Results of XRD Clay Data Analysis of Menengai Geothermal Field: Case Study of Menengai Exploration/Production wells (MW-08 and MW-11)

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ABSTRACT

Menengai geothermal field is one of the high-temperature fields located within the Central segment of the Kenya rift valley. Cuttings from two wells were selected at an interval of 10 meters and or specified depth of interest representative of subsurface lithologic units in the wells, and analyzed for clays. A total of 36 samples for MW-08 and MW-11were selected for XRD clay analysis in order to identify the alteration zones, here samples in three conditions were run, i.e. untreated, glycol treated and oven-heated samples. This paper presents the stratigraphic sequence and the hydrothermal alteration of wells MW-08 and MW-11 drilled in Menengai geothermal field. The stratigraphic column is made up of pyroclastics, trachyte, tuff ,syenite and basalt. The main hydrothermal alteration clay minerals encountered include: smectite, illite and chlorite.The aim of this report is to give an overview of hydrothermal alteration clay mineral assemblage and delineate how they relate to the formation temperatures of the well. Wells MW-08 and MW-11 are the eighth and eleventh exploration/production wells drilled in Menengai geothermal field.

1.0 INTRODUCTION

X-ray diffraction analysis is used to provide detailed information about the atomic structure of crystalline substances as such, in the identification of clay-sized minerals in rocks. Clay minerals constitute amongst the most abundant alteration minerals in samples recovered from holes drilled in both low and high temperature geothermal fields. The Kenya rift is a volcano-tectonic feature that transects the country from Lake Turkana in the North to Lake Natron in Tanzania and is part of the East African Rift System, an active continental-continental divergence zone, where the Somali and Nubian plates are drifting apart at a rate of 2cm per year (1cm in each direction) resulting in crustal thinning (Lagat, 2003). The segment is host to several Quaternary to recent volcanic complexes. Some of the volcanic centers are dotted with hydrothermal activity and are envisaged to host extensive geothermal systems driven by their still hot magma. Studies show that these volcanic centers have positive indications of geothermal resource that can be commercially exploited (GDC, 2010). Exploration drilling to prove steam, determine the resource extend, nature and chemical characteristics in Menengai geothermal field is ongoing since its commencement in February 2011; at the time of writing this report,21 wells have been drilled, among them are wells MW-08 and MW-11.

2.1 Location of mw-08 & mw-11

MW-08 and Mw-11 are located within the Menengai Geothermal field. The field is situated in an area characterized by a complex tectonic activity associated with the rift triple junction.. The Kenya rift is characterized by extension tectonism where the E-W tensional forces resulted in block faulting, which include tilted blocks as evident in both the floor and scarps of the rift. These wells were drilled to a vertical depth of 2342 m and 1832 m, respectively.

