Alteration Study of the Chatree Epithermal Au-Ag Deposit, Central Thailand by a Combination of Methods; ASDSpectrometry, Conventional and Whole Rock ICP Geochemistry

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ABSTRACT

An alteration study of the Chatree deposit in central Thailand has been performed by conventional methods including petrography, feldspar staining and X-ray Diffraction (XRD)techniquesover a number of years. Sample analysis at individual pits and cross sections was done aiming to represent alterations in volcanic and volcanic clastic host rocks. Alteration zonation surrounding Au-Ag mineralized bodies can be generally described by two different styles. In the first, a narrow zone of intense adularia with silicification grades to an illite-sericite envelope in andesitic rocks. Another zone contains similar alteration facies with broader silicificationin association with illite-sericite. Enveloping these two zones is a distal propylitic zone dominated by chlorite ± epidote assemblage.The objective of this study is to distinguish the zone of local propylitic alteration fromregional chlorite-enriched alteration. In this investigation, an Analytical Spectral Device (ASD) was applied as a major tool for analysis in conjunction with whole rock Inductive Coupled Plasma (ICP) geochemistry, petrography and XRD on selected economic ore zones. Fine grained silica replacement, pseudo-rhombohedral of adularia, partial and complete feldspar replacement by illite-sericite and chlorite replacement of both feldspar and mafic silicate minerals are the main alteration styles observed by microscopic study. Orientated XRD was also applied to confirm all the described data. Although these conventional methods are important, they are cost-consuming and robust work, therefore for more routine work, ASD is a more convenient method to use. Spectral analysis is a choice that was selected to study the whole Chatree alteration system. ASD spectrometer was used routinely to collect down whole spectrum from the first meter of fresh rock from each drill hole to identify the alteration system. In total 100,000 spectrum samples have been measured and analysed. Alteration haloes on the well-defined drill sections and system plan view are displayed and point to an epithermal low sulfidation pattern. Four alteration assemblages with their haloes have been identified. A narrow zone of intense Mg-rich chlorite alteration in the corezone, then grades to illite-sericite alteration, then to a mixture of illite-chlorite and rimmed with theillite-smectite alternatingwith an Fe,Mg-chloritezone. There is a Mg-rich chlorite core and illite-sericite envelope detectable at each ore body. A spectral wavelength analysis technique has been applied to this data set to analyse relative illite and chlorite compositions. The long wavelengths of Fe-, Mg- or K-rich illite located close to the mineralized centers grades outward to a medium wavelength illite-sericite zone and is terminated by short wavelength Na rich illite at the most distal zone. A short wavelength Mg-rich chlorite alteration halo near mineralized centers grades out to Fe, Mg-chlorite and changes to Fe-chlorite which then merges with the regional volcanic alteration. Both mineral wavelength patterns indicate mineralized fluid range from alkaline in the core to near neutral condition away from the core. A preliminary illite crystallinity study displaysa relationship between strongly crystalline to long wavelength(K-rich) and poorly crystalline to short wavelength (Na-rich) illite. Petrographic work is used for minerals which the ASD spectrometer cannot detect. An association of adularia and chlorite crystal growth appear adjacent to the silicified centre of the mineralized zone. Petrographically, illite is mostly replacedby plagioclase feldspar. The degree of illite replacement depends on the host rock types and distance to the mineralized body. More than 5,140 spectrums analyses from drill holes at the Chatree mine site were measured. Distinctive alteration patterns conform to data on the main north cross-section line. A narrow zone of Mg-chlorite is encompassed by the broader illite zone. Long wavelength illite is obvious near the mineralized zone then grades to short wavelength on the outer edge of the zone. Mixtures of illite and chlorite occur at the next zone. The outermost zone is a mixture of chlorite and smectite. 80 samples from exploration drill holes representing the Mg-rich chlorite zone, illite zone, silicified zone, altered feldspar zone, and less altered zone, have been analysed by whole rock ICP to confirm ASD spectral mapping and petrographic results. Both silicified and Mg-rich chlorite samples contain high ratios of K/Al and low Na/Al. The illite zone shows a slightly lower K/Al ratio but is still significantly higher than background of low Na/Al. Less altered rocks contain low K/Al with higher Na/Al, equivalent to the composition of andesine to labradorite. This indicates that Chatree is dominated by K-alteration replacing Na and Ca feldspars which is suggested by the K enrichment and Na depletion of the orebody. Various element plots against multi-logging alteration mineralogy from proximal to distal alteration facies display two series of relative correlation to Au plots. The first series is a positive correlation ofK, Ag, Mo, W, Sb and Pb contents to Au values. The second series is negative correlation of Fe, Mg, Ca, Ni, Co and Sc contents to Au value. The positive correlation to Au can beused as a significant pathfinder for regional exploration. The negative correlation to Au can be used to indicate evidence of mineralized fluid replacing host rocks.

