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GEOCHEMISTRY AND THE EXPLORATION OF THE NGAWHA GEOTHERMAL SYSTEM, NEW ZEALAND

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ABSTRACT

The Ngawha geothermal system is atypical of New Zealand geothermal systems, being located outside the Taupo Volcanic Zone, and contained in tight sedimentary structures. Early geochemical surveys of surface discharges indicated a high gas, high borate fluid, discharging in small quantities, to the surface. An initial well (drilled in the early 1960's, to 500m) produced a very gassy fluid before calciting. Deeper wells drilled and discharged in the early 1980's produced large flows of high gas fluid (up to 3wt%), at enthalpies around 1000 kj/kg. These low energy contents coupled with a low water to rock ratio, a very fractured structure, and consequent expected changes in the production fluid following exploitation, led to large scale exploitation plans being scrapped in 1982.

The close attention to geochemical studies before and during the drilling operations enabled predictions of fluid type, physical conditions at depth, fluid disposal problems, and hydrologic reservoir models that have proved to be correct. The project served to indicate the value of comprehensive exploration strategies which preceed the drilling phase, and the further value of, in particular, geochemical studies as an integral part of well testing procedures, for the updating of reservoir models. The close and open cooperation amongst the scientists and engineers involved was also of great value.

Location and Setting

The Ngawha (pronounced nah-fah, and meaning hot pool) Geothermal system is the only known high temperature geothermal system in New Zealand that is not within the Taupo Volcanic Zone, it being some 400km further to the north on the narrow Northland

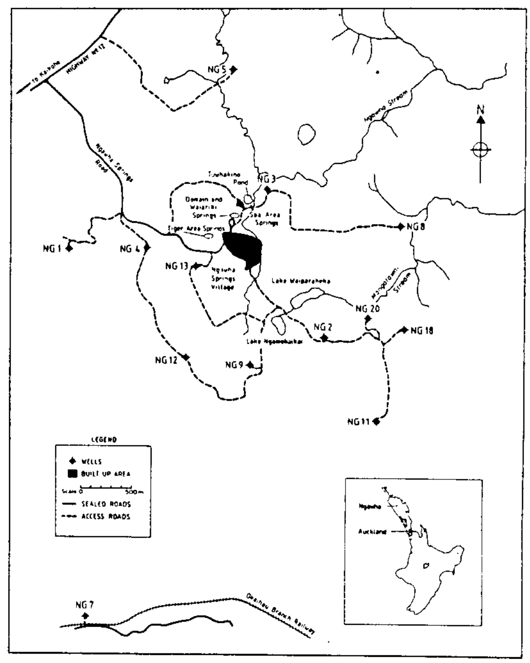

FIGURE 1: Location of the Ngawha system in the North Island, New Zealand.

Peninsula (Fig. 1). The system is contained in a lithologic environment quite different from that in the TVZ, since it is hosted in greywackes and capped by marine sediments, rather than silicic volcanics.

The Ngawha geothermal system has its surface expression in a shallow basin eroded into claystones which have been locally overlain by lake sediments and Pleistocene olivine basalt flows (Fleming, 1945). Underlying the superficial deposits the claystones continue to depths of 500m, forming part of a Cretaceous-Tertiary allocthonous 'chaos breccia', containing also mudstones, argillaceous limestones and coal measures, and of low bulk permeability. The breccia uncomformably overlies Waipapa Group greywackes and argillites which outcrop over much of the peninsula to the east; the contact zone itself tends to a coarse conglomerate which has a high permeability (Skinner, 1981).

The geothermal system occurs within a Quaternary-Holocene basaltic province which also contains at least four rhyolite centres, and an andesite dome, all probably emplaced in the Holocene.

The structural environment of the Ngawha area has been extensively discussed by Grindley (1981) and Skinner (1981), and most recently reviewed by Cox (1985). The geological and geophysical evidence suggests that the principle faults in the basement greywacke strike NNW, while the lineations of springs and other surface features have a NE alignment.

Thermal Features

The surface expression of the Ngawha system covers a wide area, but is of low intensity with few hot features. The Ngawha springs village is sited adjacent to a score or so of warm and hot pools which have a very limited liquid outflow (<2 l/s deep fluid). The dominant flow through the surface is of gas, and the outflow of this gas is very much more extensive.

