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CRYSTALLINITY OF SUBSURFACE CLAY MINERALS IN THE TE MIHI SECTOR OF THE WAIRAKEI GEOTHERMAL SYSTEM, NEW ZEALAND

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SUMMARY Lacustrine sediments of the Huka Falls Formation in the Te Mihi sector of the Wairakei geothermal system occur at depths between 180m and 370m where the measured drillhole temperatures range from 90 to 220°C. The sediments contain clay minerals of variable composition and structure, including illite/smectite, discrete illite and chlorite. The crystallinity of the (001) reflections for illite/smectite mixed-layer clays increases with increasing host rock temperature and depth, with most $\Delta°2\theta$ (Kubler Index) values ranging from 1.40 to 0.44. The Kubler Indices of the illites are from 0.35 to 0.44 $\Delta°2\theta$. An empirical relationship between the Kubler Index of the illite/smectite (001) peak (air-dried) and the measured drillhole temperatures (T) from 90 to 230°C is,

$$T (°C) = 249 - 89.3*C,$$ where C is the Kubler Index (r=0.92).

The K content per component of $O_{10}(OH)_2$ of illite/smectite increases with increasing drillhole temperature and correlates negatively with their Kubler Indices.

Chlorite crystallinity (ChC), as represented by the (002) reflectios, varies only slightly with the drillhole temperature but shows consistently high values throughout (average $\Delta°2\theta$ = 0.28). There is an approximate linear correlation between the ChC (002) of the air-dried and ethylene glycolated chlorites in both the 2-0.2µm and <0.2µm size fractions.

INTRODUCTION

Lacustrine sediments belonging to the Huka Falls Formation (HFF) are the most widespread sedimentary rocks in the Taupo Volcanic Zone (Grindley, 1965). The HFF is hydrologically important at Wairakei (Figure 1), where it occurs at shallow depths between the top of the dominantly volcanic Waiora Formation (WF) and the base of the 22.7Ka year old Wairakei Breccia (WB). In the Te Mihi area, the HFF also includes hydrothermal eruption breccias, bedded mudstones and coarse tuffaceous mudstones totalling 180 to 230m in thickness.

The hydrothermal alteration of the HFF is not as obvious as it is in the more reactive underlying volcanic rocks (Steiner, 1977), but the lacustrine sediments have, never the less, also responded to their geothermal environment. Interaction between them and the thermal fluids has produced clay minerals that reflects the thermal region prevailing in the Te Mihi area (Ma & Browne, 1991; Harvey & Browne, 1991; Ma, 1992).

The purpose of this paper is to report the crystallinity of illite/smectite, discrete illite and chlorite present in cores recovered from the Te Mihi sector of the Wairakei system.

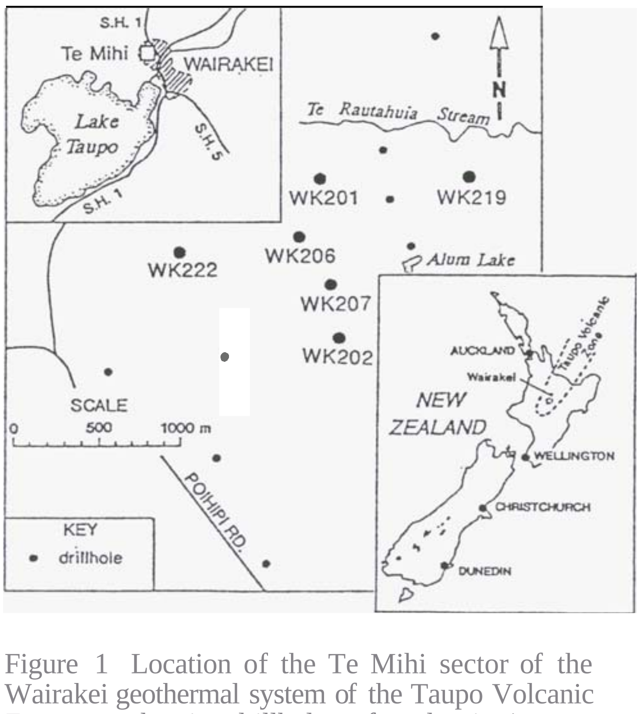


Figure 1 Location of the Te Mihi sector of the Wairakei geothermal system of the Taupo Volcanic Zone, NZ, showing drillholes referred to in the text.