Keywords: ASD (Analytical Spectral Device),Illite-Smectite, K-Increase, Na Depletion, Chatree Thailand

1. INTRODUCTION

The Chatree epithermal alteration study has been carried out over many years by internal and external research teams. Different methods and instrument such as staining, petrography, XRD, XRF and EPMA were applied to analyse the area. All previous work was focused on individual zones or detailed point analyses rather than coveringa broad area to gain information.

The aim of this exploration is to create a standard effective tool for routine alteration mapping use to extend the current Chatree mineralization and to find another deposit similar Chatree. Several routine robust alteration logging techniques such as chemical staining, portable XRF, PIMA (Portable Infrared Multispectral Analysis) and ASD (Analytical Spectral Device) have been considered. The ASD machine is the final answer due to quality and consistency of the spectrum data. The ASD is a nanometer scale of infrared spectrum measurement technique used to identify mineral species which have an OH bond in their structure (mostly hydrous minerals). The machine will generate infrared wave covering VIR, NIR and SWIR (250-3,500 nm). These waves are used to penetrate various kinds of samples such as diamond core, RC chips, rock slabs, clay and powder then return to the detector to be recorded. The machine will measure the returning spectrum then transfer it to the computer unit. Users can run spectrum processing using GMEX's software-TSG7. A specific kind of alteration mineralogy will be identified by absorption peak pattern matching either automatically or manually using a standard library. Variations in nanometer scale of peak properties composed of absorption position, width, absorption depth and shape can be applied to analyse detailed information of particular alteration minerals. Relative composition, crystallinity and mineral proportion in samples are common factors which are used in alteration mineral mapping (Fig.1).

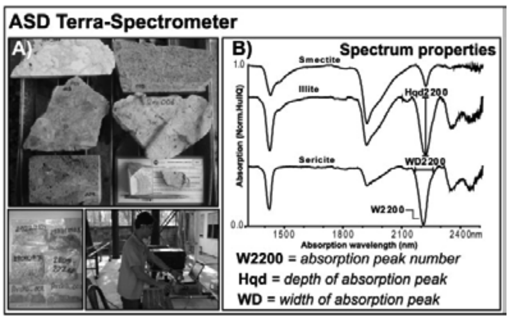

Figure 1. ASD terra spectrometer operating set showing measurement various type of geological material used to collect spectrum properties A), Essential properties of spectrum necessary use to identified mineral species, relative composition and crystallinity; spectrum pattern, position of absorption peak, depth of absorption peak and width of absorption peak B).

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2. ASSUMPTION

Chemical gradients from alteration zones in the Chatree orebody were reported by Fugushima (2009). EPMA point analysis of chlorite shows high Mg content in vein zones and a decrease to low Mg but high Fe content in andesite wall rock. Sangsiri (2010)was a study ofthe alteration halo at the Chatree north orebody. Primary feldspar conversion to illite-sericite distancing distributes from orebody and adularia crystals forming adjacent to the orebody were identified. K-feldspar staining from previous research and internal Chatree work confirms suggestions that K alteration seems to be associated with the ore body. Regarding the alteration mineralogy pattern and chemistry, ASD measurement combined with geology and standard quantitative chemical analysis techniques can be applied to point out these characteristic features. The main awareness is that ASD is an effective application (Fig. 2 and 3) used for identifying hydrous minerals and does not cover silicate or oxide minerals. It does not cover silicate or oxide minerals so when results of ASD analyses display nothing significant further work using alternative methods is required to make sure significant mineral occurrences have not been missed.