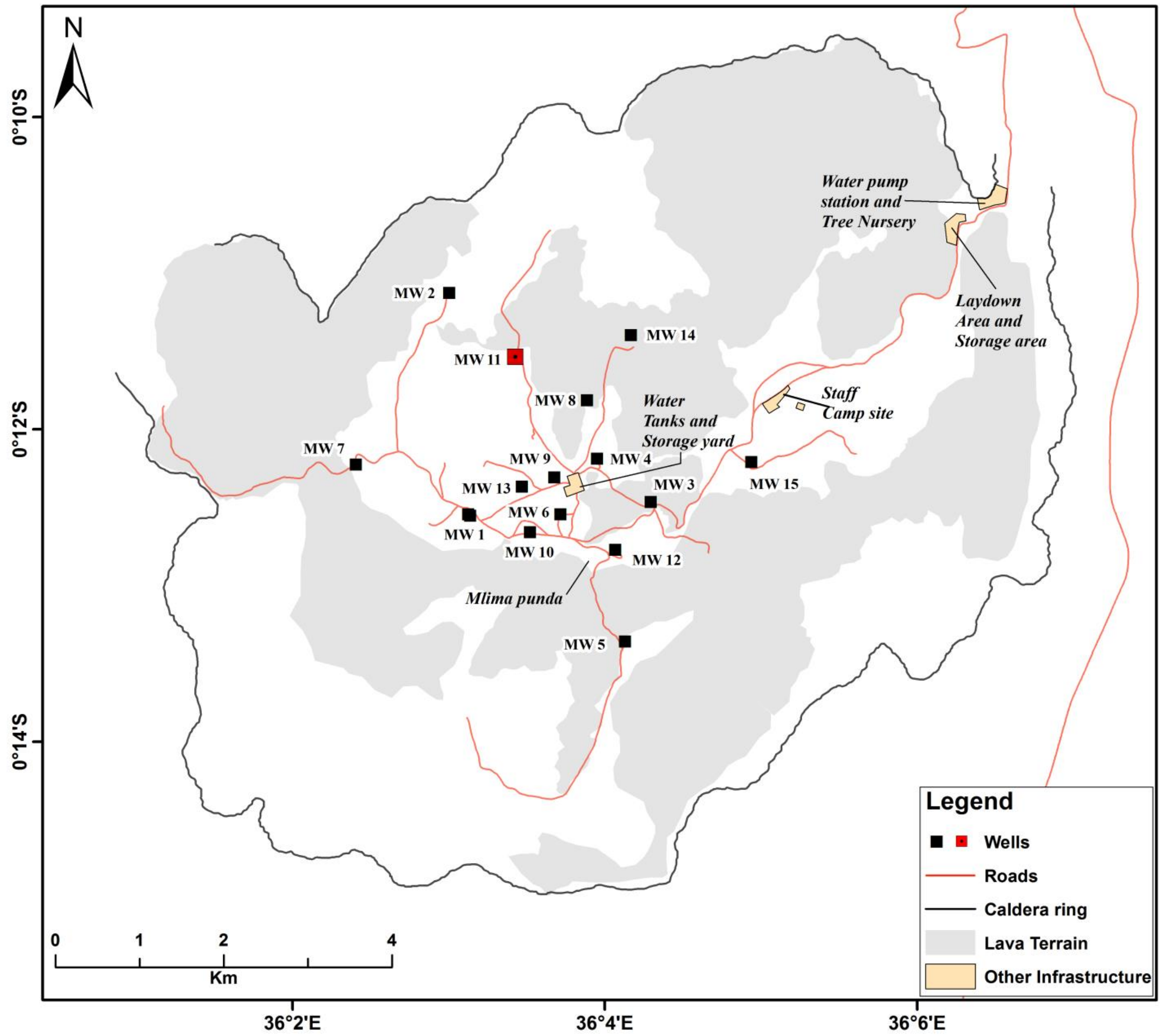

Figure 1: Location of wells MW-08 and MW-11 (GDC, 2013)

2.2 Previous work

Previously, Menengai geothermal field has been studied by different Geo-scientists for different purposes/objectives including academic based research, regional geological mapping for government institutions and regional mapping with interests in natural resources including geothermal. Some of the most relevant publications/ reports include mapping by McCall (1967) in which the geology of area around Menengai is described. GDC in 2010 conducted a detailed study in Menengai prospect to confirm all geological observations recorded in previous work that may be associated with development and occurrences of geothermal resource in the prospect area. From the study, the geophysical analysis indicated a heat source that underlies the caldera structure at Menengai and a similar at the Ol'rongai geothermal area with reservoir temperatures >250°C as deduced from gas geothermometry. Based on these findings exploratory wells were sited and a decision to commence drilling was reached.

3.0 REGIONAL GEOLOGY

The regional surface geology of Menengai is largely composed of late Quaternary volcanic. (Figure.2). The area north of Menengai is characterised by lavas from N-S trending fissures. The lavas are trachytic and trachy-phonolitic in composition are mainly exposed on the scarp walls beyond the Ol´banita swamps, Lomolo and Kisanana areas (GDC, 2010). They underlie ignimbrites and pyroclastics probably originating from Menengai eruptions to the south. Basaltic lavas dominate the Solai axis. Ol´Banita and Ol´Rongai areas which are low-lying, covered with thick soils derived mainly from pyroclastics and extensive thick ignimbrite beds from the caldera. Ol´Rongai ridge rises to 2100 m a.b.s.l approximately 400 m above the general altitude of the surrounding area. Eruptions here vary from fissure gas-poor trachytic lavas to highly explosive gas-rich volcanic ash and pumice (GDC, 2010). The caldera and its immediate surroundings are characterised by pre-caldera trachyte lavas, largely exposed in the caldera walls, syn-caldera ignimbrite at the eastern and northern rims and agglomeratic deposits of poorly sorted angular lithic and glassy/semi-pumiceous ash materials (GDC, 2010). Extensive upwelling of the ground north and west of caldera (Kampi ya moto, El bonwal and Ol´Rongai) may as well have occurred at syn-caldera times. Post-caldera materials are mainly composed of lavas which are largely found on the caldera floor in addition to minor eruption centres to the southwest of the volcano. These eruptive materials were preceded by explosive episodes of ash and pumice cinder cones and tephra sheets onto the caldera floor (Leat, 1984). Intra-caldera lake sediments of well bedded pumiceosands with rounded pebbles in the north-eastern part of the caldera floor (Leat, 1994).