METHODS

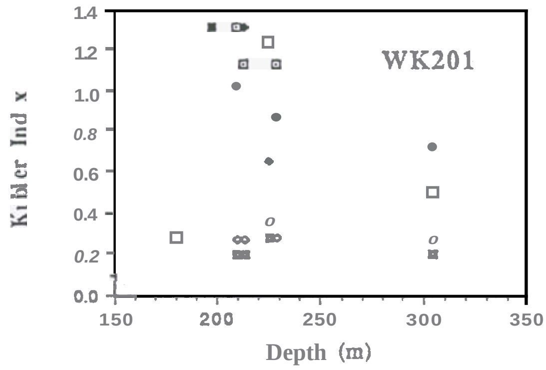
Sixty cores recovered from the shallow parts of drillholes WK201, 202, **206,** 219 and **222** (Figure 1) were selected and subjected to X-ray diffraction analysis. Air-dried, glycolated and heated (up to 550°C), fractions of less than 2 micrometers and less than **0.2** micrometers were used to identify the clay minerals present. Oriented samples were prepared by pipetting clay slurries of each onto glass slides. All samples were run from 2 to 30 degrees **2θ** on a Phillips X-ray diffractometer with CuKα (1.5418Å) radiation and a scanning speed of 2°/minute. The compositions of the mixed-layer minerals were determined by comparing the saturated ethylene glycol sample patterns with those of Reynolds (1980, 1987). The Kulber Indices of the illite/smectite mixed-layer clays (001) and chlorites (002) were measured (Table 1).

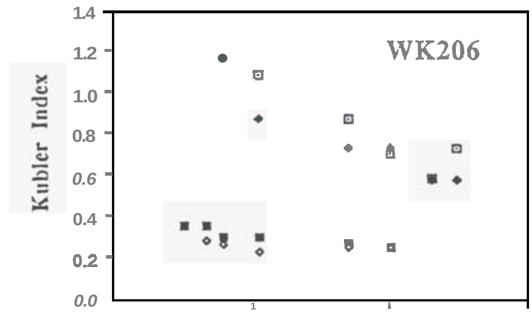
The Kubler Index is defined for illite as the half-height peak width of the (001) reflection. This method is described in Kubler (1964, 1967, 1968) and Dunoyer de Segonzac et al. (1968). The numerical value of the Kubler Index decreases with increasing 'crystallinity'. In earlier studies, the half-height peak width was expressed in millimeters, but is now generally given in Δ°2θ. The method has now been successfully applied by more than 100 authors (Frey, 1987).

