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The Significance of Crystallinity in Hydrothermal Alteration Mapping: A Case Study of Alem Tena Area of Main Ethiopia Rift, Ethiopia

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Abstract

This study examines the kaolinite crystallinity obtained from spectral characteristics of kaolinite mineral as one of the minerals revealed by short wave infra-red (SWIR) spectroscopy during the alteration mineral mapping of Alem Tena area. About forty samples were analyzed for kaolinite crystallinity using the method of Slope Parameter and Kaolinite Crystallinity Index (KCI). The results obtained from both methods indicate that the area is of high kaolinite crystallinity which is important for better understanding of the origin of formation of the kaolinite and other associated alteration minerals over the study area.

Keywords: Crystallinity, slope parameter, kaolinite crystallinity index (KCI), Alem tena, short wave infrared (SWIR).

Introduction

Preliminary study on the mapping of mineral alteration in AlemTena area of the Main Ethiopia Rift (MER) using shortwave infrared (SWIR) spectroscopy shows mineral assemblages such as Kaolinite, Halloysite, Opal, Montmorillonite, Nontronite, Calcite, Palygorskite and mixture of this minerals.Kandite mineral group (kaolinite and halloysite) strongly dominates other alteration minerals over the study area especially kaolinite[1]. As a result of this, further analysis was carried out on the kaolinite (kaolinite crystallinity) which provides more insight about the environment of origin of the alteration minerals in the area.

Crystallinity literally means the degree of structure order in a solid. Therefore, in the context of this study, kaolinite crystallinity refers to analysis of structural order of kaolinite spectra which were obtained during initial analysis of the alteration minerals over the study area. Crystallinity variations associated with kaolinite and illite/sericite group of minerals is significant in term of spectral analysis, in that both are very essential in terms of alteration and regolith mapping for mineral exploration and exploitation[2].

Generally, most crystallinity studies are performed using XRD analysis, but there is a limitation with the use of XRD analysis, such that a certain degree of longrange ordering is required within the kaolinite to allow recognition of the peaks which gives information about the crystallinity. Infrared (IR) analysis on the other hand, is sensitive to localized intra-layer variations which would not be easily detected by XRD and is therefore more useful in recognizing subtle variations in crystallinity than XRD[3]. Hence, in this study, kaolinite crystallinity was determined using Short Wave Infrared Spectrometer (SWIR), which was useful in affirming the environment of formation of the kaolinite and other alteration minerals in the study area.

Location and Geology of Study Area: The study area is situated in AlemTena area of Main Ethiopia Rift Valley (figure-1). It is located within latitudes $8^0$9'28.91"N and $8^0$16'1.95"N, and longitudes $38^0$58'30.14"E and $39^0$7'20.22"E. The study area is bounded by Lake Koka to the north and to the north-east by Wonji Sugar plantation and Gademsa caldera. It can be accessed through two main asphalted high ways, Mojo - AlemTena and Nazret - Assela road.

The study area (AlemTena) is part of the Main Ethiopia Rift (MER) which is found in the north-east of East African Rift System[4]. Main Ethiopia Riftadvanced in Late Miocene and it is associated with the Quaternary faulting system relatedto the Wonji Fault Belt[5].The Main Ethiopia Rift is divided regionally into three sectors: north, central and southern part[6]. AlemTena area exists in the central part of the MER valley which is mostly covered by ignimbrite rock[7]. The ignimbrite is the youngest unit out of the three ignimbritic units of the volcanic complex which belongs to a bimodal magmatic suite erupted between 830 Ka and 20 Ka (thousand years)[8]. The recent felsic products of the Berecha (AlemTena) unit consist of obsidian lava domes and flows as well as pantelleritic ignimbrites ranging from 240 - 20 Ka. The pyroclastics are unwelded pumice flows and ashes, which are referred to as the final products[9]. AlemTena area consist of Pleistocene - Holocene (<1.6 Ma) volcanic complex with volcano-sedimentary rocks which is Recent (< 500 Ka)[10]. Figure2 shows the geological map of the study area.