3. METHODOLOGY

In total 100,000 ASD infrared spectrums were measured from reference RC-RAB rock chip and core samples in an intensive campaign. Spectrum data were collected from the first fresh meter of each drill hole in the Chatree mining area with the aim to produce a plan view map of alteration. Well defined geological cross-sections representing the Chatree system were selected to document the pattern of alteration with depth. Multiple alteration logging methods include our manual re-logging to distinguish silicic, phyllic and propylitic alteration zones from the routine work, petrographic investigation on alteration, standard XRD analysis on clay mineralogy (Fig. 4,5), as well as whole rock ICP analysis and ASD standard routine measurement (Fig. 2A, C, and 3A) constitute the main methodology applied for this research work.

All ASD spectrum properties and chemical data sets were analysed using the ioGas program to define the groups of alteration, alteration haloes and chemical variation related to each alteration styles.

4. RESULTS

Spectrum data collection is quite fast and robust. In general it takes approximately 6 seconds per sample. For this study, the measurement time was set at 10 seconds per sample for higher spectrum quality. More than 5,140 spectrums from the first meter of fresh rock in drill holes inside the Chatree mine were measured. The resultant data was used to construct alteration halo level plans. Another 95,000 spectrums were measure down hole to get deeper information. This data set is used to illustrate alteration haloes on a Chatree representative cross-section (Fig 2A).

4.1 Spectrum processing

Mineral species identification can be broadly classified into two ways by using absorption peak matching to

GMEX's standard library. First an automatic identification is given by the TSG7 software (Fig. 3B, 3C). This method can give rise to up to 90 percent reliable result. This is a very effective tool for large amount of spectra, particular at the deposit scale analysis. The second is to manually carry out peak comparison which is appropriate for research study because gradient variation of absorption peaks, absorption position moved width and depth of characteristic peak and their ratio can be determined. This research was carried out with a large number of spectrum (Figure 3B, C). We used the automatic processing mode inside TSG7 as the basis for processing then refined mineral species using the ioGAS program. Necessary spectrum properties such as absorption peak position, width and depth of absorption were transferred to the ioGas classified group of mineral, relative composition and crystallinity(Figure3D,E).

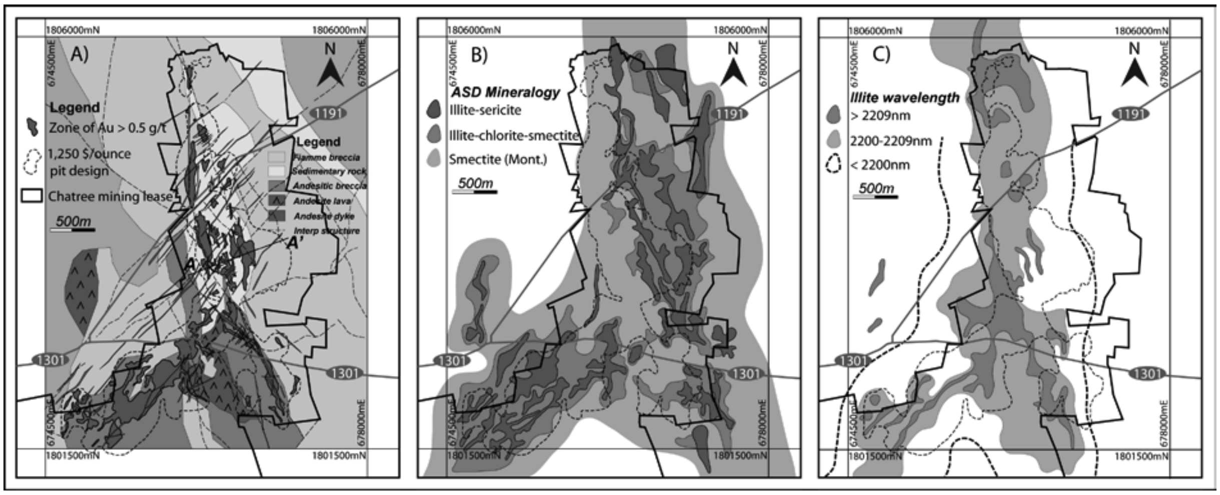

Figure 2. Map of Chatree Au-Ag mining economic orebody > 0.5 g/t (dark outline) and 1,250 dollar/ounce pit design (dashed outline) overlay district geology, Chatree representative cross-section A-A' A), ASD alteration zonation; illite-sericite at the core graded outward to illite-chlorite-smectite mixure zone and rimmed with broad smectite zone B), Illite wavelength display long wavelength at center graded outward to medium and short wavelength at outer respectively C).

