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GEOLOGY AND CERAMIC PROPERTIES OF THE IONE FORMATION, BUENA VISTA AREA AMADOR COUNTY, CALIFORNIA

By JOSEPH A. PASK and MORT D. TURNER

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OUTLINE OF REPORT

Illustrations

ABSTRACT

The Buena Vista area described in this report lies in the low foothills of the Sierra Nevada in southeastern Amador County, south of Ione. It contains commercially important clay beds of the Ione formation, Eocene in age, which were deposited in a tropical or semi-tropical climatic environment.

Surface geology was mapped and a study was made of the geology and mineralogy of the clay from samples secured from drill-hole cores. Ceramic tests, consisting of differential thermal analysis, pyrometric cone equivalent determination, and fired color of samples containing clay were used as aids in this study. It was found that the pyrometric cone equivalent (refractoriness) of a clay could be estimated from a knowledge of the differential thermal analysis and fired color of the clay. Because differential thermal analysis and fired color may be obtained more quickly, easily, and cheaply than pyrometric cone equivalent by standard procedure, this method of determining approximate refractoriness will be of great assistance to the geologist and miner looking for refractory clay.

The clay minerals of the area were found to be members of the kaolinite group, and by using differential thermal analysis three types and several subtypes of kaolinite group clay minerals were identified. These types and subtypes were found to be useful and valid aids in geologic correlation of members, and even lentils, of the Ione formation.

Underlying the Eocene sediments is the basement, or bedrock series of the Sierra Nevada. The oldest of these rocks exposed in the area consists of meta-andesites and related greenstones of the Upper Jurassic Amador group which are overlain by the Upper Jurassic Mariposa slate. One drill hole in the area reached the Mariposa slate below the overlying Tertiary cover. The Jurassic rocks were folded and metamorphosed at the close of the Jurassic period. Clay and sand of an unnamed formation were found overlying the basement rocks and underlying the Ione formation in a number of drill holes. The clay and sand may also be of Eocene age, but their lithology does not indicate deposition in a tropical environment. After the pre-Ione sedimentation the climate changed to one which was more tropical and the surface rocks were deeply weathered. Laterite was formed on outcrops of greenstone and has furnished some of the source material for the refractory clays in the later Ione sediments.

The pre-Ione sediments are overlain unconformably by the Ione formation which, in the Buena Vista area, is composed of two members separated by an unconformity.

The lower member of the Ione formation contains most of the commercial clay of the area and is characterized by the rarity of chlorite, biotite, and certain types of clays. It is divisible into three lentils in the Buena Vista area. The lower lentil contains the Edwin clay—which is mined near the town of Ione—and reworked laterite. The middle lentil contains the lignitic coal beds of the area. The upper lentil contains the Cheney Hill clays and the white Ione sand.

The upper member of the Ione formation is predominantly sandy and contains two mappable units: a hard white sandstone at the top of the member, and the Chitwood clay in the upper part of the member.

The degree of alteration of minerals in the upper member of the Ione formation indicates that the climate was becoming more temperate than during the deposition of the lower member. Temperate climate continued into the later Tertiary epochs; the Valley Springs and Mehrten formations were formed in this climate. Mean-

* Associate Professor of Ceramic Engineering, Division of Mineral Technology, College of Engineering, University of California at Berkeley.
** Assistant Mining Geologist, California Division of Mines. Manuscript submitted for publication November, 1951.

while the Sierra Nevada began to rise essentially as a westward tilted block. The uplift increased the gradient of the rivers which began to cut deep canyons rapidly.

At the close of the time of deposition of the Ione formation and during the early Miocene there was a long period of erosion, followed by the deposition of volcanic ash represented by the rhyolitic Valley Springs formation. Rhyolitic volcanism gave way to andesitic volcanism in the upper Miocene or Pliocene and the thick mantle of andesite agglomerate of the Mehrten formation accumulated over the entire area. Subsequent erosion, accelerated by the continued uptilting of the Sierra Nevada, removed all of the andesitic material and much of the rhyolitic ash from the Buena Vista area. During later stages of erosion, terraces were formed, mantled with the deposits of auriferous gravels derived from exhumed Eocene gravel channels which lay on the basement surface concealed by the Tertiary volcanic cover.

INTRODUCTION

Clays of the kaolinitic type are important raw materials for a number of industries. In California such clays have been exploited to some extent. It is desirable to add to knowledge of California clays, and to investigate the geology of as many known clay areas as possible.

At the close of World War II a series of 17 holes with a total footage of 4225 feet was drilled in Jackson Valley, southwest of the village of Buena Vista in southwest Amador County. The individual holes ranged in depth from 63 feet to 395 feet and were from 680 feet to 2350 feet apart horizontally. Summary logs and partial cores of these holes were given to the Division of Mines in 1948. Because these cores represented a unique opportunity for detailed study of the economically important Ione formation, the Division of Mines and the Ceramic Engineering Laboratories of the University of California instituted a joint study of the geology and clays of the Buena Vista area.

The logging of the cores gave a detailed lithologic column for each hole but this was not sufficient to allow correlation of individual beds from hole to hole, except in a few places. Mapping of the surface geology, experimentation with various methods of graphic presentation, and utilization of a number of ceramic techniques were necessary before a picture of the stratigraphy could be developed. The ceramic techniques, specifically differential thermal analysis, fired color, and pyrometric cone equivalent, are referred to as ceramic in the sense that they are extensively used by ceramists and that they depend upon the application of heat. Differential thermal analysis is primarily of value in aiding in the determination of the mineralogical composition. The fired color and pyrometric cone equivalent tests, in addition to providing a differentiating factor, are also of economic importance because they help to ascertain the potential value of a clay to the ceramic industry.

The purpose of the investigation was to obtain information about the detailed stratigraphy of the Tertiary sediments of the area, the position of the already exploited clay deposits in the stratigraphic sequence, the location and character of unexplored clay deposits, and the value of ceramic testing techniques as an aid in geologic investigations.

Although the geologic study was the work of M. D. Turner and the ceramic study the work of Joseph A. Pask, the interpretations and conclusions reached in each section were the result of mutual effort.

Acknowledgments. The project was aided by research grants from the Institute of Engineering Research of the College of Engineering of the University of California at Berkeley, which paid part of the cost of logging the drill cores and paid all of the cost of the ceramic testing.

The project was greatly aided by Val Freeman, who assisted in logging the drill cores, plotted the results of the logging, and fired the chip samples; by Maurice Warner, who ran the differential thermal analyses; by Ralph Adamo, who determined the pyrometric cone equivalents and ran color determinations on fired clay samples; and by Samuel R. Hoffman, who assisted with the plane table mapping.

Jack Fancher and F. M. Ringer, ranchers of the Buena Vista area, furnished valuable information concerning the history of clay production in the area. T. C. Slater of the Calaveras Cement Company, and Raymond Drew of the American Lignite Products Company cooperated by providing the logs of holes which have been drilled in prospecting for lignite, clay, and glass sand.

Geography. The Buena Vista area is in the low foothills of the Sierra Nevada between the Cosumnes and Mokelumne Rivers, about 4 miles south of Ione and 10 miles west of Jackson, an area roughly rectangular in shape and covering about 5 square miles. Elevations range from 225 feet on Jackson Creek to 848 feet at the top of Buena Vista Peak.

The Buena Vista area is a part of the Arroyo Seco dissected pediment as described by Piper.[1] The present topography was formed during the Victor epoch. The entire area is drained by Jackson Creek which heads to the northeast on the middle slopes of the Sierra Nevada and flows past Buena Vista from east to west in a mile-wide flood plain that bisects the area. Jackson Creek joins Dry Creek a few miles west of Buena Vista.

In the north the hills are smoothly rounded and rise more than 150 feet above Jackson Valley. Bare rock knobs and cliffs are common only along the greenstone ridge. In the south the lower hills are smooth and rounded like those across Jackson Creek, but at a higher elevation rocky outcrops and lines of low cliffs have been developed in the Valley Springs formation. The most prominent topographic features are the Buena Vista Peaks, which are capped by rhyolite cliffs nearly 100 feet high.

The climate of the Sierran foothills is Mediterranean, with cool wet winters and hot dry summers. The average annual precipitation is about 21 inches and falls almost entirely as rain from October to May. Snow is unusual but freezing temperatures are expected at night from December to February. Summer temperatures of over 100° F. are common.[2] As a result of the seasonal rainfall the streams are full and swift during the winter, whereas in the summer they are completely dry. Jackson Creek, however, contains water through most of the year.

The flora also reflects the fluctuating water supply by maturing in late spring. The hills are covered with trees and shrubs, in places so thickly that passage is very difficult for a person on foot. The common shrubs are

[1] Piper, A. M., Gale, H. S., Thomas, H. E., and Robinson, T. W., Geology and ground-water hydrology of the Mokelumne area, California: U. S. Geol. Survey Water-Supply Paper 780, 230 pp., 1939.
[2] Sprague, Malcolm, Climate of California *in* Climate and Man: U. S. Dept. Agr. Yearbook 1941, pp. 793-795, 1941.

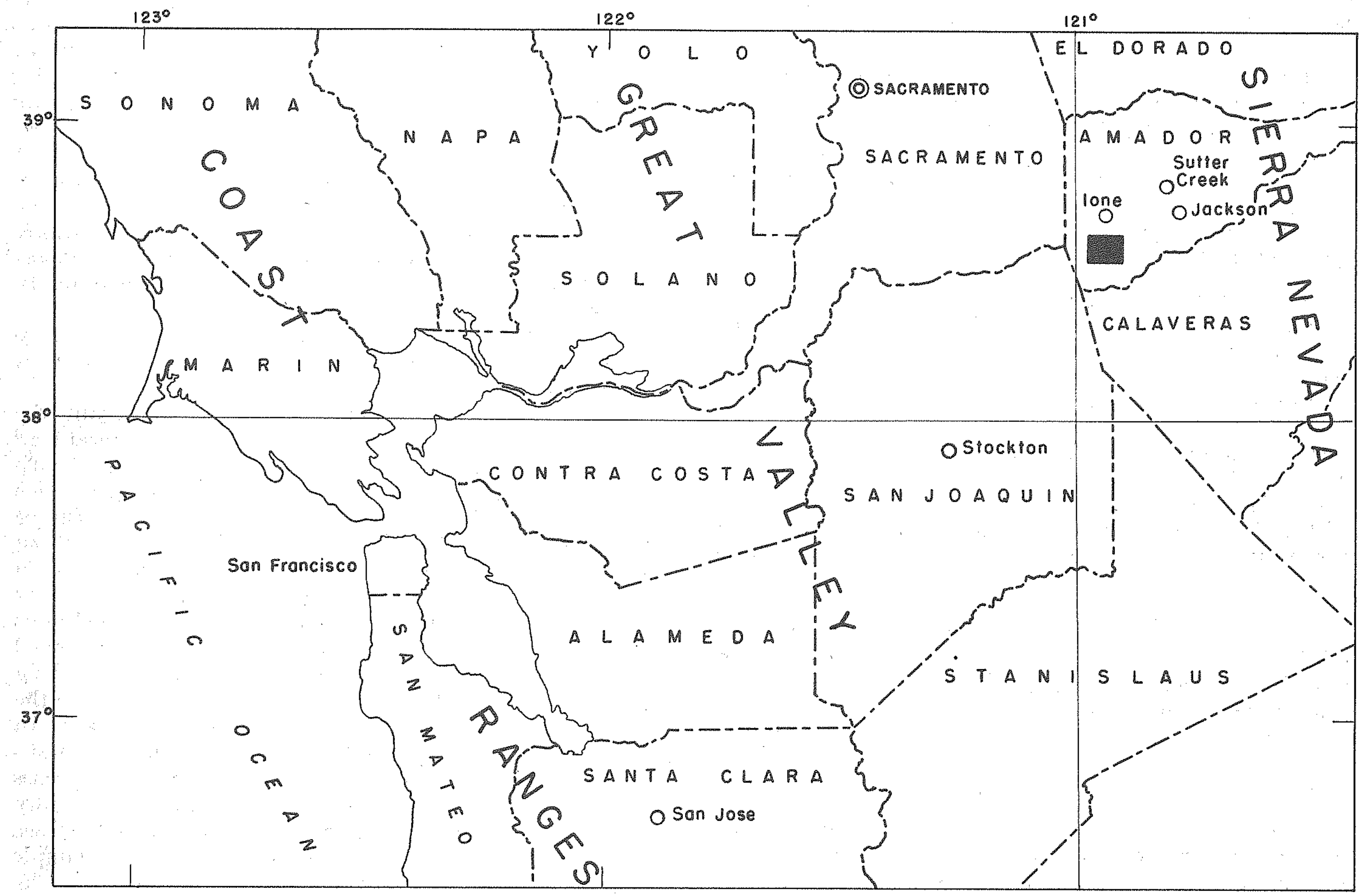

Figure 1. Index map of central California showing location of Buena Vista area.

chamise (*Adenostoma*), manzanita (*Arctostaphylos*), and poison oak (*Rhus*). The trees are various species of oak (*Quercus*) with some scattered digger pines (*Pinus sabiniana* **Douglas**). Most of the land is pasture and range. The only cultivated areas are on the alluvium of Jackson Valley, where wheat and other grains are raised; water from wells is used for irrigation. The fauna is typical of the Sierran foothills and consists of a large variety of small herbiverous and carniverous animals.

History. After a long period of Indian occupancy, the first white people reached the area in 1848, and in that year farming and cattle fattening began in Jackson Valley.[3] In 1852, Teodocio Yorba filed a Mexican grant which was finally made to cover a large part of Jackson Valley.[4] The resultant conflict in titles was not settled until the 1860's. During that time the rich alluvial valley had become a gold-producing region itself, as well as an important source of agricultural products for the Mother Lode region. Coal and clay were later produced in large quantities. The ranches and farms, however, have always remained as the main source of wealth.

[3] Mason, J. D., History of Amador County, California, p. 189, Oakland, Thompson and West, 1881.
[4] Ibid, pp. 242-250.

METHODS OF INVESTIGATION

Geology

About 17 days were devoted to field study of the surface geology by M. D. Turner during April 1950 and January and April 1951. Outcrops were plotted on U. S. Forest Service aerial photographs on a scale of 1:20,000 and on a U. S. Bureau of Reclamation topographic map, Drawing No. GI-598-D-2, at a scale of 1:12,000 and a contour interval of 10 feet. Several regions in the northeast were unsurveyed on the original map. A small portion of the unmapped area in the vicinity of the Kaolin-Fye pit was surveyed at the scale of the base map with a plane table, alidade, and stadia rod.

Work in the field stressed the identification of lithologic units of the Tertiary formations so that correlations could be made with units differentiated in the drill cores. Field identifications were supported by petrographic study of 40 thin sections and a number of crushed samples. The greatest aid in correlation was obtained through interpretation of differential thermal analyses of field samples and core samples. The cores, representing 1842 feet of hole, or 43.6 percent of the total footage drilled, were logged. Each identifiable unit was described by visual means as to color, texture, and mineral composition. These data were plotted at a scale of 1 inch equals 1 foot. Chip samples were taken for ceramic testing.

Ceramic Tests

The ceramic tests employed during this work were observation of fired color, pyrometric cone equivalent, and differential thermal analysis. As geologists are generally not familiar with these tests, the following discussion is presented. The many tests usually made to determine the degree of firing and the properties of various types of ceramic bodies or mixtures were not included in the study.

Fired Color. Small pieces of core samples, about 1 inch in diameter, were fired in an electric resistance-wire furnace to a temperature of 1000° C. or 1832° F. These retained their original shape because no fusion or disintegration occurred. Some samples were also powdered to pass a 70-mesh sieve prior to calcination. The fired colors were unchanged, but the powdered form enabled the measurement of percentage reflectance values relative to magnesia as a standard. Measurements were obtained with a Photovolt intrument. The data obtained with a green filter were used for correlation as green light most closely approaches the perceptibility of the human eye.

Clays, being hydrous aluminum silicates, should fire white, but the presence of iron oxide or minerals containing iron oxide will result in some shade of brown or red. This information is valuable, for the appearance of iron oxide in unfired samples is often masked in some manner, usually by carbonaceous material. The fired color can thus be used as an aid to correlation where the presence of iron oxide is a characteristic.

Pyrometric Cone Equivalent. The pyrometric cone equivalent values were obtained according to the specifications of A. S. T. M. Standard Test C24-46 [5] using a Remmey oxy-acetylene furnace. Briefly, the method consists of comparing the deformation rates of tetrahedral cones, about 1 inch in height, made from the clays to be tested, with standard cones. Series of numbered standard cones are available whose deformation temperatures are known for given rates of heating.