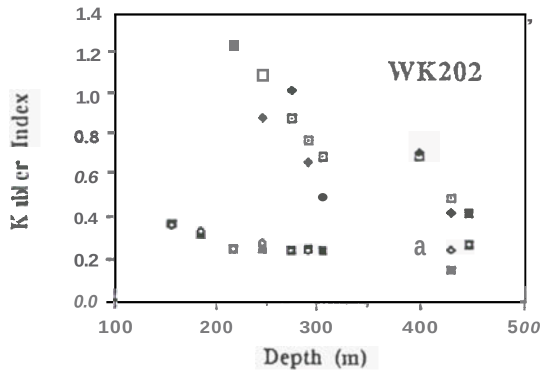
RESULTS AND DISCUSSION

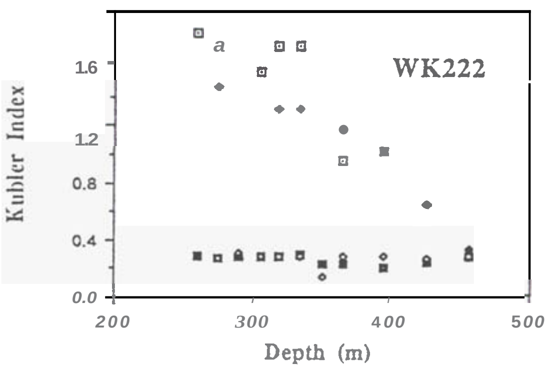
Crystallinity of Illite/Smectite

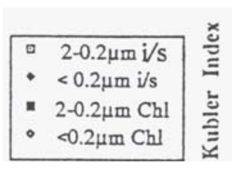
(1) The crystallinity (IC) of the illite/smectite mixed-layer clays increases with increasing temperature and depth (Figure 2). Most Δ°2θ values range from 1.40 to 0.44, but there is no measurable difference between the IC values of the two size fractions (Table 1). The Kubler Indices of the shallowest discrete illites are from 0.35 to 0.44, which coincides with the boundary from diagenesis to anchizone (Arkai, 1991).











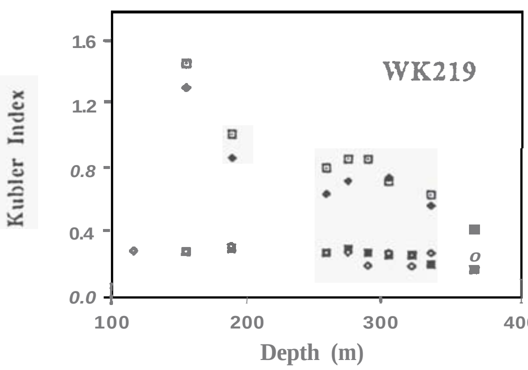


Figure 2 Crystallinity (Kubler Index, Δ°2θ) of illite/smectite (i/s) and chlorite (Chl) vs core depth.

Table 1 Representative crystallinity (Kubler Indices, Δ°2θ) of chlorite (002) and illite/smectite (001) in cores from drillholes WK201, 202, 206, 219 and 222.