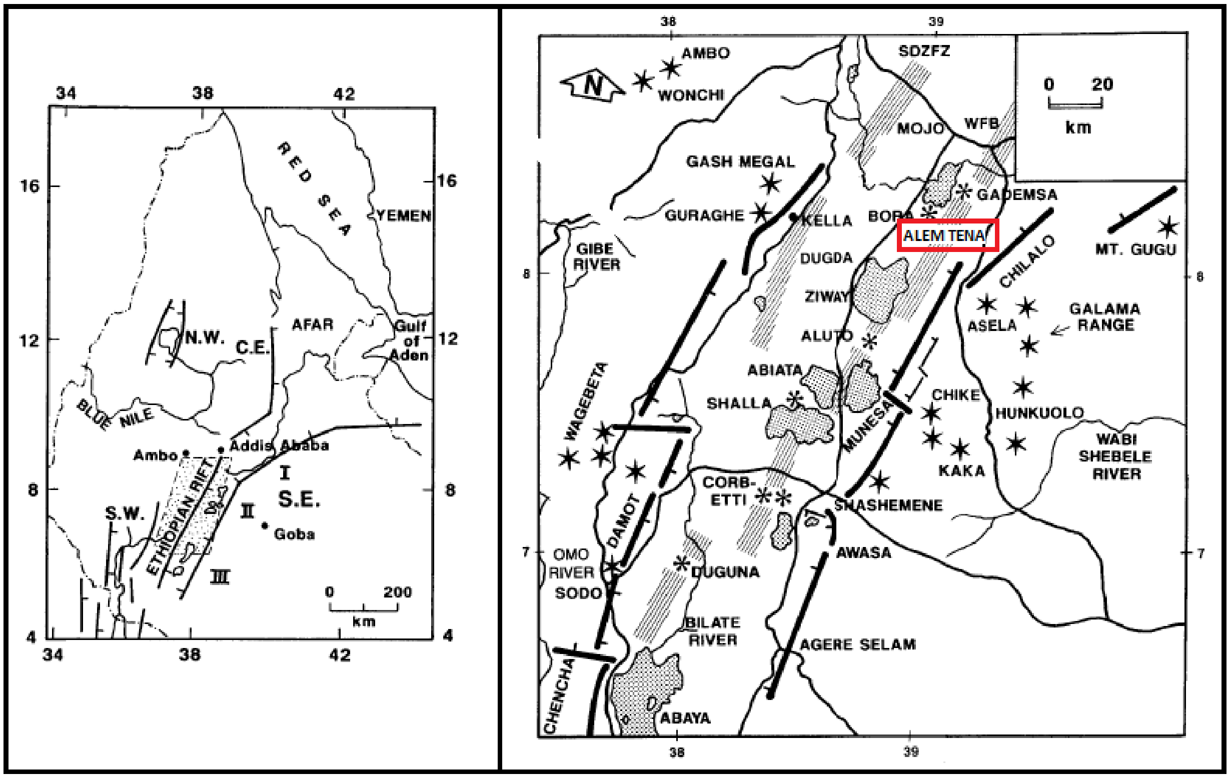

Figure-1
Map of Main Ethiopian Rift in large and Small Scale showing the location of study in red box modified after[6]

