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Using Clay Minerals to Identify Hydrothermal Fluid Pathway in Low-Grade Meta-Clastic Rocks

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ABSTRACT

This is the first work attempted to apply clay minerals as indicators for hydrothermal processes in the Tuchang-Chingshui Geothermal field, Taiwan, where is one of few geothermal power plants operated in low-grade mata-clastic rocks in the world. The bedrock of the study area consists mainly of argillite, slate, and meta-sandstone. A systemically sampling scheme was implemented on outcrops along the riverbank in the region. This effort was made for establishing the relationship between the spatial distribution of clay mineral assemblages and hydrothermal processes by using XRD. Analysis results show that smectite and mix-layer of clay minerals are coexistence with local geothermal activities in the area. This indicator can be used to help identify the hydrothermal fluid pathway.

1. INTRODUCTION

Taiwan and other countries located on the Pacific Rim of Fire possesses rich geothermal resources of the world due to volcanic activities and plate collisions. The exploration of geothermal resources in Taiwan can be dated back to the 1970s. A 3-MWe geothermal energy power plant was installed in Chingshui, Ilan, where is one of few geothermal power plants operated in low-graded mata-clastic rocks region in 1981 (Hartmann and Moosdorf, 2012; Bertani, 2012, 2015; and Zhang, 2019). Few studies have been done on the relationship between clay minerals and geothermal fluid in the low-grade meta-clastic rock region.

This study is the first to attempt to establish relationship between the spatial distribution of clay mineral assemblages and hydrothermal processes by using XRD and to link the transformation of clay minerals with the influence of geothermal fluid.

2. GEOLOGICAL SETTING AND SAMPLING

The study area, the Tuchang-Chingshui geothermal field, is located in the Backbone Range belt in the northeastern Taiwan (Figure 1). The Backbone Range belt is composed of mainly slate with well-developed cleavages, and argillite and sandstones. The study area is located in the Miocene Age Lushan Formation, which can be divided into two members: Chingshuihu and Jentse. The Chingshuihu member is composed of thick slate or phyllite in gray to black color with thin beds of meta-sandstone, and the Jentse member is mainly composed of alternation argillite in light grey in color.

The fault system of the region lies the Dahsi, Xiaonanao and Hanshi faults from north to south and is cut by the Chingshuihsi fault, a right-lateral fault. Most geothermal manifestoes appear along the Chingshui river bank between the Dahsi and Xiaonanao faults (Tseng, 1978; Lin and Lin, 1995; Lu et al., 2011).

73 samples were collected along the Chingshui river bank from slate, meta-sandstone, and argillite respectively (Figure 2). There are 20 of 73 samples were collect from Chihlukenga river, a tributary of the Chingshui river.

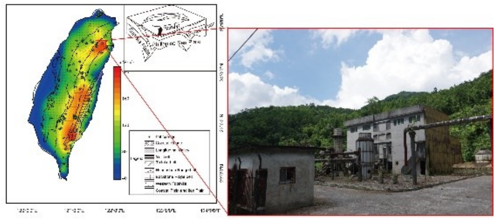

Figure 1: The study area located in low-grade meta-clastic rocks. A 3-MWe geothermal energy power plant was installed in Chingshui Geothermal Field, Ilan of Taiwan.

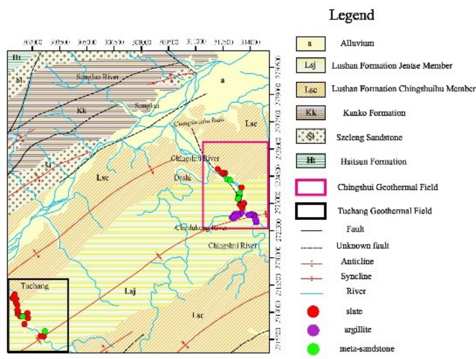

Figure 2: This study collected 147 samples including slate, argillite and meta-sandstone which located in Tuchang-Chingshui Geothermal Field.

3. RESULTS AND DISCUSSION

3.1 The slate region of the Chignshui River

Slate and meta-sandstone are two major rock types of this region. Clay mineral assemblages of slate include illite,64%-93%, kaolinite, 2%-16%, chlorite, 2%-32%, and smectite, 4%-31%. The crystallinity values are 0.324-0.491Δ°2θ of illite and 0.35-0.43 Δ°2θ of the smectite. On the other hand, clay mineral assemblages of meta-sandstone include illite, 19%-100%, kaolinite, 1%-34%, chlorite, 12%-79%, and smectite, 27%-58%. The crystallinity values are 0.307-0.536Δ°2θ of illite and 0.35-0.43 Δ°2θ of the smectite (Figure 3).

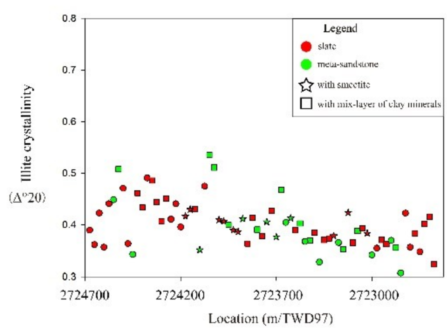

Figure 3: The illite crystallinity of slate and meta-sandstone. The samples included smectite and mixlayer of clay minerals are marked as star and square in the slate area of the Chignshui River.

3.2 The argillite region of the Chignshui River

Argillite is the only rock type appears in the region. Clay mineral assemblages of slate include illite, 76%-100%, kaolinite, 2%-13%, chlorite, 3%-23%, and no smectite. The crystallinity values are 0.409-0.75 Δ°2θ of illite (Figure 4).