In a system of oxides reacting according to the phase rule without any, or a small amount of solid solution, exposed to increasing temperatures, liquid will first appear at a eutectic temperature, the amount of liquid being dependent upon the composition. As the number of oxides in the system is increased the temperature at which the liquid appears is lowered because the new eutectic temperature is lower. As the temperature is further increased, the amount of liquid increases until the crystals disappear entirely. Complete melting at one temperature occurs only for compositions corresponding to true compounds or to the eutectic composition. In aluminous silicate systems the liquids formed have high viscosities, or low fluidities, resulting in slow deformation instead of rapid collapse of the cone. Thus, time becomes a factor, but the heat-work for deformation remains the same. A given cone will, therefore, deform at a higher temperature if heated at a faster rate and at a lower temperature if heated at a slower rate. This method of determining "temperature" and refractoriness is of value and used extensively because it offers an opportunity to compare a number of ceramic mixtures under similar physical conditions.

Differential Thermal Analysis. Differential thermal analysis determines the temperatures at which endothermic (heat-absorbing) and exothermic (heat-evolving) effects take place by measuring the temperature difference between an unknown and a standard (alumina) during a constant rate of increase of the furnace temperature. For a given mineral these effects are the same and therefore constitute a means of identification. Endothermic effects are caused by vaporization, decomposition, crystal inversion, and fusion; exothermic, by oxidation (usually of carbonaceous material) and crystallization. Other research tools and techniques, however, are used to identify the causes for the various heat effects if the information is desired.

The experimental arrangement used to obtain the curves was similar to those described in the literature.[6] The main difference was in the use of a recording potentiometer with a range of —0.25 to +0.25 millivolts which allowed a visible record of the differential temperature between the alumina and the unknown throughout an analysis. The thermocouples were platinum vs. platinum —10 percent rhodium. The heating rate was constant at 8.45 mv./hr., equivalent to approximately an average of 13½° C. or 24° F. per minute. The amount of material per test was approximately 1.8 grams. Changes in heating rates cause slight shifts in peak temperatures because the heat-work for a certain reaction remains constant. In instances where reactions are dependent upon the addition of gases, such as oxidation, or dissipation of gases or vapors, such as decomposition, the shifts are generally greater because they also are dependent upon the ease of movement of the gases or vapors through the sample and the experimental set-up. Peaks are deviations in the curve, both above and below the zero line.

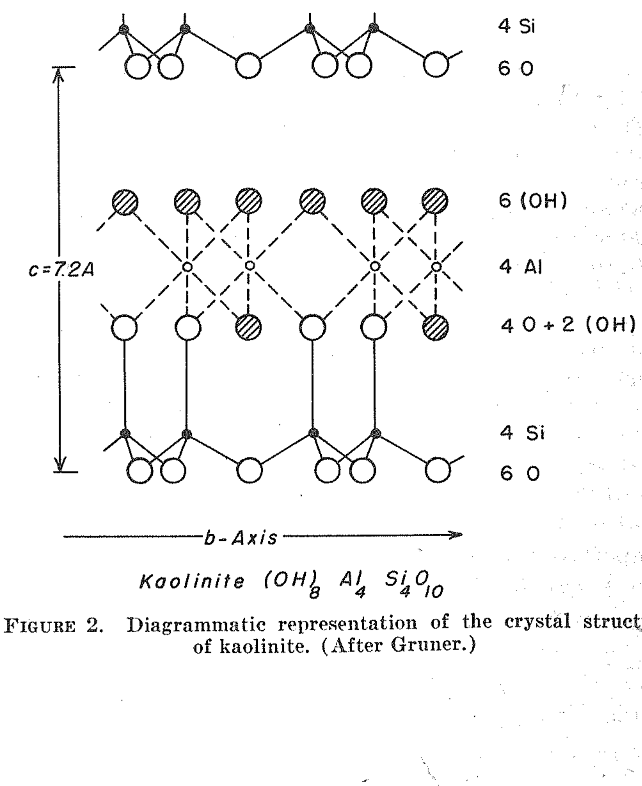

FIGURE 2. Diagrammatic representation of the crystal structure of kaolinite. (After Gruner.)

[5] Manual of A. S. T. M. standards on refractory materials: Am. Soc. Testing Materials, pp. 69-72, 1948.

[6] Spiel, Sidney, Berkelhamer, L. H., Pask, J. A., Davies, Ben, Differential thermal analysis—its application to clays and other aluminous minerals: U. S. Bur. Mines Tech. Paper 664, 81 pp., 1945.

APPLICATION OF DIFFERENTIAL THERMAL ANALYSIS TO CLAY MINERALOGY

Clay minerals and quartz predominate in the sediments in the Buena Vista area, although other minerals are present in smaller amounts. The accurate determination of the minerals was desirable both for geologic logging and for economic importance. Once curves are obtained for representative type-clay minerals, the differential thermal analyzer enables identification of unknown clays. The analyzer also easily detects minor variations that are difficult to discern by regular petrographic or X-ray methods.

Hydrous minerals, such as clay, mica, talc, amphibole, and the serpentine-chlorite series, show a characteristic endothermic peak at characteristic temperatures due to the evolution of (OH)— ions as water molecules. Sometimes subsequent endothermic peaks due to further breakdown and exothermic peaks due to crystallization become additional identifying characteristics. Characteristic endothermic effects are also obtained for carbonate-containing minerals.

Carbonaceous material is usually oxidized at relatively low temperatures and over a wide range of temperatures and produces a broad exothermic peak. Anhydrous or undecomposable minerals usually are not discernible unless they undergo an inversion, such as quartz does in changing from the alpha to the beta crystalline form at 573° C. or 1063° F. with an absorption of heat.

Standard Clay Minerals

The clay minerals are divided into three main groups:[7] kaolinite, illite or hydrated mica, and montmorillonite. A number of minerals, such as attapulgite and beidellite, do not fit into this classification and are included in a miscellaneous grouping. Most clay minerals are essentially hydrous aluminum silicates and are layerlike in crystalline structure. A brief description of the structures will offer a greater appreciation of the differences between the minerals.

The sizes of the silicon, aluminum, and oxygen ions are such that a compact packing of oxygen and hydroxyl anions around each of the cations forms $(SiO_4)^{----}$ and $(AlO_6)^{---------}$ or $(Al(OH)_6)^{---}$ groups. The superscript refers to the valence charge remaining because of more negative valences from four or six O^{--} or six $(OH)^{-}$ than can be satisfied by Si^{++++} or Al^{+++}. These groupings persist although there are several instances of structure where aluminum substitutes for silicon and has only four oxygen neighbors forming the $(AlO_4)^{-----}$ group.

The $(SiO_4)^{----}$ groups assemble to form a continuous structure in two directions resulting in a silica sheet. Looking at the edge of the sheet all of the oxygen valences on one side have been satisfied whereas on the other side unsatisfied oxygens exist that still have one negative valence or charge. Looking down on the sheet the oxygens are arranged in a hexagonal network. The $(AlO_6)^{---------}$ groups likewise are packed to form

[7] Brindley, G. W. (editor), X-ray identification and crystal structures of clay minerals: The Mineralogical Society (Clay Minerals Group), 345 pp., London, 1951.
Grim, R. E., Modern concepts of clay materials: Jour. Geology, vol. 50, pp. 225-275, 1942.
Marshall, C. E., The colloid chemistry of the silicate minerals, p. 14, Academic Press, 1949.

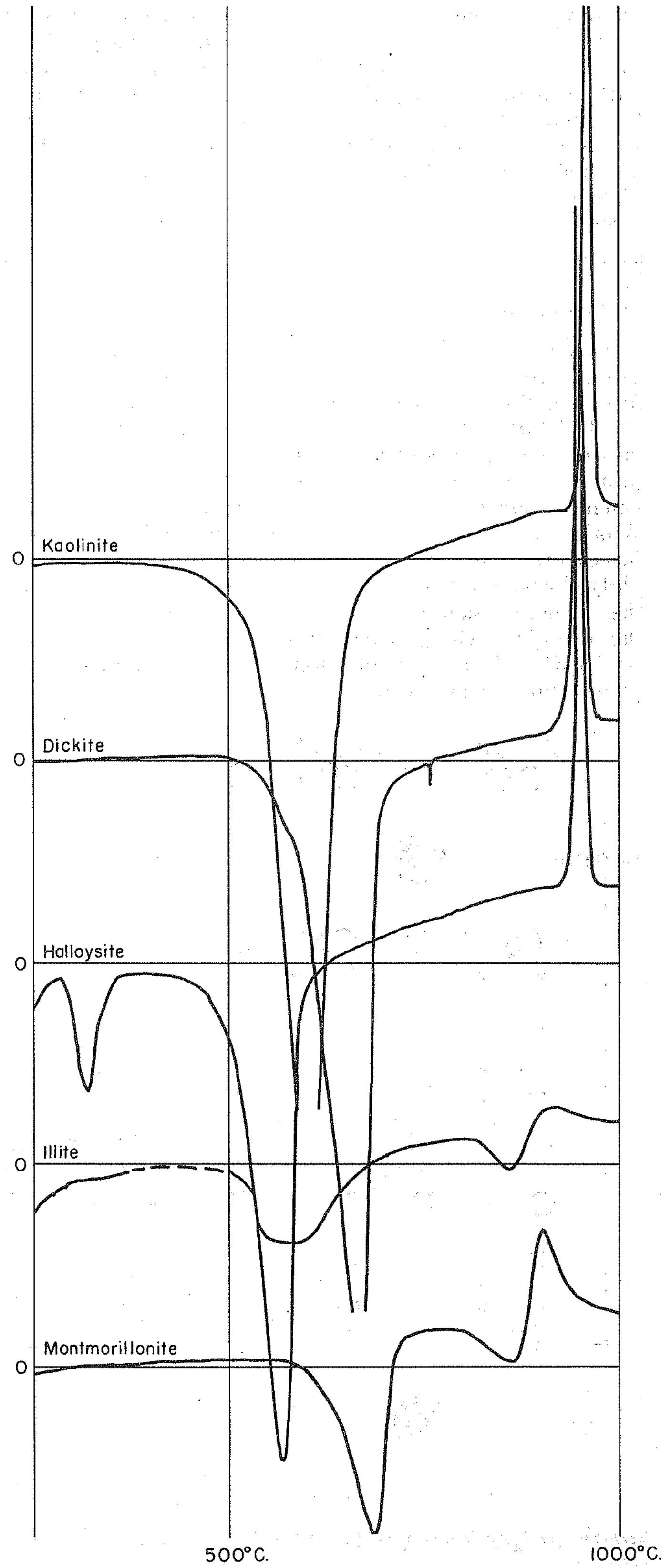

FIGURE 3. Differential thermal analyses of standard clay minerals.

a continuous assemblage in two directions resulting in a structure similar to a gibbsite sheet. Looking at its edge the oxygen valences on both sides have not been satisfied because of an insufficient number of positive charges from the Al^{+++}. Thus, a step toward valence balance is taken with each substitution of an $(OH)^-$ ion for an O^{--} ion. Complete substitution results in $(Al(OH)_6)^{---}$ groups. A compact assemblage of these groups so that each $(OH)^-$ ion is shared between two Al^{+++} ions forms the mineral gibbsite.

The sheets may assemble in several combinations with isomorphous substitutions of Al^{+++} for Si^{++++}, and also Mg^{++}, Fe^{++}, and Fe^{+++} for Al^{+++} to form the several groups of clay minerals.

Kaolinite Group. The recognized minerals of this group are: kaolinite, dickite, nacrite, halloysite—hydrated halloysite, and anauxite. They are referred to as the 1:1 lattice type for they are made up of layers containing one silica and one gibbsite sheet. The sheets are joined by sharing oxygens wherever necessary to satisfy valence charges. Layers are held together by van der Waals forces, which are not direct valence bonds. These forces are weak and are responsible for the dominant platy character of the crystals. As can be determined from the schematic sketch of the kaolinite molecule (figure 2) the formula is $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$ or, structurally, $(OH)_4 Al_2(Si_2O_5)$. It is probable that very little or no isomorphous substitution occurs.

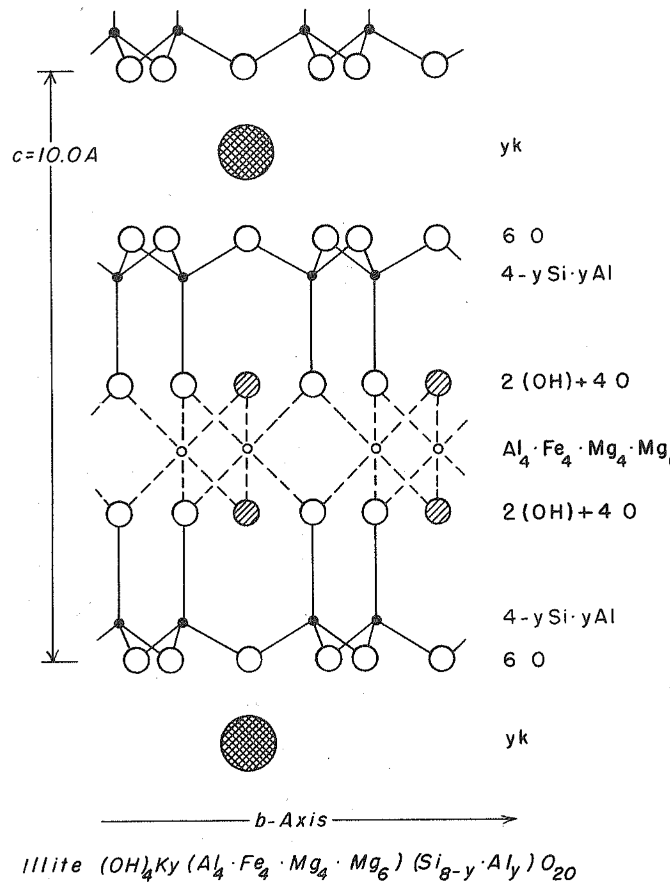

FIGURE 4. Diagrammatic representation of the crystal structure of illite. (After Grim, 1942.)

A differential thermal analysis of a typical kaolinite is shown in figure 3. The endothermic peak at approximately 600° C. or 1112° F. results from driving off water from the structure. Two theories exist for the appearance of the sharp exothermic peak at 980° C. or 1796° F. One states that it is due to the crystallization of gamma-alumina and the other, to the microcrystallization of mullite $(3Al_2O_3 \cdot 2SiO_2)$. Nevertheless, this peak, with the endothermic one, are identifying characteristics of kaolinite.

Dickite and nacrite are similar to kaolinite in all respects except in the degree of orientation of the layers over one another.[8] The curve for dickite (figure 3) has its endothermic peak at a higher temperature than kaolinite; and nacrite,[9] for which a curve is not available, presumably would show a still higher endothermic peak because of the less random packing of layers.

Halloysite has the formula $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$ and hydrated halloysite $Al_2O_3 \cdot 2SiO_2 \cdot 4H_2O$.[10] The latter is formed by the addition of oriented layers of water between the kaolinite layers. A series exists between the two forms. The chief differentiating characteristics of the halloysite differential thermal curve (figure 3) are the appearance of a large endothermic peak at approximately 150° C. or 302° F. due to the vaporization of the interlayer water (the size of the peak depends upon the amount of inter-layer water) and a sharp return to the neutral temperature after the main endothermic peak at 600° C., in contrast with a symmetrical endothermic peak as exhibited by kaolinite. The particles of halloysite are rod-shaped, formed by the curling of thin plates.

Anauxite is formed by the addition of oriented silica layers between the kaolinite layers—the formula being $Al_2O_3 \cdot 3SiO_2 \cdot 2H_2O$.[11] A series can thus exist between kaolinite and anauxite. The nature of the differential thermal analysis is, as yet, not certain. Several analyses of samples considered to be anauxite produced curves similar to those for kaolinite but with smaller heat effects. Work is in progress to settle this point.

Illite or Hydrated Mica Group. Sufficient work has not been done on this group to classify its members under specific mineral names. It is referred to as the 2:1 lattice type, for it is made up of layers containing a gibbsite sheet sandwiched between silica sheets. These are joined by the sharing of oxygens between alumina and silica sheets wherever necessary to satisfy valence charges leaving only a few excess charges at the sheet interfaces that have to be satisfied with $(OH)^-$ ions. The schematic sketch (figure 4) shows this arrangement.

It is essential for the constitution of this group to have isomorphous substitutions of Al^{+++} for Si^{++++} in the silica sheets. The resultant loss of the positive charge, and thus unbalance, is made up by the introduction of K^+ ions between the layers. In addition, isomorphous substitutions of Mg^{++}, Fe^{++}, and Fe^{+++} can easily occur for Al^{+++} in the gibbsite sheet. A series of illites is formed

[8] Hendricks, S. B., On the crystal structure of the clay minerals: dickite, halloysite and hydrated halloysite: Jour. Mineralog. Soc. America, vol. 23, pp. 295-301, 1938.
[9] Hendricks, S. B., The crystal structure of nacrite $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$ and the polymorphism of the kaolin minerals: Zeitschr. Krystallographie, band 100, pp. 509-518, 1939.
[10] Hendricks, S. B., Crystal structure of clay minerals, op. cit.
[11] Hendricks, S. B., Concerning the crystal structure of kaolinite $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$ and the composition of anauxite: Zeitschr. Krystallographie, band 95, p. 247, 1936.

