A Study on the Characteristics and Genesis of Smectite Deposits in the Georgia Kaolin Belts

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ABSTRACT

Deposits of smectite clay, of unknown origin, have been found in association with kaolin in the Marion Member of the Huber Formation and Buffalo Creek Formation in both Wilkinson and Washington County, Georgia. The presence of smectite within kaolin deposits in both the KT Tucker and Crutchfield mines is atypical for Coastal Plain kaolins. X-ray diffraction analysis of samples from these locations shows predominantly large, high Hinckley Index kaolinite crystals, consistent with Buffalo Creek Formation or Marion Member kaolin deposits. The most probable origin of the smectite inclusions is that the smectitic clays, or their source material, were deposited in mixed beds with the pre-existing Cretaceous age kaolin during sea level regressions or other erosional events. The irregular locations of the smectite deposits can be attributed to the mechanism of deposition as well as the numerous erosional events the occurred in the region since that deposition.

INDEX WORDS: Kaolinite, Kaolin, Smectite, Georgia, Buffalo Creek Formation
A STUDY ON THE CHARACTERISTICS AND GENESIS OF SMECTITTE DEPOSITS

IN THE GEORGIA KAOLIN BELTS

by

CHRISTOPHER S. ORMSBY

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

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IN THE GEORGIA KAOLIN BELTS

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1 INTRODUCTION

1.1 The Kaolin Deposits of the Eastern United States

Deposits of kaolin clays occur throughout the Coastal Plain of the southeastern United States, particularly in Georgia and South Carolina, where these clays engender a significant mining interest. Although most of the crude kaolin deposits in the Coastal Plain range in content from about 85-95% kaolin minerals, less than 5% of the kaolin deposits are of sufficient size, quality, and purity to be commercially viable (Hurst and Pickering, 1997). Despite this, Georgia kaolins support a large and valuable industry due to the clay's white color, low level of impurities, and low organic content (Shelobolina et al., 2005). Once mined and processed this kaolin is utilized by a host of industries, such as ceramics, the chemical industry, and in fiberglass manufacturing (Murray, 2000). The largest consumer of kaolin is the paper manufacturing industry, which uses it as both a filler and as a coating, an application that requires kaolin of the utmost purity (Murray, 2000).

Deposits of smectite clays have been found to be associated with kaolin deposits in Wilkinson and Twiggs Counties, Georgia (Jones, 1988). Smectite possesses a higher level of expandability than kaolin, and thus a higher viscosity (Jones, 1988). Because kaolinite is handled as a slurry, high viscosity can cause processing problems. Even smectite concentrations as low as one percent can have a significant effect on the rheology of the kaolin slurry (Jones, 1988). High viscosity due to impurities such as smectite is also of concern in the paper industry, where properties, such as viscosity, color and density, must be controlled carefully during the clay-coating process (Murray, 2000). By analyzing the nature and occurrence of these smectite deposits, mining can consider the presence of smectite. The provenance of the smectite can also be studied as a result of these mining activities.
1.2 The Georgia Kaolin Deposits and Their Uses

The Georgia kaolin deposits are composed of several kaolin minerals, primarily kaolinite with varying amounts of metahalloysite, halloysite and dickite (Hurst and Pickering, 1997). The crude kaolins mined in the Coastal Plain of the southeastern United States are about 85-95% kaolin minerals (Hurst and Pickering, 1997), and typically 50-90% kaolinite by weight (Moll, 2001). This kaolin is extremely important in the ceramic and paper industries, where many of its relevant properties can be improved and altered during processing (Murray, 2000).

Figure 1.2.1: Southeastern Kaolin District (Reproduced from Kogel (2009)).