The springs at Ngawha were well known to the Maori people; the earliest recorded European encounters were largely concerned with the mercury mineralisation associated with the thermal features. Small scale mining has been persued on several occasions, but the deposits proved to be superficial, and of limited extent. Interest in the thermal features themselves gave rise to some analyses (Park, 1906) and a comprehensive descriptive narrative by Bell and Clarke (1909). Water temperatures up to 66°C have been commonly recorded, although higher temperatures under the pools are easily located. The smell of hydrogen sulphide in the area of the baths is frequently quite strong, but it was only after a detailed survey in 1944 (Fleming, 1945), that the high boron content of the waters was discovered. Since then there have been several thorough chemical and isotopic surveys, reported by Ellis and Mahon 1966), Giggenbach and Lyon, (1977), and also a monitoring of the discharges during exploration, summarized in Sheppard and Johnston, (1984), and Sheppard, Giggenbach and Johnston (1985).

These surveys showed that the fluids arising in the Ngawha system differ in a number of significant ways from all other New Zealand systems, and have only a few similar analogues throughout the world. While the salinities of Ngawha waters are similar to the TVZ systems, they are higher in ammonia, bicarbonate and borate, relative to chloride (Table 1). The gases are composed primarily of CO_2, and also have comparatively high concentrations of CH_4 (2-3 mol %) and about 1 mol % H_2S (Table 2). The isotopic compositions of the waters shows a very large $\delta^{18}O$ shift (+11‰) with respect to the local metoric water, and a smaller but possibly significant δD shift of -5‰.

The deep well drilling programme began in the early 1960's with the drilling of the 591m deep NG1; in the period 1978 to 1983 a further 14 wells were drilled, mostly to depths about 1200m, but finishing with in the well NG13 to 2333m. Most of these wells have been discharged, but for short periods only, due to the limited ability to dispose of large quantities of discharge fluid. Sampling tended to be intensive, to compensate. In addition, the early wells (NG1, NG2, NG5, NG7) either would not discharge, or sealed due to calciting. The next well discharged, NG4, discharged at more than 500 tonne/hour, which surprised all associated with the field. Usual production fluid temperatures were between 220 and 230°C (i.e. enthalpies about 1000 kj/kg. The bottom temperature in NG13 exceeded 300°C.

Geochemical Models of the field

Most of the data and results of investigations into the Ngawha system are freely avalable, and this allows an assessment of the predications made by the various disciplines at the various stages of the exploration programme. Most such studies were undertaken by the New Zealand Department of Scientific and Industrial Research, and are published in two of their Geothermal Report Series, Numbers 7 (1981) and (1985).

Until the report of Ellis and Mahon (1966) the local basalt flows were assumed to be the heat source and mineralisation source for the fluids

Source	T °C	pH*	Li	Na	K	Rb	Cs	Mg	Ca	NH_3 mg/kg	SiO_2	B	F	Cl	SO_4	HCO_3	$\delta^{18}O$ ‰	δD ‰	CO_2 Wt%
NG 4	224	5.7	11.7	891	77	0.27	0.65	0.09	2.5	111	399	929	1.8	1260	40	271	5.8	-35	0.85
NG 8	209	5.6	9.5	762	69	0.29	0.66	0.40	6.8	222	363	762	1.4	1054	28	394	4.7	-35	1.39
NG 11	225	5.8	10.4	876	78	0.31	0.73	0.13	2.5	100	394	877	1.5	1211	25	458	5.6	-36.5	1.23
NG 18	220	5.3	9.7	818	69	0.26	0.64	0.16	5.4	293	357	844	1.1	1155	29	258	4.8	-36.1	2.37
Jubilee Bath	46	7.4	7.4	621	49	0.20	0.51	1.5	13.7	90	154	603	1.3	831	145	260	-	-	-
Tiger Bath	45	2.4	0.5	125	10	0.05	0.07	4.3	13.5	62	107	40	0.32	162	745	-	-	-	-
Omapere Soda Spring	30	6.6	0.16	58	9	0.03	0.015	13.0	36	2.9	140	6	0.15	15	<10	325	-	-	-
Latera 2	-	-	9.4	2223	318	2.4	4.3	1.6	19	22	368	274	-	2853	390	-			2-4
Latera 3D	-	-	13	2796	495	4.2	7.0	0.3	3.2	5	359	571	-	2942	1394	-			2-4
Geysers																			
Clear Lake	42	6.6	0.51	125	22	-	-	144	155	-	163	19	37	78	1	1310			
Calistoga Geyser	100	8.4	1.9	193	8.7	-	-	-	25		150	12	.01	206	13	184			

TABLE 1: Compositions of reservoir and spring fluids from the Ngawha field and other fields. Data from Sheppard, 1984; Sheppard et al., 1985; Carella et al., 1986; Thompson, Sims, Yadav and Rymer, 1981; Thompson, Goff and Donnelly-Nolan, 1981. Well fluids corrected to preflash compositions.

