METHYLENE BLUE ADSORPTION: A REAL TIME RIG GEOLOGIST TOOL FOR ESTIMATING GEOTHERMAL RESERVOIR TEMPERATURES AND FORECASTING DRILLHOLE STABILITY PROBLEMS

C.C. HARVEY[1], R GUNDERSON[2] & W. CUMMING[2]

[1]GENZL Division, PB Power, Auckland

[2]Unocal Geothermal and Power Operations, Santa Rosa, California, USA

SUMMARY - Smectite and smectite-illite clays are the predominant rock alteration products that form in the 50° to 200°C zone of most high temperature volcanic-hosted, neutral pH geothermal systems. Methylene Blue is an organic dye which shows a high selectivity for adsorption by smectitic (swelling) clays in the interlayer site. The dye is also adsorbed by the smectite component of mixed-layer clays such as illite-smectites and chlorite-smectites. This selectivity permits it to be used to estimate, on a semi-quantitative basis, the amount of smectite and/or mixed-layer clays in alteration mineral assemblages in hydrothermal systems.

The technique is rapid, requires very little sample and can readily be carried out by the rig geologist, as drilling proceeds, under relatively unsophisticated field conditions. The method cannot be considered sufficiently accurate to replace the more traditional analytical techniques of X-ray diffraction studies. Its relevance is that immediate information can be obtained on the clay mineral composition and likely reservoir temperatures, since X-ray diffraction studies carried out in central laboratories may not be completed until much later after the well has been completed and perhaps discharged. It has been successfully applied in several geothermal fields in Indonesia.

In high clay content formations, routine methylene blue analysis may also immediately identify high clay zones which may cause wall collapse and blockages. In addition, if the rig geologist regularly analyses cuttings by methylene blue, good correlations have been found between methylene blue adsorption and resistivity data.

1. INTRODUCTION

Smectite and smectite-illite clays are the predominant rock alteration products that form in the 50 to 200°C zone in mast high temperature volcanic-hosted, neutral pH geothermal systems. Geothermal alteration assemblages including smectite or mixed-layer illite-smectite are typically found at temperatures below about 200°C Jennings and Thompson (1986) and Harvey and Browne (1 991).

Methylene Blue (abbreviated here to MeB) is an organic dye which shows a high selectivity for adsorption by smectitic (swelling) clays in the interlayer site (Johnston, 1995). MeB has been used for determining the cation exchange capacity of swelling clays since the 1950s. Detailed work on the technique was reported by Hang and Brindley (1970). The MeB molecule exchanges for the exchangeable cations in the interlayer sites. Traditionally, MeB has been used by the drilling industry to estimate the amount of bentonite mud in circulation fluids (API RP 13B, 1974).

The dye is also adsorbed by the smectite component of mixed-layer clays such as illite-smectites and chlorite-smectites. This selectivity permits it to be used to estimate, on a semi-quantitative basis, the amount of smectite and/or mixed-layer clays present in alteration mineral assemblages produced by high temperature water-rock interaction in hydrothermal systems.

During the 1980's the technique was successfully adapted to identify high levels of smectite in formations encountered during the drilling of exploration wells in the Philippines (Harvey, pers.comm.). Such formations were recognized to have potential for caving or slumping during drilling. In 1994 a search was conducted for methods that could be used at a remote drilling location to improve mineral geothermometry and validate resistivity interpretations while drilling. Various approaches were considered, including on-site XRD and several well logging techniques. After a preliminary review a combination of on-site petrography and analysis of rock cuttings by the methylene-blue method was pursued. One of the authors (Harvey) was contracted to develop the MeB procedure and use samples from New Zealand geothermal fields to validate a quantitative analysis for geothermal cuttings.

2. HYPOTHESIS

Since the MeB technique has a high selectivity for smectite minerals, can it be used for estimating formation temperatures during geothermal drilling? This statement is made on basis of established clay mineral geothermometry:

3. EXPERIMENTAL METHOD

Only simple unsophisticated equipment is required consisting of a balance capable of weighing to 1g with a sensitivity of 0.05g; a 25ml or 50ml burette; a lml pipette and a combined hot plate/magnetic stirrer. The method involves the addition of a known concentration of MeB solution to a 10 ml solution of a powdered 1 g sample acidified with 1 ml of 10% H_2SO_4. The acid converts the clay to a hydrogen clay. The MeB is progressively added from the burette to the sample where the MeB is absorbed by the smectite until the point where the smectite is saturated. Beyond this point there is free MeB in solution which can be recognized by a blue tinge (or end point) using filter paper. After each 1 ml addition of MeB a drop of the clay suspension is dabbed onto a filter paper. The rim of the dab is clear until the end point is reached when a faint blue tinge appears.