The origins of the Georgia (and Coastal Plain) kaolins have been studied for many years. The origins are still controversial. Sedimentation, in-situ weathering, and even microbial processes are considered to explain the occurrences of the Coastal Plain kaolin deposits. For example, Shelobolina et al. (2005) state that the Georgia kaolin deposits are derived from sedimentary processes, being composed
of Piedmont and Blue Ridge material that eroded and was deposited during the Late Cretaceous to the Eocene. The capability of Piedmont and Blue Ridge rocks to supply the necessary large quantities of kaolin minerals has been supported by several evaluations of these two areas, as well as soil studies of the general region (Bates, 1964). While it was originally supposed that the Georgia kaolins had been deposited as white, monomineralic clays, recent evidence shows that this is not the case (Shelobolina et al., 2005). Hurst and Pickering (1997) state that sedimentary processes alone are not capable of forming a commercial grade kaolin, as the weathering process also produces smectite, illite and ferric particles. Furthermore, the transportation of these sediments would also have introduced biogenic silica and organic material. These associated materials cannot be completely separated/winnowed by sedimentary processes (Hurst and Pickering, 1997). This absence of associated phases (biogenic silica, and organic material) indicates that these kaolins are the result of post-depositional alteration. Consequently, two processes are likely to produce kaolin: weathering or hydrothermal alteration (Hurst and Pickering, 1997). Isotopic measurements of oxygen ($^{18}\text{O}/^{16}\text{O}$) and hydrogen (D/H) show that these kaolins crystallized at low temperatures, between approximately 20°-30°C (Hassanipak and Eslinger, 1985). This isotopic evidence rules out hydrothermal alteration as the manner of alteration forming kaolinite (and halloysite). In situ weathering, thus, is the likely mechanism responsible for creating the minerals in these kaolin deposits (Hurst and Pickering, 1997). The parent sediments were most likely fluvial and deltaic sediments consisting of coarse micaceous and arkosic sands; fine, impure kaolinitic sands and clays, smectites, illites, and carbonates (Hurst and Pickering, 1997). The clay-size particles were separated from the coarser particles during hydraulic transport and deposition (Hurst and Pickering, 1997). In situ weathering along with bacterial activity removed or altered most smectite, illite, silicates, iron sulfides, and organic matter (Hurst and Pickering, 1997).

These kaolin deposits commonly divided into two types, based on texture; “soft”, which is typically found east of Macon and west of Sandersville; and “hard”, found in eastern Georgia and South
Carolina (Moll, 2001). Moll (2001) describes the soft kaolins as being associated with Cretaceous age sediments, with a few soft kaolins being Eocene in age. These soft kaolins break easily with conchoidal fracture. They have coarser crystals with more than 70% by weight larger than 2µm (Schroeder et al., 2004). These deposits contain almost no fossils and rarely show sedimentary features due to extensive re-crystallization (Moll, 2001). The kaolinite crystals themselves exist as vermiform crystals and large, euhedral, interlocking plates (Moll, 2001). The hard kaolins are found in Eocene age strata. They break with difficulty to show a rough, hacky fracture texture. (Moll, 2001; Schroeder et al., 2004). These kaolinite crystals are finer, with more than 70% by weight smaller than 2µm. They show a face-to-face arrangement and more defects when compared to the soft kaolins (Moll, 2001; Schroeder et al., 2004).

Kaolin is further subdivided based on its color, which ranges from gray, to red, to cream (Schroeder et al., 2004). Both the red and cream colored kaolins have been oxidized, with the red kaolin deriving its color from hematite and the cream kaolin colored by goethite and anatase (Schroeder et al., 2004; White et al., 1992). The gray kaolins are darker-colored, due to the presence of pyrite, marcasite, ferrous silicates, kerogen and organic matter (Schroeder et al., 2004). Schroeder et al. (2004) describe how the gray kaolins change in color to pink and then cream with increasing oxidation. Oxygenated groundwater diffusing into the kaolin beds and the actions of Fe(III)-reducing and Fe(II)-oxidizing bacteria remove both Fe sulfides and organic matter. These oxidation processes result in cream colored kaolins with a relatively lower iron content (Schroeder et al., 2004).