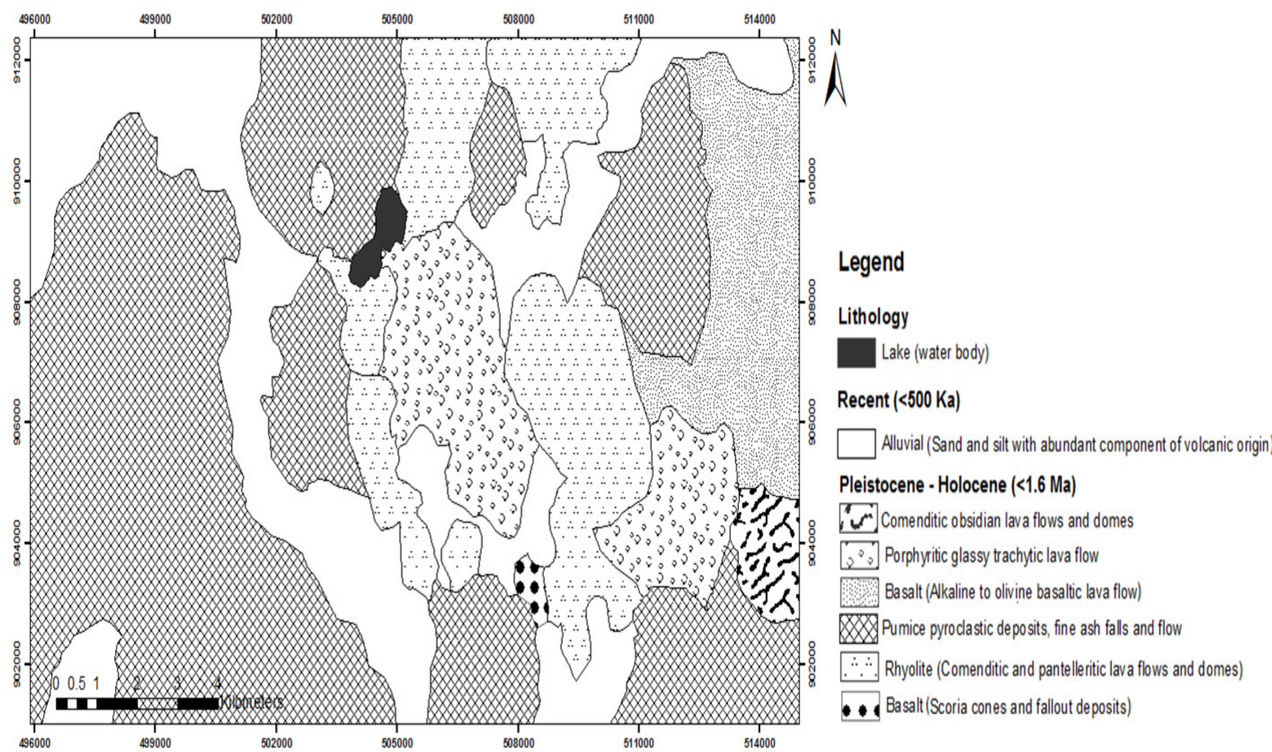

Figure -2
Geological map of study area after[1]

Methodology

Forty (40) samples out of the eighty-three (83) samples initially analyzed for alteration mineral mapping were observed as pure kaolinite (as shown by their spectra characteristics) and these were used for the crystallinity study. The shortwave infrared spectra of the minerals display vibrational features associated with bending and stretching of the bonds in the hydroxyl ion. Kaolinite crystallinity was analyzed based on the shape and wavelength spacing of the Al-OH band doublets absorption feature. This is described using two different methods; *Slope parameter* and *Kaolinite Crystallinity Index.*

Slope Parameter: Kaolinite crystallinity can be described in terms of two values proportional to the gradient or slope of the spectrum in the 2160-2180 nm region. Figure 3 shows a spectral of a typical kaolinite and the wavelength band within this region. These values are referred to as slope '2160' and slope '2180' parameter.

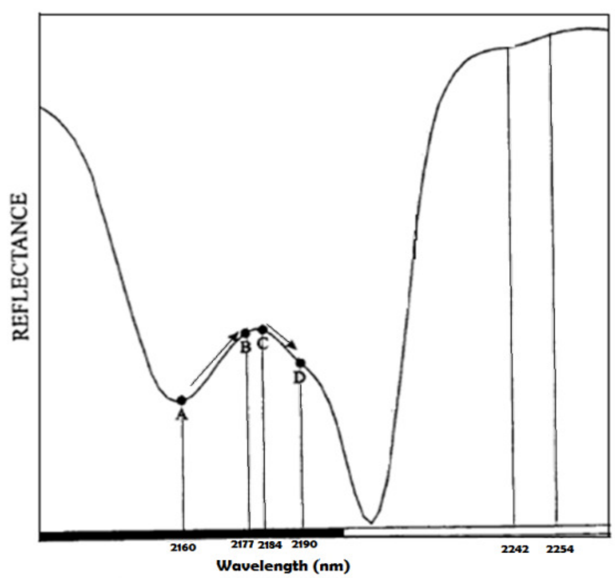

Figure-3
Kaolinite Spectral with wavelength band useful in slope parameter calculation