The standard technique that is used for smectites (API method) is a MeB concentration of 3.74 g/l. This concentration may be reduced to provide greater sensitivity, because of the low clay content in some of the samples tested and the fact that the smectite might be a minor component of I/S structures.

4. INITIAL SAMPLE SELECTION

A series of core samples fkom the Wairakei hydrothermal system known to contain smectite and/or mixed-layer illite-smectites and/or illite were initially tested by the MeB technique. The reasons for selecting these samples were:

(i) the alteration mineral assemblage was known.
(ii) the downhole temperatures were known.
(iii) X-ray dieaction data provided a control on the MeB data

These tests showed a consistent decrease in MeB adsorption with increasing depth. The first appearance of illite co-incided with almost zero methylene blue adsorption.

5. APPLICATION TO INDONESIAN GEOTHERMAL SYSTEMS

The MeB technique has been successfully in Indonesia during the 1994-1998 Sarulla exploration drilling program in which three new geothermal fields were discovered (Gunderson et al., 2000).

The success of this application in Sarulla led to a new project to apply the MeB method to stored cuttings from wells from the 330 MW Awibengkok geothermal field. This analysis led to a better appreciation of the detailed correlation of the distribution of smectite alteration with high resolution TDEM resistivity data and the more averaged and general MT data.

The simplicity, speed, low cost and effectiveness of the MeB method of measuring smectite clay in geothermal cuttings led to its adoption as a routine measurement in Unocal exploration drilling. Case histories of its application in the newly discovered Namora-I-Langit field in Sarulla, North Sumatra and the developed 330 MW Awibengkok field in West Java, Indonesia illustrate the potential value of this method in geothermal exploration and development.

6. NAMORA-I-LANGIT RESULTS

The Namora-I-Langit geothermal field is located in the Sarulla contract block in North Sumatra (Gunderson et al., 1995). Four exploration wells were drilled in the field in 1997-1998, encountering a highly permeable, predominantly neutral geothermal system with production temperatures of 255-270°C and maximum recorded temperature of 276°C. Geophysical surveys confirmed an extensive low resistivity layer that was exposed at the surface in the area of the thermal .manifestations using MT (magnetotelluric) and TDEM (time domain electromagnetic) surveys. This was interpreted as a clay alteration halo overlying a high temperature reservoir. Exploration wells were targeted using this low resistivity zone as a proxy for the clay cap to the reservoir. The bulk cuttings of each of the Namora-I-Langit wells were analyzed by the MeB method at the wellsite as the wells were being drilled. The sampling interval was 15-30 meters. The results of analyses in Well NIL 1-1 (Figure 1) found a smectite-rich layer extending from the surface at 800 meters elevation down to around 500 meters elevation.

