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GEOLOGY AND ALTERATION OF THE KLINE MOUNTAIN KAOLIN DEPOSIT, SIERRA COUNTY, NEW MEXICO

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Abstract—The kaolinized tuff of the Kline Mountain area lies on the eastern margin of the Mogollon-Datil volcano-tectonic province, a major mid-Tertiary volcanic center. On the eastern margin of this center is the extensional environment of the Rio Grande rift. Faults in the study area display dominant northwest and northeast trends. The stratigraphy in the Kline Mountain clay deposit area consists of mid-Tertiary bimodal volcanic and volcaniclastic deposits. The kaolin deposit occurs within the advanced argillic zone of the tuff of Kline Mountain as a result of hydrothermal alteration. The deposit is a result of kaolinization, alunitization and silicification that is related to mid-Tertiary hydrothermal activity associated with a rhyolite porphyry intrusion. On the basis of calculated mineral compositions from chemical analyses and XRD data, there is an inverse relationship between kaolinite percentage and proximity to the intrusion. Conversely, there is a proportional relationship between alunite content and proximity to the intrusion. XRD data indicate that kaolinite is a principal mineralogical constituent in the deposit whereas smectite was identified locally. The other major constituent is fine-grained silica (cristobalite and/or tridymite?). Small amounts of opaque oxides, and hematite-cassiterite mineralization associated with fractures, have also been identified. That part of the deposit that was investigated in detail contains over 3 million tons of clay and the whole deposit is reported to contain over 200 million tons. In spite of high standard brightness of 94%, the silica content is considered to be a drawback for use in the paper industry. In 1969, 900 tons of the deposit were sold as an oil absorbent. Recently, experiments have shown the suitability of the deposit in the manufacture of white brick.

INTRODUCTION

The Kline Mountain (White Horse) kaolin deposit occurs within an advanced-argillic alteration zone in volcanic and volcaniclastic rocks of mid-Tertiary age (Patterson and Holmes, 1965; Ericsen et al., 1970; Coney, 1976; Eggleston, 1987; Eggleston and Norman, 1983; Harrison, 1986). The deposit is situated on the northwestern flank of Kline Mountain in the Black Range, Sierra County, New Mexico (Fig. 1). The elevation of the deposit is 2338 m above sea level, and it is located on the south side of NM-59 where it crosses the Continental Divide in Sierra County, and within the Gila National Forest. Nearby settlements are Winston and Chloride. The prevailing climate in the area is semi-arid, and precipitation varies from about 20 cm/yr to more than 50 cm/yr. Rainfall occurs predominantly in July and August.

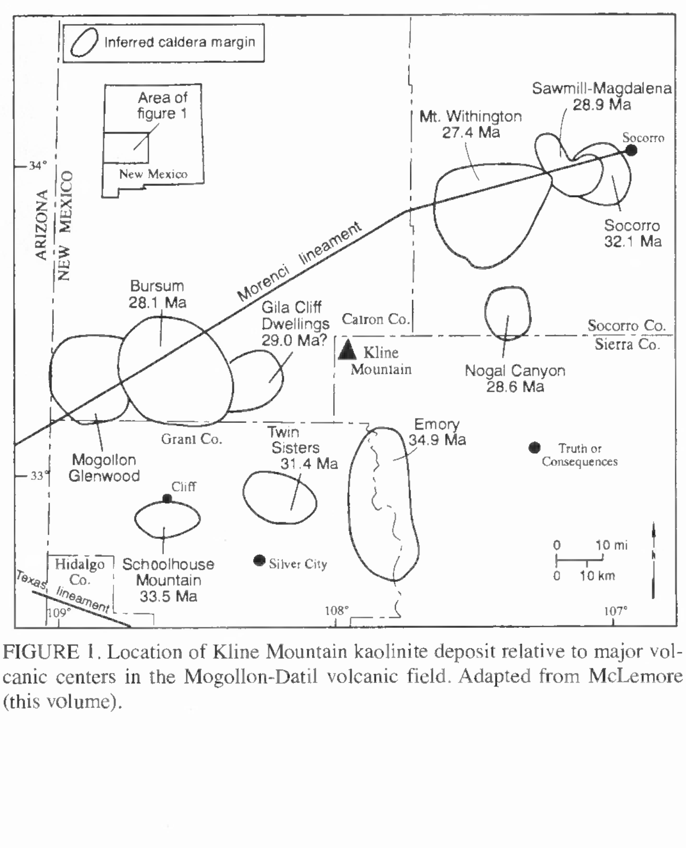

FIGURE 1. Location of Kline Mountain kaolinite deposit relative to major volcanic centers in the Mogollon-Datil volcanic field. Adapted from McLemore (this volume).