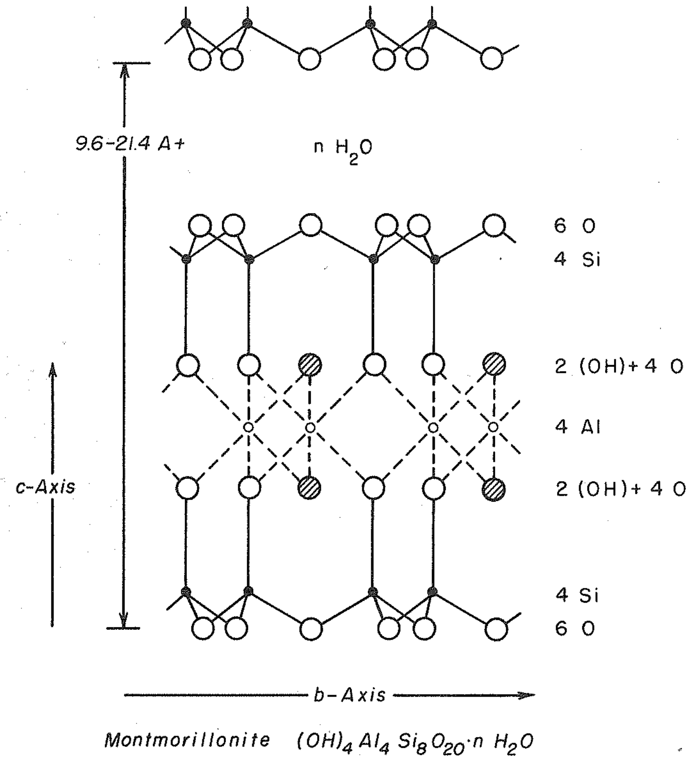

FIGURE 5. Diagrammatic representation of the crystal structure of montmorillonite. (After Hoffman, Endell, and Wilm.)

as Al^{+++} is substituted for Si^{++++} up to a maximum of 15 percent of the silicon ions. If 25 percent of the positions are replaced, mica results, showing the close relationship of the group to mica. The resultant formulae become:

Illite—$K_2O \cdot 5Al_2O_3 \cdot 14SiO_2 \cdot 4H_2O$ or
$(OH)_4K_y(Al_4,Fe_4,Mg_6)\ (Si_{8-y} \cdot Al_y)\ O_{20}$.
Mica—$K_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$ or
$(OH)_4K_2(Al_4,Fe_4,Mg_6)\ (Si_6 \cdot Al_2)\ O_{20}$.

Differential thermal analyses of illites (figure 3) show the presence of three peaks: two similar to those for kaolinite but smaller and less sharp, and another small endothermic peak at about 800° C. or 1472° F. The smaller, broader peaks are due to a comparatively slow rate of breakdown of the structure.

Montmorillonite Group. This group is also referred to as the 2:1 lattice type consisting of a gibbsite sheet sandwiched between silica sheets.[12] The isomorphous substitutions recognized in montmorillonites are Mg^{++}, Fe^{++}, and Fe^{+++} for Al^{+++} in the gibbsite sheets. The generally accepted structure suggested by Hoffman, Endell, and Wilm [12] is shown in figure 5; figure 6 pictures the structure proposed by Edelman and Favejee,[13] which is favored by some workers.

[12] Hoffman, U., Endell, K., and Wilm, D., Crystal structure and swelling of montmorillonite: Zeitschr. Kristallographie, band 86, pp. 340-348, 1933.
[13] Edelman, C. H. and Favejee, J. Ch. L., On the crystal structure of montmorillonite and halloysite: Zeitschr. Kristallographie, band 102, pp. 417-431, 1940.

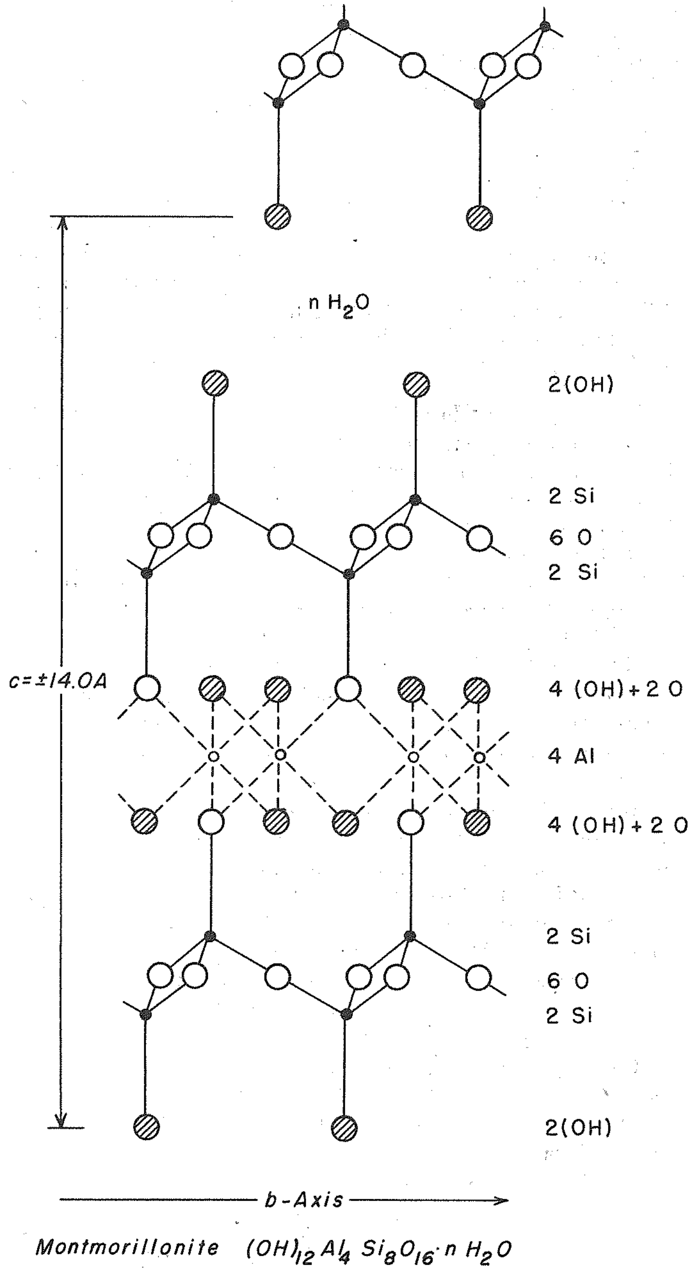

FIGURE 6. Diagrammatic representation of the crystal structure of montmorillonite. (After Edelman and Favejee.)

The group can be represented by a composition triangle with apexes of the oxides of the middle sheet (Al_2O_3, MgO,Fe_2O_3). The pure end members then are:

Pyrophyllite—
$Al_2O_3 \cdot 4SiO_2 \cdot H_2O$ or $(OH)_4Al_4(Si_2O_5)_4$
Talc—Saponite—
$3MgO \cdot 4SiO_2 \cdot H_2O$ or $(OH)_4Mg_6(Si_2O_5)_4$
Nontronite—
$Fe_2O_3 \cdot 4SiO_2 \cdot H_2O$ or $(OH)_4Fe_4(Si_2O_5)_4$

The end members themselves do not exhibit such properties as high base exchange, plasticity, and expanding lattice, that are characteristics of this group. The typical montmorillonitic clays, such as bentonite, occur within this composition triangle close to the Al_2O_3 apex and the

Al_2O_3–MgO side. The expanding lattice is associated with the presence of additional water between the layers which is driven off completely at drying temperatures of about 200° C. or 392° F. The structural formula for the typical montmorillonite becomes: $(OH)_4(Al_4,Fe_6,Mg_6)(Si_2O_5)_4 \cdot nH_2O$.

The differential thermal analysis shown (figure 3) is representative of a typical montmorillonite. The reactions generally occur more rapidly than in the illite group, resulting in three sharper, more distinct peaks, and the first endothermic peak is at a higher temperature (about 700° C. or 1292° F.). Changes in relative size and slight shifts in position of all three peaks occur with changes in composition, but the exact pattern is not known.

Miscellaneous Clay Minerals. Attapulgite and beidellite are the best known of the clay minerals that do not fall into one of the three main groups. The structure of attapulgite, as worked out by Bradley,[14] is similar to the 2:1 lattice type except that the silica sheets are arranged so that the silicon ions occur in strips alternately on either side of the oxygens, and the gibbsite sheet occurs in corresponding strips, producing a fibrous structure. Substitutions of Mg^{++} for Al^{+++} occur extensively, the magnesium end member being $(OH)_2Mg_5Si_8O_{20} \cdot 8H_2O$.

Beidellite is often included in the montmorillonite group because of its close similarity. However, as it does not exactly follow the structural pattern of the montmorillonites, it should be listed separately.

Marshall[15] suggests that the mineral is formed by substitutions of Al^{+++} for Si^{++++} in the silica sheets of the montmorillonite structure. The extra charges are, however, not balanced by introduction of K^+ ions between the layers as in illite but by introduction of additional positive charges in the gibbsite sheet by simply adding Mg^{++} ions or replacing an Al^{+++} ion by two Mg^{++} ions. This is possible because not all of the available cation positions in the gibbsite sheet are filled.

Pask[16] suggests that the mineral is formed by an interlayer mixing of the montmorillonite and kaolinite-type layers. Such a structure pattern can account for all beidellites giving a series or partial series between kaolinite and montmorillonite.

Variations in Kaolinite Group

The classifications of the main clay groups, as outlined, are based on representative specimens from type areas. During the present studies it became apparent that less of the type mineral kaolinite was present than other members of the kaolinite group. Practically all the Buena Vista area clays examined with the differential thermal analyzer, however, gave kaolinitic-type curves—an endothermic peak at about 500-600° C. or 932-1112° F. and an exothermic peak at about 880-980° C. or 1616-1796° F.—with variations in intensity and shape of the peaks, particularly of the exothermic. Future mineralogical studies will probably show that the variations are due to interlayer mixtures.

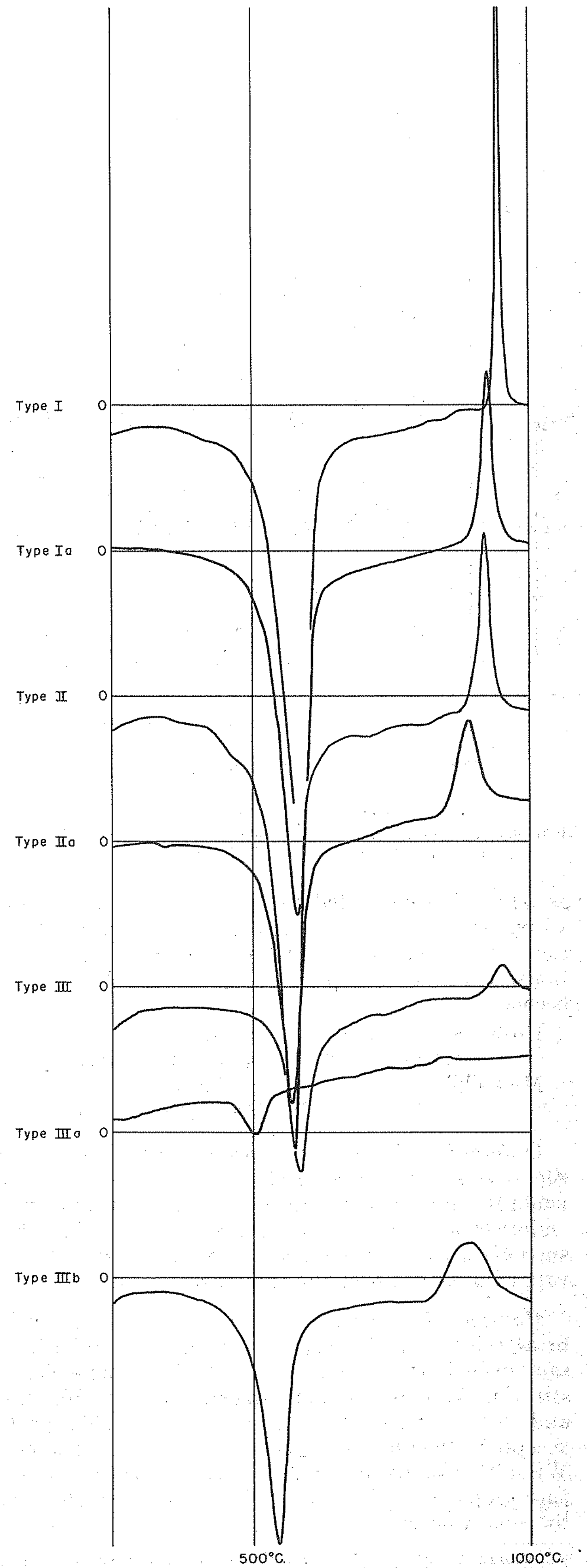

FIGURE 7. Differential thermal analyses of kaolinitic-type minerals from the Buena Vista area.

[14] Bradley, W. F., The structural scheme of attapulgite: Am. Mineralogist, vol. 28, p. 1, 1943.
[15] Marshall, C. E., Soil science and mineralogy: Soil Sci. Soc. America Jour., vol. 1, pp. 23-31, 1937.
[16] Pask, J. A. and Davies, Ben, Thermal analysis of clay minerals and acid extraction of alumina from clays: U. S. Bur. Mines Rept. Inv. 3737, 28 pp., 1943.

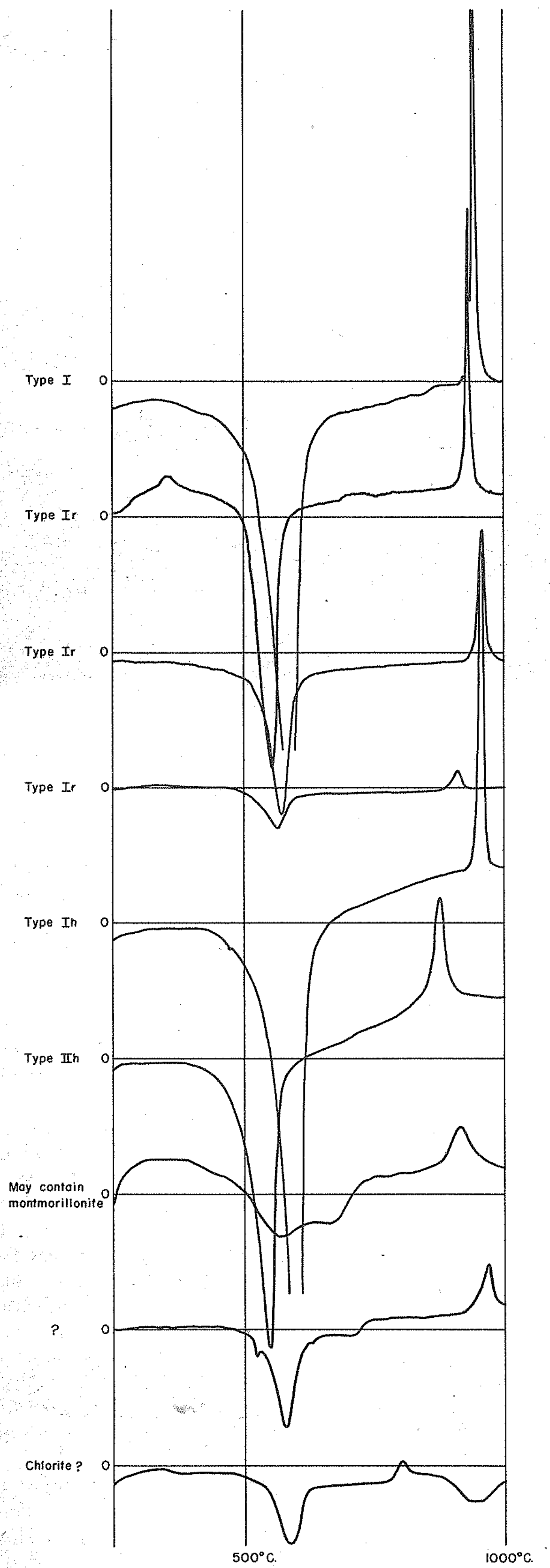

FIGURE 8. Differential thermal analyses of kaolinite having increasing quartz content, and differential thermal analyses of non-kaolinitic minerals from the Buena Vista area.