Depth (m)	Unit	Measured Temp.(°C)	ChC 2-0.2 μm Airdried	ChC 2-0.2 μm Glycolated	ChC <0.2 μm Airdried	ChC <0.2 μm Glycolated	IC 2-0.2 μm Air-dried	IC <0.2μm Airdried
180	HFF	120	0.29	0.43	0.29	0.43		
198	HFF	130					1.32	1.32
210	HFF	135	0.21	0.22	0.28	0.22	1.32	1.03
213	HFF	140	0.21	0.22	0.28	0.27	1.18	1.32
229	HFF	150	0.15	0.32	0.29	0.29	1.18	0.88
244-259	HFF	160	0.29	0.32	0.37	0.51	1.25	0.66
305	HFF	185	0.21	0.22	0.26	0.28	0.51	0.74
WK202								
152	WB	89						
155	HFF	90	0.38	0.32	0.37	0.43		
183	HFF	109	0.32	0.32	0.34	0.32		
215	HFF	140	0.29	0.28	0.29	0.29	1.25	1.25
244	HFF	160	0.29	0.26	0.31	0.29	1.10	0.90
274	HFF	182	0.28	0.28	0.28	0.28	0.90	1.03
290	HFF	192	0.29	0.19	0.28	0.26	0.79	0.68
305	HFF	202	0.28	0.26	0.21	0.22	0.71	0.51
399	HFF	216	0.26	0.26	0.29	0.44	0.72	0.74
430	WF	221	0.16	0.15	0.26	0.26	0.51	0.44
433-457	WF	225	0.29	0.28	0.29	0.29	0.44	0.44
WK206								
201	HFF	185	0.37	0.32		0.31		
217-218	HFF	185	0.37	0.34	0.29	0.36		
230	HFF	190	0.31	0.29	0.28	0.29		1.18
244-274	HFF	192	0.31	0.29	0.24	0.22	1.10	0.88
320	HFF	200	0.28	0.22	0.26	0.21	0.88	0.74
351	HFF	200	0.26	0.22	0.26	0.28	0.71	0.74
381	HFF	205					0.60	0.59
398	WF	210					0.74	0.59
WK219								
116	WB				0.29	0.31		
154	HFF		0.29	0.29	0.29	0.26	1.47	1.32
188	HFF		0.31	0.31	0.32	0.29	1.03	0.88
259	HFF		0.29	0.29	0.29	0.29	0.82	0.66
274-276	HFF		0.31	0.29	0.29	0.29	0.88	0.74
290-291	HFF		0.29	0.28	0.21	0.22	0.88	
305	HFF		0.28	0.26	0.29	0.26	0.74	0.76
320-322	HFF		0.28	0.26	0.21	0.19		
335	HFF		0.22	0.21	0.28	0.26	0.66	0.59
366	WF		0.19	0.21	0.26	0.22	0.44	0.44
WK222								
260	HFF	91	0.29	0.29			1.84	
274	HFF	100	0.28	0.28	0.28	0.28	1.76	1.47
290-291	HFF	111	0.29	0.28	0.32	0.29		
306	HFF	121	0.29	0.28	0.29	0.28	1.62	
320	HFF	130	0.29	0.28	0.29	0.29	1.76	1.32
335	HFF	140	0.31	0.29	0.29	0.29	1.76	1.32
351-352	HFF	150	0.24	0.18	0.15	0.15		
366	HFF	160	0.24	0.18	0.29	0.18	0.96	1.18
396	HFF	180	0.22	0.28	0.29	0.22	1.03	1.03
427	HFF	200	0.26	0.22	0.28	0.29		0.66
457	WF	220	0.29	0.29	0.29	0.29		0.35

Temperature data from Grindley, 1965.
** ChC -- chlorite crystallinity. IC -- illite/smectite crystallinity.
WB -- Wairakei Breccia; HFF -- Huka Falls Formation; WF -- Waiora Formaiton.