In terms of stratigraphy, all of the Coastal Plain kaolin deposits of commercial quality are found within the Oconee Group. The depositional age of the kaolins within the Oconee Group is Late Cretaceous to Eocene (Moll, 2001). The Oconee Group is primarily made up of sand with interbedded lenses of kaolin (Moll, 2001). The base of the Oconee Group is made up of the late Cretaceous Buffalo Creek Formation, which holds many of the principal deposits of soft kaolin (Moll, 2001). Moll (2001) also describes the Buffalo Creek Formation as showing typical fluvial and deltaic depositional characteristics,
such as cross-bedding and upward-fining deposits. A distinct unconformity separates the top Buffalo Creek Formation from the base of overlying Paleocene and Eocene Huber Formation (Moll, 2001). The base of the Huber Formation is made up of the Marion Member, a unit of Paleocene age which contains no commercially viable kaolin deposits (Moll, 2001). Another unconformity lies between the top of the Marion Member and the base of the Eocene Jeffersonville Member in the Huber Formation. The Jefferson Member contains much of the hard kaolin deposits (Moll, 2001). The TiO$_2$ bearing phases in the Huber Formation show vertical patterning typical of marine transgression and regression sequences. The sympathetic variation of these Ti-bearing phases indicate that these sediments were deposited in marine environments (Schroeder and Shiflet, 2000). Moll (2001) asserts that a significant amount of clastic sediments were deposited during highstands of the sea. The top of the Oconee Group is bounded by another unconformity separating it from the Eocene age Barnwell Group, which is made up of the Clinchfield Sand Formation and the Twiggs Clay Formation (Moll, 2001). The Twiggs Clay Formation was also deposited during transgression sequences and contains abundant and thick layers of smectite. The smectite forms an impermeable layer that seals the underlying sediments away from groundwater circulation (Moll, 2001). It is the selective erosion of the Twiggs Clay smectite in certain localities that allowed renewed groundwater circulation, and the associated oxidative conditions, the reach some of the underlying kaolin deposits (Moll, 2001).
Despite the fact that less than 5% of the Coastal Plain kaolins are of sufficient purity and in large enough continuous deposits to qualify as useful commercial kaolin (Hurst and Pickering, 1997), their white color, low level of impurities and low organic content make Georgia kaolins a large and valuable industry (Shelobolina et al., 2005). Murray (2000) describes the largest user of kaolin being the paper industry. The kaolin is used for coating paper and as a filler, where it affects the dispersion, viscosity, brightness, whiteness smoothness, strength and ink absorption, all properties which can be controlled using kaolin additives (Murray, 2000). The purity of the kaolin is of great importance here and in many other industries, as even small amounts of other clays, such as smectite or illite, can adversely affect the viscosity of the kaolin slurry (Murray, 2000). With processing, many of the properties of kaolin can be altered or enhanced as needed, a process that is becoming more common due to demand from the paper industry (Murray, 2000). Murray (2000) also states that the capabilities of kaolins as a filler and extender are not limited to paper but are also used as such in paint, plastics, rubber, and ink. Another important use of kaolin is in the ceramics industry, where it is used in whiteware, insulators, refractories,
tile and pottery (Murray, 2000). Murray (2000) states that many kaolins that are too poor in quality for use the paper and chemical industries industry display good ceramic properties. A relatively recent user of kaolin is the fiberglass industry, which uses low iron and low titanium kaolin as a source of both silica and alumina (Murray, 2000).

1.3 Georgia Smectite Deposits and Their Uses

Along with kaolins, smectite clays are mined for commercial purposes, including Eocene age deposits in east-central Georgia and Miocene age deposits in southwestern Georgia and Florida (Shelobolina et al., 2005). The most commonly mined smectite from this region, a form of fuller’s earth from the Twiggs Clay formation, which is rich in calcium montmorillonite (Kogel, 2009). The smectitic clay from this formation is useful in industry for as a sorbent, as a thickener or gelling agent, and is a principal component in pet litter (Shelobolina et al., 2005). Calcium montmorillonite is also a primary component in the molding sands used in foundries and as a component in the filtering and decolorizing of vegetable, animal, and mineral oils (Murray, 2000). Another common use for smectite clay is as a filtering agent in the winemaking industry, positively charged colloidal impurities are attracted and trapped by the negatively charged smectitic clay (Murray, 2000).