Because classification desirable for purposes of the study was based on the shape of the peaks of the differential thermal curves, the following types were differentiated (fig. 7):

Type I. Typical kaolinite. A sharp and narrow exothermic peak equal to, or greater in size than, the endothermic.
Type Ia. Between I and II.
Type II. A sharp and narrow exothermic peak one-half or less in size than the endothermic.
Type IIa. Between II and III.
Type III. Exothermic peak small, broad, and rounded; endothermic peak smaller than that for I and II.
Type IIIa. Exothermic peak very small or non-existent.
Type IIIb. Similar to III; exothermic peak larger in area, and more rounded; both peaks at a slightly lower temperature.

A sub-type of any of these, identified by the letter "h" (as: Type Ih), has a tendency toward a halloysite-type endothermic peak. A sub-type identified by the letter "r" (as: Type Ir) has the heights of the peaks reduced by presence of quartz or other relatively inert minerals. Types I, II, and III were differentiated early in the work but many samples were found that had intermediate characteristics that were responsible for establishment of Types Ia, IIa, IIIa, and IIIb. There are still some samples that are obviously intermediate in structure and are listed, for instance, as I (tending toward Ia). Indications thus exist of a continuous series between Types I, and II, and II and III.

As indicated, dilution of the quantity of clay mineral by quartz and other relatively inert minerals causes only a diminution of both peaks. Figure 8 shows a selection of Type I curves with decreasing peak sizes. The presence of quartz was determined when desired by rerunning the curve after the sample cooled below the β—α quartz inversion temperature of 573° C. or 1063° F. This procedure is necessary because the quartz peak is normally masked by the endothermic peak of the kaolinitic clay minerals, which is not reversible.

Carbonaceous material in small amounts does not affect the clay mineral peaks but causes the superposition of a broad exothermic peak due to oxidation of the organic material. The size and position of the peak varies with the amount and nature of the carbonaceous material.

Several additional types of curves were encountered as shown in figure 8. The minerals responsible for the differences have not been identified definitely and the curves were used only for geologic correlation.

DESCRIPTIVE GEOLOGY

Earlier Work. Because the Buena Vista area was an early source of minerals, it has been studied by several geologists. Mason [17] gave a general geological account, including a stratigraphic section of Buena Vista Peak. The monumental geological survey of the Sierra Nevada, published in the folio series of the U. S. Geological Survey, contained the first modern geologic study of the area. The Buena Vista area was included in the Jackson quadrangle mapped by Turner.[18] He considered the rhyolitic clay rock to be in the Ione formation. Lindgren [19] showed that the

[17] Mason, J. D., op. cit., pp. 125-136.
[18] Turner, H. W., U. S. Geol. Survey Geol. Atlas, Jackson folio (no. 11), 1894.
[19] Lindgren, Waldemar, The Tertiary gravels of the Sierra Nevada of California: U. S. Geol. Survey Prof. Paper 73, pp. 21-28, 196-197, 1911.

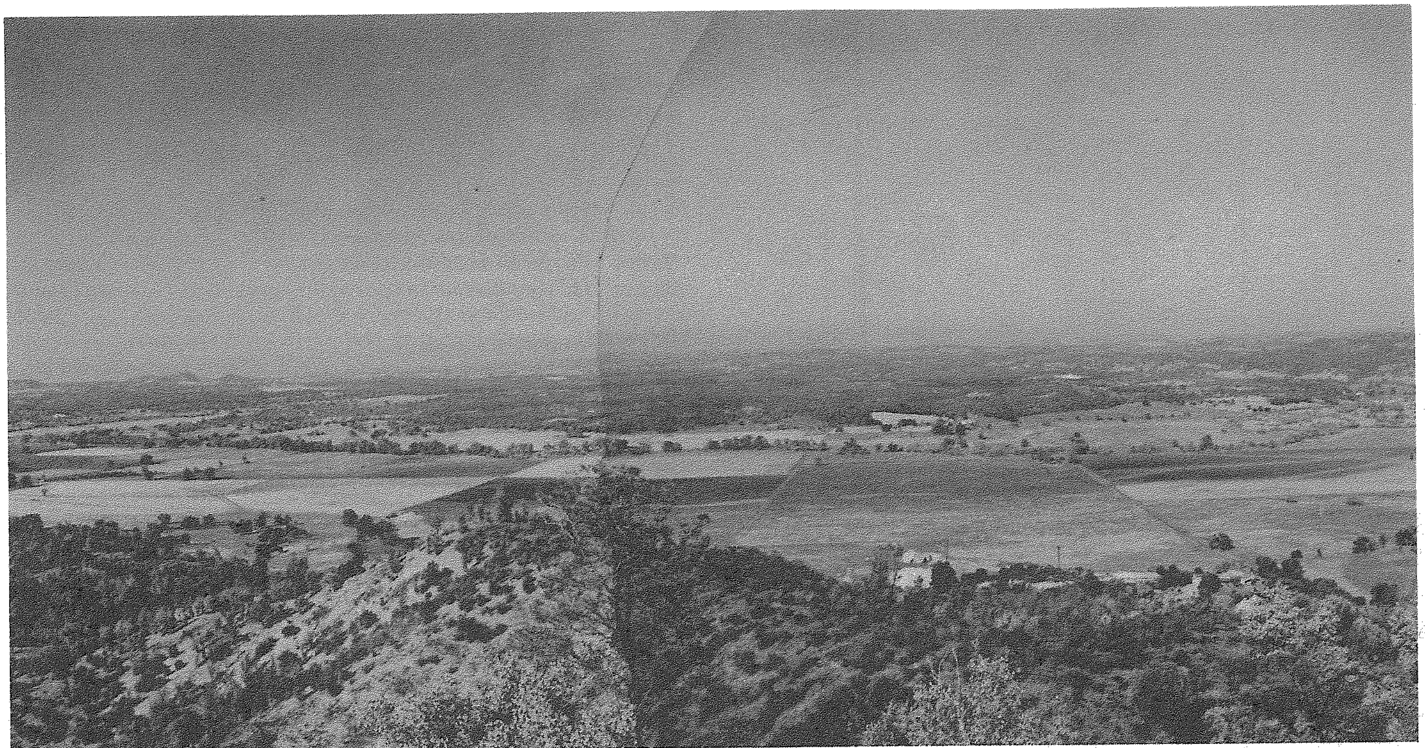

FIGURE 9. Buena Vista area from the top of Buena Vista Peak. Jackson Valley in center. Camera facing north-northwest.

early Tertiary rivers were the source of the sediments deposited in Ione time and delineated their courses. Dickerson,[20] Clark,[21] and Clark and Vokes [22] determined the age of the Ione formation during studies of the Eocene of California.

An overall study of the Ione formation was made by Allen [23] who paid particular attention to the Amador County area. The Ione formation was restricted to exclude all of the rhyolitic sediments, which had previously been included as the upper part of the Ione, and to include sediments of a specific lithologic character. Stearnes [24] published a geologic map covering the Buena Vista area that was essentially adapted from the Jackson folio.[25] Piper [26] remapped the entire Ione area on a larger scale, using the restricted Ione, set up by Allen, and introduced the Valley Springs and Mehrten formations. The bedrock series, since it was mapped in the 1890's, received little attention until Taliaferro defined the Amador group and its component formations.[27]

Bates [28] made a detailed study of the commercial clays of the Ione area, including some of the clays discussed in this paper.

General Geology. The oldest rocks in the area, the bedrock series, consist of the Upper Jurassic Amador group and Mariposa slates. They are folded metamorphic rocks that are more resistant to erosion than the later sediments of the area.

No Cretaceous rocks crop out in the area, although they have been encountered during drilling of wells in the Great Valley and at the surface at Folsom, 27 miles north.

Lying on the bedrock in the Buena Vista Basin are gray and green shale and sand of probable Eocene age. They are nowhere exposed at the surface but were penetrated in several of the drill holes. The Ione formation, probably of Eocene age, overlies these earlier Eocene (?) sediments, and is divided into the lower Ione and upper Ione members. The lower Ione clay and sand beds are exposed throughout most of the area north of Jackson Valley; the best exposures of upper Ione are on the lower slopes of Buena Vista Peak. The Valley Springs formation, possibly of Miocene age, was laid down on the eroded surface of the Ione formation and is characterized by unmetamorphosed rhyolitic debris. It forms the highest part of Buena Vista Peak and covers the region to the west of the bedrock ridge. No evidence of the Mehrten formation was found in the Buena Vista area although it rests on the Valley Springs formation in surrounding regions.

Quaternary terrace gravel and sand from various sources were deposited throughout the area, covering the tops of many of the higher hills. Jackson Valley, and all of the small valleys that drain into it, are blanketed with Recent alluvium. The gradients of most of the streams are low and the alluvium reaches the heads of the valleys in many places.

[20] Dickerson, R. E., Fauna of the Eocene at Marysville Buttes, California: California Univ. Dept. Geol. Sci., Bull., vol. 7, pp. 257-298, 1913.
Dickerson, R. E., Stratigraphy and fauna of the Tejon Eocene of California: California Univ., Dept. Geol. Sci., Bull., vol. 9, pp. 387-417, 1916.
[21] Clark, B. L., The stratigraphy and faunal relationships of the Meganos group middle Eocene of California: Jour. Geology, vol. 29, pp. 161-165, 1921.
[22] Clark, B. L., and Vokes, H. E., Summary of the marine Eocene sequence of western North America: Geol. Soc. America Bull. vol. 47, pp. 851-878, 1936.
[23] Allen, V. T., The Ione formation of California: California Univ., Dept. Geol. Sci., Bull., vol. 18, pp. 347-448, 1929.
[24] Stearnes, H. T., Robinson, T. W., and Taylor, G. H., Geology and water resources of the Mokelumne area, California: U. S. Geol. Survey Water-Supply Paper 619, 402 pp., 1930.
[25] Turner, H. W., op. cit.
[26] Piper, A. M., op. cit.
[27] Taliaferro, N. L., Manganese deposits of the Sierra Nevada, their genesis and metamorphism: California Div. Mines Bull. 125, pp. 280-286, 306-307, 1943.
[28] Bates, T. F., Origin of the Edwin clay, Ione, California: Geol. Soc. America Bull., vol. 56, pp. 1-38, 1945.

Table 1. Summary of rock formations in the Buena Vista area.

Era	Age	Group and formation			Thickness in feet	General character
QUATERNARY	Recent	Alluvium (Qal)			0-50 ±	Silt, sand, and gravel in present stream beds and beneath flood plains. Includes alluvial fan material.
		—Unconformity—				
QUATERNARY	Pleistocene	Terrace Gravels (Qt)			0-18	Auriferous sand, gravel, and water-worn cobbles on remnants of stream terraces at elevations of from 250 feet to 400 feet.
		—Unconformity—				
TERTIARY	Miocene (?)	Valley Springs formation (Tvs)			0-458	Rhyolite tuff, weathered rhyolite tuff ("clay rock"), and rhyolite-bearing sands and conglomerates.
		—Unconformity—				
TERTIARY	Middle (?) Eocene	IONE FORMATION	Upper Ione member		0-225 ±	White to brown sands and sandy clays. White to gray hard sandstone at top of member. Includes the Chitwood clay.
			Unconformity—			
		IONE FORMATION	Lower Ione member	Upper lentil	0-415 ±	White, gray, tan, brown, and red clay, lignite, clayey sands, and reworked laterite. Upper lentil includes the Ione sand and Cheney Hill clay. Middle lentil includes three lignite beds. Lower lentil includes Edwin clay.
				Middle lentil		
				Lower lentil		
		—Unconformity—				
TERTIARY (?)	Eocene (?)	Unnamed pre-Ione beds			0-131+	Gray, green, and greenish white sands and clays (not exposed at surface).
		—Unconformity—				
JURASSIC	Upper Jurassic	Mariposa formation (Jm)			?	Buff to pink clay derived by weathering from black slate (not exposed at surface).
JURASSIC		Amador Group	Logtown Ridge formation (Jlr)		?	Greenstone (augite andesite flows and agglomerates with associated intrusives), weathered to laterite in many places.

The Tertiary formations have not been folded or faulted since deposition, but the whole area was tilted toward the southwest as a unit during the Tertiary and Quaternary periods when the Sierra Nevada was being elevated.[29] The Tertiary sediments, however, were deposited with initial dips. The lower Ione member, which was laid down in a wide shallow valley, the Buena Vista Basin, conformed to the slope of the sides of the basin and has since been little disturbed. The long axis of the valley seems to be parallel to the strike of the underlying bedrock, about N. 30° W., and a ridge of greenstone may be traced along the west side of the basin and for many miles north and south. By upper Ione time the basin was essentially full and the sediments and volcanic rocks have a general dip away from the crest of the Sierra Nevada.

[29] Lindgren, op. cit., pp. 46-48.
Matthes, F. E., Geologic history of the Yosemite Valley; U. S. Geol. Survey Prof. Paper 160, pp. 43-44, 1930.

FIGURE 10. Greenstone ridge south of Jackson Valley. Greenstone cropping out as rounded boulders in grassy meadow. Buena Vista Peaks in background. Camera bearing east-southeast.

Bedrock Series

The bedrock formations in the area are the Upper Jurassic Logtown Ridge and associated feldspar porphyry intrusives of the Amador group, commonly called greenstone, and the Upper Jurassic Mariposa slate.

Amador Group

Amador metavolcanic rocks and Mariposa slate underlie the entire area, but only the Amador group has been exposed by erosion. Greenstone crops out as rough, rocky hills in the extreme northwest corner of the mapped area and in a small area a third of a mile southwest of the Chitwood pit. Several of the drill-holes reached greenstone, as indicated on the cross-sections. Taliaferro[30] found that the Logtown Ridge formation was originally composed of augite andesite tuffs, agglomerates, and flows that have since been metamorphosed to amphibolite and chlorite schists.

Three differential thermal analyses were run on the greenstone; two were weathered samples from the bottoms of holes 7-1 and 24-4, and the third was an unweathered surface sample collected on the greenstone ridge just outside the boundaries of the area. Each of the curves was very irregular but showed peaks characteristic of chlorite. Only in the highly weathered greenstone from hole 7-1

[30] Taliaferro, N. L., op. cit., pp. 283-284.

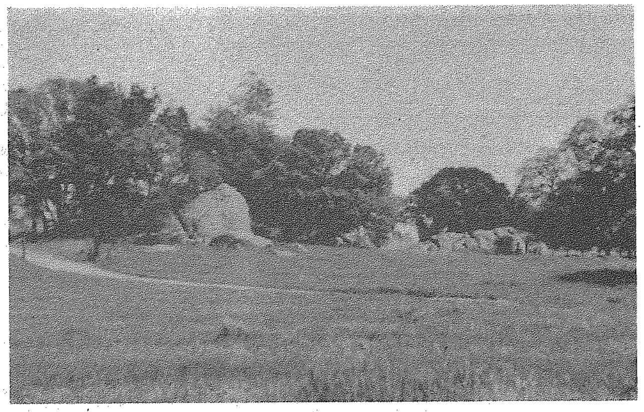

FIGURE 11. South end of main greenstone outcrop area north of Jackson Valley. Camera bearing east-northeast.

were there incipient peaks of the type characteristic of kaolinite.

In adjacent areas where the base of the Logtown Ridge formation is exposed, it rests on the Cosumnes formation of the Amador group. The Amador group rests with profound angular unconformity on the highly metamorphosed Calaveras rocks of Paleozoic age. There is no direct evidence that the Cosumnes formation and Paleozoic rocks underlie the Buena Vista area but it is probable that they do. Upward, the Amador group grades into the Mariposa slates.

Taliaferro [31] says that "the exact age of the Amador is not known, but it is believed to extend from the upper Middle to the lower Upper Jurassic. . . . the best available evidence indicates that the Mariposa is Oxfordian and, possibly, lower Kimmeridgian."

Climate, rate of erosion, or both, changed at the beginning of Ione time in such a way that intense tropical weathering caused the formation of laterite on exposed stable greenstone surfaces. Krumbein and Sloss [32] described the process of laterization as "the normal, soil forming process in the tropics. It concentrates iron or aluminum oxides, or both, in the B-horizon (zone of reprecipitation below leached zone), at the expense of the silica, which is leached out. Chemical weathering is rapid. Kaolinitic clay minerals are normal end products in some circumstances but, in others, the clay minerals are not stable. Where clay breakdown occurs, silica is removed, and the aluminum remains behind as a hydrate. Soil formed by the process is laterite."

The weathering of the laterite is not known to have progressed to the point of producing bauxitic material anywhere in the Buena Vista area nor was highly pisolitic laterite, such as that found near Jones Butte,[33] found in the area. Most of the laterite on the surface and in the drill-hole cores is mottled smooth clay which is not especially plastic. It is colored from nearly solid red to combinations of red, yellow, purple, gray, buff, and white.