The deposit, investigated by F. L. Schneider in 1958, was used experimentally for its kaolin content in making ceramic tile. The deposit was sampled by the U.S. Bureau of Mines in 1959, and results of tests showed the kaolin to range from intermediate to a heavy-duty refractory material (Patterson and Holmes, 1965). Samples from the deposit were examined in some detail by DeVilliers (unpubl. reports for Inst. Paper Chemistry, Appleton, Wisconsin), Sallee in 1962 (unpubl. report for Inst. Paper Chemistry, Appleton, Wisconsin) and by Chowdhury in 1980 (unpubl. report for Dresser Industries). Evaluation for use of the kaolin as a paper coater was completed by the private sector. Fine-grained silica (cristobalite and/or tridymite?) within the kaolin has been reported as a major drawback for use in the paper industry. The whole deposit is estimated to have 200 million tons reserve (P. Roche, personal commun., 1991) with 38 to 39% Al_2O_3 and a very high standard brightness of 94%. About 900 tons of kaolin were sold in 1969 for use as an oil absorbent by Union Oil. The production of kaolin was by open-pit mining methods. After screening, crushed kaolin ore was shipped by trucks to Elephant Butte Lake for use in the Santa Barbara channel oil spill (P. Roche, personal commun., 1991). In 1993, firing experiments, conducted in El Paso, demonstrated the potential use of the Kline Mountain clay in white brick manufacture. This includes favorable characteristics of water absorption, plasticity and compressive strength. As of July, 1993, three different groups have shown interest in the Kline Mountain kaolin deposit: American Eagle Brick Company, El Paso, Texas; Internacional de Ceramica, Chihuahua, Mexico; and one unknown group that drilled the deposit between February and July, 1993 (Isik, 1993).

GEOLOGICAL SETTING

The kaolinized tuff of the Kline Mountain area lies on the eastern margin of the Mogollon-Datil volcano-tectonic province, a major mid-Tertiary volcanic center (Fig. 1). The eastern margin of this center is adjacent to the extensional environment of the Rio Grande rift. Local faults in the study area could have originated by the intrusion of the rhyolite porphyry of Kline Mountain dome, which may be part of the ring fracture intrusions related to the Gila Cliff Dwellings cauldron to the west (Rhodes, 1976). These faults have probably been reactivated by Basin-and-Range extension in the past 21 Ma (Elston, 1976). Faults in the study area display dominant northwest and northeast trends. The dominant structural style found in the study area is high-angle normal faulting. The stratigraphy in the Kline Mountain kaolin deposit area consists of mid-Tertiary bimodal volcanic and volcanoclastic deposits that consist of basaltic andesite lavas, high-silica rhyolite lavas and pyroclastic material. (Fig. 2). The lower units of the volcanic sequence were then intruded by the rhyolite porphyry of Kline Mountain (Coney, 1976; Eggleston, 1987). Accompanying hydrothermal alteration produced several mineralogical assemblages within and peripheral to the intrusion. Alunite in the advanced argillic assemblage was dated by the K-Ar method at 28.4 ± 1.2 Ma (Eggleston and Norman, 1987).

HYDROTHERMAL ALTERATION

Volcanic units and the rhyolite porphyry of Kline Mountain have undergone hydrothermal alteration. Alteration is most intense near the intrusive contact of the rhyolite porphyry and gradually diminishes distally. The altered zone has an elliptical shape that trends roughly northwest. Four distinct alteration assemblages are recognized in the study area (Isik, 1993): (1) weak propylitic alteration, (2) argillic alteration, (3) advanced argillic alteration, and (4) silicification. Alteration of the volcanic units occurs primarily as replacement, that is, a new mineral assemblage takes the place of the primary minerals. However, silicification is also due to primary introduction of silica by fluids and residue. The basaltic andesite of Poverty Creek displays weak propylitic alteration which is characterized by epidote, calcite and chlorite. It diminishes in intensity towards the northwest from the clay deposit (Eggleston, 1987).

The argillic alteration assemblage overlaps the advanced-argillic assemblage, being first noticeable about 2 km northeast of where highway NM-59 crosses the Continental Divide. It increases in intensity southward (Eggleston, 1987), and is characterized by a kaolinite and chalcedony assemblage that has replaced alkali feldspars in ignimbrites in this area. Alteration assemblages are distributed peripherally to the contact of the Kline Mountain intrusion, located approximately 1 km south-southeast of the open pit. The transition from argillic to advanced argillic assemblage occurs in a zone about 1 km wide and is characterized by the first occurrence of alunite.