4.2 Alteration zonation and pattern by spectrum

Based on our data gathered from ASD measurement, it is visualized that chlorite, illite and sericite formed as major clay species for low temperature hydrothermal alteration zone throughout the Chatree system. Analysis of the data set after processing by ioGAS detected 4 mains alteration haloes. A narrow zone of Mg rich chlorite (short wavelength <2250nm, Figure 3A) is strongly intense at the corezone, then grades to illite-sericite, and to a mixture of illite-chlorite that is rimmed with illite-smectite (Figure 2B) alternating with an FeMg chlorite zone (medium wavelength 2250-2255nm, Figure 3A). A Mg rich chlorite coreand illite-sericite envelope are detectable at each ore body. The advantage spectrum wavelength analysis technique has been applied to this data set to analyse relative illite and chlorite compositions. The long wavelength of Fe, Mg or K rich illite (>2209nm) located closed to mineralized centres grades outward to a medium wavelength illite-sericite zone (2200-2209nm) and is terminated by short wavelength Na rich illite (<2200nm) at the most distal zone (Fig 2C). The short-wavelength Mg-rich chlorite close to mineralized centres grades to FeMg chlorite and changes to Fe chlorite merging into regional volcanic alteration (Fig 3A). It is also visualized that the Chatree chlorite and illite reveal moderate to deep OH peak at 1400 to 1410 nm, very deep peak at 1900 nm and sharp peak at 2180 to 2230 nm. Similar situation has been found for the chlorite (Figure 3D), which reveal chlorite peaks at 1394 nm for the Mg member and 1409 nm for the Fe member, very deep water peak at 1900 nm, and spurious peaks with absorption patterns at 2250 and 2350 nm decreasing to 2240 and 2340 nm. Analysis of the illite and chlorite wavelengths, is based on population and pattern.ASD plots of illite wavelength at 2200nm versus its width showing characteristic peaks at short, medium and long wavelengths (Figure 3D). However, ASD plots of chlorite wavelength versus HQD at 2250 nm width showing only a broad zone without characteristic peaks. So we just applied the general standard interval (Figure 3E). hydrothermal alteration associated with Au- Ag mineralization. It is noted that among the alterations encountered in this study two important assemblages are important illite – sericite and Mg- & Fe- rich chlorite. The former has been observed to overprint the latter. Interesting petrographic features are shown in Figure 4. Pseudo-rhombohedral crystal of adularia with inclusions of apatite surrounded by later stage silicification (Figure 4A). Relict outline of altered plagioclase is replaced by sericite – illite assemblage along cleavages and grain boundaries (Figure 4B). Early-formed adularia occurs contemporaneous with Mg-rich chlorite and fine –grained sulfides (Figure 4C). Late-stage alteration of illite-sericite clay overprints the earlier-stage Mg-Fe chlorite and adularia alteration minerals (Figure 4D).