Slope '2160' parameter is calculated as a ratio at wavelength 2160 nm over 2177 nm; while *Slope '2180' parameter*is calculated as a ratio at wavelength 2184 nm over 2190 nm. Both calculations are performed on a hull quotient corrected spectrum[3].

Kaolinite Crystallinity Index (KCI): This method combine the two slopes (2160 slope and 2180 slope) mentioned above into one parameter using this formula:
KCI = (2180 slope – (2160 slope – 2180 slope))

where KCI is kaolinite Crystallinity Index

The KCI increases in value with increasing kaolinite crystallinity and has advantage over the slope parameters because it can be represented as a histogram or line profile[1].

Results and Discussion

The results obtained from the analysis of kaolinite crystallinity using both methods described above shows generally that, the area has moderate - high kaolinite crystallinity. Evaluation of result from slope parameter (i.e. slope 2160 and slope 2180) shows that the kaolinite in the area falls mostly to high crystallinity. The results obtained were interpreted based on slope parameter guide in table 1.

K1, K2 and K3 group indicates kaolinite with poor to very poor crystallinity, and the result for slope 2160 is usually greater than 1.00 while the slope 2180 is usually less than 1.00. K4a and K4b show kaolinite with moderate and high crystallinity with slope 2160 usually less than 1.00 and slope 2180 usually greater than 1.01.Values representing K4a and K4b were observed in almost all the samples (table 2). The increase order of the crystallinity was determined using the second method, kaolinite crystallinity index (KCI) method, the result from this show some variation in the kaolinite crystallinity over the study area, however most samples falls within the moderate-high kaolinite crystallinity group. Lowest value of KCI obtained is 1.011 and the highest value is 1.120, (details of KCI in table 2). Spectral of some analyzed kaolinite samples with their crystallinity shape was compared with the spectral of standard kaolinite crystallinity shown in (figure 4a and 4b). The outcome shows that similar crystallinity shape exists in samples analyzed in comparison with the standard kaolinite crystallinity shape.

Table-1
Slope parameter guide for kaolinite crystallinity analysis

Group	Slope 2160	Slope 2180	Crystallinity type
K1	> 1.02	< 1.01 and > 1.00	Very poor
K2	> 1.02	< 1.00	Very poor
K3	> 1.00 and < 1.03	> 0.99 and < 1.02	Poorly crystalline
K4a	< 1.00	> 1.01 (often > 1.02)	Moderately-highly crystalline
K4b	< 1.00 (often > 1.02)	> 1.01 (often > 1.02)	Very highly crystalline