The advanced argillic alteration zone contains commercial kaolin deposits that have been exploited intermittently. This alteration, characterized by a kaolinite-alunite-silica (chalcedony, tridymite[?], and quartz) mineral assemblage, is widespread in the study area. This pervasive alteration in the area developed in situ and is related to hydrothermal regimes developed concurrent with the emplacement of the Kline Mountain intrusion.

Kaolinite and alunite are the most diagnostic indicators of advanced-argillic alteration. On the basis of calculated mineral compositions, kaolinite is the dominant clay mineral in the northern part of this alteration zone where the abandoned mines are located, whereas alunite is the dominant mineral to the south near the contact of the intrusion (Fig. 3). The alunite-rich mineral assemblage is located around the intrusion and contains hematite-cassiterite(?) mineralization. Tin mineralization in this area, and associated with the Taylor Creek Rhyolite, has been documented by Eggleston and Norman (1986). On the basis of representative drill core fragments furnished by the New Mexico Bureau of Mines and Mineral Resources, the depth of kaolinization zone is at least 48 m (Fig. 4). According to Mr. P. Roche, the owner of some of the claims and agent for the others, the location of this drill core is estimated to be between the two clay mines in the study area. Between 0 and 48 m the tuff is completely altered to the kaolinite-alunite-silica mineral assemblage with a characteristic white color and softness. The texture of the tuff of Kline Mountain has been obliterated throughout most of this interval. However, drill core fragments display a relatively fresh breccia texture below 48 m, indicating the bottom of the commercially viable kaolin deposit at this location.

Silicification is considerable in the study area, but primarily located in three localities within the tuff of Kline Mountain and the rhyolite porphyry of Kline Mountain. They are (1) silicified tuffs at the top of the Kline Mountain tuff, which forms a cap up to 1000 m in lateral extent, (2) chalcedonic quartz within the kaolin deposit, and (3) widespread silicification at the top of the rhyolite porphyry of Kline Mountain, which forms a 500-m-wide cap. In the study area, silicification mainly occurs as fine-grained replacement of the groundmass and matrix of the tuff.

Hydrothermal activity, responsible for the silicification as well as kaolinization in the study area, is commonly associated with faults. Some of the silicified units exhibit fragments and chalcedonic nodules. Their origin is due to hydrothermal brecciation and/or redistribution by weathering and erosion. Many chalcedonic nodules and fragments are distributed on the surface to the north of the open pit location and are believed to be eroded silica fragments, possibly from the silica cap. These chalcedonic nodules and fragments developed a spongy porous texture, suggesting a possible ancient geothermal vent that produced acid leaching and resulting silica residue.

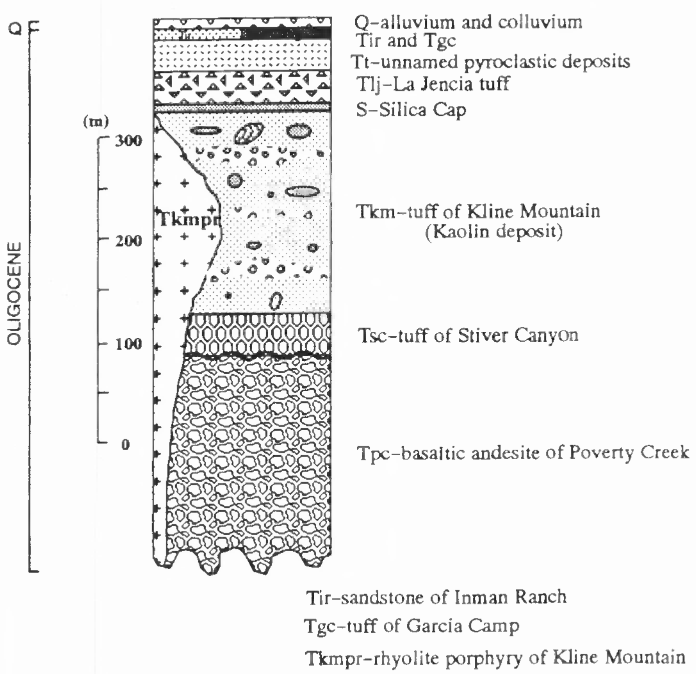

FIGURE 2. Stratigraphic column of the Kline Mountain kaolinite deposit (after Eggleston, 1987).