1.4 Purpose of Study

The purpose of this study is to ascertain the genesis and nature of the smectite occurring with kaolin deposits associated with the Buffalo Creek Formation and Marion Member in Washington County. This includes determining the specific variety of smectite, its pattern of occurrence, and its probable origin. This was be done by examining the mineralogy and chemistry of both the kaolin and associated smectite.
2.1 Field Data Collection

Samples of possible smectitic kaolin deposits and accompanying kaolin were collected on April 20th, 2012 from two open pit mines owned by IMERYS, one located in Washington County, Georgia the other in Wilkinson County, Georgia. The first sampling location was in the southern portion of the KT Tucker Mine (approximate location: 33.012136N, 83.045379W). The exposed beds of kaolin showed nodes and grains of a light tan clay that are potentially smectitic (see Figure 2.1.1). The first, second and third samples were collected from this bed, at locations about three meters apart and at the same elevation. This bed also contained minor bioturbationin seen as sand filled burrows as well as slight amounts of small pyrite crystals.

Figure 2.1.1: Western wall of KT Tucker Mine with kaolin beds in foreground. 1: Twiggs Clay Formation. 2: Top of Buffalo Creek Formation. Huber Formation is absent in this location. 3: Bed from which samples KT-1, KT-2, and KT-3 were collected from.
The next sampling site was at the northern portion of the KT Tucker Mine. The fourth sample was collected from the poorly consolidated sediments found in significant amounts on the mine floor. These sediments are brown in color and possess a waxy texture not shared by the other samples. This clayey sample strongly resembles Fuller’s Earth. These sediments are in place and are not the result of backfilling or other mining activity. The fifth sample was collected from an oxide rich clay that was found on the mine floor near the fuller’s earth deposits. The sixth sample is a kaolin with possible smectite inclusions found in a bed directly above the mine floor and is similar to samples one, two and three. Sample seven is from a second deposit of possible Fuller’s Earth from the mine floor near several iron oxide deposits.

The third sampling location was the Crutchfield Mine (approximate location: 32.97072N, 82.970052W), where samples number eight, nine and ten were collected from a bed at the center of the mine, adjacent to the water collection pond. This bed is composed of kaolin with an increasing smectite concentration as it grades from top downwards to base. The eighth sample was collected from the kaolin sediments at the top of the bed. The ninth sample is from directly below sample eight and is richer in smectite, with a visibly darker color and rougher texture. The tenth and final sample is from the base of the bed and has the highest concentration of smectite; it shows a pisolithic texture and is a mottled white and tan in color.

2.2 Sample Preparation

All of the collected samples were prepared using identical procedures so as not to introduce bias or error into the results. All samples were first gently ground with a mortar and pestle, with care taken to avoid excessive grinding. In order to remove the carbonate components from the samples, each sample was placed in a solution of sodium acetate(NaOAc)-acetic acid (HAc ) solution and heated at 50°C for four hours, after which the samples were washed to avoid damaging the samples (Ostrum, 1961). The
iron oxides were removed using the citrate-dithionite-bicarbonate method with addition of sodium hy-
posulfite (Jackson, 1985). Finally the samples were soaked in deionized water along with a 2% solution of sodium metaphosphate to aid in dispersing to clay particles. Separation of the two micron clay size fraction was accomplished by sorting the sample particles by size using the settling rates of particles in a fluid according to Stokes law which is:

\[ V_T = g(d_p - d_l) \frac{D^2}{18\eta} \]

Where \( V_T \) is terminal velocity, \( g \) is the force of gravity, \((d_p - d_l)\) is the difference in density between the particle and the liquid, \( D^2 \) is the particle diameter squared, and \( \eta \) is the viscosity of the liquid (Moore and Reynolds, 1997). This equals a settling time of four hours for every five centimeters of solution height, in order to separate the clay size particles from the larger size fractions (Jackson, 1985). The clay particle size fraction was then added to deionized water in order to form a slurry (Moore and Reynolds, 1997).