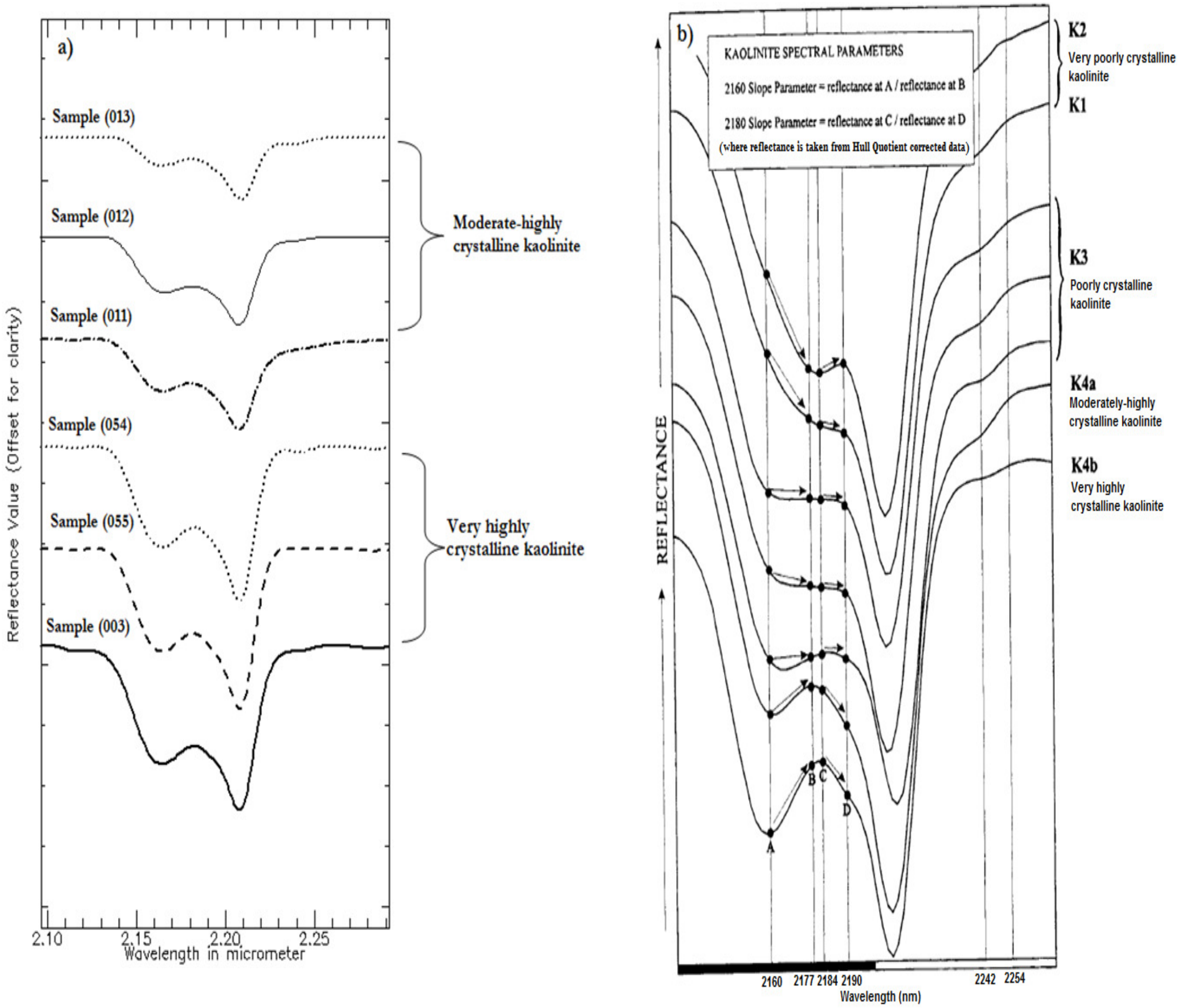

Figure-4
(a) Some kaolinite spectra from analyzed samples showing differences in kaolinite crystallinity
(b) Kaolinite crystallinity spectra shape and parameter guide after [1]

Conclusion

The condition under which kaolinite form is characterized by high acidity and high water to rock ratio. These combined factors facilitate the removal of mobile cations such as (Ca, Na, Mg and K) and the retention of less mobile elements like (Al and Si). These conditions are commonly found in hydrothermal alteration system and under conditions of lateritic weathering. Generally, high kaolinite crystallinity usually indicate formation of kaolinite under high temperature and mostly hydrothermal origin while low crystallinity indicate kaolinite that forms at surface conditions due to weathering processes[1,11]. This study thus suggest that hydrothermal alteration is most likely the origin of kaolinite mineralin the study area due to high crystallinity results obtained from the analysis and association of the kaolinite with other high-temperature alteration minerals (halloysite and some alunite) and the absence of deep weathering. In other words, high kaolinite crystallinity indicates high temperature formation, hence hydrothermally formed kaolinite as observed in the study area. The kaolinite crystallinity studyis therefore useful in providing more insight about the environment of formation of kaolinite and other alteration minerals over the study area.