(Bell and Clarke, 1909; Fleming, 1945). By 1966 the experiences gained in the exploitation and exploration of geothermal systems in general had led to the realisation that such was unlikely to be a significant source of heat. Ellis and Mahon, on the basis of the fluid compositions, notably the constant value of Cl/B over the field, argued for a larger heat source, and they postulated a magma injected at a deep level into the sediments underlying the field, releasing water by dehydration, also the other volatiles boron, ammonia, bicarbonate (as CO_2), and chloride, by leaching. The well fluids showed a quartz equilibration temperature of 228°C (close to measured temperatures), and a high gas content in the deep water, this gas having a high (7%) hydrocarbon content.

On the basis of more chemical data from the spring waters and gases, and also water and gas isotope measurements, Giggenbach and Lyon (1977) were able to model the system in more detail (Fig. 2). The essential inferences made from this set of data were:

- that there is an extensive layer of warm, shallow water at about 145°C.
- that the rising thermal waters are subject to processes preventing chemical geothermometers set at depth being preserved, implying a very slow upflow of liquid.
- rather higher temperatures at depth (>360°C) are indicated by the sulphate isotope geothermometer, while gas phase isotope geothermometers indicate temperatures between 200 and 260°C over the centre of the field, and possibly much higher temperatures at greater depth.
- that Ngawha is a gas-rich system.
- there is a low liquid water content, and vapour transport of volatiles at greater depth e.g. B.

Subsequent investigations have resulted in but minor amendments to this model of the upper, central part of the system, apart from the realisation that structural features

Source	CO_2	H_2S	NH_3	He	H_2	Ar	O_2	N_2	CH_4
				millimoles/mole$_{\text{total gas}}$					
NG 4	948	10.5	9.0	0.004	2.81	0.002	<0.002	2.5	27.6
NG 8	949	7.5	12.0	0.005	3.65	-	<0.002	2.9	25.3
NG 11	961	13.4	3.3	0.004	2.02	0.0052	<0.002	1.9	18.0
NG 18	935	6.9	7.4	0.009	7.09	-	<0.028	4.7	38.8
Jubilee Bath	907	2.2	0.03	0.007	8.28	0.043	0.024	11.9	70.8
Tiger Bath	913	1.8	0.03	0.008	2.03	0.010	0.010	10.9	71.9
Omapere Soda Spring	969	0.39	0.067	0.003	0.001	0.032	0.56	18.2	11.4

TABLE 2: Compositions of selected steam samples from wells and pools. Data from Sheppard et al., 1985.

provided vertical and horizontal permeability barriers, resulting in vertical stratification of vapour-rich, two phase fluid from more dense fluids, with mainly gas *percolating* upwards through structural features of higher permeability (Giggenbach and Sheppard, 1980). This predication has been confirmed by subsequent interference testing on wells (Grant and McGuiness, 1985).

A number of other observations made over this period required explanation. These observations include:

- the observation of Ar^{40}/Ar^{36} in NG2 at 310 to 315 (ie above the atmospheric ratio), which can be taken to indicate long residence time and a very limited access of meteoric water to the system. High He contents, and high gas contents in general support this observation.
- the large $\delta^{18}O$ shift indicates low water/rock and limited water throughput.
- the high nitrogen content of ther gases, usually interpreted as being an indicator of magmatically derived fluids.
- the observed small but significant variations in chemical and isotopic parameters across the field (as determined in the 230°C production fluid) showing