### 2.3 X-Ray Diffraction (XRD) Analysis

Three oriented mounts were made for each sample by dropping the clay slurry onto three glass petrographic slides (Moore and Reynolds, 1997). These slurries were allowed to dry for 48 hours at room temperature. Following this, one slide per sample was treated with ethylene glycol for 24 hours while another slide per sample was heated to 550°C for one hour. Samples KT-2, KT-6, KT-7, CF-8, and CF-9 bubbled or were otherwise damaged during this heating process. Heat treated XRD analyses could not be obtained for these samples. The final 10 air dried slides were run as is. All of the samples were then scanned, using the PANalytical XPERT-PRO X-ray diffractometer at Georgia State University, with CuKα radiation, produced at 45kV and 40mA. A nickel filter was used to reduce the CuKβ radiation. The samples were scanned from 3° to 44° for 10 minutes and 17 seconds. Once the d-spacings, in Angstroms, were calculated for the resulting XRD pattern, Moore and Reynolds (1997) was consulted to identify the mineral phases present. The d-spacings used to identify the minerals in these samples are shown in Table 2.3.1.
Once the mineral phases of the samples were identified, the Hinckley Index was calculated for the samples identified as predominantly kaolinite. This was accomplished by the method described by Plançon et al. (1988), whereby the combined intensities of the (020) and (111) peaks, measured from inter-peak background, are divided by the intensity of the (110) peak, measured from the general background. The resulting dimensionless value, generally ranging between 0.2 and 1.5, indicates the level of crystallinity of the kaolinite (Plançon et al., 1988). These measured Hinkley Index values obtained could be considered minimum values.

| Table 2.3.1: Relevant d-spacings in Angstroms to Identify Phyllosilicates |
|-----------------------------|-----------------------------|
| Kaolinite                   | Montmorillonite             |
| 7.12                        | 13.6 (17 after glycol solvation) |
| 4.4                         | 5.1 (5.64 after glycol solvation) |
| 3.57                        | 3.77 (4.25 after glycol solvation) |
| 2.55                        | 3.02 (3.38 after glycol solvation) |
| 2.49                        | 2.50 (2.82 after glycol solvation) |

3 RESULTS

3.1 Sample Descriptions

Sample KT-1 was collected from the southern part of the KT Tucker mine. It is light tan to white in color and is primarily clay sized kaolin with nodules of darker material. Sample KT-2 was also collected from the southern part of the KT Tucker mine. It is light tan to white in color and contains visible sand grains as well as pyrite and marcasite in very small amounts. Sample KT-3 was collected from the southern part of the KT Tucker mine and is light tan to white in color and contains small pyrite inclusions.
Sample KT-4 was collected from the northern part of the KT Tucker mine and is granular brown in color, with a soft and slightly waxy texture. Sample KT-5 was collected from the northern part of the KT Tucker mine and is brown and orange in color, with a large component of iron oxides. Sample KT-6 was collected from the northern part of the KT Tucker mine and is light tan in color with inclusions of a darker colored clay. Sample KT-7 was collected from the northern part of the KT Tucker mine and is brown in color, granular, and is nearly identical to sample KT-4.

Sample CF-8 is from the Crutchfield mine and is nearly white with a uniformly very fine grained texture. Sample CF-9 is from the Crutchfield mine and is a very light tan coloration. Sample CF-10 is from the Crutchfield mine and is mottled white and tan in color with a pisolitic texture.

3.2 Mineralogy

All of the samples analyzed show the presence of abundant kaolinite, indicated by the strong peaks at 7.15Å and 3.57Å, as shown in the following figures. There is further confirmation shown in the patterns for the heated samples, which lack peaks at these locations due to kaolinite becoming amorphous at high temperatures (Moore and Reynolds, 1997). The samples KT-4 and KT-7 (Figures 3.2.4 and 3.2.7) both exhibit large diffraction peaks indicative of smectite at approximately 13.6Å. Similar, albeit less intense peaks are also found in samples CF-9 and CF-10 (Figures 3.2.9 and 3.2.10) also indicate significant traces of smectite in these samples. The fact that this peak shifts to 17Å after the ethylene glycol treatment is strong conformation that this is smectite. As the rest of the patterns show, these two minerals, kaolinite and smectite, make up the entirety of the clay-size fraction of each of the samples. These results are summarized in Table 3.2.1. There was no evidence of interstratification of kaolinite with smectite (kaolinite peak asymmetry).