The only outcrops of laterite are along the sides and on top of the greenstone ridge, both north and south of Jackson Creek. It is well exposed south of the Woolford pit and around hole 24-5, where 63 feet of lateritic material was drilled through. Nearly all the drill holes on the sides of the greenstone ridge passed through at least some laterite before encountering unaltered bedrock. In most places, however, the presence of sand grains and water-worn pebbles suggests strongly that much of the laterite has been reworked or transported a short distance and has become part of the lower Ione beds. For example, hole 24-3 was drilled through lateritic material from 144 feet to 220 feet, where greenstone was encountered. The interval from 214 feet to 220 feet contained pebbles of greenstone and quartz indicating that the laterite was transported after its formation. Laterite in a stream bed about 1000 feet south of the Woolford pit is definitely residual, however, because the original texture and structure of the parent rock are still visible, including phenocrysts and small faults.

Six differential thermal analyses were made of samples of laterite. Four were of definitely residual material and two of material reworked in the lower Ione member. All the curves were Type I, with a suggestion of halloysite in the two sedimentary laterites. The residual laterites were picked to represent a range in the degree of weathering. The least weathered sample was brownish yellow with residual texture quite evident and would more properly be called lithomarge. The production of a Type I curve from each of these samples indicates the very early formation of kaolinite in the process of laterization.

Allen [34] and Bates [35] both believed that the laterite was formed in pre-Ione time. The evidence from the Buena Vista area showing that the laterite was eroded into the lowest beds of the Ione formation and that the Ione formation rests on laterite in many places agrees with this conclusion. The basal lower Ione beds in holes 7-1 and 18-2 are highly colored by iron oxides and the thermal analyses give Type Ia (tending toward Type II) curves which would suggest strongly that laterite was a source of part of the material in the beds. On the other hand, the pre-Ione Eocene (?) sediments (which are more fully discussed in a following section) give no suggestion of intense tropical weathering, as they have a higher percentage of fresh feldspar, contain micas and chlorite, and give Type II and III thermal curves. Only at its contact with the Ione formation in hole 18-1 does there appear to have been weathering of the upper several feet of the pre-Ione Tertiary after deposition. In hole 7-1, where it overlies greenstone, the greenstone is weathered but not in a manner which suggests laterization. Apparently the pre-Ione Eocene (?) sediments were derived from a source where mechanical weathering predominated over chemical weathering. This helps show that the laterite formed after the pre-Ione Eocene (?) was deposited and before the basal lower Ione at Buena Vista was deposited because the formation of laterite does not normally take place where erosion is rapid; on the contrary, the presence of laterite implies a long period of surface stability with little erosion or deposition.

Mariposa Slate

The Mariposa slate is predominantly black slate with lenses of sandstone and conglomerate, and characteristically contains no interbedded volcanics. The Amador group grades upward into the Mariposa slate in most places and

[31] Taliaferro, N. L., op. cit., p. 284.
[32] Krumbein, W. C., and Sloss, L. L., Stratigraphy and sedimentation, pp. 150-151, San Francisco, W. H. Freeman and Company, 1951.
[33] Bates, T. F., op. cit., p. 15.
[34] Allen, V. T., op. cit., p. 391.
[35] Bates, T. F., op. cit., p. 27.

the contact marks the end of the Jurassic volcanism. The Mariposa slate in adjacent areas usually occurs intricately folded in synclines. No Mariposa slate crops out in the Buena Vista area but it was found at the bottom of hole 18-3. Although it was weathered to pink to greenish-gray clay, the original slaty cleavage is still apparent. The degree of weathering is not that of complete tropical weathering such as the weathering which has altered the Mariposa elsewhere in the Ione area. At Irish Hill, about 3 miles northwest of the town of Ione, for example, the Mariposa slate has been completely weathered to very white clay.

Differential thermal analyses were made on four samples of weathered Mariposa slate from the bottom of hole 18-3, one sample of fresh black Mariposa slate from Chili Bar in El Dorado County, and a sample of white residual clay derived from Mariposa slate at Irish Hill, near the town of Ione. Although the curve for the fresh slate showed a little carbon and possibly some chlorite, it showed no clay minerals. The Irish Hill clay gave a Type II (tending toward IIa) curve. The curves for the Buena Vista area samples were intermediate between Types III and IIIa. It is significant that the Irish Hill clay is apparently at the end point for weathering of the type that acted on the pre-Ione surface, and yet gives a poor Type II curve. This suggests that the weathered products of the Mariposa slate did not contribute significantly to the Cheney Hill and Edwin clays of the Ione formation.

Tertiary System

Eocene (?) Pre-Ione Beds

In the lower parts of several of the Buena Vista drill holes, the drilling passed through sediments with lithologic characteristics of the lower Ione member and into sands and shales showing no evidence of intense weathering except near their contact. These beds are distinguished from the lower Ione member by the presence of biotite, chlorite, and clays of Type III. These beds appear to be present along the northeast side and bottom of the Buena Vista Basin as indicated by holes 7-1, 13-1, 13-2, 18-1, 18-2, and 19-1. In none of the holes were they encountered at a depth of less than 231 feet. Geologic mapping in other parts of the Ione region has not yet revealed outcrops of any rocks which appear to be part of these beds.

Typical sections of the pre-Ione Eocene (?) were those in hole 7-1 from 231 feet 4 inches to 259 feet 6 inches, in hole 18-1 from 311 feet to 375 feet, and in hole 18-2 from 235 feet to 254 feet. These sections are given in the appendix. The section in hole 7-1 represents the full thickness at that point but the sections in holes 18-1 and 18-2 were not drilled to bedrock, and at the contact with the lower Ione member in hole 18-1 the top of the pre-Ione Eocene (?) is not definite.

Silty clay is the predominant rock, with beds of sandy clay, sandy silt, and clay. Conglomerate composes less than 10 percent of the beds. The colors of the sediments are largely grays and greens, but a few yellow, brown, and red beds were present in the weathered section in hole 18-1. Almost the entire section in hole 7-1 is highly carbonaceous but very little carbonaceous matter was seen in any of the other holes. In the center of the basin the sediments all range from green to white, except in the weathered zone.

The ratio of feldspar grains to quartz grains is three to four times greater than was found in the lower Ione sand, which would indicate less severe weathering or more rapid erosion of the source rocks than occurred during Ione time. Chlorite, biotite, and muscovite were also common detrital minerals in the samples checked.

In spite of the rapid lateral and vertical variation in appearance of the sediments of the pre-Ione Eocene (?) the clay minerals show a remarkable similarity. Thirteen differential thermal analyses were run and all gave kaolinitic curves of Types IIa and III. Of the four curves that were Type IIa, three were approaching Type III. This similarity was not only very useful in correlation but also shows the lack of development of clays of Types I and II and would indicate mild weathering due to climatic conditions or rapid erosion before extensive weathering could take place. The results of one differential thermal analysis suggested the presence of some montmorillonite-type clay in a bed of very dense tough green siltstone in hole 19-1; however, kaolinite was also present and gave a Type III curve.

The 28-foot 2-inch section in hole 7-1 was the only thickness of the pre-Ione Eocene (?) sediments that was measurable from its lower contact with bedrock to its upper contact with the Ione formation; however, this section is on the side of the basin and the surface may have been eroded an unknown amount. The thickest section is apparently in hole 19-1, from the questionable upper contact at a depth of 265 feet (12 feet above sea level) to the point where the drilling was stopped at a depth of 396 feet (119 feet below sea level), a total of 131 feet.

The base of the pre-Ione Eocene (?) sediments rests with a very low dip on weathered greenstone in hole 7-1 but was apparently not reached in any of the other drill holes in the area. It probably rests on greenstone and Mariposa slate everywhere in the deeper parts of the basin unless some older post-Jurassic formation exists below it.

An unconformity between the pre-Ione Eocene (?) sediments and the lower Ione is indicated at several places along the contact. In hole 18-1 the upper 12 feet of the pre-Ione Eocene (?) sediments are highly weathered, but in hole 18-2 there is only a very thin weathered zone at the top, and in hole 7-1 there is none. Weathering of this type, suggesting the beginning of laterization, would indicate a period of time with neither deposition nor erosion. Weathering would be either general or else more active on the higher slopes which were more exposed to alternate moisture and relative dryness. The absence of a highly weathered zone in hole 7-1 indicates that there may have been subsequent erosion before the overlap of the Ione sediments. Although the sediments of the pre-Ione Eocene (?) were not derived from a source undergoing intense laterite-forming weathering, the laterite was present at the beginning of Ione deposition. The laterite served as a source of material for the basal beds of the lower Ione, and required an interval between the pre-Ione Eocene (?) and lower Ione deposition for development.

The pre-Ione Eocene (?) beds cannot be correlated definitely with any other geologic unit on the basis of our present knowledge. However, the Ione formation is underlain in many other areas by units which bear a lithologic resemblance to the pre-Ione Eocene (?) beds of the Buena Vista area. Piper [36] states that "wherever the Ione formation crops out in the Mokelumne area it rests directly upon the pre-Cretaceous crystalline rocks. In a few deep wells, however, and in outcrops at several districts in central California it appears to be underlain by gray micaceous shale and sand that constitute a distinct stratigraphic unit."

The nearest point to the Buena Vista area that Piper refers to is the well he calls Well 4712A1 (Allen's Clements well) which went through a sedimentary bed at a depth of 1779 to 1975 feet, just below the Ione. This bed was "chiefly dark gray to brown shale and gray sand, mostly fine, contained many fossils, and included carbonaceous streaks or flakes." [37]

Stewart [38] describes the "Dry Creek" sandstone member of the Ione formation at Sutter Buttes as "a silty, micaceous, fine sandstone with plant remains and massive fossils. . . ."

Allen [39] discusses the gray Walkup clays, below the Ione formation at Lincoln, and "the Dry Creek formation" at Oroville Table Mountain, composed of gray shales overlain by biotite sandstone. The age of the Walkup clay,[40] the Marysville formation,[41] the "Dry Creek" sandstone member of the Ione,[42] and the gray shale under the Ione in the Clements well [42a] have been considered middle Eocene. Paleontologic examination of a suite of samples of pre-Ione sediments by Standard Oil Company of California showed them to be barren of microfauna.[42b]

No definite correlation between these middle Eocene formations and the pre-Ione Eocene (?) beds of the Buena Vista area can be made as no fossils were found in the latter but we believe that the stratigraphic and lithologic evidence is sufficient to consider the beds tentatively to be Eocene.

Eocene Ione Formation

The Ione was originally named by Lindgren,[43] and the type area around the town of Ione, including the Buena Vista area, was described by Turner,[44] who distinguished three divisions in the formation. From oldest to youngest they were:

1. White clay, some portions sandy, containing lignite.
2. Sandstone, passing into conglomerate in places. Usually white but red in one place.
3. Clay rock.

Allen [45] restricted the name Ione formation to the beds along the foothills of the Sierra Nevada that have a mineral composition and history similar to the lower two members of the formation at the type locality. The beds are shown as Euc on the geologic map of California.[46]

FIGURE 12. Woolford clay pit. White area in right center is Cheney Hill clay. Overburden is white, buff, and brown sandstone and conglomerate. The pit is now idle.

During the work on the Buena Vista area the geologic mapping, the study of drill cores and thin sections, and the ceramic tests showed that there are two major mappable units, separated by an unconformity and lithologic differences, in the Ione formation as described by Allen. These two units are defined as members. The upper and lower boundaries of the Ione formation remain the same as the boundaries of the Ione formation defined by Allen.

Lower Ione Member. The older of the two units in the Ione formation is characterized by a high proportion of quartz to feldspar, and clay minerals that give differential thermal curves of Types I, Ia, II, and IIa; and by the absence or rarity of biotite, chlorite, and clay minerals that give differential thermal curves of Types III, IIIa, or IIIb.

It is proposed that the name "lower Ione" member be used for the lower unit of the Ione formation.

The lower Ione member crops out over large areas north of Jackson Valley, but continuous sections are not found in most places and whatever sections are measurable usually yield data on relatively short stratigraphic sections only. The most complete and typical sections available are those shown in the drill-hole logs published with this paper. Lateral variation prevents any section from bearing more than resemblance to any other section but holes 18-1 and K-10 are together considered to give the longest and most representative section of the lower Ione. The type section of the lower Ione member was chosen as the intervals from 10 feet to 42½ feet in hole K-10 and from 109 feet to 311 feet in hole 18-1. The lignite at the bottom of hole K-10 is believed to be the same lignite as the one at 109 feet in hole 18-1 and the type section therefore represents a thickness of 234 feet of lower Ione sediments.

In the Buena Vista area there are three recognizable units or lentils in the lower Ione. These are a lower lentil which consists predominantly of clayey sand, in many places colored gray by carbonaceous matter but containing only a few very thin partings of lignite; an intermediate lentil which is made up largely of clay and lignite with minor amounts of clayey sand and containing three distinct lignite beds; and an upper lentil of clayey sand and sandy clay locally called the Ione sand and Cheney Hill clay. The commercial lignite from this area is all in the middle lentil; the Fancher, Woolford, and Kaolin-Fye clay and sand pits are in the upper lentil.

[36] Piper, A. M., op. cit, p. 85.
[37] Ibid.
[38] Stewart, Ralph, Lower Tertiary stratigraphy of Mount Diablo, Marysville Buttes, and west border of Lower Central Valley of California: U. S. Geol. Survey Oil and Gas Prelim. Chart 34, Sheet 2, 1949.
[39] Allen, V. T., op. cit., pp. 364-368.
[40] Ibid., p. 364.
[41] Ibid., p. 366.
[42] Dickerson, R. E., op. cit. 1916, p. 388.
Clark, B. L., op. cit. 1921, p. 125.
Stewart, Ralph, op. cit.
[42a] Allen, V. T., op. cit., pp. 402-403.
[42b] Hastings, D. D., and Stone, Charity M., personal communication, May 1952.
[43] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Sacramento folio (no. 5), p. 3, 1894.
[44] Turner, H. W., op. cit.
[45] Allen, V. T., op. cit., pp. 353-354.
[46] Jenkins, O. P., Geologic map of California: California Div. Mines, scale 1:500,000, 1938.

FIGURE 13. Fancher clay pit. Cheney Hill clay largely hidden by caving. Overburden is brown sandstone of the upper Ione member and Quaternary terrace gravels. Camera bearing northeast.

The mineral assemblage of the lower Ione member is characterized by the absence or rarity of minerals such as biotite, plagioclase, and chlorite that do not persist through intense weathering. There are some muscovite flakes in the lower part of the lower member, however. The three clay types in the lower Ione of the Buena Vista area that have been given names by the local miners are the Edwin clay, Cheney Hill clay, and Ione sand. The Ione sand is a quartz sand with 25 to 80 percent kaolinite and anauxite. The color of the Ione sand ranges from white through brown to red because of iron oxide stains. It crops out in the eastern part of the area and is reported from wells in the central part of the area.[47] Farther west, away from the source of the sediments, is the sandy Cheney Hill clay. The Cheney Hill clay and the Ione sand are apparently in the same stratigraphic position and all gradations are found between the Ione sand of the Kaolin-Fye pit and the Cheney Hill clay of the Fancher pit. The Cheney Hill clay seems to represent a finer-grained phase of the Ione sand farther from the source of sediment supply. Bates[48] points out the similarities between the Edwin and Cheney Hill clays and considers the Edwin a nearly sand-free variety of the Cheney Hill clay. Our work did not bear this out but instead showed the Edwin clay of this area to be in the lower lentil and the Cheney Hill clay to be in the upper lentil of the lower Ione member.

Allen[49] showed that the large pearly flakes of clay mineral, which are almost restricted in California to the Ione formation or its equivalent, are anauxite. Anauxite is present throughout the lower and upper Ione but is especially common in the Ione sand in which it comprises a large proportion of the clay fraction.

Several beds in the lower Ione are colored by iron oxides. Some of the iron was apparently derived from laterite eroded from the greenstone ridge or from greenstone and similar rocks in the higher Sierra Nevada. All along the flanks of the greenstone ridge large quantities of lateritic material have been reworked into the base of the lower Ione, and in many places it is distinguishable from laterite still in place only by the sedimentary sand grains or pebbles in some beds or by non-lateritic beds lower in the section.

A different type of iron-oxide coloring is found at the upper surface of the lower Ione where clays and sands crop out or are overlain by terrace gravels. Commonly at these places there are heavy concentrations of iron oxides as coloring material and as concretions.

A large number of differential thermal analyses were made on samples from all parts of the lower Ione. These showed the differences between the lower Ione and other formations of the area, and the less distinct but nevertheless significant differences between the three lentils of the member.