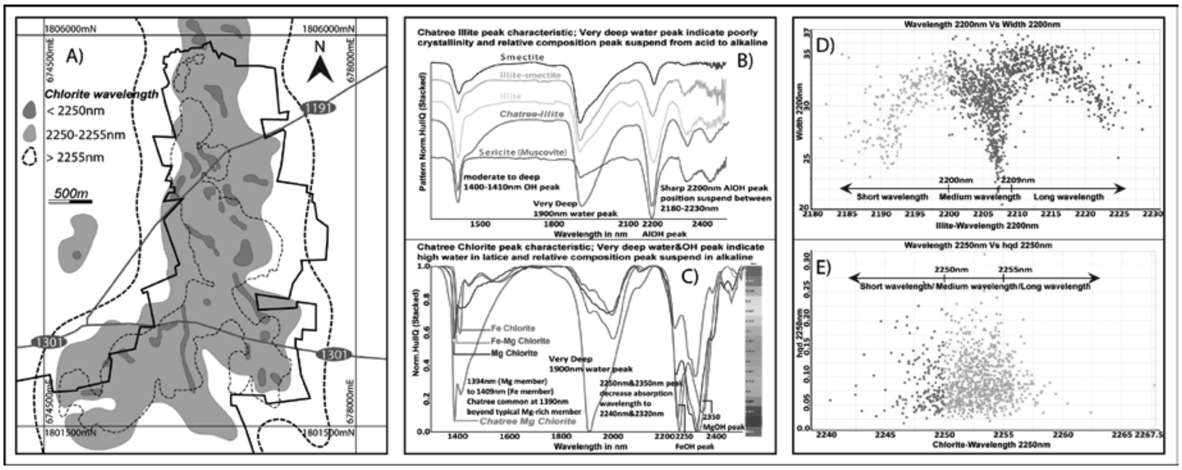

Figure 3. Map of Chatree mining area showing zonation of Chlorite display narrow zone of short wavelength at center enveloped by medium wavelength then rimmed by long wavelength A), Typical characteristic spectrum of illite and chlorite from Chatree deposit (green line) compare to standard library in TSG7, deep absorption water peak at 1900nm is strongly characteristic B) and C), Plot of illite absorption wavelength w2200nm versus width of absorption peak showing characteristic peaks at short, medium and long wavelength from ASD measurement D), Plot of Chlorite absorption wavelength w2250nm versus hqd2250 showing a broad zone without characteristic from ASD measurement.

4.3 Whole rock ICP analysis

Our petrographic together with XRD analyses (Figure 4 and 5) and previous data reveal that the Chatree volcanic rocks have been affected by multiple stages of hydrothermal alteration associated with Au- Ag mineralization. It is noted that among the alterations encountered in this study two important assemblages are important illite – sericite and Mg- & Fe- rich chlorite. The former has been observed to overprint the latter. Interesting petrographic features are shown in Figure 4. Pseudo-rhombohedral crystal of adularia with inclusions of apatite surrounded by later stage silicification (Figure 4A). Relict outline of altered plagioclase is replaced by sericite – illite assemblage along cleavages and grain boundaries (Figure 4B). Early-formed adularia occurs contemporaneous with Mg-rich chlorite and fine – grained sulfides (Figure 4C). Late-stage alteration of illite-sericite clay overprints the earlier-stage Mg-Fe chlorite and adularia alteration minerals (Figure 4D).

4.4 Whole rock ICP analysis

Eighty samples of the Chatree altered volcanic rocks have been selected for whole-rock ICP analyses. Results of these data along with those of the multi-logging method and ASD data have been used to plot in the feldspar Na-K GER diagram (Figures 6A and B). It is recognized that the less altered rocks show molar Na/Al from 0.2 to 0.5 and Na/Al less than 0.15 whereas the altered volcanic rocks with K- alteration replacing Na feldspar show lower Na/Al (from 0.2 to 0.05) and higher amount of K/Al (viz. 0.2 to 0.3). For the stronger alteration, rocks with illite – sericite clay alteration indicate very small amount of molar Na/Al but much higher amount of K/Al. Up to 0.6 K/Al has been observed in the adularia –silica rich altered rocks.

Alkali ratio plots in comparison with those of the Na/Al and K/Al based on ICP MS data (Fig. 6C) and multi-logging data (Fig. 6D) show Na depletion and K increment from less toward stronger alteration activities. Similar situations have been found for the major element (e.g., Fe, Mg, Ca, Na, and K) plots (see Figs. 6E and F) and trace element (e.g., Au, Ag, Mo, W, Sb, Ni, Co, Sc) plots vs. strong, less and unaltered alteration. Regarding to various elements plot suggesting two series of relative correlation to Au plots. The first series is a positive correlation of K, Ag, Mo, W, Sb and Pb contents to Au values. The second series is negative correlation of Fe, Mg, Ca, Ni, Co and Sc contents to Au value (Fig 6F, 6H).