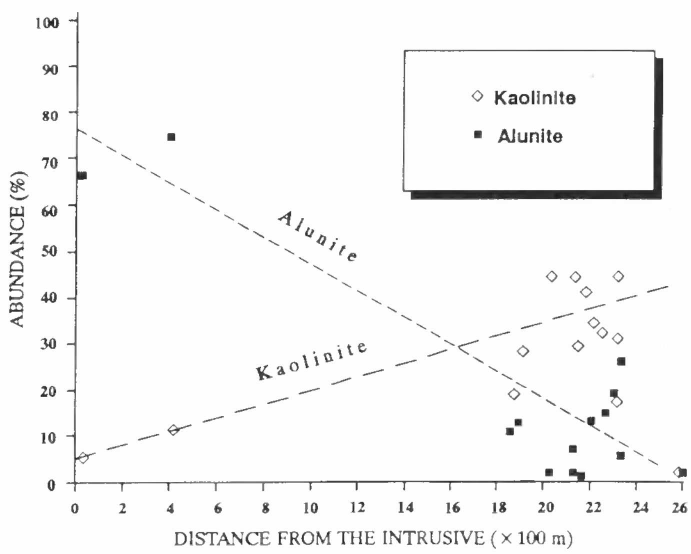

FIGURE 3. Graph showing kaolinite and alunite abundance in surface samples relative to the distance from the Kline Mountain intrusion (from Isik, 1993).

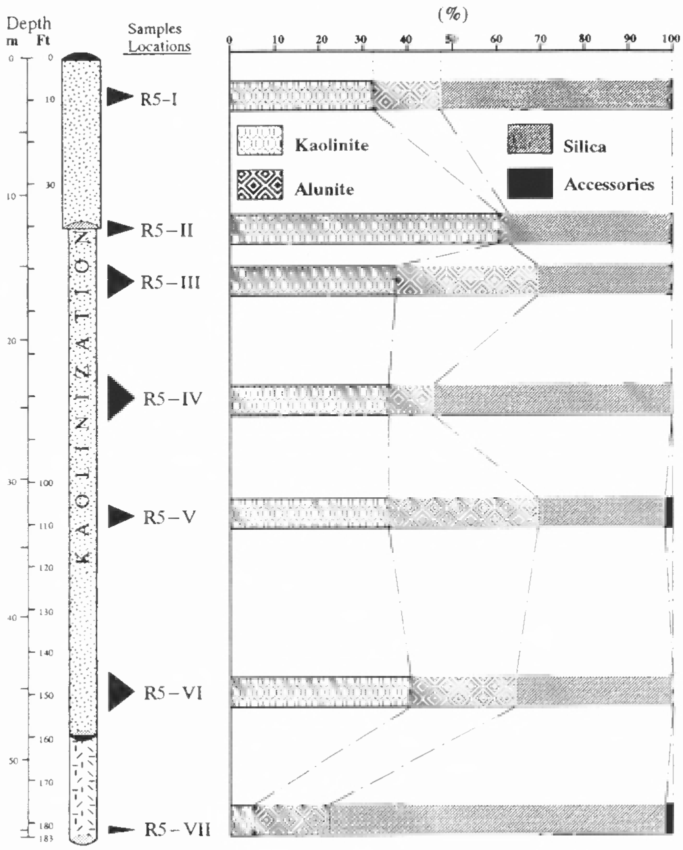

FIGURE 4. Kaolinization zone and mineral distribution in drill core R5 (from Isik, 1993).

Post-depositional weathering may have affected the hydrothermal minerals in the deposit to some extent. However, the extensive silica caps on the top of the deposit have protected the underlying clay at least in part, against the effects of post-depositional weathering, since they are highly resistant to both chemical and physical erosion.

MINERALOGY

Chemical analysis of 24 samples from the surface and core were accomplished by X-ray fluorescence at the New Mexico Bureau of Mines and Mineral Resources. Relative mineral proportions were then calculated from these analyses (Isik, 1993) and show that within the kaolinization zone, the kaolinite content varies from 31 to 58 weight percent. Also, XRD data from these 24 samples (Isik, 1993) indicate the widespread occurrence of kaolinite, while smectite was identified in two clay-size samples. Locally, alunite-rich samples show weak, small peaks of kaolinite reflection that would indicate a minor kaolinite content. Cristobalite is detected only in one of the bulk samples as a major constituent. Tridymite(?) is present in each sample at different concentrations except for alunitic tuff. As seen in Table 1, most of the tuff is composed of kaolinite, alunite, tridymite(?), quartz, cristobalite and accessory minerals. The clay minerals (<2 μm) of the tuff of Kline Mountain as determined by X-ray analysis, are listed in Table 2, in order of decreasing abundance. Scanning electron microscope images obtained by Isik (1993) show variable kaolinite textures in three surface samples from the advanced argillic assemblage. These textures are columnar and covered by silcretes, relatively poorly crystallized, and in stacks. Similarly, alunite crystals were imaged and reveal hexagonal and pseudo-rhombohedral crystals associated with silica lepispheres. Energy-dispersive spectroscopy clearly distinguished the chemistry of all these crystals.

