Proc. 10th New Zealand Geothermal Workshop 1988

APPLICATION OF THE VTTRINrrE REFLECTIVITY METHOD TO SAMPLES FROM THE WAIRAKEI-TAUHARA AND OHAAKI GEOTHERMAL FIELDS

Heike Struckmeyer* and P.R.L. Browne

Geothermal Institute, University of Auckland
Private Bag, Auckland, New Zealand

* German Academic Exchange Service visitor

ABSTRACT

Organic material occurs as disseminate grains between 0.2 and 10 microns in diameter in samples of lacustrine sediments of the Huka Falls Formation. Thirtysix cores from wells drilled at the Wairakei-Tauhara (TH4, THM4, 219 and 35) and Ohaaki fields (Bfs 10, 1 and 5) were examined; thirtytwo contain organic matter (vitrinite) whose reflectivity was measured using a reflected light microscope with photometer attachment. Mean random vitrinite reflectivities, Rornd, ranged from 0.24 to 1.45% with highest values generally present in samples coming from the greatest depths where the hottest bore temperatures occur. Vitrinite reflectivity has thus been demonstrated to be a useful geothermometric method for sediments of geothermal systems in the Taupo Volcanic Zone where it records maximum temperatures.

These reconnaissance results also suggest that the duration of heating of the Ohaaki samples was shorter than those from Wairakei-Tauhara but different parts of the latter field had timespans of different duration.

INTRODUCTION

Determining the four dimensional thermal parameters of an active geothermal field is obviously an important object of investigation. Although downwell temperatures are measured directly, independent estimates of the pre-drilling temperatures are needed to learn if a reservoir, or even part of it, is heating, cooling or thermally stable. Further, drilling and exploitation always disturb a field and measured downwell temperatures are not always the same as those which prevailed immediately prior to drilling. For these reasons, temperature estimates are commonly made based upon the chemical and isotopic composition of the thermal fluids; other types of geothermometers rely upon the reservoir rock samples recovered as cores and cuttings. These commonly contain mineralogical indicators of the temperature of formation of the hydrothermal minerals; for example, the calc-silicates and clays are proven temperature indicators (Bird et al 1984; Browne, 1979) and fluid inclusion geothermometry can give very close estimates of mineral growth temperatures provided standard assumptions are met (Roedder, 1984). Unfortunately the appropriate minerals are sometimes absent or else fluid inclusions are too small to measure homogenisation temperatures so additional methods for estimating reservoir geothermometry are being constantly sought. This is especially true for reservoirs composed of sedimentary rocks as they react less readily with geothermal fluids than do volcanic rocks.

In 1979, however, C.E. Baker working upon samples from the Cerro Prieto field, Baja California, Mexico successfully demonstrated a usable relationship between vitrinite reflectivity and bore temperature (Barker and Elders, 1979); subsequent studies by Struckmeyer (1983), Taguchi et al (1983) and Gonzales (1985) have confirmed the value of the method and applied it to sediments of geothermal systems in Japan and the Taupo Volcanic Zone of New Zealand.

This paper describes the method briefly and reports preliminary results of the technique applied to sediments, belonging to the Huka Falls Formation, encountered by drillholes at the Wairakei-Tauhara and Ohaaki geothermal fields.

LACUSTRINE SEDIMENTS IN GEOTHERMAL SYSTEMS OF THE TAUPO VOLCANIC ZONE

Lacustrine sediments comprising the Huka Falls Formation are common in several geothermal fields in the Taupo Volcanic Zone where they are exposed and were encountered by many drillholes (e.g. Grindley, 1965). Their precise ages are unknown but stratigraphic relationships suggest most deposited between 20 and about 300 thousand years ago. However, it is unlikely that lacustrine sediments present at one field correlate with lithologically similar sediments present at another; rather, during the Quaternary there has been a series of ephemoral lakes throughout the Taupo Volcanic Zone. However, as lacustrine sediments attain a thickness of 400m at Wairakei (Grindley, 1965) it follows that some lakes were long lived and that sedimentation in them was very fast

Exposed Huka Falls Formation sediments are brown, thinly bedded, near flat, porous and show regular and reversely graded bedding. They are dominantly tuffaceous in composition, typically comprising subangular crystals of quartz, plagioclase, iron oxides, glass shards and fragments of pumice and rhyolite. The glass readily alters to montmorillonite at low temperatures and even at the type area (Huka Falls) these sediments are hydrothermally altered.