Further detail into the crystallinity of these samples is provided by samples KT-1, KT-2, KT-3, KT-5, KT-6, and CF-8, all of which are pure kaolinite. Due to the thickness of the clay slurry applied to each slide, the diffraction patterns of these samples show the (020), (110), and (111) diffraction peaks. These
peaks can be used to calculate an approximate Hinckley Index value for the kaolinite, using the method put forth by Plançon et al. (1988). The values for these samples ranged between 0.9 and 1.6, which indicates a high degree of crystallinity and a low number of defects in the structure of the kaolinite (Plançon et al., 1988).

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Minerals Present</th>
<th>Hinckley Index Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>KT-1</td>
<td>Kaolinite</td>
<td>1.6</td>
</tr>
<tr>
<td>KT-2</td>
<td>Kaolinite</td>
<td>1.6</td>
</tr>
<tr>
<td>KT-3</td>
<td>Kaolinite</td>
<td>1.4</td>
</tr>
<tr>
<td>KT-4</td>
<td>Smectite, Kaolinite</td>
<td>N/A</td>
</tr>
<tr>
<td>KT-5</td>
<td>Kaolinite</td>
<td>0.92</td>
</tr>
<tr>
<td>KT-6</td>
<td>Kaolinite</td>
<td>1.17</td>
</tr>
<tr>
<td>KT-7</td>
<td>Smectite, Kaolinite</td>
<td>N/A</td>
</tr>
<tr>
<td>CF-8</td>
<td>Kaolinite</td>
<td>1.01</td>
</tr>
<tr>
<td>CF-9</td>
<td>Kaolinite, Smectite</td>
<td>N/A</td>
</tr>
<tr>
<td>CF-10</td>
<td>Kaolinite, Smectite</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Figure 3.2.1: XRD Pattern of Sample KT-1. Red is air dried, blue is ethylene glycol saturated, and green is heated. Notations show d-spacing in angstroms.

Figure 3.2.2: XRD Pattern of Sample KT-2. Red is air dried and blue is ethylene glycol saturated. Notations show d-spacing in angstroms.
Figure 3.2.3: XRD Pattern of Sample KT-3. Red is air dried, blue is ethylene glycol saturated, and green is heated. Notations show d-spacing in angstroms.

Figure 3.2.4: XRD Pattern of Sample KT-4. Red is air dried, blue is ethylene glycol saturated, and green is heated. Notations show d-spacing in angstroms.
Figure 3.2.5: XRD Pattern of Sample KT-5. Red is air dried, blue is ethylene glycol saturated, and green is heated. Notations show d-spacing in angstroms.

Figure 3.2.6: XRD Pattern of Sample KT-6. Red is air dried and blue is ethylene glycol saturated. Notations show d-spacing in angstroms.
Figure 3.2.7: XRD Pattern of Sample KT-7. Red is air dried and blue is ethylene glycol saturated. Notations show d-spacing in angstroms.

Figure 3.2.8: XRD Pattern of Sample CF-8. Red is air dried and blue is ethylene glycol saturated. Notations show d-spacing in angstroms.
Figure 3.2.9: XRD Pattern of Sample CF-9. Red is air dried and blue is ethylene glycol saturated. Notations show d-spacing in angstroms.

Figure 3.2.10: XRD Pattern of Sample CF-10. Red is air dried, blue is ethylene glycol saturated, and green is heated. Notations show d-spacing in angstroms.
4 DISCUSSION

The occurrence of smectite within the Georgia kaolin deposits is rather enigmatic; as such interbedded deposits are atypical for the region. The depositional environment, as well as the Piedmont and Blue Ridge source material containing illitic clays and feldspathic phases, would favor the formation of pure kaolinite, as is seen in the majority of the Georgia kaolin deposits (Hurst and Pickering, 1997). While these smectites only make up a small portion of the mixed clay deposits, even smectite concentrations as low as one percent can have a significant effect on the rheology of the kaolin slurry, due to its high viscosity (Jones, 1988).