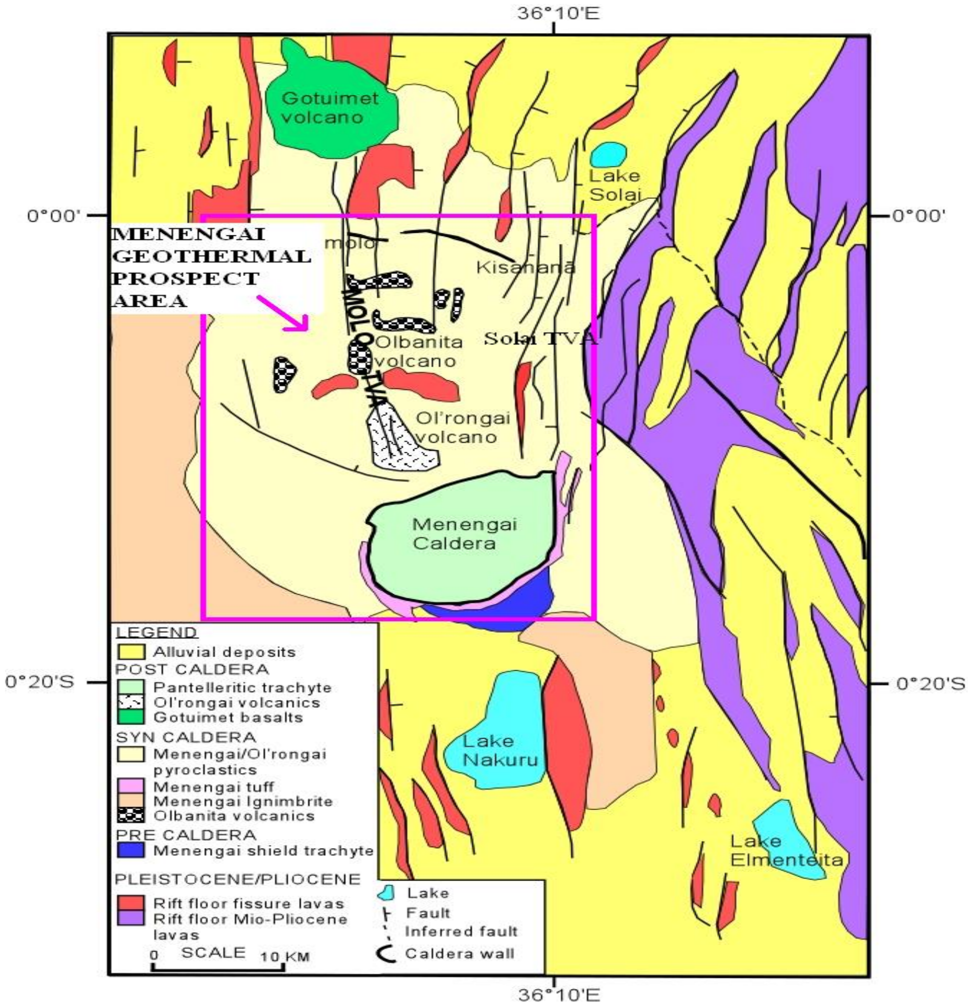

Figure 2: Regional surface geological map (GDC, 2010)

4.0 STRATIGRAPHY

From the analysis, five types of rock units were found to form the litho-stratigraphy of wells MW-08 and MW-11. They include; pyroclastics, trachyte, tuff, syenite and basalt. Syenite occurred as intrusive. Pyroclastics formed the top 20 m column from the ground surface. It is made up of grey to brownish grey vesicular fragments of pumice lapilli particles, obsidian, and glass and lithics of trachytic composition. Trachyte was the most dominant rock penetrated by both wells. It was encountered from 4 m to the bottom of the wells alternating with lenses of tuff, basalt and syenite. The rock ranges from light to dark grey, brownish grey and greenish in colour. The texture ranged from fine to coarse grained and porphyritic with prismatic sanidine phenocrysts embedded in the feldspar rich groundmass. This textural and grain size variation could be linked to different episodes of lava eruptions during the Pre, Syn and Post caldera volcanic activity.

Tuff is the second abundant rock (after trachyte) encountered in both wells. In Menengai, tuff has been identified as the marker horizon separating pre- caldera and post- caldera volcanic stages. MW-08 and MW-11 saw this formation at the depth 474 and 280 m respectively. Significant tuff layers were also at a depth of 850m, 962-1022m and 1198-1222m. It mainly occurred as a grey to brownish poor crystalline vesicular rock. From the binocular analysis, the vesicles at the 300-490 m range are seen to be partially infilled with chalcedony. Calcite, quartz and clays filled both the vesicles and veins in the rock at the greater depths. In all the occurrences the tuff is bleached and moderately to highly altered.

Syenite was encountered only in well MW-08 at depths of 1830-1854 m, 1926-1948 m and 1978-2002 m respectively. It appears as thin lenses between the thick trachytic lavas. The rock is grey, coarse grained and porphyritic consisting primarily of alkali feldspars together with some mafic minerals. The rock is hard and compact when encountered as deduced from the low penetration rates recorded during drilling and disappearance of pyrite.

A thick column of basalt was encountered at 1558-1810 m in well MW-08 and from 1680 m to the bottom of the well in MW-11. In both occurrences, three types of basalt were identified; Glassy grey fine grained, greyish fine grained porphyritic and a more crystalline dark fine grained basalt respectively. These three types occurred in one column and systematically with the glassy fine grained on top, fine grained porphyritic in the middle and the more crystalline fine grained basalt at the bottom. Importantly noted was the degree of alteration, the glassy type is extensively altered and this was marked by the first appearance and abundant deposition of the high temperature epidote, wollastonite and actinolite. The fine grained porphyritic and the more crystalline types of basalt appeared compact and less altered compared to the host basalt. In well MW-11 the greyish fine grained porphyritic type of basalt was not seen. Below is a detailed description of the lithological units seen in wells MW-08 and MW-11.