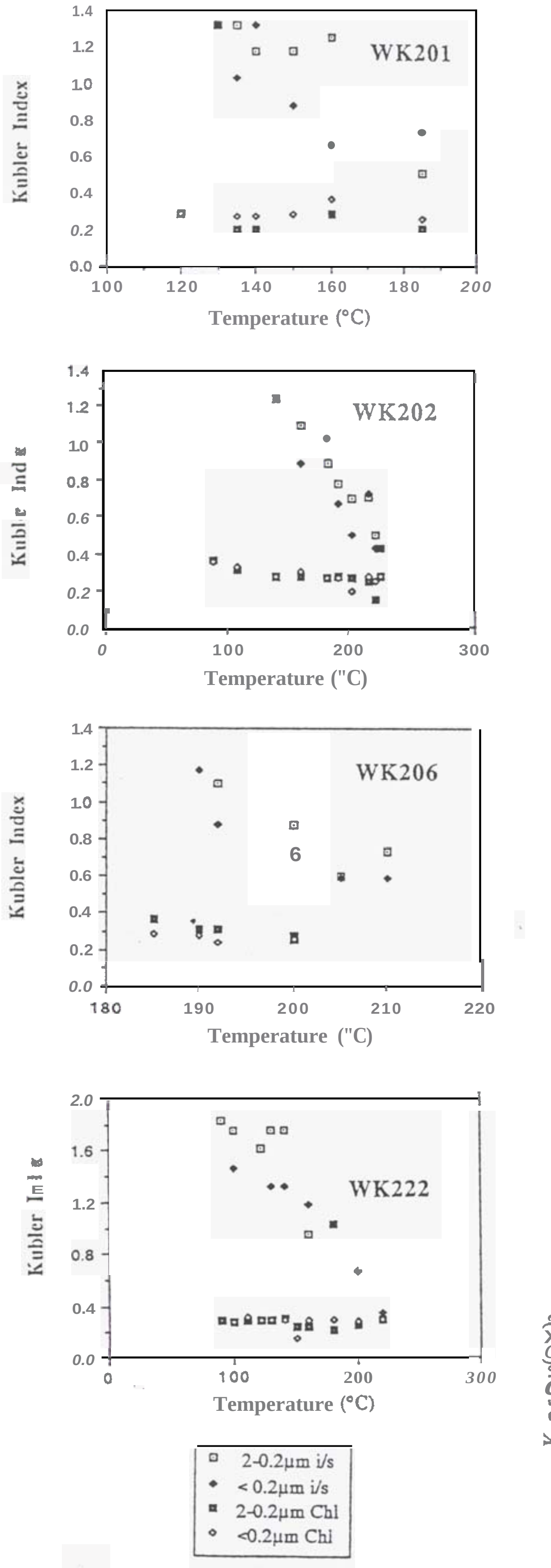


Figure 3 Crystallinity (Kubler Index, Δ°2θ) of illite/smectite (i/s) and chlorite (Chl) vs measured drillhole temperature (temperature data from Grindley, **1965).**

Temperature is believed to **be** the most important factor affecting illite crystallinity. This is evident in contact metamorphic zones (e.g. Kubler et al., **1974)** and is also supported by the results of numerous hydrothermal experiments (Frey, 1986). For the Wairakei samples, **an** empirical relationship was determined between the Kubler Indices **(Δ°2θ)** of the illite/smectite (001) **peaks** (air-dried) and the measured downhole temperatures. This was calibrated from 90" to 230°C (Figure **4),** based on data given in Table **1.** The relationship is :

$$T\ (''C) = 249 - 89.3 * C,$$

where C is the Kubler Index **(Δ°2θ)** of the illite/smectite (001) **peak** and T is the measured drillhole temperature (Grindley, 1965). The correlation coefficient is 0.92.

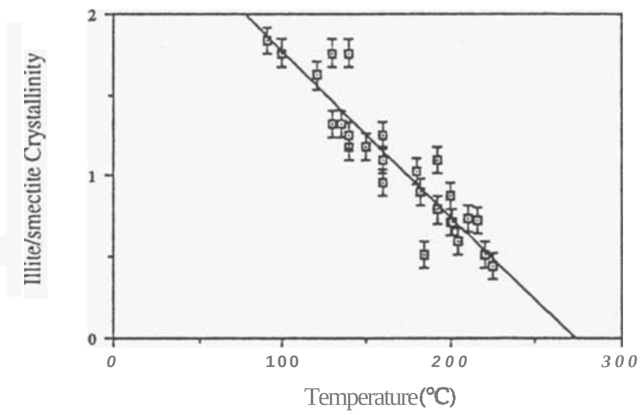


Figure **4** Relationship between temperature and illite/smectite crystallinity in cores from drillholes at Te Mihi.

Determination of the crystallinity of illite/smectite **(001) peaks** therefore **offers** a rapid and convenient method to deduce thermal conditions prevailing at Wairakei at the time these clays formed.

(2) The K contents of illite/smectite clays increases with their increasing degree of crystallinity and the temperature of their host rocks (Ma, **1992)** (Figure **5).**