Acknowledgement

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Table-2
Table showing Kaolinite crystallinity index values and the crystallinity group based on slope parameter method

	Station Number/ Sample Location	Kaolinite Crystallinity index	Crystallinity Code /Group	Mineral-1	Mineral-2	Mineral-3
1	AL_10_001	1.024	K4a	Kaolinite	Null	Null
2	AL_10_003	1.094	K4b	Kaolinite	Null	Null
3	AL_10_004	1.049	K4b	Kaolinite	Null	Null
4	AL_10_005	1.071	K4b	Kaolinite	Null	Null
5	AL_10_007	1.044	K4b	Kaolinite	Opal	Halloysite
6	AL_10_011	1.050	K4b	Kaolinite	K-alunite	Halloysite
7	AL_10_012	1.029	K4a	Kaolinite	Halloysite	Null
8	AL_10_013	1.035	K4a	Kaolinite	Montmorillonite	Halloysite
9	AL_10_019	1.016	K4a	Kaolinite	Kaolinite	K-alunite
10	AL_10_020	1.053	K4b	Kaolinite	Opal	Null
11	AL_10_021	1.052	K4b	Kaolinite	Null	Null
12	AL_10_025	1.071	K4b	Kaolinite	Halloysite	Null
13	AL_10_027	1.056	K4b	Kaolinite	Opal	Halloysite
14	AL_10_032	1.074	K4b	Kaolinite	Opal	Null
15	AL_10_034	1.064	K4b	Kaolinite	Halloysite	Null
16	AL_10_036	1.066	K4b	Kaolinite	Halloysite	Null
17	AL_10_037	1.050	K4b	Kaolinite	Halloysite	Null
18	AL_10_038	1.062	K4b	Kaolinite	Opal	Null
19	AL_10_039	1.032	K4a	Kaolinite	Halloysite	Opal
20	AL_10_040a	1.071	K4b	Kaolinite	Halloysite	Null
21	AL_10_044	1.052	K4b	Kaolinite	Halloysite	Null
22	AL_10_045	1.047	K4b	Kaolinite	Halloysite	Null
23	AL_10_047	1.084	K4b	Kaolinite	Null	Null
24	AL_10_048	1.109	K4b	Kaolinite	Null	Null
25	AL_10_049	1.062	K4b	Kaolinite	Halloysite	Null
26	AL_10_050	1.083	K4b	Kaolinite	Halloysite	Null
27	AL_10_051	1.057	K4b	Kaolinite	Opal	Halloysite
28	AL_10_052	1.067	K4b	Kaolinite	Halloysite	Null
29	AL_10_053	1.036	K4b	Kaolinite	Halloysite	Opal
30	AL_10_054	1.075	K4b	Kaolinite	Null	Null
31	AL_10_055	1.083	K4b	Kaolinite	Null	Null
32	AL_10_056	1.048	K4b	Kaolinite	Opal	Halloysite
33	AL_10_057	1.107	K4b	Kaolinite	Halloysite	Null
34	AL_10_058	1.076	K4b	Kaolinite	Halloysite	Null
35	AL_10_059	1.077	K4b	Kaolinite	Halloysite	Null
36	AL_10_060	1.059	K4b	Kaolinite	Halloysite	Null
37	AL_10_062	1.048	K4b	Kaolinite	Null	Null
38	AL_10_063	1.042	K4b	Kaolinite	Halloysite	K-alunite
39	AL_10_065	1.078	K4b	Kaolinite	Null	Null
40	AL_10_066	1.060	K4b	Kaolinite	Null	Null

Note: Mineral-1 indicates the predominant mineral in each sample shown by the spectral analysis (crystallinity study was based on the occurrence of this main mineral or mineral-1) while Mineral-2 and Mineral-3 are other accessory minerals in same sample, which are not considered in the kaolinite crystallinity study.

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