5.0 DESCRIPTION OF WORK

5.1 Methodology and analytical method

Methodology adopted includes: Interpretation of petrographic investigations conducted on representative samples to determine clay lithologies and their related mineral parageneses and correlate the above observations with relevant literature with the aim to identify the significances of the identified clays in aid to interpolate the prevailed paleoconditions i.e. Permeability and Paleotemprature. This was mostly based on XRD analysis on the two wells. X-ray diffraction (XRD) analysis was carried out on selected samples in order to identify the types of clay minerals present. Prepared Samples were air dried, glycolated and heated according to standard procedures.

5.2 Sample preparation of clay minerals for analysis for MW-8 and MW-11

The samples as received were pulverized for ten minutes with the purpose to reduce all mineral particles to a relatively small size. Size differences may have an influence on the XRD peak intensities of the different clay mineral components of this rock type. The samples were side-mounted to minimize the effect of preferred orientation. The reflection intensities of basal peaks are enhanced by preferred orientation while others become smaller or even disappear. Side mounting the sample obtains a more random orientation of the mineral particles and that insures that the incident X-rays have an equal chance of diffracting from any crystal lattice face of mineral present in the sample. From the micronized material, three representative subfractions were obtained for the following purposes:

1. XRD on the first fraction was done on the material after micronizing and labelled 'untreated'.

2. The second fraction was treated with ethylene glycol— this is used as an auxiliary treatment to expand swelling clays if present. Swelling clays include smectites (e.g. montmorillonite, nontronite), and some mixed-layer clays, and vermiculite. The sample was directly side loaded into the XRD sample holder and placed in a dessicator where it was exposed to ethylene glycol fumes for 12 hours at 60°C. Thereafter XRD was carried out on the sample.

3. The third fraction was loaded into a porcelain crucible and heated for 2 hours in a muffle furnace in air at 550°C. XRD was carried out on the product. This was followed by a consecutive session of another two hours, heat treatment under the same conditions and
XRD repeated.

6.0 RESULTS AND DISCUSSION

The objective of this survey was to determine the distribution of clays in cuttings obtained from MW-08 and MW-11 and to evaluate their usefulness as mineral geothermometers and indicators of reservoir permeability. The presence or absence of certain clays may coincide with specific temperature range. The formation of clay minerals involve the chemical actions and physical movement of hydrothermal fluids and in many cases there is a zonal arrangement of the clay minerals around the source of alteration depending on the parent rock and the nature of the hydrothermal solutions . Hence different types of clays were seen to occur throughout the wells column ranging from low temperature smectites occuring at surface and shallower depths to chlorite occuring at deeper and relatively higher temperature. X-ray diffraction analysis was done on the selected samples in addition to the petrography and binocular microscope analysis to better identify the types of clay minerals. Three types of clay were identified and they included:

Smectite was mainly observed under the petrographic microscope as light green in plane-polarized light and slightly pleochroic and was found as vesicles and vein filling. On XRD analysis, it showed peaks commonly occuring between 12.8 to 15 Å when untreated, 13 to 17 Å when treated with glycol and collapsing to 10.3 Å when heated (Figure 1 in Appendix I). Smectite is a low temperature clay and its occurrence is an indication of temperatures lower than 200°C. In thin section, smectite was first seen at depths 68m in well MW-08 and at 62 m in well MW-11 respectively, where as XRD analysis indicated smectite at greater depths of 796 and 1784 m in wells MW-08 and MW-11(Table 1& 2 in Appendix II).

Chlorite was identified in all the two analyses i.e binocular, petrographic and X-ray diffraction analysis. In the cuttings, chlorite has a light to dark green colour and often associated with high-temperature alteration minerals like epidote, actinolite and wollastonite. In thin-section it is characterised by fine to coarse grained, light green coloured and fibrous in plane polarized. Light grey to white in cross polarized light, showing feather texture and sometimes radial forms. It occured as both replacement of primary mineral in the rock and vesicle filling. In thin-section it was first identified at 538 m depth in well MW-11 and at 774 m in well MW-08 and extends to the bottom of the well. Chlorite is an indicator of temperatures exceeding 250°C. In XRD it shows peaks at 14.4 Å and 7.1 Å, which do not change upon glycolation and heating (Figure 2 in Appendix I). It is only in well MW-08 that chlorite was identified in the XRD analysis at depths 1640-1988 m.

Illite was identified through X-ray diffraction analysis. Illite forms at temperature of 220°C and above. Under XRD analysis, its first appearance was at depths 666 and 288 m in wells MW-08 and MW-11. It prevailed down to depths 2314 and 1734 m respectively. From the analysis, illite showed peaks between 10.2 to 10.3 in untreated, glycolated and heated samples (Figure 3 in Appendix I).