CONCLUSIONS

The stratigraphy in the Kline Mountain kaolin deposit area consists of mid-Tertiary bimodal volcanic and volcaniclastic deposits that consist of basaltic-andesite lavas, high-silica rhyolite lavas and pyroclastic material. Faults in the study area display dominant northwest and northeast trends. They are silicified, altered and mineralized in some localities. Volcanic units in the field have undergone hydrothermal alteration. Alteration is most intense near the intrusive contact of the rhyolite porphyry of Kline Mountain and gradually diminishes distally. On the

TABLE 1. Whole rock mineralogy of the Kline Mountain kaolinite deposit, showing distribution of the minerals in the samples detected by X-ray diffraction (m: minor constituent). From Isik (1993).

Sample	Kaolinite	Alunite	Tridymite	Quartz	Cristobalite
R5-I	X	X	X	X	
R5-II	X	m	X	X	
R5-III	X	X	X	X	
R5-IV	X	X	X	X	
R5-V	X	X	X	X	
R5-VI	X	X	X	X	
R5-VII	m	X	X	X	
SM 200	X	X	X	m	
CS 200	X	X	X	m	
Tkm 1			X		X
Tkm 2	X	m	X		
Tkm 3	m	X	X	m	
2Tkm 2	X	X	X	X	
2Tkm 4	X	m	X	X	
2Tkm 5	X	X	X	X	
3Tkm 1	m	X	X		
3Tkm 3	X		X	X	
3Tkm 5	X		X	X	
Tkm 8	X		X	X	
S7	X	X	X	m	
S7.5		X	X	X	
S8	m	X	X	m	
Tkm 18	m	X	X		
Tkm 20	m	X		X	

TABLE 2. Clay-size fracture (<2μm) mineralogy, showing the distribution of minerals in samples of the tuff of Kline Mountain detected by X-ray diffraction analysis (the numerical order indicates decreasing order of abundance). From Isik (1993).

Sample	Kaolinite	Alunite	Tridymite	Quartz	Smectite
R5-I	1	3	2	4	
R5-II	1	2	3		
R5-III	1	2	4		3
R5-IV	1	3	2	4	
R5-V	1	2	3		
R5-VI	1	2	3		
R5-VII	2	1	3	4	
SM 200	1	2	4		3
CS 200	1	2	3		
Tkm 1	3		2		
Tkm 2	1	2	3		
Tkm 3	2	1			
2Tkm 2	3	1	2		
2Tkm 4	1		2	3	
2Tkm 5	2	1	3	4	
3Tkm 1	3	1	2		
3Tkm 5	1		2		
Tkm 8	1		2		
S7	4	2	1	3	
S8	2	1	3	4	
Tkm 18	?	1	2		
Tkm 20	?	1		2	

basis of X-ray diffractogram patterns, most of the whole-rock minerals are composed of kaolinite, alunite, tridymite(?), quartz, cristobalite and accessory minerals. Four distinct alteration assemblages are recognized in the study area. Alteration of the volcanic units and intrusion occur primarily by replacement, but also silicification has been produced by direct introduction of fluids and by formation of silica residue. The advanced argillic alteration zone contains commercial kaolin deposits that have been exploited intermittently. Advanced argillic alteration, characterized by a kaolinite-alunite-silica (chalcedony, tridymite[?], and quartz) mineral assemblage, is widespread in the study area. On the basis of chemical and XRD data and resultant calculation of mineral compositions, kaolinite is the dominant clay mineral in the northern part of this alteration zone where the abandoned clay mines are located, whereas alunite is the dominant mineral to the south near the contact of the intrusion. The resulting alteration mineral assemblages may best be described, form north to south, as a kaolinite zone with alunite grading to an alunite zone with kaolinite. On the basis of representative drill core fragments, the depth of the kaolinization zone is at least 48 m. Silicification is considerable in the study area, and is primarily located in three localities within the tuff of Kline Mountain and the rhyolite porphyry of Kline Mountain. Hydrothermal activity was responsible for silicification as well as kaolinization in the study area. Calculated mineral composition of outcrop samples from chemical analysis show an inverse relationship between kaolinite percentage and proximity to the intrusion. Conversely, there is a proportional relationship between alunite content and the proximity to the intrusion. Variations in the proportions of minerals found with respect to depth of the drill core show that kaolinite content varies from 31 to 58% but drops abruptly to about 5% at a depth of 48 m.

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