ORGANIC MATTER AND REFLECTIVITY

Many samples of Huka Falls Formation sediments contain organic matter that occurs as disseminated grains between 0.2 and 10 microns in diameter, very rarely, however, do these comprise more than 1% of the rock. This organic matter, or macerals, originally consisted of humic substances derived from wood and made up from lignin, cellulose and tannins but as the sediments were heated, these evolved aromatic liquids, such as benzenes, which ascended and still discharge at the surface; for example, from a seep at Waiotapu (Czochanska, et al, 1986).

The residue (kerogen) in the host rock is relatively enriched in carbon and the extent of its enrichment can be determined from its atomic ratios of carbon, hydrogen and oxygen (Tissot and Welte, 1984). This enrichment, or ranking, is the same as occurs in the coalification process and could theoretically be measured from changes in physical properties such as volatile content and calorific value. However, it has long been known that the reflectivity of the macerals (commonly vitrinite) increases with increasing rank (and hence inversely with volatile content); reflectivity is a property easily measured using a reflected light microscope and photometer. Thus the mean random reflectance, Rornd, of vitrinite (Luminite) ranges from 0.2 to 11% (graphite).

Factors that affect the rank, and hence reflectance, of organic matter are temperature, duration of heating and depth of burial. The relationship between maximum temperature and vitrinite reflectivity has been described by Teichmuller and Teichmuller (1966), Bostick (1971) and Waples (1980) who noted that for every 10° rise in temperature there is a doubling of the rank producing reaction rate, although a mathematical approach to this relationship has been questioned (Barker, 1984). Vitrinite reflectance, however, changes slowly in the range 0.2 to 0.8%, more rapidly in the range 0.8 to 2.5% and quickly above 2.5% Rornd.

The geothermal environment is one where 'coalification' proceeds extremely fast but still slowly enough to be recorded by vitrinite reflectivity since the process can occur even over laboratory time scales (Bostick, 1971). However, the duration of heating also has an effect on vitrinite reflectivity so that a curve of reflectivity/temperature values determined for a single field cannot be used for samples from a different field. Although this is a disadvantage it in fact allows the relative ages of the different fields to be determined; for example, Barker (1984) showed that the Cerro Prieto field is younger than the Salton Sea field.

Depth of burial will have only a slight effect on coak rank (Teichmuller and Teichmuller, 1966) compared with temperatures in a geothermal environment so that it is here ignored, as is any effect likely to result from the presence of steam or water in the sediments.

METHODS

The methods of vitrinite reflectance used for this study are based on the standard techniques of organic petrography discussed by Bostick and Alpern (1977), ICCP (1973), Stach at el, (1975) and Barker (1979).

Approximately lOOg of each sample were ground and then sieved through a 2mm mesh sieve. The sample was treated with 25% HC1 and washed several times in distilled water. 45% to 50% HF was slowly added to the wet sample until all material was disaggregated. After 3 to 7 days reaction time the sample was washed in distilled water to a pH of 4.5 to 5. The gained residue was concentrated by centrifuging, and then air-dried. No density separation was applied, because the amount of residue present was usually very small.

The grey to black powder was mounted in a mounting press (Buehler 20-1320 Simpliment II) using transoptic powder (Buehler 20-3400-080). The mount was ground in 5 steps of 180, 220, 320, 400, and 600 carborundum abrasive paper. Polishing involved three steps of 1.0, 0.5, and 0.3 micron aluminium oxide on canvas cloth, nylon cloth and silk.

Vitrinite reflectance was measured on a Leitz microscope photometer (model MPV 2) with a stabilized light source and a narrow band filter of 546 nm. An aperture diaphragm was adjusted to restrict the area of measurement to 5 microns. A 50x/0.85 oil immersion lens and an optovar setting of 1.25x were used to gain a total magnification of 625x. Before and after each sample run the photometer was standardized, using a glass prism with a reflectance of 1.24% (Leitz standard 196) in an immersion oil of Ne= 1.5180. To gain representative results the sample mount was moved in a mechanical stage with a line-to-line distance of 1 to 2 mm, depending on the frequency of vitrinite phytoclasts. For the initial measurement an average sample size of 40 vitrinite phytoclasts was used. As some samples contained only a few organic particles, this was not always possible. After all samples were measured, a rerun of 10 to 20 measurements was made to control the results. As there were no major differences, the rerun values were added to the results of the first run and the mean random reflectance, R̄ornd calculated.