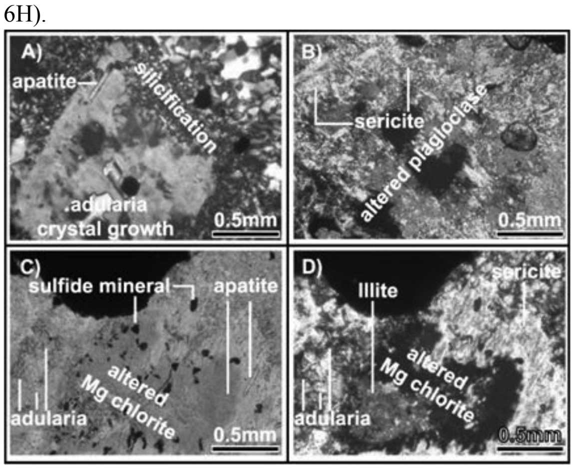

Figure 4. Photomicrographs of ore – bearing altered volcanic host from the Chatree mine area showing multi-stages of alteration mineralogy, especially illite – sericite assemblage overprinting Mg chlorite assemblage. Pseudo-rhombohedral crystals of adularia with inclusions of apatite are surrounded by very fine silica in Chatree volcanic rocksA. Relict outline of altered plagioclase is replaced by sericite – illite along cleavages and grain boundaryB. Association of adularia, chlorite and fine –grained sulfides in ore – bearing volcanic sample (without nicols)C. Late-stage alteration of illite-sericite clay overprinting the earlier-stage Mg chlorite and adularia alteration minerals in ore – related volcanic sampleD.

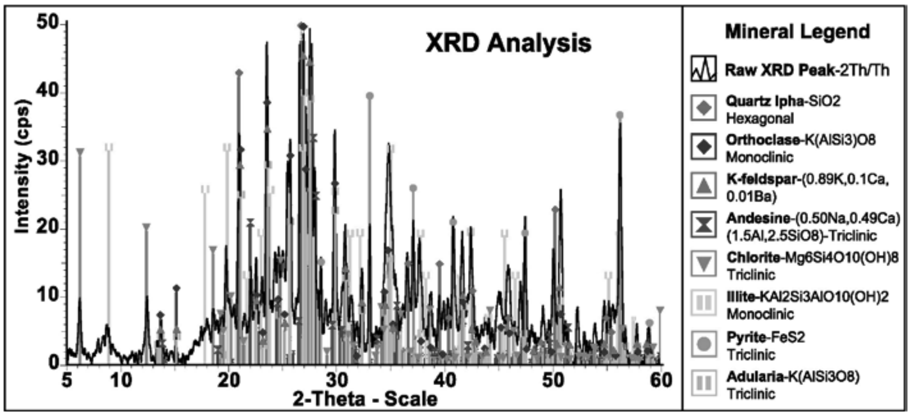

Figure 5. Orientate XRD reflection peak of strongly altered mineralise sample; result pick up the association of quartz, pyrite, adularia, K-rich illite and Mg-rich chlorite, weak signature of andesine, orthoclase and K-bearing feldspar.