The lower Ione clay minerals consistently gave Type I and Type II curves and variants of these curves. Only one sample, from near the base of the formation, gave a Type III curve. Clays which gave a Type I curve were common, especially the Edwin and Cheney Hill clays which almost invariably gave Type I curves.

Allen[50] believed that the physical and chemical properties of the Edwin Clay suggested the presence of the clay mineral halloysite. Bates,[51] after detailed study, concluded that the Edwin clay was kaolinite. Differential thermal analyses on several samples of Edwin and Cheney Hill clays from the Buena Vista area showed kaolinite with a tendency toward halloysite.

In the lower Ione the clays are usually Type I on the southwest side of the basin and are, by comparison, a mixture of Types I and II on the northeast side. In several individual beds which were traced through a number of holes the differential thermal analyses approached Type I in the higher parts of the basin and Type IIa in the center of the basin. Similarly, there is a greater thickness of solid, pure lignite toward the margins of the basin than in the center. Clays close beneath lignite generally gave differential thermal analyses approaching Type I more closely than did clays farther below lignite. This apparent relation between lignite and clays approaching Type I suggests that the clays were altered by organic solutions from the overlying lignite after deposition. Evidence in-

[47] Fancher, Jack, personal communication, 1951.
[48] Bates, T. F., op. cit., pp. 25-26.
[49] Allen, V. T., op. cit., pp. 377-378.
[50] Allen, V. T., op. cit., pp. 380-382.
[51] Bates, T. F., op. cit., p. 17.

dicates this alteration of lower Ione sediments was an important factor in producing the present assemblage of clay minerals.

The lower Ione member underlies most of the Buena Vista area except along the crest of the greenstone ridge. It crops out along the flanks of the greenstone ridge and on the north side of Jackson Valley east of the Fancher clay pit. The main outcrop area to the north is entirely in the upper lentil of the lower Ione.

No definite lower Ione beds were found around the base of Buena Vista Peak and the drill-holes there do not seem to have reached it. The Buena Vista coal mine, at an elevation of about 300 feet on the south edge of Jackson Valley, due south of Buena Vista, is reported [52] to have reached gray clay at a vertical depth of 50 feet and lignite at 59½ feet. The gray clay is probably lower Ione and the lignite is certainly lower Ione.

The thickest single section of the lower Ione is in hole 13-2 with an interval of 285 feet between the upper lignite and the apparent contact with the pre-Ione Eocene (?) beds. The upper lentil, which is not represented in hole 13-2, is in places about 130 feet thick, although the measurement of the section is an estimate because of lack of topographic control in some of the area. This would give a total maximum thickness of 415 feet. The thickness of the type section is 234 feet. There is a range of thickness due to thinning along the margins of the basin and to removal of portions of the upper lentil by erosion.

The sediments of the Ione formation have been shown by Lindgren [53] to have originated from the basement rocks of the Sierra Nevada. He was the first to show that the pre-volcanic gravel channels represented the beds of the rivers that had emptied into the Ione sea and pointed out the continuity of the auriferous gravels with the Ione sands and clays. Lindgren [54] traced the major Tertiary pre-volcanic rivers and found that the Tertiary Mokelumne River mouth was about 12 miles north of Buena Vista and the Tertiary Calaveras River mouth was 9 miles to the south. These two large rivers plus many streams, emptying into the sea at intermediate points, probably furnished the Ione sediments now found in the Buena Vista area. One such small stream formed a gravel delta about 3 miles north of the area. Jenkins [55] has illustrated the relationship between the auriferous gravels and the Ione formation. Bates [56] studied quartz grain inclusions in the Cheney Hill and Edwin clays and felt that a large proportion of the quartz grains were from the granitic rocks of the Sierra Nevada.

The lower Ione member rests with an apparent unconformity on the pre-Ione Eocene (?) beds, as noted in the previous section, and underlies the upper Ione member with a definite unconformity. At the Fancher pit coarse brown upper Ione sand with abundant biotite grains unconformably overlies the Cheney Hill clay. The contact is irregular and dips to the south. In several places in the area, such as in the drill holes west of the greenstone ridge, southeast of the Woolford pit, and at the Fancher pit, upper Ione sediments occur in positions that are topographically lower than adjacent or nearby lower Ione beds. The relationship is such as to indicate that the upper Ione beds were deposited on an irregular erosion surface formed on the lower Ione beds.

No direct evidence of the geologic age of the lower Ione was found in the Buena Vista area but the formation can be correlated with Ione exposures in other regions where age determinations are possible.

The mineral analyses given by Allen [57] for Ione formation samples from various points along the east side of the Great Valley indicate that lower Ione lithology is found from Butte County to Madera County. Mineral analyses [58] of the Ione formation at Chalk Bluffs, Nevada County indicate that the beds considered by MacGinitie as Ione are probably the lower Ione member. They are overlain unconformably by pre-volcanic sediments with biotite and a high percentage of feldspar which are probably the upper Ione member.

Stewart [59] considers a formation above the Meganos at Rio Vista and north of Mount Diablo to be questionable Ione.

The Ione formation sediments are largely deltaic or lagoonal and fossils are rare. In the few localities where marine fossils occur, the material is poorly preserved and identifiable specimens are scarce. Fossils from the Ione formation at the Buena Vista stone quarry, about 3 miles southeast of Buena Vista, have been identified by Clark [60] as Meganos (middle Eocene) types. Stewart [61] considers the Meganos as lower Eocene, however, and places the Ione above it in the middle Eocene. MacGinitie,[62] on the basis of work on the fossil flora of the Lower Ione at Chalk Bluffs, correlates the lower Ione with the Capay of the Coast Ranges.

Upper Ione Member. The younger of the two units in the Ione formation is characterized by a generally higher proportion of feldspar to quartz than in the lower Ione and by the presence of biotite, chlorite, and kaolinitic clay minerals that give differential thermal curves of Types II, IIa, III, and IIIb; and by the absence of kaolinitic clay which would give the differential thermal curve of Type I. It is proposed that the name "upper Ione" member be used for the upper unit of the Ione formation.

North of Jackson Creek, the upper Ione member crops out below the terrace gravels on the lower hills west of Buena Vista. The lower slopes of Buena Vista Peak are also composed of upper Ione sediments. Upper Ione was intersected in several of the drill holes along the greenstone ridge. The thickest section of definitely upper Ione beds is on the north slope of Buena Vista Peak but it is so sandy and unconsolidated that surface exposures are rare. Chosen as a type section of the upper Ione, is the section through which hole B. V. 5 was drilled, and extending above the hole to the base of the Valley Springs formation. The vertical distance from the base of the Valley Springs formation at an elevation of about 475 feet, to the bottom of hole B. V. 5 at an elevation of about 312 feet, represents approximately 163 feet of upper Ione

[52] Logan, C. A., Sacramento field division—Amador County: California Min. Bur. Rept. 23, p. 146, 1927.
[53] Lindgren, Waldemar, Tertiary gravels, op. cit., p. 24.
[54] Ibid., plate 1 and fig. 3.
[55] Jenkins, O. P., Geology of placer deposits: California Div. Mines Bull. 135, 2nd ed., fig. 64, p. 176, 1950.
[56] Bates, T. F., op. cit., pp. 28-30.

[57] Allen, V. T., op. cit., p. 375.
[58] MacGinitie, H. D., A middle Eocene flora from the central Sierra Nevada: Carnegie Inst. Washington Pub. 534, pp. 13-23, 1941.
[59] Stewart, Ralph, op. cit.
[60] Clark, B. L., personal communication in Allen, V. T., op. cit., p. 358.
[61] Stewart, Ralph, op. cit.
[62] MacGinitie, H. D., op. cit., pp. 28 and 91.

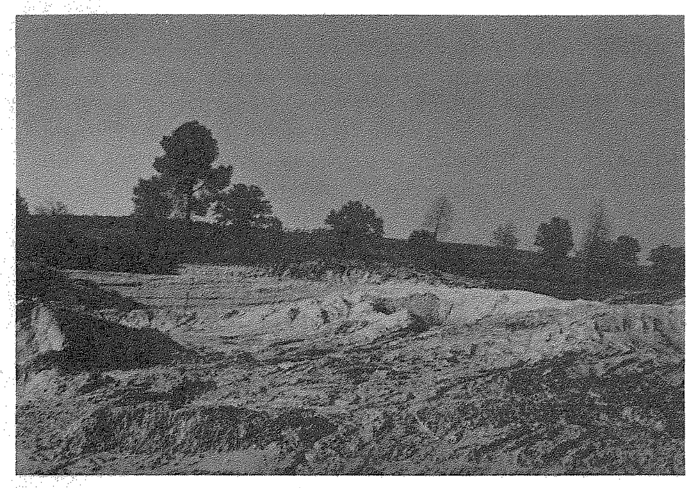

FIGURE 14. Kaolin-Fye sand pit. White Ione sand with overburden of buff Ione sand and Quaternary terrace gravel. Camera bearing north-northwest.

sediments. The hole, however, does not reach the base of the upper Ione member. The upper Ione, below the bottom of hole B. V. 5 has poor surface exposure, and other holes in the vicinity do not give additional information, so these lower beds are not included in the type section.

The upper Ione member is predominantly sand and clayey sand, with a little clay and minor amounts of conglomerate. No lignite is present but some of the clays contain enough carbonaceous material to be chocolate colored. The clays persistently have a greenish color that is rare in the lower Ione.

Biotite was almost universally present in the samples checked, and chlorite was common. Feldspar comprised from 20 to 25 percent of the sand grains and is, therefore, two to three times as abundant as in the lower Ione.

Two lentils in the upper Ione member are persistent over most of the area. One is the hard white or gray sandstone at the top of the formation. This sandstone was referred to by H. W. Turner [63] as the middle member of the Ione formation and by Piper [64] as the upper member of the Ione formation. It crops out on the northwest side of Buena Vista peak, on top of a high hill about 3000 feet east of the Woolford pit, on top of Chitwood Hill, and on a small hill about one-half mile west of Chitwood Hill. The hard sandstone is cross-bedded in places and has a typical upper Ione mineral assemblage except that the clay mineral matrix is largely anauxite in wormlike and fan-shaped aggregates. The other persistent unit is the Chitwood clay that was mined at the Chitwood pit. It also crops out 500 feet southeast of the Fancher Pit and in the canyon on the west side of Buena Vista Peak. It is about 70 percent sand, 30 percent clay, contains no anauxite, and is usually gray in color. The clays and sands between and below these two members are so lenticular that only very tentative correlation could be made between the various drillholes on the north slope of Buena Vista Peak.

[63] Turner, H. W., op. cit.
[64] Piper, A. M., op. cit., p. 80.

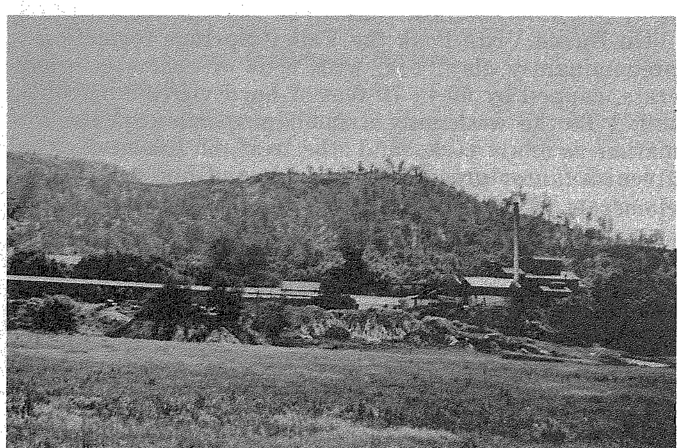

FIGURE 15. Wax-extraction plant for the removal of Montan wax from lignite, operated by American Lignite Products Company. Type section of the upper Ione member is on the hill beyond the plant. Camera bearing south-southwest.

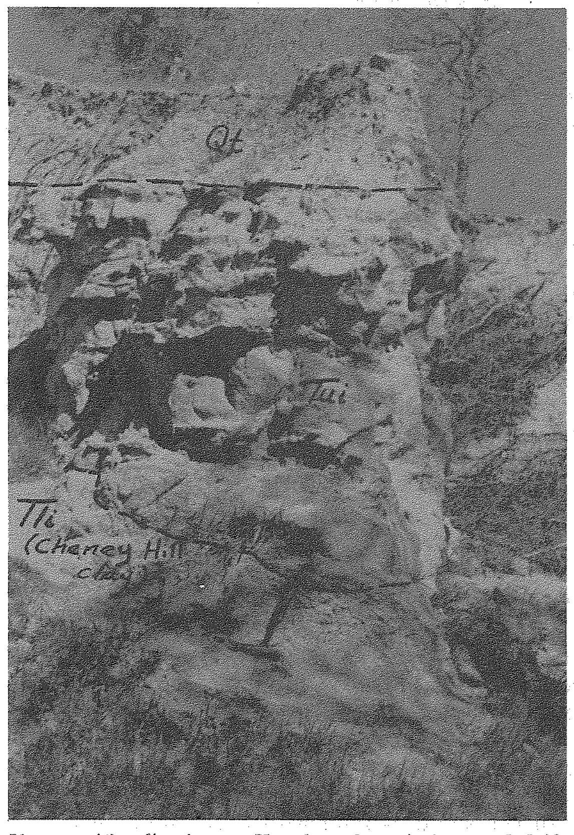

FIGURE 16. Section at Fancher clay pit in caved drift at north end of main face. Cheney Hill clay overlain by brown sandstone of the upper Ione member and Quaternary terrace gravel. The pit is now idle.

A large number of differential thermal analyses were made of samples from various parts of the upper Ione. Differential thermal analyses of upper Ione samples did not approach standard kaolinite closer than Type II (tending toward Ia), and most of the samples gave differential thermal analyses of Types III and IIIb.

A tendency for the differential thermal curves to approach Type I toward the top of the formation was indicated, with the closest approach, Type II curves (tending toward Ia) in the Chitwood clay and the hard sandstone.

This development of the kaolinitic minerals toward kaolinite may be the result of weathering on the upper part of the formation during the interval between the close of the deposition of the upper Ione member and the beginning of the deposition of the Valley Springs formation.

The surface on which the upper Ione member was deposited was irregular, and extensive erosion has taken place since it was deposited. Because of this, the upper Ione member has a large range in thickness throughout the area. In the vicinity of the type section the base of the upper Ione member is not exposed but the shaft of the Buena Vista coal mine, with the collar about 300 feet in elevation, reached lower Ione lignite at a vertical depth of 59½ feet [65] and 9½ feet of gray clay above the lignite is probably also in the lower Ione member. The elevation of 250 feet is then the lowest probable elevation for the base of the upper Ione member. The thickness of the upper Ione member in the vicinity of the type section is thus more than 163 feet and less than 225 feet. At Chitwood Hill the upper Ione beds rise 130 feet above the valley floor with no evidence of lower Ione beds at the base. At the high hill 3000 feet east of the Woolford pit, 70 feet of upper Ione sediments rest on lower Ione beds and in the valley to the southwest there are an additional 50 feet of upper Ione sediments.

The source of the upper Ione sediments was probably the crystalline rocks of the Sierra Nevada. The effects of weathering were not as prominent as in the lower Ione member, either because the climate had become less tropical or because erosion was proceeding too rapidly to allow deep weathering. No marine upper Ione beds were recognized in the area, but there is a hard red sandstone containing marine fossils a mile and a half east, which appears to be the same sandstone that is at the top of the upper Ione type section.

The contact between the upper and lower Ione members is irregular and obviously an unconformity. The maximum differential relief measurable on the erosion surface is about 130 feet in the region east of the Fancher Pit. The upper surface of the upper Ione member was also deeply eroded before the deposition of the Valley Springs formation. In the small canyon west of Buena Vista Peak the base of the Valley Springs formation has a difference in elevation of 85 feet over a distance of 400 feet.

Sands with upper Ione lithology have been described in or above the Ione formation at several points on the east side of the Great Valley and in the Sierra Nevada. Allen [66] described outcrops near Valley Springs and at Knights Ferry as follows:

"One mile west of Valley Springs is a small sandstone quarry. The sandstone contains, in addition to anauxite and quartz, altered biotite and more feldspar than is in the usual Ione sandstone. It probably should receive a separate name, as the mineral assemblage is not typical, but the outcrop is small and hardly warrants it." In describing a section at Knights Ferry, he says [67] "Seventy feet of cross-bedded sandstone forms the upper part of the section. This sandstone contains biotite and about 30 percent of orthoclase, and like the sandstone at Valley Springs probably should have a separate name, but for the same reason a name has not been given."

[65] Logan, C. A., op. cit.
[66] Allen, V. T., op. cit., p. 359.
[67] Ibid.

