ngawha geothermal area, Northland. Report 16 N.Z. Geol. Surv. p.3-19

Skinner, D. N. B. 1967, Geology of the Coromandel region with emphasis on some economic aspects. Ph.D. thesis, University of Auckland.

Skinner, D. N. B. 1976, Geological map of N.Z. 1:63,360 Sheet N40 and part sheets N35, N36 and N39 Northern Coromandel. N.Z. DSIR. Wellington.

Smith, I. E. M., Chappell, B. W., Ward, G. K. and Freeman, R. S. 1977, Peralkaline rhyolites associated with andesite arcs of the southwest Pacific. Earth and Planetary Science letters v. 37, p.230-236

Stipp, J. J. and Thompson, B. N. 1971. K/Ar ages from the volcanics of Northland, New Zealand. N.Z. Jl. Geology and Geophysics v. 14 (2) p 403-413.

Thompson, B. N., 1961, Geological Map of N.Z. 1:250,000. Sheet 2A Whangarei. N.Z. DSIR.

Waterhouse, B. C. 1978, Geological map of N.Z. 1:63,360 Sheet N51 Onewhero. N.Z. DSIR.

Wellman, H. W. 1954, Stress pattern controlling lode formation and faulting at Waihi Mine and notes on the stress pattern in the northwestern part of the North Island of New Zealand. N.Z. Jl. Science and Technology v B36 p.201-206.

Wellman, H. W. 1962, Holocene of the North Island of New Zealand; a coastal reconnaissance. Royal Society of N.Z. Transactions geology v. 1 (5), p. 29-99.

Wodzicki, A., and Weissburg, B. G. 1970, Structural control of base metal mineralisation at the Tui Mine, Te Aroha, New Zealand. N.Z. Jl. Geology and Geophysics v 13 (3), p.610-630.