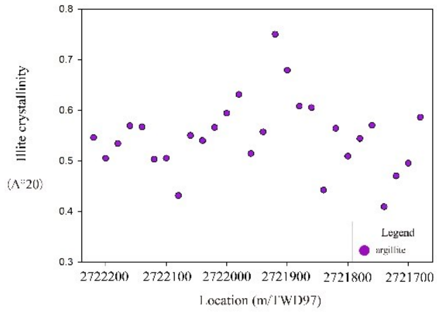

Figure 4: The illite crystallinity in argillite in the argillite area of the Chignshui River.

3.3 The argillite region of the Chihlukeng River

Argillite and meta-sandstone are two major rock types of the region. Clay mineral assemblages of argillite include illite, 66%-97%, kaolinite, 0.7%-12%, kaolinite + chlorite, 6%-20%. The crystallinity values are 0.469-0.701 Δ°2θ of illite. On the other hand, clay mineral assemblages of meta-sandstone include illite, 68%-100%, kaolinite, 4%, kaolinite + chlorite, 0.7%-33%, and smectite, 27%-58%. The crystallinity values are 0.452-0.827 Δ°2θ of illite (Figure 5).

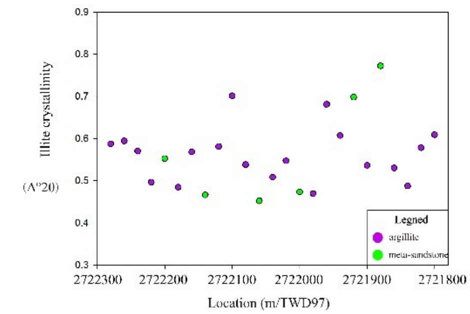

Figure 5: The illite crystallinity of argillite and meta-sandstone in the argillite area of the Chihlukeng River.

3.4 The slate region of the Tuchang

Slate and meta-sandstone are two major rock types of the Tuchang region. Clay mineral assemblages of slate include illite,66%-93%, kaolinite, 6%-17%, kaolinite +chlorite, 11%-24%, smectite, 12% and mixed-layer, 2%-3%. On the other hand, clay mineral assemblages of meta-sandstone include illite, 77%-79%, kaolinite+ chlorite, 12%-17%, and mixed-layer, 2%-9% (Figure 6).

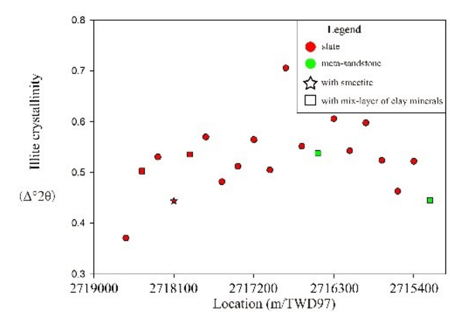

Figure 6: The illite crystallinity of slate and meta-sandstone. The samples with smectite and mixed-layer of clay minerals are marked as star and square in the slate area of Tuchang.

3.5 The Conceptual model of hydrothermal alterations in a low-graded meta-clastic rocks

We have proposed a conceptual model to describe the possible transformation of clay minerals in a low-graded meat-clastic rocks region.

The existence of widely distributed smectite and kaolinite in the region become gradually rich due to the burial depth increased, and the minerals begin to transform into smectite and illite mixed-layer minerals. As the temperature increases with depth increased, the content of kaolinite become illite in the mixed-layer mineral increases with smectite content decreases. In this chemical reaction of the transformation, potassium ions and aluminum ions are consumed, and replaced by the ions most come from detrital minerals such as mica and potassium feldspar minerals by involving pore water to form illite (Weaver,1967；Hower,1976; Meunier, 2005). The well-developed cleavage systems of the region provide the pathway for geothermal hot fluid water to react with rocks to initiate and enhance the transformation. Figure 7 illustrates the model of hydrothermal alteration, from smectite and kaolinite become smectite and illite mixed-layer and then illite, in low-grade meta-clastic rocks with the influence of geothermal fluid.

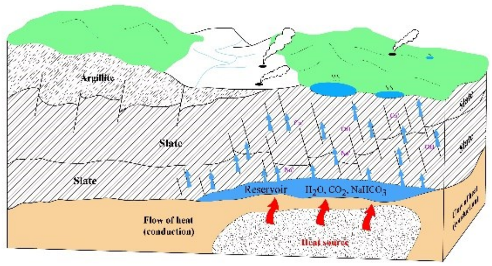

Figure 7: The conceptual model of hydrothermal alteration with help from well-developed cleavages in low-grade meta-clastic rocks.

4. CONCLUSIONS

(1) The slate region of the Chignshui River: Clay mineral assemblages of slate include illite, kaolinite, chlorite, and smectite. The crystallinity values are 0.324-0.491Δ°2θ of illite. Clay mineral assemblages of meta-sandstone include illite, kaolinite, chlorite, and smectite. The crystallinity values are 0.307-0.536Δ°2θ of illite. The crystallinity values decrease from the North to the south in general.

(2) The argillite region of the Chignshui River: Clay mineral assemblages of argillite include illite, kaolinite, and chlorite. No smectite has been found in this region. The contents of kaolinite and chlorite are lower than that of the slate region with higher crystallinity values,0.505-0.608 Δ°2θ.

(3) The argillite region of the Chihlukeng River: Clay mineral assemblages of this region include illite, kaolinite, and chlorite. No smectite and mixed-layer have been found in this region. The higher crystallinity values are found in this region than that of the Chignshui River.

(4) Illite, kaolinite, and chlorite are found in all geologic regions of the study area while smectite and mixed-layer are found restricted in geothermal manifestos areas to indicate its hydrothermal alteration origin.

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