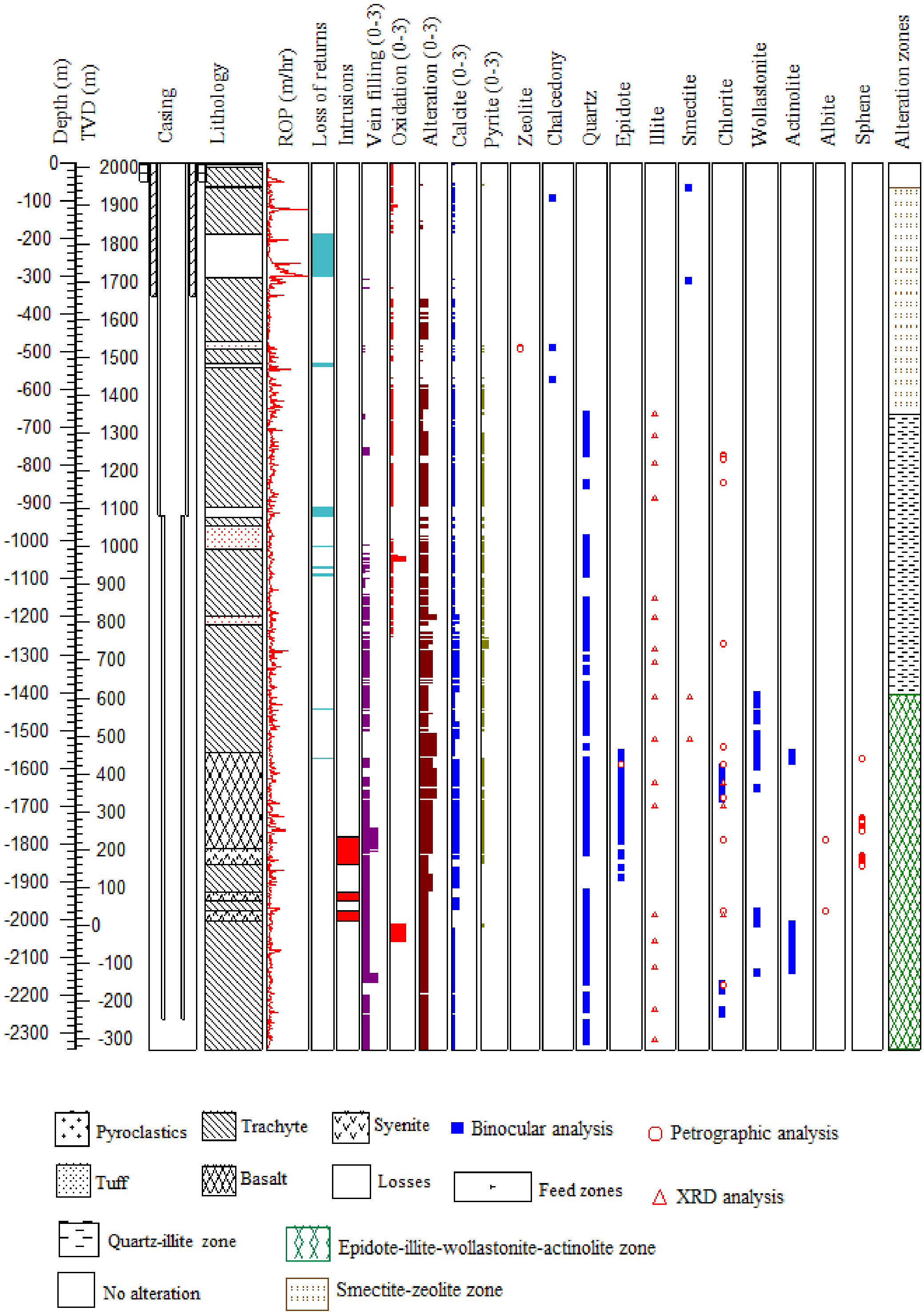

Figure 3: Distribution of hydrothermal clay minerals in well MW-08

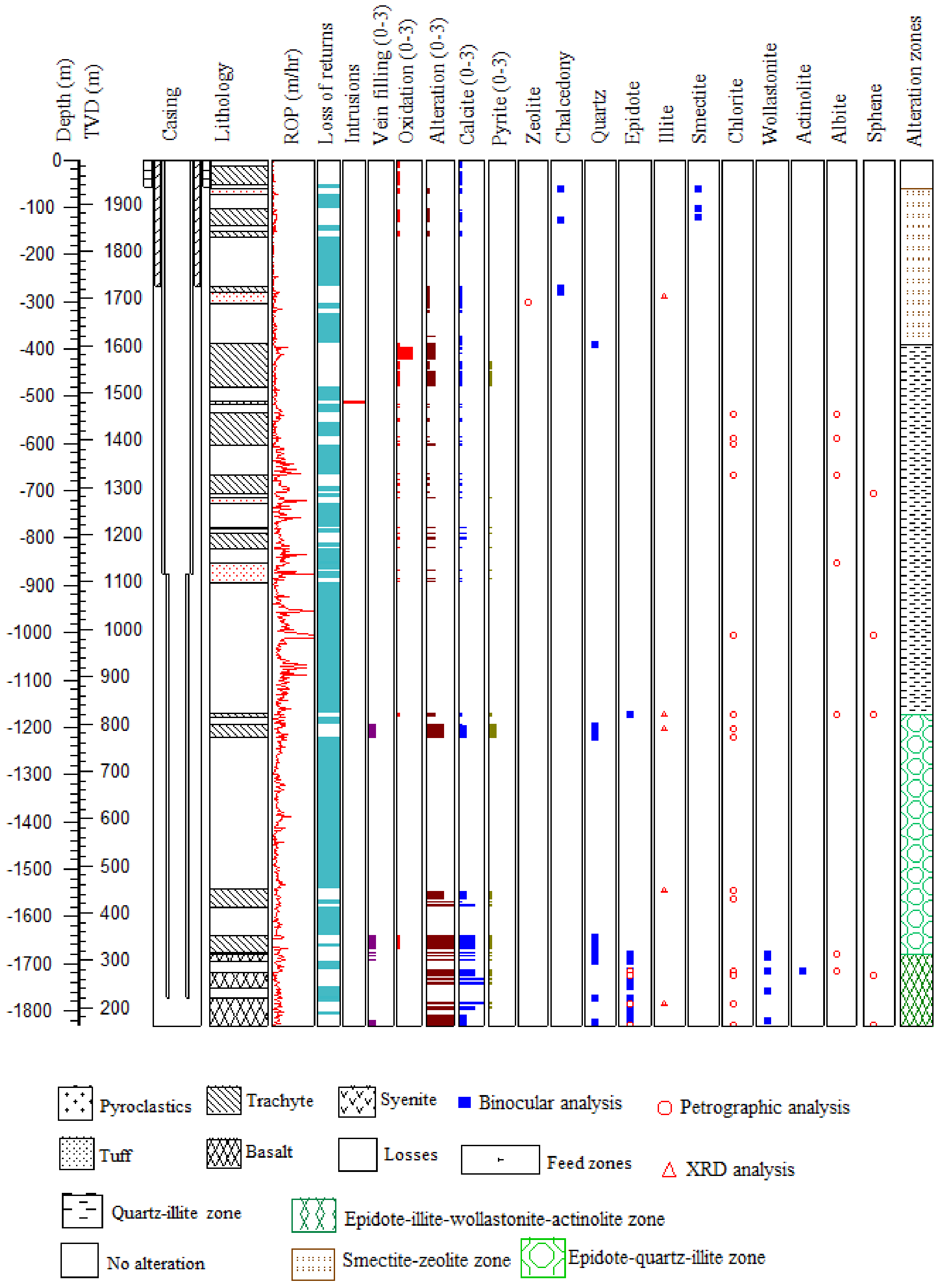

FIGURE 4: Distribution of hydrothermal clay minerals in well MW-11

7.0 CONCLUSIONS

Five rock units form the litho-stratigraphy of wells MW-08 and MW-11. They include; pyroclastics, trachyte, tuff, syenite and basalt.

Hydrothermal alteration minerals in MW-08 and MW-11 geothermal wells are controlled by rock type, permeability and temperature.
Three hydrothermal clay mineral zones are found to be located in order of increasing temperature and depth. They include: (1) smectite, (2) illite zone, (3) chlorite.

Low temperature clay minerals are noted at shallow depths and subsequently higher temperature clay alteration minerals occurring with increase in depth.

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APPENDIX I: selected XRD interpreted graphs for MW-08 and MW-11