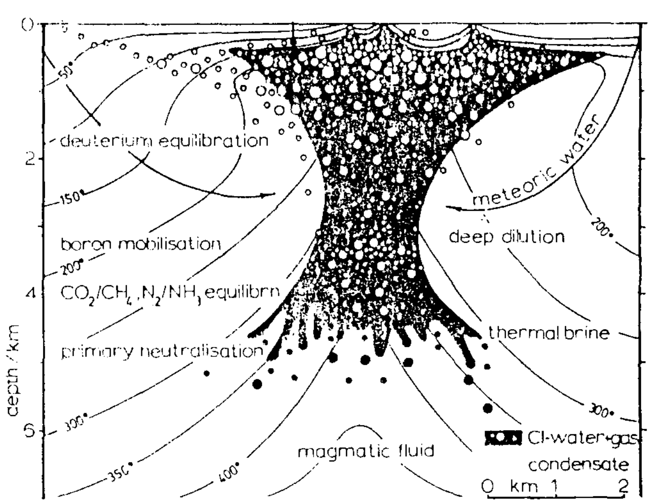

FIGURE 2: Hydrologic model of the subsurface system at Ngawha. Figure from Giggenbach and Lyon, 1977.

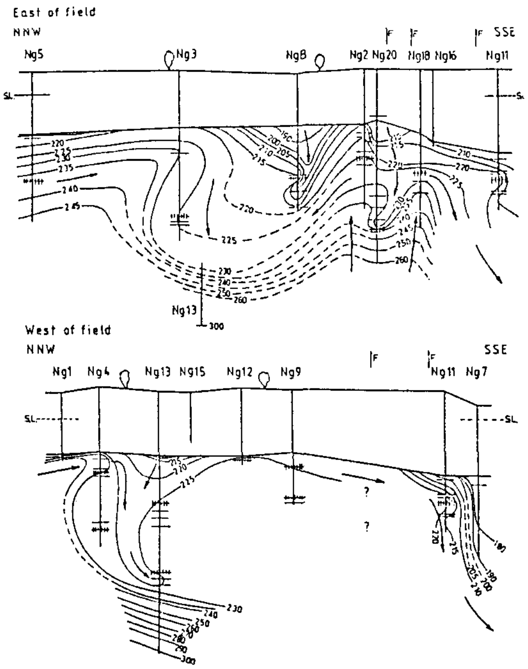

FIGURE 3: NNW-SSE profiles of downhole temperatures, representing the characteristics of the east and west sides of the field. Main feeds are indicated by ++++, inferred fluid flow directions are shown by arrows. Figures from Cox, 1985.

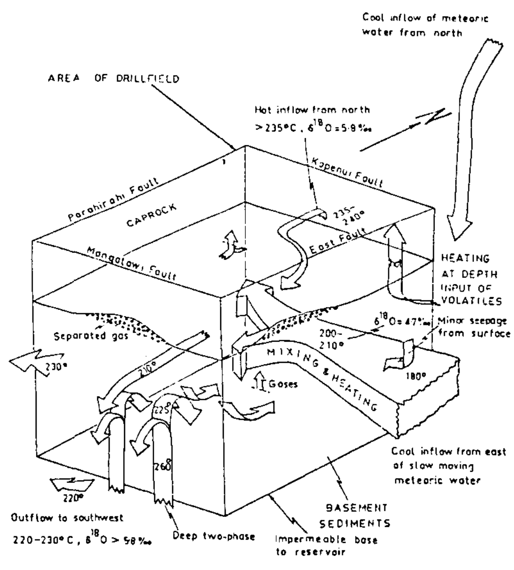

FIGURE 4: Three dimensional block diagram of the Ngawha drillfield, displaying the inferred main hydrological features. From Cox, 1985.

increasing dilution by meteoric water toward the eastern field margin.

- the large interval of near constant temperature with depth between 220 and 240°C, 500 to 1500m depth.

Grant (1981) postulated an upflow over a recirculating, gas depleted reservoir. While this concept is at odds with chemical indicators showing that the reservoir water has had gas added rather than extracted, the large constant temperature reservoir may well be the result of a recirculation process, but with gas being added from below. Cox (1985) has more recently assessed available data from a number of disciplines and has presented the flow models of the system shown in Figures 3 and 4. If this model of the present state is valid, it must explain the observations listed above, particularly those requiring low meteoric water throughput. An explanation for this could be that the fluid presently in the system largely predated the thermal event, which has mobilised the fluid, and that the thermal event was quite recent.

It is clear that there exist higher temperatures at easily accessable depths beneath the explored field. Other fields do exist in the world with the shallow structures and similar chemistry to the Ngawha fluid. These are the Geysers field, in California; Larderello and Latera in Italy (Table 1). All of these fields have large, extensive steam fields at depth. Does Ngawha?

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