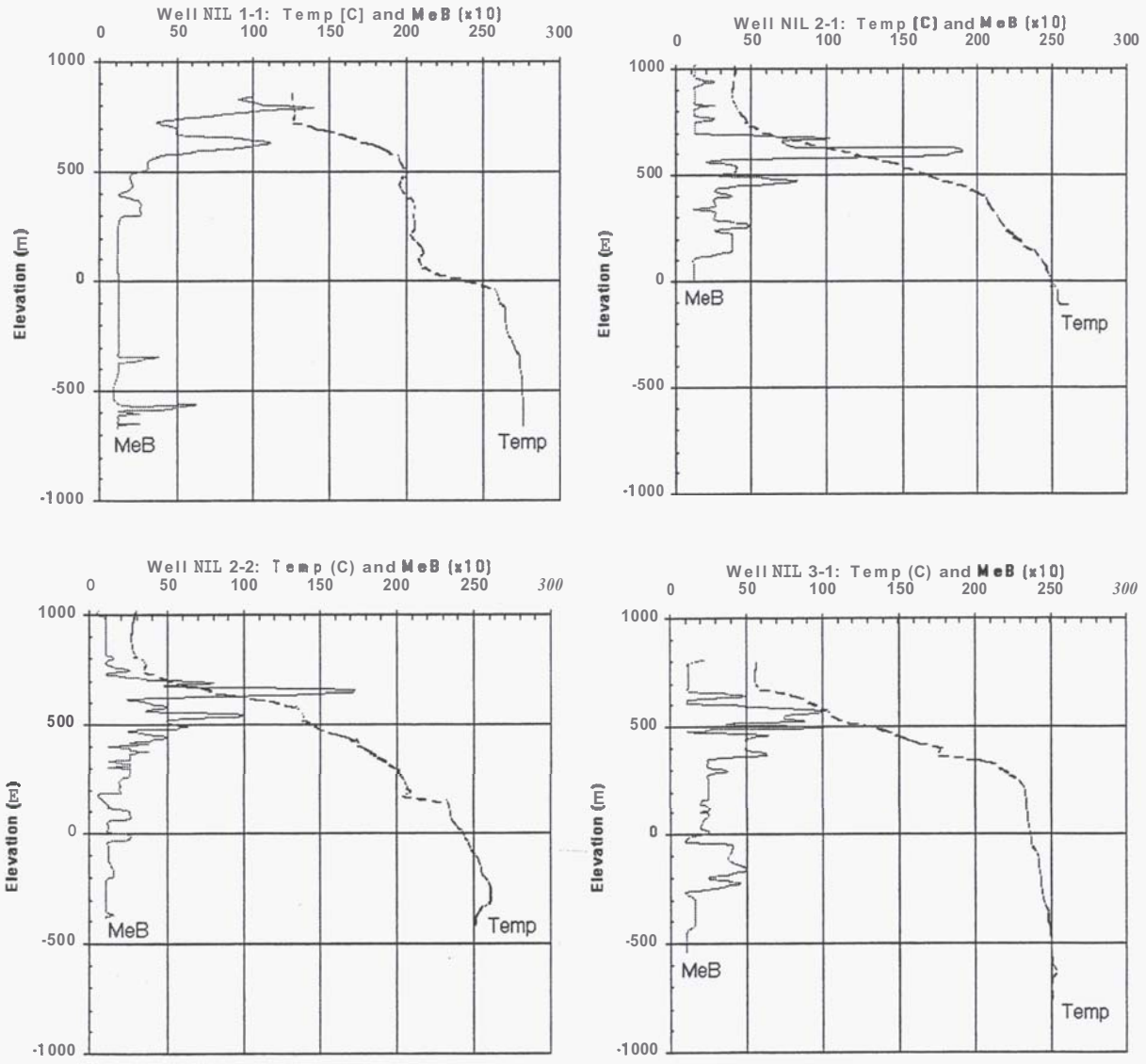

Figure 1: Relationship between MeB and Temperature in Namora-I-Langit wells (after Gunderson et al. 2000).

This directly reflects the abundant alteration and elevated temperatures found at this location. Each of the other wells found smectite-poor rocks from the surface down to 600-700 meters elevation, followed by 200-300 meters of smectite-rich rocks (Figure 1). Once again this correlates well with the shallow temperature and resistivity data. The abundance of these clays declines with depth over this interval in three of the wells, gradually settling down to background levels. Below about 300 meters elevation all the wells have rocks fairly devoid of smectite clays; however occasional thin, low permeability smectite-bearing paleosols are found in all of the wells. This apparently continuous layer of smectite overlying the geothermal system represents a clay alteration layer, and is largely independent of rock type. The clay-rich rocks include intermediate to silicic lavas and tuffs, but surprisingly does not include the fine-grained sedimentary rocks interbedded with the tuffs.

Comparison of the Namora-I-Langit MeB results with the temperature profiles shows two interesting characteristics (Figure 1). First, as expected, rocks with a significant component of smectite clay are found at temperatures between 50 and 200°C. This corresponds very well with the empirical thermal stability distribution derived from other geothermal

fields. Additionally, essentially no smectite was found in the shallowest 200-300 meters of wells NIL 2-1, 2-2, and 3-1. This barren zone represents the cool vadose region overlying the underpressured Namora-I-Langit reservoir in which surface waters slowly downflow toward the reservoir. This contrasts strongly with the same vadose region in NIL 1-1 in which the clay cap has been breached and there is a strong upflow of steam to the surface. The distribution of clays and observed alteration pattern clearly reflect the current state of the geothermal system and its ongoing processes.

The distribution of smectite in the Namora-I-Langit wells (Figure 1) also corresponds very well with the location of the electrical conductor interpreted fiom the geophysical surveys. These results confirmed that the identity of the MT/TDEM conductor is a zone of clay alteration within the volcanic lavas and tuffs overlying the reservoir, and validate its northern extension as a viable target for stepout exploration.

7. AWIBENGKOK RESULTS

The initial success of the MeB technique at Sarulla led to its application to Unocal's developed Awibengkok field. In 1994, MT and TDEM data were being reviewed to plan step-out drilling for a 220 MW field expansion. Although cultural noise severely distorted all of the MT data collected at Awibengkok, data from a 1982 survey provided a key early indication that the bulk of the reservoir was offset to the west of the major thermal manifestations. Following the drilling of the first two wells in 1983, subsurface resistivity was correlated with clay fraction estimates from lithology logs. Together with sparse XRD analyses, these data confirmed that the MT was identifying the low resistivities in the smectite clay cap overlying the reservoir and that this could be used to indirectly map the reservoir structure. However, the poor quality and sparse coverage of the MT left the detailed structure of the clay cap poorly resolved. In 1994, this was a particular concern in the western field area where many new injection wells were to be targeted.