As the X-ray diffraction results show, the majority of the samples are pure kaolinite, with two others being mixed smectite and kaolinite, with kaolinite making up the bulk of the sample. Only two of the samples contained primarily smectite, being similar to the Fuller's earth deposits of the Twiggs Clay Formation in texture, granularity, and smectite content. As seen in Figures 3.2.4, 3.2.6, 3.2.9, and 3.2.10, the smectite diffraction peak at 14Å is noticeably broader than the kaolin diffraction peak at 7.12Å. The relatively narrow peaks of the kaolinite in the diffraction patterns are indicative of relatively coarse crystals, as peak width is relatively proportional to scattering domains (Moore and Reynolds, 1997). This relationship of larger kaolinite crystals and relatively smaller smectite crystals was also seen during a study of Cretaceous age Georgia clay deposits by Jones (1988). This larger crystal size could indicate an age difference between a diagenetic smectite and detrital kaolin phases. This difference may also be a result of Ostwald ripening increasing the kaolin crystal size (Moore and Reynolds, 1997).

The kaolinite in each sample also exhibits a high Hinckley Index value, typically between 0.9 and 1.6, which indicates a low amount of structural defects in the kaolinite crystals (Plançon et al., 1988). This crystallinity index is indicative of Cretaceous age kaolin, primarily the Buffalo Creek Formation (Kogel, 2009).
Multiple features, including the relatively large crystal size, the high Hinckley Index, as well as the smooth fracture exhibited by the pure kaolin samples, are similar to kaolin samples from the Cretaceous age Buffalo Creek Formation or the Marion Member of the Huber Formation. The Buffalo Creek provides 70% of all minable kaolin deposits in Georgia (Kogel, 2009).

It has previously been established by Hurst and Pickering (1997) that the kaolins of the Cretaceous age Buffalo Creek Formation had formed through *in situ* alteration of feldspathic materials deposited in fluvial and deltaic environments. However, the inclusion of these smectite deposits, typically produced through the weathering of volcanic ash in marine or other alkaline environments suggests the possibility that these two varieties of clays were not formed concurrently or had different provenances (Moore and Reynolds, 1997). As the smectite deposits are not interstratified with the kaolin, less developed, smaller, and irregularly located, one hypothesis for the origin of these deposits is that the smectitic clays, or their source material, were deposited in mixed beds with the pre-existing Cretaceous age kaolin during sea level regressions or other erosional events. That idea the pre-existing kaolin mixed with smectite from a nearby source is supported by Jones (1988), where Scanning Electron Microscopy analysis of clays from this region confirms that the kaolinite crystals show no displacement by the smectite, and vice versa. This displacement would have occurred if the kaolin crystals developed during or after the smectite was deposited. The irregularity of these of the locations and sizes of the smectite deposits can be attributed to the depositional environment, as well as the numerous erosional events that have occurred in the region since the time of deposition.

A second possibility for the co-occurrence of smectite and kaolinite in these deposits is presented by samples KT-4 and KT-7, both of which are almost purely smectite and very similar to the fuller's earth deposits found in the overlying Twiggs Clay Formation. It is possible that the Twiggs Clay material was simply translocated into the underlying kaolin deposits. As was seen in Figure 2.1.1, the Huber Formation, which separates the Buffalo Creek and Twiggs Clay Formations, is absent in the study area.
This supports the possibility of Twiggs Clay materials being translocated into the Buffalo Creek Formation. Further study into the samples' Ca-montmorillonite content, compared to the Ca-montmorillonite content of Twiggs Clay material, will be need to address this hypothesis.

5 CONCLUSION

The presence of smectite within kaolin deposits in both the KT Tucker and Crutchfield mines is atypical for Coastal Plain kaolins. X-ray diffraction analysis of samples from these locations shows predominantly large, high Hinckley Index kaolinite crystals, consistent with Buffalo Creek Formation or Marion Member kaolin deposits. In each sample the kaolin crystals were also of a greater size than the smectite crystals. These findings regarding both the kaolin and smectite are consistent with earlier work by Jones (1988).

The most probable origin of the smectite inclusions is that the smectitic clays, or their source material, were deposited in mixed beds with the pre-existing Cretaceous age kaolin during sea level regressions or other erosional events. The irregular locations of the smectite deposits as well as the wide range of purity can be attributed to the mechanism of deposition and well as the numerous erosional events that occurred in the region since that deposition.
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