At Chalk Bluffs, MacGinitie [68] found about 100 feet of "biotite sands" followed by 22 feet of conglomerate overlying sediments with lower Ione lithology and underlying the rhyolite series. He described them as rusty, cross-bedded, quartz-biotite sands with fresh feldspar. He also refers [69] to biotite sands below tuffaceous yellow clay in the Cherokee hydraulic pit at Oroville Table Mountain, Butte County, and correlates them with the biotite sands at Chalk Bluffs.

The lithology and stratigraphic position of the biotite sands at Valley Springs, Knights Ferry, Cherokee, and Chalk Bluffs are the same as the lithology and stratigraphic position of the upper Ione member at Buena Vista and there is no reason to doubt that they may be correlated.

No direct evidence of the age of the upper Ione member was found in the area. However, Allen [70] considered the marine sandstone of the Buena Vista quarry to be part of the upper member of his Ione formation, which is apparently the same as the sandstone at the top of the type section of the upper Ione member. This sandstone contains fossils identified as of middle Eocene age.[71] If this fossil zone is at the top of the upper Ione member then that member is certainly Eocene in part, at least.

Miocene (?) Valley Springs Formation

The Valley Springs formation was defined [72] as rhyolite-containing beds with no fresh andesitic material and as being stratigraphically above the non-volcanic Ione. The type section is an exposure on the west slope of Valley Springs Peak, near Valley Springs, Calaveras County. The lower beds in the Buena Vista area are altered to greenish-buff clay and are the clay rock originally included in the Ione by H. W. Turner.[73] A bed of coarse, erosion-resistant conglomerate, not far above the base of the formation, was originally mapped as part of the Pleistocene shore gravels,[74] but Piper [75] presented evidence for its inclusion in the Valley Springs formation.

Sediments containing fresh rhyolitic material crop out on Buena Vista Peak above an elevation of 400 to 450 feet. A regional dip to the northwest carries the base down to about 250 feet along the crest of the greenstone ridge, and almost all of the hills west of the ridge are composed of Valley Springs sediments.

On Buena Vista Peak the Valley Springs formation is predominantly clay rock, with beds of coarse conglomerate, capped by 60 to 70 feet of hard vitreous rhyolitic tuff.[76] To the west, only a small proportion of the formation is clay rock, and the rest is unconsolidated greenish-tan or greenish-buff sands and one bed of conglomerate. A mesa about 3000 feet long and 1000 feet wide, just east of Buena Vista Peak, is capped by a bed of coarse, hard conglomerate 10 to 20 feet thick. Neither Piper [77] nor we found any Tertiary andesite in this conglomerate, so apparently it is part of the Valley Springs

[68] MacGinitie, H. D., op. cit., p. 14.
[69] Ibid., p. 28.
[70] Allen, V. T., op. cit., pp. 357-358.
[71] Clark, B. L., personal communication in Allen, V. T., op. cit., p. 358.
[72] Piper, A. M., op. cit., pp. 71-72.
[73] Turner, H. W., op. cit.
[74] Ibid.
[75] Piper, A. M., op. cit., pp. 57 and 72.
[76] See Turner, H. W., Further contributions to the geology of the Sierra Nevada: U. S. Geol. Survey 17th Ann. Rept., pt. 1, p. 721, 1896 for a chemical analysis of this rock.
[77] Piper, A. M., op. cit., pp. 57 and 72.

formation and not a Quaternary terrace gravel. Although most of the rhyolitic glass in the lower beds has been devitrified, a few small masses of rhyolite tuff are still glassy. One such rock body crops out on the county road about 700 feet south of hole 24-7.

Only four differential thermal analyses were made of material from the Valley Springs formation. This was not a sufficient number to establish any curve types as characteristic of the formation. Three of the curves were Type III (tending toward IIIa) and one was Type II (tending toward IIa).

In most of the area the thickness of the Valley Springs formation has been reduced by erosion so that only the lower beds are present, but on Buena Vista Peak the base of the Valley Springs formation ranges in elevation from 390 feet to 475 feet and the top of the highest bed is 848 feet. The maximum thickness is therefore about 458 feet. The range of 85 feet in the elevation of the base in a small area indicates differential erosion during the interval between Ione and Valley Springs sedimentations, and the presence of an unconformity.

The source of the rhyolite was considered by H. W. Turner [78] to lie to the east in the higher parts of the Sierra Nevada; Piper [79] traced the source from the higher Sierra Nevada by way of channels that followed the valley of Lindgren's Tertiary Calaveras River.[80] These channels emptied into a basin at the present position of Valley Springs and the sediments spread out north and south. The Buena Vista area was on the northeastern edge of the area of original deposition as outlined by Piper.

Gale [81] "... feels that (the Valley Springs formation) may be correlated tentatively with deposits of somewhat similar composition that extend across the California Trough into the Coast Ranges. Thus, although coincidence has not been proved, it seems likely that the well known marine Salinas shale of the Monterey group in the Coast Ranges is not only derived from the siliceous rocks and products of this epoch but throughout a wide area in the Pacific Border province actually includes tuffs that represent the epoch of rhyolite volcanism."

MacGinitie,[82] on a basis of fossil flora, correlates the Valley Springs with the San Pablo formation, and says it is uppermost Miocene or possibly lower Pliocene.

Quaternary System

Terrace Deposits

Coarse-grained conglomerate cemented by clay, rests on the tops and flanks of most of the hills north and northwest of Buena Vista and on some of the lower hills south of Jackson Creek. The cobbles in the conglomerate are very well rounded and are as much as 12 inches in diameter. Most of the cobbles are siliceous metamorphic rocks of the type present in the Calaveras formation, but some are white vein quartz or, rarely, Tertiary andesite. The matrix is usually greenish-brown to red-brown sandy clay. The terrace gravels contain gold and have been extensively mined wherever water was available.

[78] Turner, H. W., The rocks of the Sierra Nevada: U. S. Geol. Survey 14th Ann. Rept., pt. 2, p. 485, 1894.
[79] Piper, A. M., op. cit., pl. 5.
[80] Lindgren, Waldemar, The Tertiary gravels of the Sierra Nevada of California: U. S. Geol. Survey Prof. Paper 73, pl. 1, 1911.
[81] Gale, H. S., in Piper, A. M., op. cit., pp. 79-86.
[82] MacGinitie, H. D., op. cit., p. 28.

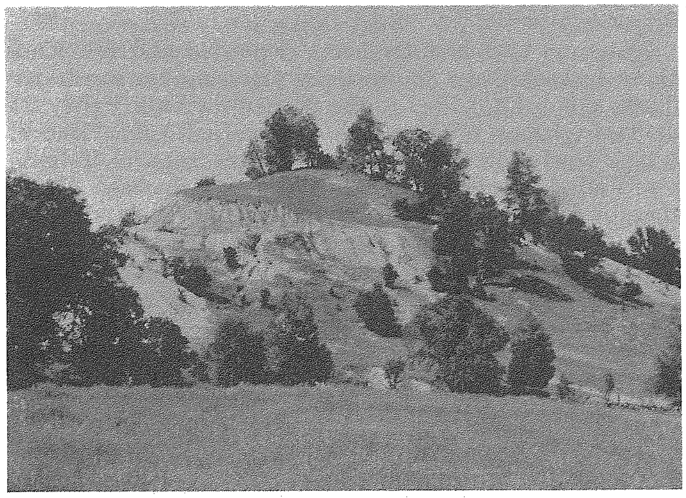

FIGURE 17. Chitwood clay pit and Chitwood Hill. Entire hill is composed of upper Ione sediments. The hard sandstone at the top of the member is on the top of the hill. Pit is now idle. Camera bearing northeast.

The conglomerates are a thin veneer on terraces whose heights range from a few feet above the level of Jackson Valley to over 400 feet to the north and on the flanks of Buena Vista Peak. Measured thicknesses ranged from 1 foot to 18 feet. A much greater thickness was indicated in many places by the mapping but this was usually the result of sliding and creeping of the gravel down over lower beds and of the complete covering and masking of a number of terraces arranged in step-pattern on hillsides.

The area is in what Piper [83] calls the Arroyo Seco dissected pediment. The pediment was eroded to approximately its present form during the Victor epoch. The terrace deposits of the area are not high enough, in most places, to have rested on the original surface of the pediment nor are they low enough to be correlated with the Victor formation which, in this area, is at the level of the floor of Jackson Valley. They were probably formed during the Victor epoch by the rivers which dissected this portion of the Arroyo Seco pediment.

[83] Piper, A. M., op. cit., pp. 21-22, 28-29.

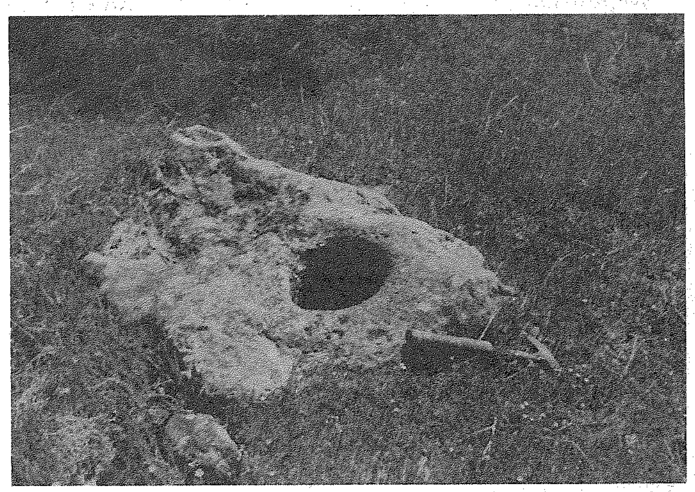

FIGURE 18. Chitwood clay south of Fancher pit. The clay is hard enough to have been used by Indians for grinding nuts and seeds.

Recent Alluvium

Alluvium is constantly being deposited and reworked along Jackson Creek and its tributaries, and during major floods it is being added to the floor of Jackson Valley. It is thin over most of the area but, from drill hole evidence, it may reach a thickness of 25 to 50 feet in parts of Jackson Valley. At Buena Vista Bridge on Jackson Creek there is 5 feet to 10 feet of dark red-brown clayey alluvium immediately below the surface followed by 4 feet to 10 feet of auriferous red or green sandy or clayey conglomerate with cobbles up to 6 inches in diameter. The conglomerate is like the present stream gravel and is cross-bedded and channeled. There is little organic matter compared to the soil above.

GEOLOGIC HISTORY

The oldest rocks that crop out in the area are the metamorphosed andesites and associated rocks of the Amador group, which were deposited during the Upper Jurassic on the already folded and metamorphosed sediments of the Paleozoic Calaveras formation. At the close of the Amador volcanism, sedimentation continued, forming the Mariposa slate. These formations were folded in Upper Jurassic[84] time to form the ancestral Sierra Nevada. Metamorphism took place during the folding and during the subsequent batholithic intrusion. Erosion gradually reduced the height of the mountains and furnished sediments for Jurassic, Cretaceous, and early Tertiary beds to the west. By Eocene time the mountains were low but the rivers had sufficient gradient to carry cobbles and boulders; and, even in the Buena Vista area, there was a relief of several hundred feet at the beginning of pre-Ione Eocene (?) sedimentation.

At the beginning of Ione time conditions changed in such a way that the sediments carried to the foot of the mountains became highly weathered. In discussing the reason for the change MacGinitie [85] presented evidence to show that the weathering took place during transportation and suggested that a rise in base level may have been the main cause. However, the evidence presented earlier in this paper concerning the development of the laterite and its relation to the sediments of the pre-Ione Eocene (?) and lower Ione suggests that there was a change to a more tropical climate after pre-Ione Eocene (?) time.

Deposition of the Ione-type sediments continued with minor interruptions until the major period of erosion that closed Ione time. Upper Ione sediments do not show as great a degree of weathering as do lower Ione sediments. This may have been due to a change to more temperate climate or to a change in the conditions of erosion.

During the Tertiary the Sierra Nevada began to rise and as a result the gradient of the southwestward flowing rivers was increased. The first slight Tertiary uplift of the Sierra Nevada may have come at the end of Ione time. Valley Springs deposition began with the eruption of rhyolite in the higher parts of Sierra Nevada. At the close of the rhyolite period, or possibly simultaneously with the last of the rhyolite eruptions, andesitic eruptions began in the east which resulted in a series of mud flows down the west slope of the mountains. The Buena Vista area was flooded with andesite breccia and conglomerate until the surface reached an elevation of about 800 feet.[86]

[84] Taliaferro, N. L., op. cit., p. 285.
[85] MacGinitie, H. D., op. cit., pp. 17, 25-26.
[86] Piper, A. M., op. cit., pl. 4.

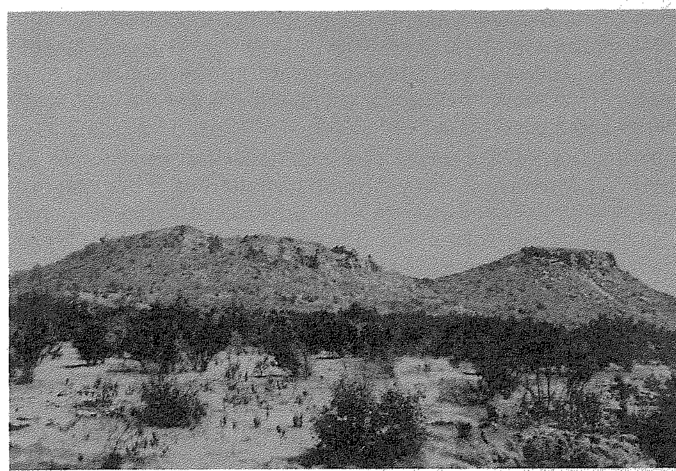

FIGURE 19. Buena Vista Buttes. Foreground is flat top of mesa held up by hard conglomerate in Valley Springs formation. Camera bearing east.

The present drainage pattern of the Sierra Nevada began to evolve in late (?) Miocene or possibly early Pliocene time with the cessation of the andesite mud flows and the initiation of consequent stream patterns on the Mehrten surface.[87] The land forms of the Buena Vista area were the result of the late Pleistocene dissection of part of the Arroyo Seco pediment. Erosion was accelerated during these periods by further elevation of the mountains. Lindgren [88] and Matthes [89] said that the major elevation of the Sierra Nevada took place in the Pleistocene, and estimated that the elevation of the crest of the range was increased by 6000 feet at that time.

ECONOMIC GEOLOGY

Clay

The present production of clay in the area is limited to a deposit of the Ione sand with a low iron content for use in the manufacture of white portland cement. Clay deposits occur in the area, however, that would furnish raw material for the manufacture of refractories and white-wares and for use as fillers in rubber and paper. Because there is a critical need for clays with high deformation temperatures for the manufacture of refractories, the investigation of deformation temperatures was emphasized in the study of the clays in the area.

Technical Data on Refractory Clays. Pyrometric cone equivalent (P. C. E.) is used as a measure of refractoriness of clays and fireclay refractories. The industry adheres to the following classification for fireclay brick on the basis of refractoriness:

super duty—equal to or more than P.C.E. 33, greater than 1745° C. or 3173° F. at a temperature increase of 100° C. per hour.

high heat duty—P.C.E. 31-32, greater than 1680° C. or 3056° F. at a temperature increase of 100° C. per hour.

medium heat duty—P.C.E. 29-30, greater than 1640° C. or 2984° F. at a temperature increase of 100° C. per hour.

low heat duty—P.C.E. 19-28, greater than 1515° C. or 2759° F. at a temperature increase of 100° C. per hour.

[87] Ibid., pp. 24-25.
[88] Lindgren, Waldemar, The Tertiary gravels of the Sierra Nevada of California: U. S. Geol. Survey Prof. Paper 73, pp. 46-48, 1911.
[89] Matthes, F. E., Geologic history of the Yosemite Valley: U. S. Geol. Survey Prof. Paper 160, pp. 43-44, 1930.

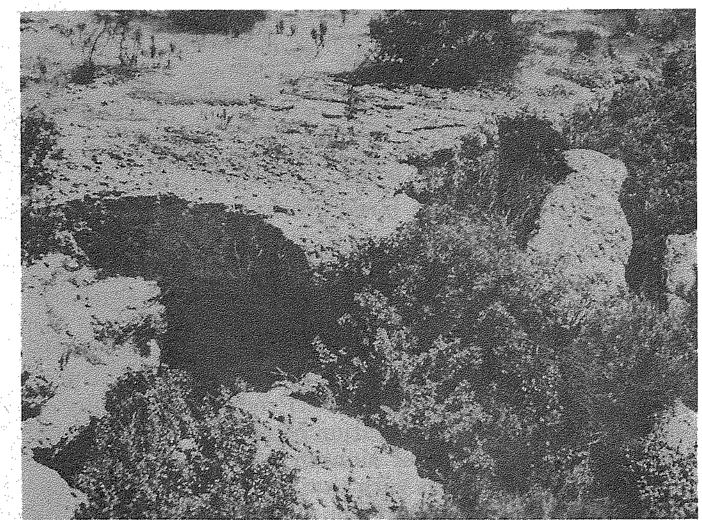

FIGURE 20. South side of mesa shown in figure 19. Overhang of hard conglomerate caused by erosion of soft clay and sandstone below.