Initial interpretations of high resolution, shallow penetration TDEM acquired in 1994 suggested that the distribution of the conductive clay alteration was more complex than the MT or earlier well analyses could reliably resolve. Since a detailed MeB analysis of cuttings from all existing wells could be completed at a fraction of the cost of even a few XRD results, this approach was used to attempt to better resolve the resistivity structure in the wells. (In fact, the cost of storage and management of the cuttings exceeded the cost of the MeB analyses).

A study was made at Awibengkok to compare the MeB data with the resistivity and temperature data. Despite the poor quality of the MT data, the MeB smectite meaasurements correlated very well with the resistivity contours and the reservoir isotherms. The MeB results were particularly helpful in resolving the nature of a shallow conductive body detected by the TDEM survey that partially interfered with the clay alteration signal and turned out to be a shallow lthologic unit.

The MeB data also identified several thin impermeable tuff/paleosol units within the deep reservoir that had not previously been recognised. These examples illustrate how the detailed MeB studies can be useful for unraveling details of the resistivity interpretation.

The results from Awibengkok also illustrate some relevant issues for use of the method in exploration. For example, sampling at 15 meter intervals, although far denser than is normally done for XRD, were not sufficiently dense to resolve all reservoir paleosols: Some wells that encountered a paleosol showed significant carry-over of smectite from that paleosol into most subsequent samples. Despite such difficulties, especially with respect to detecting drilling hazards, the Awibengkok experience confirmed the utility of MeB for clay characterization in geothermal fields.

8. CONCLUSIONS

1. The MeB procedure can provide valuable data when routinely used while drilling geothermal exploration and development wells. The benefits include the use of MeB method as a mineral geothermometer to assist in setting intermediate and production casing strings. Such "real time" smectite detection can also be used to characterize drilling hazards.

2. MeB can identify high clay content lithologies which conceivably could cause formation instability during drilling. Such clay rich formations also could cause problems when setting casing.

3. Either during or after drilling, the detailed picture of smectite clay distribution provided by MeB

measurement, combined with local XRD analysis, can assist in preparing conceptual field models, particularly when correlated with resistivity data.

4. Additional benefits could include calibration of geophysical resistivity measurements and potential correlation with downhole resistivity measurements and perhaps FMS logs.

5. The low cost and potential benefits of MeB make it a desirable method to apply in many geothermal development drilling programmes and a few already drilled fields if the necessary semi-skilled manpower is available to handle the simple tasks involved.

6. The method has been applied to smectite and illite-smectite clays hosted in silicic to andesitic terrains. It should be equally applicable in basalt hosted geothermal systems where mixed-layer chlorite-smectite clays may be present (Harvey and Browne 2000).

9. ACKNOWLEDGEMENTS

The study benefited from discussions with Dr. Pat Browne of the Geothermal Institute, University of Auckland and the late Dr. Terry Sameshima who introduced us to the technique.

10. REFERENCES

API RP 13B, (1974). API recommended practice standard procedure for testing drilling fluids, 9.32-9.36.

Gunderson, R.P., Dobson, P.F., Sharp, W.D., Pudjianto, R., and Hasibuan, A. (1995). Geology and Thermal Features of the Sarulla Contract Block, North Sumatra, Indonesia. Proceedings World Geothermal Congress, 1995, v.2, 687-692.

Gunderson, R.P., Ganefianto, N., Riedel, K.L., Sirad-Azwar, L., Suleiman, S. (2000) Exploration Results in the Sarulla Block, North Sumatra, Indonesia, Proc. World Geothermal Congress (2000), 1175-1181.

Harvey, C.C. and Browne, P.R.L. (1991) Mixed-layer clay geothermometry in the Wairakei geothermal field, New Zealand, Clay and Clay Minerals, v. 39, 614-621.

Harvey, C.C. and Browne, P.R.L. (2000) Studies of mixed-layer clays in geothermal systems. A review of developments and their effectiveness as mineral geotherrnometers, Proc. World Geothermal Congress (2000), 1201-1205.

Huang,P.T. and Brindley,G.W., (1970). Methylene blue absorbtion by clay minerals. Determination of surface areas and cation exchange capacities (Clay-Organic Studies XVIII), Clays & Clay Miner., 18: 203-212.

Jennings, S. and Thompson, G.R (1986) Diagenesis of Plio-Pleistocene sediments of the Colorado River Delta, southern California: J. Sediment. Petrol. 56, 89-98.

Johnston, C.T. (1995) Sorption of organic compound on clay minerals: a surface functional group approach in CMS short course "Oganic Pollutants in the Environment" 2-44. Ed. B.L. Sawhney. Clay Minerals Soc. 197pp

Marguiles,L., Rozen,H. and Nir,S.(1988)Model for competitive adsorbtion of organic cations on clays: Clays and Clay Min.36,270-276.