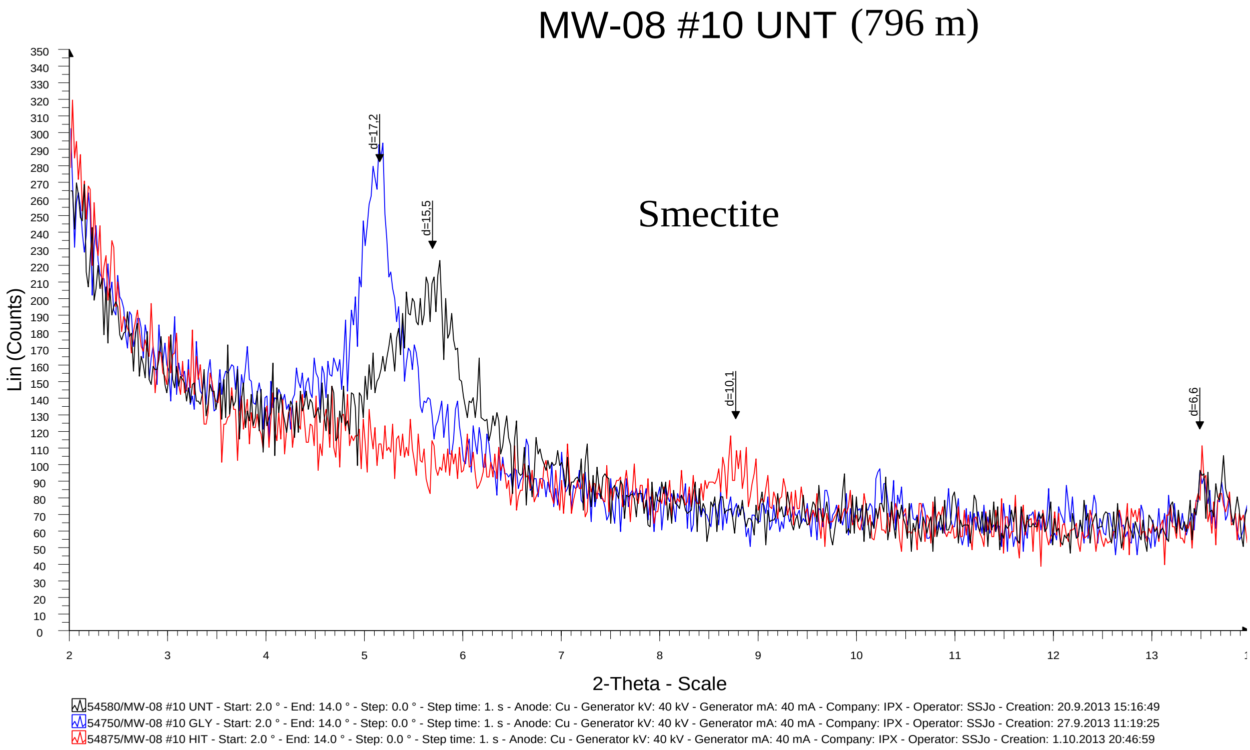

FIGURE 1:Diffractograms of smectite and illite clays at 796 m in well MW-08

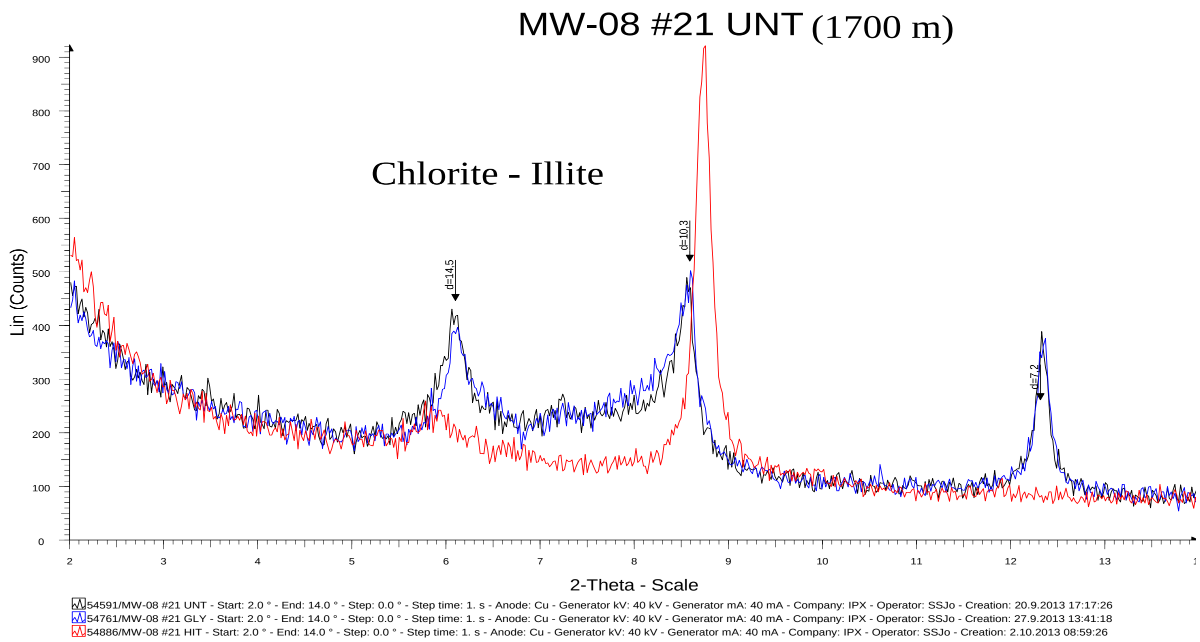

FIGURE 2:Diffractograms of chlorite and illite clays at 1700 m in well MW-08

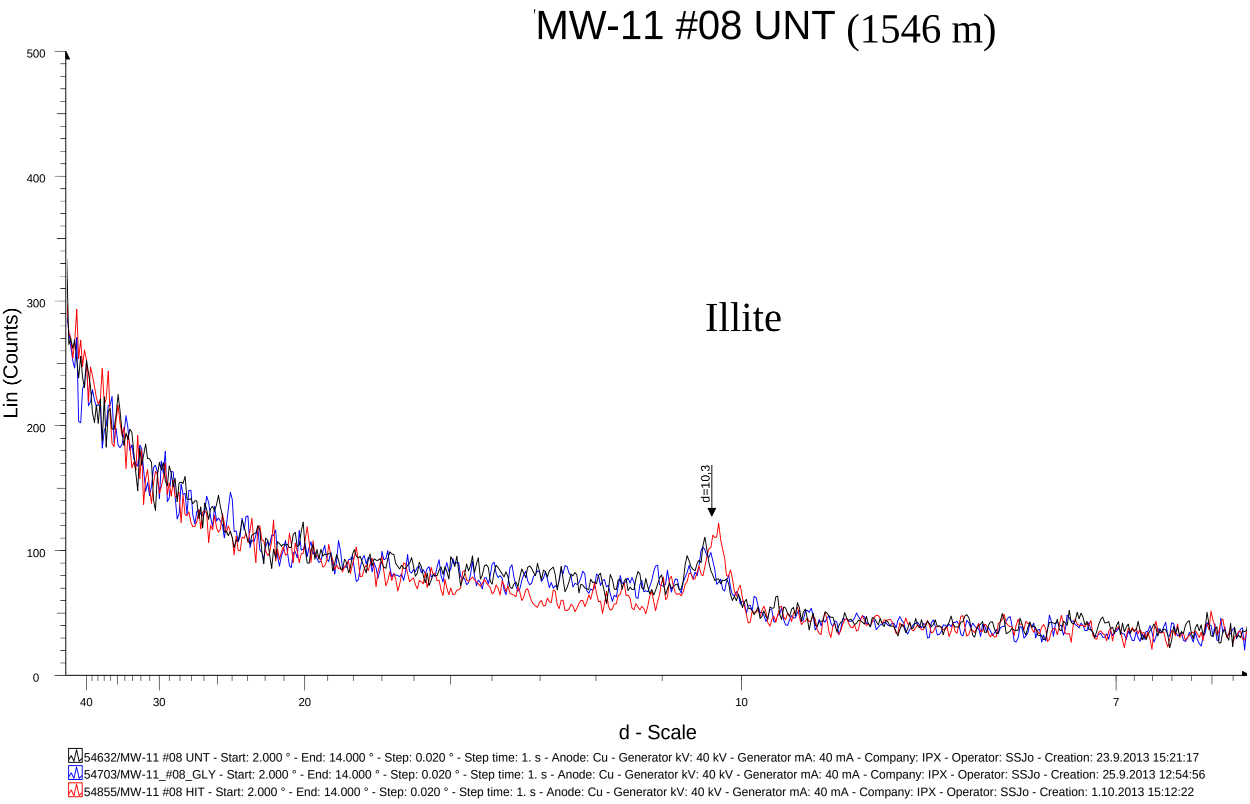

FIGURE 3:Diffractograms of illite at 1546 m in well MW-11

APPENDIX II: XRD graph analyses of chlorite,illite and smectite clay peaks

TABLE 1: Well MW-08 XRD results

NO. #	DEPTH (m)	d(001) UNT	d(001) GLY	d(001) HIT	MINERAL	TYPE	REMARKS	Other minerals
#1	26				no clay			
#2	86				no clay		8,6Å	amphibol
#3	140				no clay		8,6Å	amphibol
#4	188				no clay			
#5	312				no clay		9,2Å	amphibol/zeolite
#6	466				no clay		8,6Å	amphibol
#7	532				no clay			
#8	666	10.3	10.3	10.3	Illite	ill		
#9	722	10.3	10.3	10.3	Illite	ill	8,6Å	amphibol
#10	796	15.5	17.2	10.1	Smectite	sm		
#11	888	12.8	13.1	10.1	Smectite	sm		
#12	962				no clay		8,6Å	amphibol
#13	1056				no clay			
#14	1154	12,8/10	143,3/10	10.1	Smectite/illite sm/ill	sm-ill		
#15	1202	10.3	10.3	10.3	Illite	ill	7,2Å	kaolinite
#16	1288	10.3	10.3	10.3	Illite	ill		