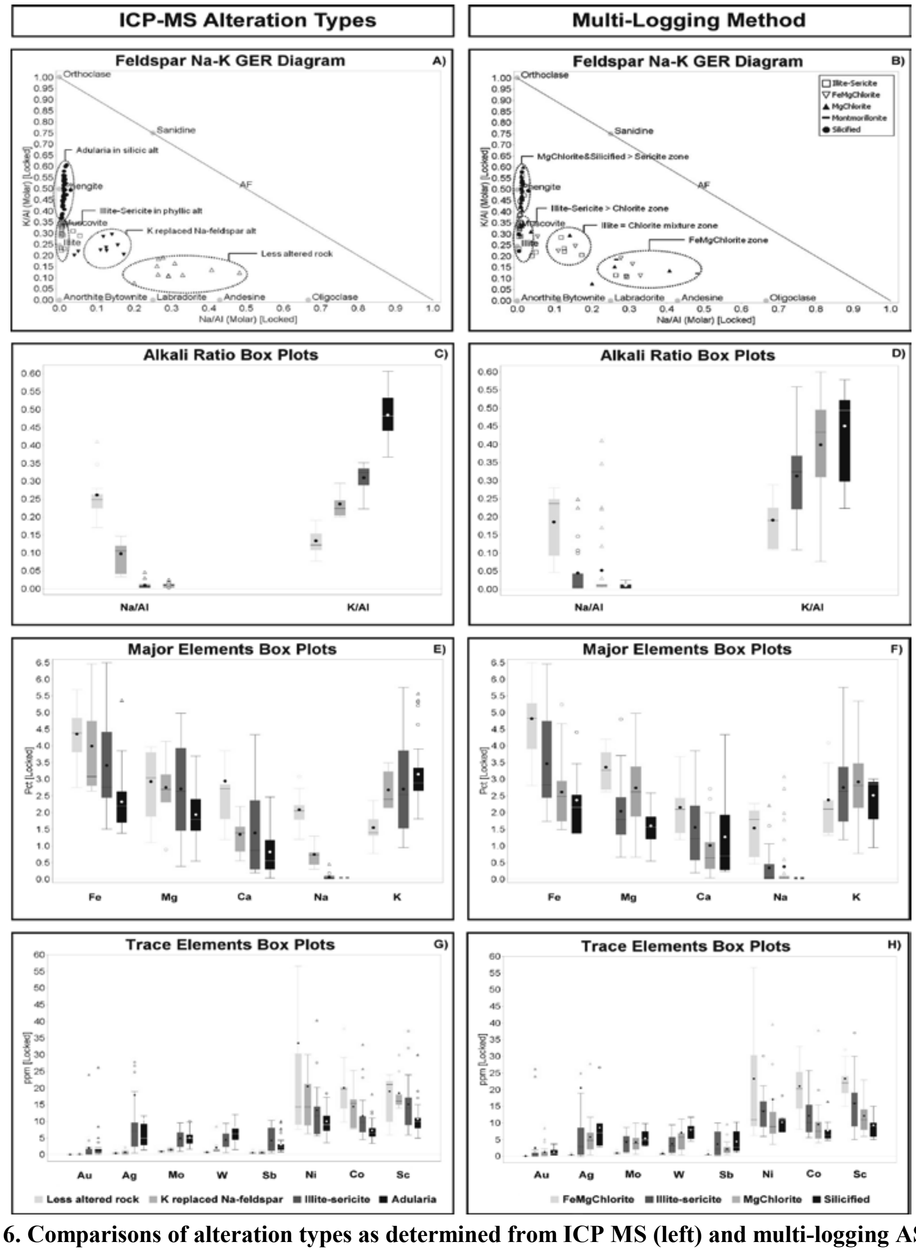

Figure 6. Comparisons of alteration types as determined from ICP MS (left) and multi-logging ASD (right) methods for the analyzed Chatree altered volcanic rocks. Na/Al and K/Al plots (A and B). Alkali ratio plots (C and D). Major element plots (E and F). Trace element plots (G and H).Every box plots are arrange distal to proximal alteration zone from left to right hand site.

4.5 ASD and whole rock alteration Chemistry

The Chatree alteration style is discussed by using whole rock ICP results base on the feldspar Na-K GER Diagram. Alteration trends clearly start from Andesine to Labradorite equivalent composition. The alteration line moves up to K replaced Na then makes a sharp turn to illite-sericite zone (0.25< K/Al<0.35) before pass through adularia (K-feldspar) zone (K/Al>0.35). ASD spectrum logging detected FeMg-chlorite at less altered zones then increased the proportion of illite at moderate altered zones. At the same area of K/Al ratio turn to rapid increasing ASD could detect plenty of illite-sericite. The alteration line that finishes at the highest K/Al ratio was detected as Mg-rich chlorite zone using the ASD and visual logging described it to be a silicified zone (Fig 6A, 6B). Comparing the multi-logging method to the whole rock ICP data method suggests an association of K rich, silicification and Mg-rich chlorite zones being located or overprinted at the core of mineralized zone then grading outward to an illite-sericite envelope (due to weaker K replacing effect). The outer zone transitions to an altered feldspar associate Fe,Mg-chlorite zone which contains very low Potassium.

5. RESULTS AND DISSCUSSION

Based on the overall results presented above for the Chatree Au-Ag deposit, a schematic model for the alteration mineralogy zonation on the bases of clay mineralogy and illite wavelength from ASD measurement is visualized and shown in Figure7.Alteration haloes on the well-defined drill section (position show in Figure 2A) are displayed and point to epithermal low sulfidation pattern. Four alteration assemblages with their haloes had been obviously identified. An illite-sericite formed intense at corezone corresponding or just above economic orebody, then grades to mixture of illite-chlorite envelop and rimmed with broad of the illite-smectite alternating with FeMg chlorite zone (Figure 7). The Mg rich chlorite core which appears on plan view is very narrow unable to display on cross-section. Illite-sericite envelope iscertain detectable at each orebody. Illite wavelength suggests significant long wavelength >2209nm are corresponding or just below economic orebody (Au > 0.5 g/t). The long wavelength of Fe, Mg or K rich illite located closed to mineralise centre grades outward to medium wavelength illite-sericite zone and terminated by short wavelength Na rich illitic at most distal zone.Illite wavelength patterns indicate mineralized fluid ranges from alkaline in the core to near neutral condition outward. This indicates that Chatree is dominated by K alteration replacing Na and Ca feldspar system which is suggested by K increase and Na depletion of the orebody. ASD is practical routine implement and cost-time effective tool for Chatree alteration mapping work. The result fit very with the Au ore zone at ca. >0.5 g/t. This is important for the regional exploration when using ASD data for the routine measurement. However, interpretation for individual mine camps needs to be aware because there is a limitation for the measurement using ASD as explained earlier. So the ASD measurement required academic back up particularly from petrographic and XRD data before decision will be made for the detailed exploration. Future work author team will expand scope of study to micro scale chemical and physical analysis on alteration mineral grains to defined relationship between ASD spectrum properties changing to chemical and physical variation of mineral.