RESULTS

The organic matter contained in the examined samples mainly consists of vitrinite, liptinite (derived mainly from spores) and occasionally fusinite. The vitrinite can mostly be referred to the 'low-gray' group, described by Bostick (1971, 1979), which represents the phytoclasts which had a minimum rank during sediment deposition. Following the method of Bostick (1971, 1979), the low-gray vitrinite was used for reflectance measurements in this study. In most examined samples the low-gray vitrinite, with R̄ornd of 0.24 to 1.45%, can easily be distinguished from the 'high-gray' group, which shows a range of 3.4 to 6.6% "Sornd and is considered to be redeposited from older sedimentary rocks (Bostock, 1971, 1979).

Low-gray vitrinite represents the dullest grey particles (not counting exinite) in the sample. It is usually unstructured, but occasionally cell wall material was observed. High-gray phytoclasts sometimes show a different reflectance in different parts of the same particle.

Liptinite macerals are recognisable by their distinctive external morphology; sporinite and resinite are common in all samples and occasionally predominate. They usually show a dull brown to grey colour and have a very low reflectance. Fusinite is minor and shows the highest reflectance; it is often indistinguishable from high-gray vitrinite.

Non-organic matter in the form of pyrite is common to abundant in all samples.

Table 1 summarises the results obtained on cores from 4 wells each at the Wairakei-Tauhara and Ohaaki. Also shown are the best estimates of the appropriate measured well temperatures kindly made available by the Ministry of Works and Development. Note, however, that the cited bore temperatures may not be the same as the pre-drilling temperatures because of perturbation caused by drilling and well discharge; this is likely to be especially true for the shallow temperatures.

Figure 1 plots vitrinite reflectivity versus sample depth and also shows the measured downwell temperatures.

<u>Comments on Wells</u>

<u>Hole ThM4</u>

Vitrinite is common to abundant in most samples but there are no data for sample No. 4. Hornd values range from 0.70 to 1.11% corresponding to a bore temperature increase from 197°C at 137m depth to 219°C at 337m. This represents a rank gradient of 0.2%/100m and a temperature gradient of 11.0°C/100m.

<u>Hole Th4</u>

Vitrinite is abundant in sample Nos. 1, 2, and 5, rare in No. 3; sample No. 4 contains no organic matter. Rornd values range from 0.74 to 1.32% corresponding to a bore temperature increase from 115°C at 152m to 250°C at 670m. This represents a rank gradient of 0.1%/100m and a temperature gradient of 26°C/100m. Compared with respective temperatures in holes ThM4 and B219 the R̄ornd values of samples 1, 2, and 3 seem high. This suggests that temperatures have probably been higher than the present downhole temperatures since vitrinite reflectivity records the maximum temperatures.

<u>Hole B219</u>

Vitrinite is common to abundant in all samples. An increase in R̄ornd from 0.98% at 151m to 1.34% at 334m represents a rank gradient of 0.2%/100m over a temperature change from 222 to 246°Corl3°C/100m.

Hole B35

Vitrinite is rare to common; no data are available for samples 1 and 3. Compared with all other examined holes Rornd values are very low, which corresponds to the low downhole temperatures measured here of 127 to 138°C. Sample Nos. 4, 7, and 8 give Rornd values of 0.6 to 0.75%, whereas the R̄ornd of sample Nos. 2, 5, and 6 ranges from 0.24 to 0.29%. This agrees with the low rank hydrothermal alteration of minerals present in these samples (fresh glass, andesine and hydrothermal mordenite and montmorillonite) and suggests a more irregular temperature gradient than the one shown in the temperature log.

Hole Br10

Vitrinite is rare to common in samples from this hole. An increase in Rornd from 0.57% at 78m depth to 1.45% at 342m represents a rank gradient of 0.3%/100m over a temperature change from 68 toJMTC or 65°C/100m. Compared with the results from other holes, R̄ornd data obtained from sample Nos. 1 to 3 suggests a higher formation temperature than that now prevailing.

Hole Br1

Vitrinite is abundant and shows a rank of 0.79% R̄ornd compared with the downhole temperature of 80°C at 138m.

Hole Br5

Vitrinite is very rare in this sample. An R̄ornd value of 0.50% corresponds to a downhole temperature of 61°C at 475m.