#17	1322	10.3	10.3	10.3	Illite	ill		
#18	1412	15,4/10	~17/10	10.3	Smectite sm/ill	sm-ill	8,6Å	amphibol
#19	1524	12,2/10,3	12,3/10,3	10.3	Smectite sm/ill	sm-ill	8,6Å	amphibol
#20	1640	14,5/10,3	14,5/10,3	14,5/10,3	Chlorite/illite Chl: ill.	Chl: ill		
#21	1700	14,5/10,3	14,5/10,3	14,5/10,3	Chlorite/ilite Chl: ill.	Chl: ill		
#22	1782				no clay			

#23	1988	14,5/10,3	14,5/10,3	14,5/10,3	Chlorite/illite Chl: ill.	Chl: ill		
#24	2058	10.3	10.3	10.3	Illite	ill	8,6Å	amphibol
#25	2128	10.3	10.3	10.3	Illite	ill	8,6Å	amphibol
#26	2238	10.3	10.3	10.3	Illite	ill	8,6Å	amphibol
#27	2318	10.3	10.3	10.3	Illite	ill		

TABLE 2: Well MW-11 XRD results

NO. #	Depth (m)	d(001) UNT	d(001) GLY	d(001) HIT	Mineral	Type	Remarks	Other minerals
#1	68				no clay			
#2	124				no clay		8,6Å	
#3	288	10.2	10.2	10.2	Illite	ill	9,1Å/8,6Å	
#4	462				no clay		8,6Å	
#5	706	17.4	17.4	none	??			
#6	1172	10.3	10.3	10.3	Illite	ill	7,2Å	Kaolinite
#7	1202	10.3	10.3	10.3	Illite	ill	7,2Å	Kaolinite
#8	1546	10.3	10.3	10.3	Illite	ill		
#9	1784	~19/15, 1/10,3	~19/15, 1/10,3	15,1/10,3	Sm: ill. (MLC)	sm-MLC: ill	uncertain	