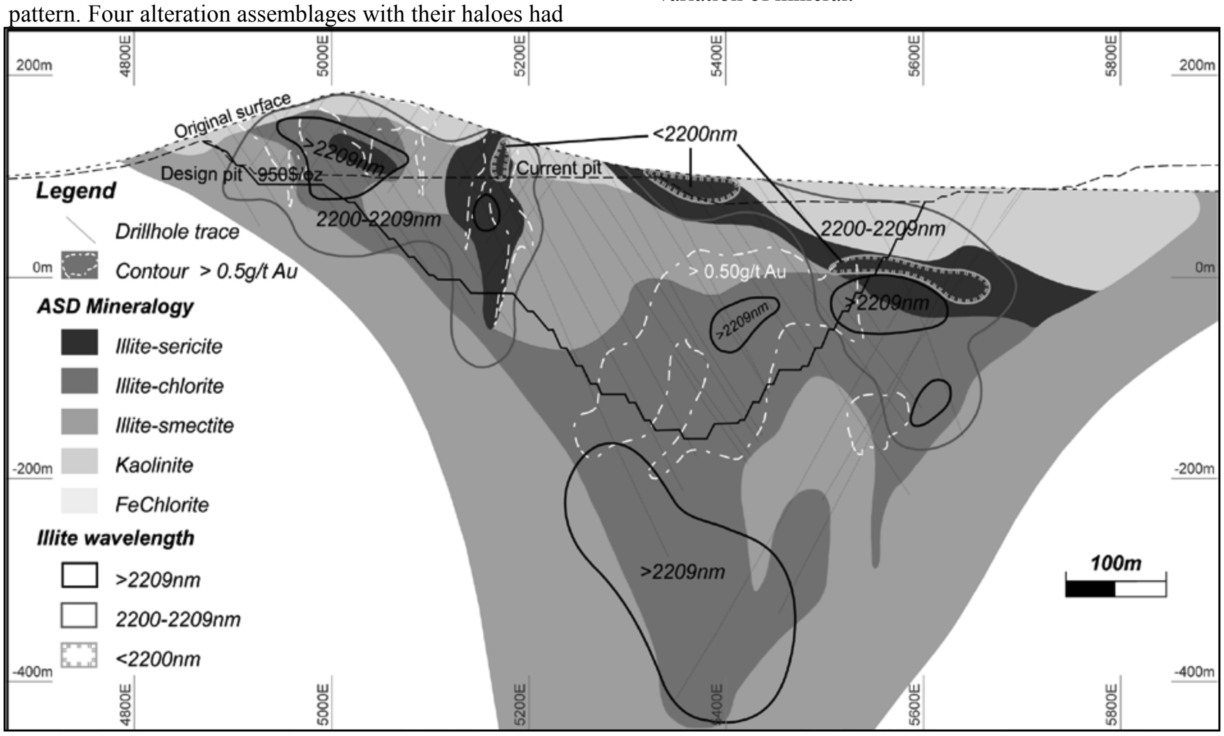

Figure 7. Schematic model for ASD alteration mineralogy zonation on well defined Chatree Au-Ag deposit drill section; four main alteration facies ordering from core to outer are illite-sericite, illite-chlorite mixture, illite-smectite and Fe,Mg-chlorite. Illite wavelength display long wavelength >2209nm at center then graded to shorter wavelength outward and upward, >2209nm illite wavelength contouring are almost corresponding to >0.5 g/t economic ore zone.

6. CONCLUSION

The result from this study shows that there is a high possibility for the application of using ASD data to point out the target areas for regional exploration because the result shows very well defined information on the clay mineralogy related to alteration and mineralization.

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