DISCUSSION

The results show that there is a general increase in vitrinite reflectivity with increasing depth and temperature for samples from both the Wairakei-Tauhara and Ohaaki fields; the R̄o numbers, however, are lower than those measured on material from Cerro Prieto, some of which exceed 3% (Barker and Elders, 1979). However, the vitrinite reflectivity method has been demonstrated to be a worthwhile investigatory method for geothermal systems of the Taupo Volcanic Zone. The wide range of reflectivities measured on vitrinite present in a single sample clearly demonstrates the need to obtain as many numbers as possible and that making only a few measurements is probably worse than useless.

Plots of reflectivity against measured well temperature (figure 1) shows that there is an approximately linear relationship between them; this relationship is closer for the Ohaaki samples than it is for those from Wairakei-Tauhara. The scatter shown could be due to:

(a) The bore temperatures are different from the maximum field temperatures, as described earlier, and that parts of the Wairakei-Tauhara field have cooled. Alternatively, the measured bore temperatures are in error and do not represent those of the undisturbed system.

(b) The duration of heating has been different at Ohaaki than it has at Wairakei-Tauhara; there is near linear relationship between bore temperature and vitrinite reflectivity for the Ohaaki samples (figure 1) but a greater scatter for those from Wairakei-Tauhara. It is possible to use the equations of Lopatin and Bostick (1973) and Royden, et al (1980) to calculate the duration of heating but we have too few data to justify this exercise here. However, the bore temperature/vitrinite reflectivity results do suggest that the Ohaaki field is younger than Wairakei-Tauhara and that different parts of the latter have had timespans of different duration.

Although the results described in this paper are preliminary they demonstrate that vitrinite reflectivity can be used as a routine method to estimate maximum reservoir temperatures. This is quite easily done but should be combined with other mineral geothermometers such as fluid inclusion geothermometry, clay crystallinity and the identity and occurrence of calc-silicates.

ACKNOWLEDGEMENTS

We thank P.M. Black and Peter Crosdale of the Geology Department, University of Auckland for their help and useful comments on this paper. Heike Struckmeyer thanks the German Academic Exchange Service (DAAD) for her post-graduate scholarship. We thank Beryl Reeves for typing the paper and Louise Cotterall for draughting the figure.

REFERENCES

BARKER, C.E., 1979: Vitrinite reflectance geothermometry in the Cerro Prieto Geothermal System, Baja California, Mexico. MSc thesis, University of California, Riverside, 127p.

BARKER, C.E., 1984: A problem with estimating the pseudo-activation energy of kerogen thermal maturation from Connan's Time-Temperature relation in oil genesis. Journal of Petrology and Geology, 1, 109-112.

BARKER, C.E. and W.A. ELDERS, 1979: Vitrinite reflectance geothermometry in the Cerro Prieto geothermal field Baja California, Mexico. Transactions of Geothermal Resources Council, 3, 27-30.

BIRD, D.K., SCHIFFMAN, P., ELDERS, W.A., WILLIAMS, A.E. and S.D. McDOWELL, 1984: Calc-silicate mineralisation in active geothermal systems. Economic Geology, 79, 671-695.

BOSTICK, N.H., 1971: Time as a factor in thermal metamorphism of phytoclasts (coaly particles). Congrés International de Stratigraphie et de Geologie du Carbonifére, Septieme, Krefeld. Compte Rendu, 2, 183-193.

BOSTICK, N.H., 1979: Microscopic measurement of the level of catagenesis of solid organic matter in sedimentary rocks to acid exploration for petroleum and to determine former burial temperatures - a review. SEPM Special Publication, 26,17-43.

BOSTICK, N.H. and B. ALPERN, 1977: Principles of sampling, preparation and constituent selection for microphotometry in measurement of maturation of sedimentary organic matter. Journal of Microscopy, 109 Part 1, 41-47.

BROWNE, P.R.L., 1979: Hydrothermal alteration in active geothermal fields. Annual Reviews Earth and Planetary Science, 6, 229-250.

CZOCHANSKA, Z., SHEPPARD, CM., WESTON, R.J., WOOLHOUSE, A.D. and R.A. COOK, 1986: Organic geochemistry of sediments in New Zealand. Part 1. A biomarker study of the petroleum seepage at the geothermal region of Waiotapu. Geochimica et Cosmochimica Acta, 50, 507-515.