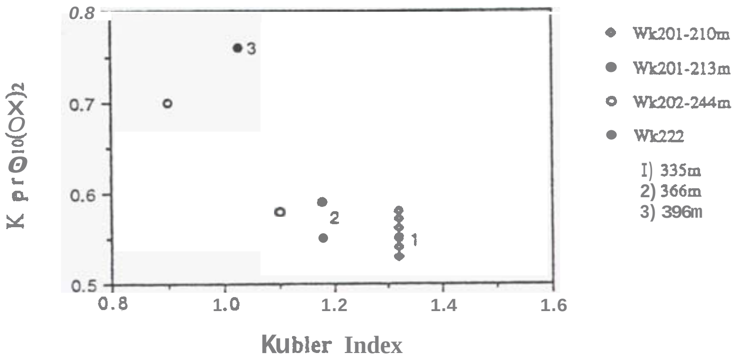


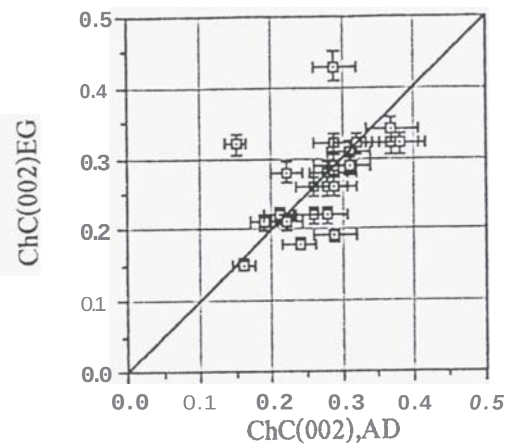
Figure **5** Relationship between the K contents per $O_{10}(OH)_2$ component and the Kubler Indices of illite/smectite clays from Te Mihi drillholes.

The K contents of the clays were determined by electron microprobe analyses (Ma, 1992) and range from 0.53 to 0.76 per $O_{10}(OH)_2$ component (Figure 5).

Weaver and Beck (1971) and Hunziker et al. (1986) also pointed out that the K content of illite increases with crystallinity.

(3) Besides temperature and composition, host rock lithology and time also affect clay crystallinity (Essene, 1982). Coarse-grained clastic sediments usually contain more highly crystallized illites than do fine-grained sediments (Frey, 1986) and this is also indicated by the present study (Table 1), whereby the, 2-0.2µm fractions mostly have lower Kubler Indices than the <0.2µm fractions present in the same sample. Time is unlikely to have had any appreciable effect in producing illites with different crystallinity since the thermal regime established after the sediments deposited.

a) 2-0.2µm fraction



b) <0.2µm fraction

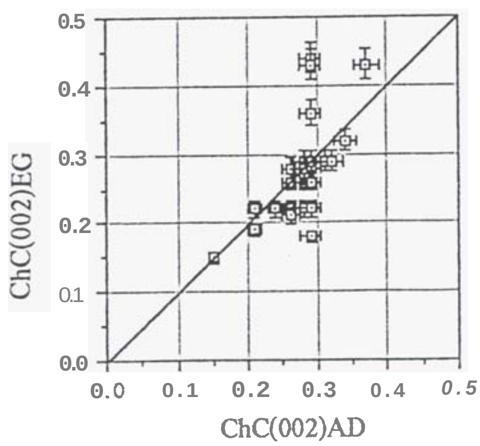


Figure 6 Relationship between chlorite crystallinity (ChC) values measured on air-dried (AD) and ethylene-glycolated (EG) separates. Half-height peak width values of the 7Å reflection are from Table 1. (a) 2-0.2µm fraction; (b) <0.2µm fraction.

Chlorite Crystallinity

Chlorite crystallinity (ChC) measured on the (002) reflections changes only slightly with temperature, showing a high and uniform degree of crystallinity throughout (average $\Delta°2\theta$ = 0.28; Figures 2 & 3).

There are no differences in the $\Delta°2\theta$ values between air-dried and glycolated samples (Table 1). There is a positive correlation between the ChC (002) of the air-dried (AD) and the ChC (002) of the ethylene glycolated samples (EG) for both size fractions (Figure 6). At higher $\Delta°2\theta$ values, EG treatment caused a small increase in ChC (002), presumably due to the presence of minor expandable smectite layers within the chlorite.

Chlorites are much more highly and uniformly crystallized than are illite/smectites present in the same samples and the former have a crystallinity which is independent of grain size.

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