GONZALEZ, R.C., 1985: Vitrinite reflectance of cores and cuttings from Ngatamariki Well NM-2, New Zealand. Geothermal Institute Report No 85.10, 60p.

GRINDLEY, G.W., 1965: The geology, structure, and exploitation of the Wairakei geothermal field, Taupo New Zealand. New Zealand Geological Survey Bulletin No 75,131p.

INTERNATIONAL COMMITTEE FOR COAL PETROLOGY (ICCP), 1971, 1973: International handbook of coal petrography, supplement to 2nd edition. Centre National Recherche Scientifique, Paris.

LOPATIN, N.V. and N.H. BOSTICK, 1974: The geological factors in coal catagenesis. Illinois State Geological Survey Reprint Series 1974Q, 16p [translation with minor revision from original Russian article in Nature of Organic Matter in Recent and Fossil sediments, Moscow, Nauka Press, 1973, 79-90].

ROEDDER, E., 1974: Fluid Inclusions. Reviews in Mineralogy, Volume 12, Mineralogical Society of America, 644p.

ROYDEN, L., SCLATER, J.G. and R.P. VON HERZEN, 1980: Continental margin subsidence and heat flow: important parameters in formation of petroleum hydrocarbons. American Association of Petroleum Geologists Bulletin, 64, 2, 173-187.

STACH, E., CHANDRA, D., MACKOWSKY, M-TH., TAYLOR, G.H..TEICHMULLER, M. and R. TEICHMULLER, 1975: Stach's textbook of coal petrology, 2nd edition. Gebruder-Borntraeger, 428p.

STRUCKMEYER, H. 1983: Vitrinite reflectivity and illite crystallinity in geothermal fields of the Taupo Volcanic Zone, New Zealand. Geothermal Institute Report, 62p.

TAGUCHI, K., MITANI, M., INABA, T and I. SHIMADA, 1983: A comparative study of geothermal and non-geothermal areas with respect to vitrinite reflectance - case studies in the Kakkonda and Hijori geothermal fields, Northeast Japan (Extended Abstract). 4th International symposium Water-Rock Interaction, Japan, 455-458.

TEICHMULLER, M. and R. TEICHMULLER, 1966: Geological causes of coalification in Coal Science, American Chemical Society, Advances in Chemistry Series, 55,133-155.

TISSOT, B.P. and D.H. WELTE, 1984: Petroleum formation and occurrence. 2nd edition, Springer Verlag, Berlin.

WAPLES, D.W., 1980: Time and temperature in petroleum formation: application of Lopatin's method to petroleum exploration. American Association of Petroleum Geologists' Bulletin, 64, 6, 916-926.

TABLE 1: Vitrinite reflectivity of samples from wells at Wairakei-Tauhara and Ohaaki compared with measured drillhole temperatures.

Hole	Sample No.	Depth (m)	Measured bore temp. PC)	at. Rornd.(oil) (mean)	(Range)	Number of measurements
ThM4	1	137	197	0.70	0.22-1.76	117
	2	138	197	0.70	0.22-1.54	75
	3	143-146	200	0.83	0.24-1.34	60
	4	149-152	201	-	-	-
	5	263-266	215	0.98	0.35-1.63	63
	6	275-276	217	1.07	0.65-1.55	25
	7	304-305	218	1.11	0.73-1.66	50
	8	335-337	219	1.03	0.74-1.58	37
	1	152-154	115	0.86	0.41-1.62	75
	2	153-154	115	0.74	0.39-1.76	90
	3	243-246	150	1.05	0.73-1.31	14
	4	364-366	210	-	-	-
	5	669-671	250	1.32	0.85-1.72	50
B219	1	151-153	222	0.98	0.48-1.68	55
	2	167-168	223	1.02	0.72-1.72	30
	3	258-259	245	1.33	0.96-1.84	50
	5	322-334	246	1.34	0.85-1.76	61
B35	1	215	127	-	-	-
	2	221-225	129	0.27	0.16-0.51	50
	3	231-234	130	-	-	-
	4	239-241	132	0.60	0.23-1.20	50
	5	262-265	133	0.29	0.16-0.78	50
	6	274-277	134	0.24	0.12-0.41	12
	7	299-302	136	0.75	0.28-1.27	6
	8	341	138	0.69	0.24-1.17	20
BrlO	1	77-78	68	0.57	0.24-1.10	22
	2	78-79	69	0.62	0.27-1.19	36
	3	91-93	76	0.63	0.26-1.44	65
	4	182-183	216	1.22	0.66-1.92	69
	5	236-238	232	1.30	0.89-1.84	23
	6	341-343	240	1.45	0.68-2.05	31
Brl		138	80	0.79	0.40-1.22	50
Br5		475	61	0.50	0.24-1.26	11

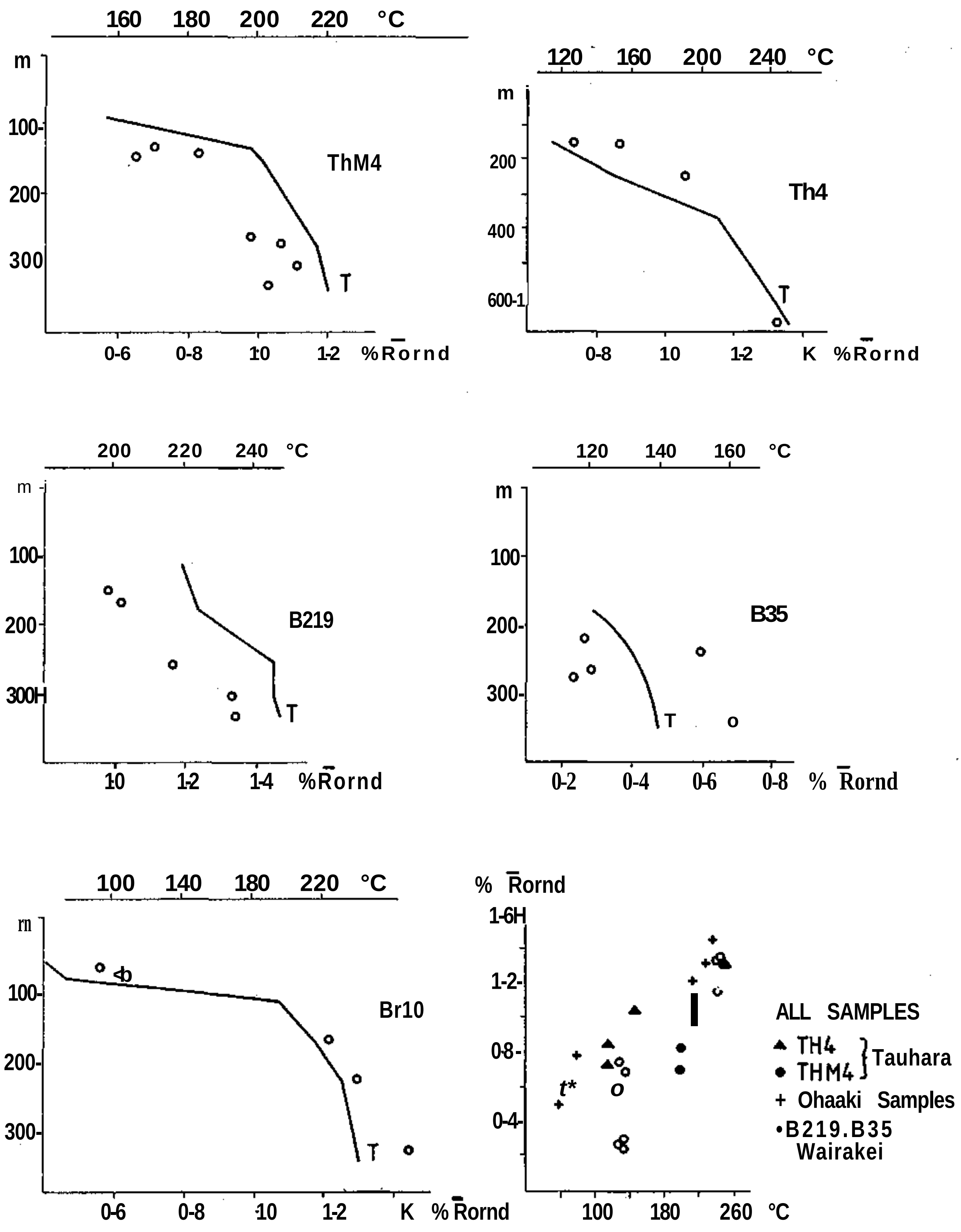

FIGURE 1: Depth and Vitrinite Reflectivity of cores from Drillholes; line is measured downwell temperature (MWD data).