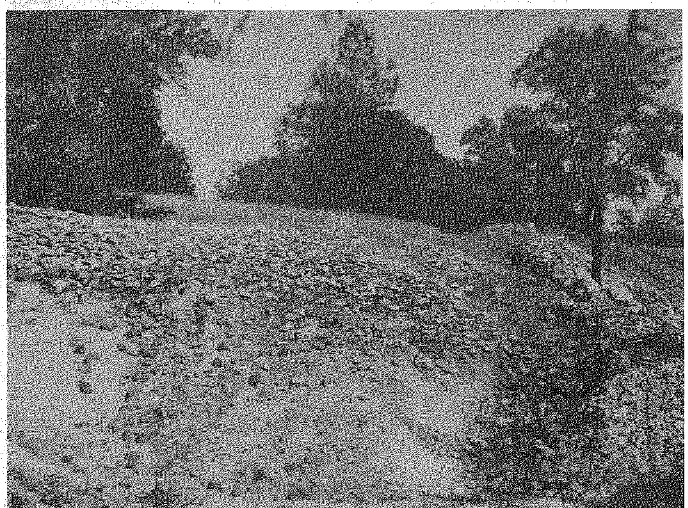

FIGURE 21. Terrace gravel resting on Cheney Hill clay in old gold-placer workings about 1000 feet northeast of Buena Vista. Camera bearing east.

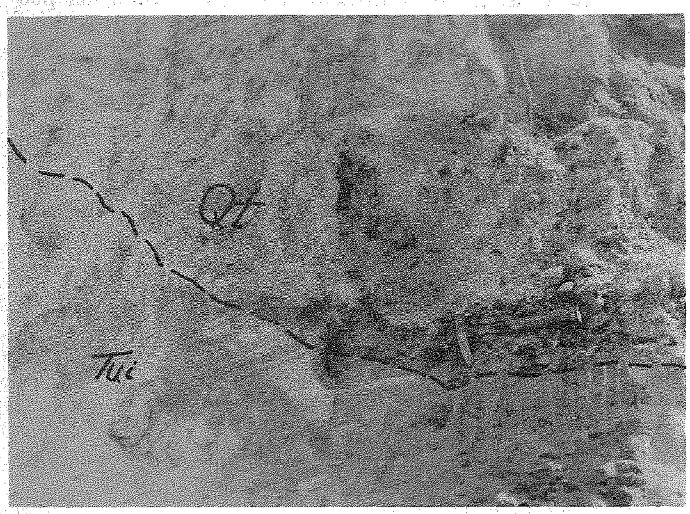

FIGURE 22. Channel cut into upper Ione brown sandstone, filled with terrace gravel. East face of Fancher pit.

When equipment is not available for determination of the P.C.E., especially at the high heat and super duty temperature levels, a knowledge of the relationship of P.C.E. to other properties may be of considerable value. In this study the possible relationships between P.C.E., fired color, and the type of kaolinitic curve, as determined by the differential thermal analyzer, were explored.

The data for 49 clays are listed in table 2 and plotted as fired color versus P.C.E. in figure 24. Sufficient correlation exists to enable the estimation of the probable P.C.E. range for a given clay where fired color and the differential thermal analysis are known. On this basis the following grouping can be used as a guide:

Clay	P. C. E.
Reflectance of 60%-100% for green filter *	
Type I	31-35
Type I modified	26-32
Type II	28-33
Type II modified	23-30
Type III	no examples
Reflectance of 30%-60% for green filter	
Type I	20-28
Type II	15-28
Type III	15-23
Reflectance of 0%-30% for green filter	
Types I, II, III	< 19

* In general, the high reflectance values correspond to white or very light tints or shades, usually of cream, buff, tan, and pink; the lower values to deeper colors.

A more specific classification is not possible with the present available knowledge of the structure and composition of the clays. The marked dependence of refractoriness on color is due to the fact that the iron oxide responsible for the color is also a flux, an especially strong one if present in the form of ferrous compounds.

An important conclusion is that the only clays suitable for super duty are kaolinites with unmodified or halloysite-tending Type I curves and with fired color (1000° C.) reflectance values greater than 60 percent for green filter as measured with a reflectometer type of instrument.

Clay Production. Four clay pits are in the area. Three, the Woolford, Fancher, and Kaolin-Fye pits, are in the upper lentil of the lower Ione member, and the other, the Chitwood pit, is in the Chitwood clay of the upper Ione member. The Fancher pit has been described by Dietrich [90] for the period during which it was operated by W. S. Dickey Clay Manufacturing Company. Until 1927 the operations were entirely open pit but in that year tunneling was started in order to get under a thick overburden. The clay production was from Cheney Hill clay which had a P.C.E. of 33 to 34.[91] The Woolford pit is also in Cheney Hill clay. At the Woolford locality the Cheney Hill clay has a P.C.E. of 31 to 33.[92] The Kaolin-Fye pit is operated by the Calaveras Cement Company and supplies a mixture of nearly iron-free clay and quartz sand for the manufacture of white portland cement. Work on the pit was first begun in January 1950. The Chitwood pit was worked as a source of the upper Ione Chitwood clay. The clay is very sandy and has a P.C.E. of 30 to 31.[93]

[90] Dietrich, W. F., The clay resources and the ceramic industry of California: California Div. Mines and Mining Bull. 99, pp. 58-59, 1928.
[91] Ibid., p. 280.
Bates, T. F., op. cit., p. 24.
[92] Ibid.
[93] Ibid.

FIGURE 23. Old gold-placer workings in alluvium just east of Fancher pit. Camera bearing east.

Table 2. Differential thermal analysis, pyrometric cone equivalent, and fired color for samples of clay from the Buena Vista area and of commercial clays from near the town of Ione.

Hole no.	Depth	D.T.A. type	P.C.E.	Photometer data (Clay calcined to 1,000° C.) Filter color		
				Green	Amber	Blue
18–1	126′ -129′	Ia	31+	70.5	76.0	55.0
	132′ -138′	I→Ia	33½	77.0	82.0	62.5
	139′ -143′	II	31+	72.0	77.0	56.0
	149′ -151′	IIa	23	70.5	74.5	52.5
	155′ -155′7″	I	33	81.0	85.0	66.0
	177′1″	II→Ia	33—	65.5	75.0	--------
	192′ -193′6″	II	20–23	39.0	48.0	31.5
	217′ -229′	Ia	31½	75.0	79.5	62.0
	242′3″–246′	II	31½	77.0	83.0	64.0
	250′	II	26	34.5	51.0	--------
	265′9″–269′	Ir	26	51.0	58.0	42.5
	324′ -325′	III	19—	47.0	55.0	35.5
	326′ -329′	III	19+	48.5	56.5	36.5
	329′ -334′	III	18½	51.5	60.0	35.0
	334′ -338′	III	18½	49.5	58.0	32.0
	366′	III	16	43.0	55.5	--------
18–2	69′	II	31—	73.0	78.5	--------
	83′	II	31—	70.0	75.5	--------
	100′	IIr	23	69.0	73.0	--------
	159′	Ir	31—	83.0	86.5	--------
	225′	Ia→II	26	47.0	61.0	--------
	253′	IIa→III	20+	48.0	60.5	27.0
18–3	168′	II→Ia	28	61.0	70.0	46.0
	216′	Ia	26	66.0	75.0	46.0
	256′	? (carbon)	14⅓	21.5	31.0	11.5
	274′ -277′4″	III	23—	50.5	65.5	24.5
	287′	III	16	40.0	52.0	18.0
24–2	164′6″	Ih	31½	67.5	76.0	56.0
24–3	36′6″	III→IIIb	15½	49.0	60.0	24.0
	103′	III	19	54.0	61.0	35.5
	125′6″	Ih	33+	69.0	74.0	58.0
	137′	Ih	34+	72.0	77.5	62.0
	202′	Ih	17+	19.0	28.0	7.0
13–1	289′	I	23—	31.0	39.5	23.0
	304′	IIa	14	18.0	25.0	9.0
7–1	40′	II	33—	74.0	79.0	--------
	57′	I	33	81.0	84.5	--------
	82′6″	Ir	26	47.5	63.0	--------
	169′	Ir	26	80.5	84.0	--------
	221′	II→Ia	15	40.0	48.5	--------
No. 1*	--------------	Ih	33—	81.0	85.0	--------
No. 2*	--------------	I→Ia	31½	74.0	79.5	--------
No. 3*	--------------	Ih	34	77.5	81.5	--------
No. 4*	--------------	I→Ia	33	74.5	80.0	--------
No. 5*	--------------	Ir	30½	83.5	86.5	--------
No. 6*	--------------	I	34+	70.0	77.0	--------
No. 7*	--------------	Ih	34	63.0	73.0	--------
No. 8*	--------------	IIr	30	82.5	86.0	--------
No. 9*	--------------	II→Ia	20	29.5	46.5	--------

* Samples no. 1 to no. 9 are typical commercial clays from the lower Ione member in the vicinity of the town of Ione.

No Edwin clay has been mined in the area, but the geologic mapping and the study of the drill cores revealed the presence of Edwin clay at the surface and at depth along both sides of the greenstone ridge south of Jackson Creek. In every place where the Edwin clay is found, it rests directly on sedimentary laterite. The largest outcrop area of Edwin clay is in a stream bed immediately east of the large greenstone outcrop south of Jackson Valley.

Other Minerals

Lignite, gold, and building stone have been produced in the area in the past. Lignite was mined from the middle member of the lower Ione for many years at the Buena Vista coal mine, about a mile south of Buena Vista.[94] The American Lignite Products Company is operating a plant at the location of the Buena Vista coal mine for the extraction of Montan wax from lignite. The plant started operations with raw material from the same area but now uses lignite from near Ione. Gold was discovered in the area in 1854 or 1855,[95] and in 1856 a 15-mile ditch was built to supply water for placer mining. These operations continued until at least 1880 [96] and covered most of the slopes and gulches that are below deposits of terrace gravel. The latest gold production was from dredge operations in the upper end of Jackson Valley.

Stone was quarried from the hard sandstone member of the upper Ione, probably for local construction of buildings and fences. The quarries still in evidence are at the tops of Chitwood Hill and the hill 3000 feet east of Woolford pit, and on the side of Buena Vista Peak. Hard rhyolite tuff at the top of Buena Vista Peak has also been quarried.

VALUE OF CERAMIC TESTS IN GEOLOGIC INVESTIGATION

Each of the ceramic techniques employed in this study was valuable in helping to interpret the geology and mineralogy of the area and to indicate the economic value of the clays. It is apparent that these techniques would have many applications in other geologic studies as well as in the search for clays useful in industry.

Clay mineralogy is complicated by the numerous possible isomorphous substitutions and, for that reason, a breakdown of the kaolinite group minerals into a number of types, as presented here, would be extremely difficult based only on microscopic and X-ray diffraction analyses. In contrast, the interpretation of a series of differential thermal curves was relatively simple. It is therefore a powerful aid in indicating the presence of minor variations in structure. Differential thermal analyses aid greatly in the identification and determination of formations and strata and in correlating them from hole to hole. The determination of the type of clay resulting from the weathering of certain rock types provides valuable information for the interpretation of geologic his-

[94] Tucker, W. B., Amador County: California Min. Bur. Rept. 14, p. 11, 1915.
Logan, C. A., Auburn field division—Amador County: California Min. Bur. Rept. 17, p. 413, 1921.
Logan, C. A., Sacramento field division—Amador County: California Min. Bur. Rept. 23, pp. 146-147, 1927.
Allen, V. T., op. cit., pp. 408-409.
Piper, A. M., op. cit., pp. 82-83.
[95] Mason, J. D., op. cit., p. 265.
[96] Stretch, R. H., A report on the Amador Canal and Mining Company, p. 27, San Francisco, 1880.

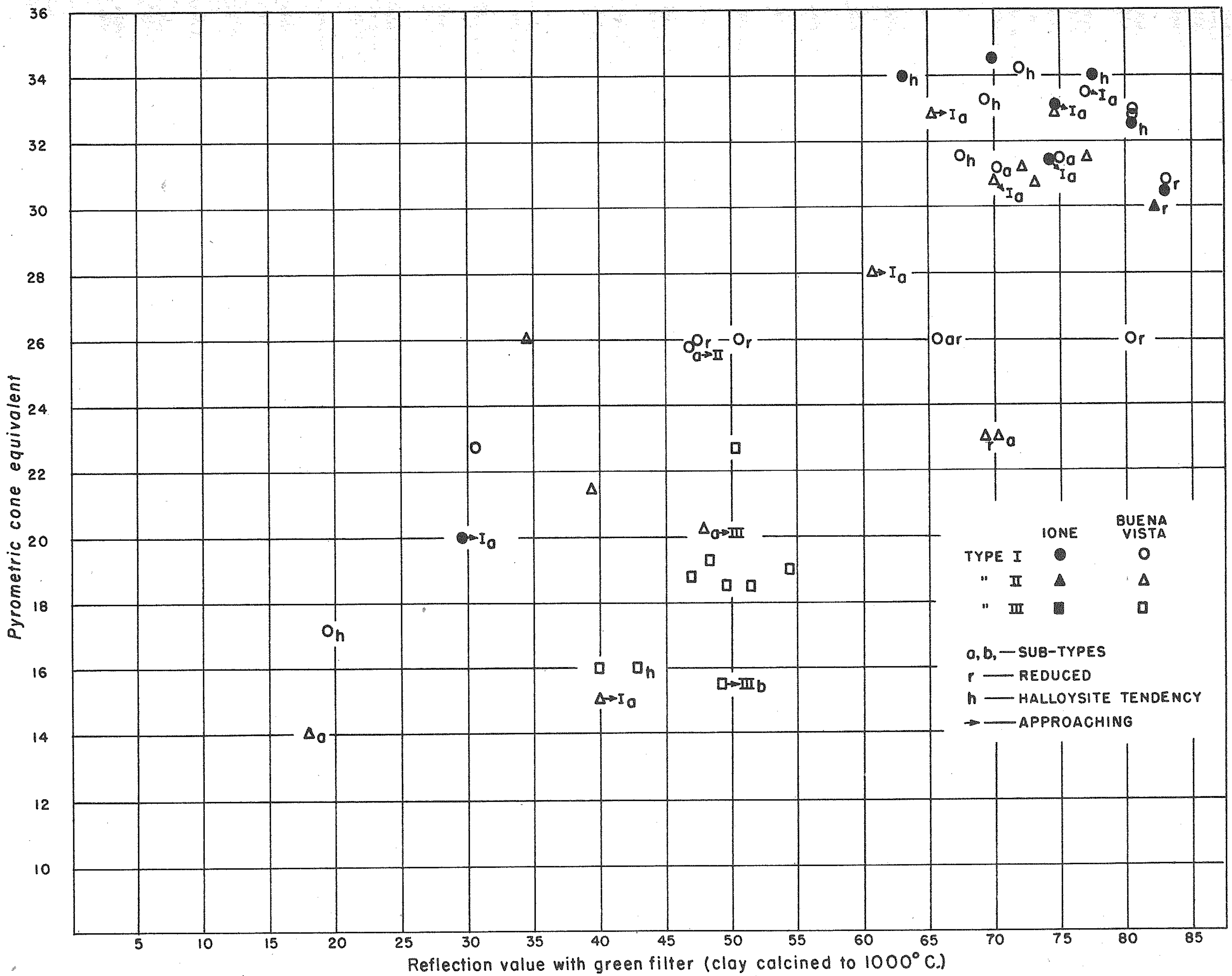

Figure 24. Relation between differential thermal analysis, fired color, and pyrometric cone equivalent for Buena Vista area clay and commercially produced clay from the Ione Valley.

tory. The fact that Type I kaolinitic clay results from the weathering of greenstone and Types II and III kaolinitic clays are a product of the weathering of Mariposa slate is indicative of sources of sedimentary clays of these types. It is of economic value to know that only clays of Type I, with very light shades of color (approaching white) are known sources of super duty clays. It is therefore indicated that the lower Ione member is probably the only commercial source of super duty clays in the Buena Vista area.

An indirect value of the differential thermal analyzer is the relative simplicity of the apparatus and the ease with which curves can be obtained by untrained operators, in contrast with the amount of training necessary to undertake petrographic and X-ray diffraction analyses and the time required for P.C.E. determinations.

It is hoped that the paper has shown the value of ceramic tests in the interpretation of geology, and that they should be considered as an aid in geologic studies, particularly of sedimentary areas.

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APPENDIX

Record of drill holes in the Buena Vista area.

HOLE 7-1

220 feet S of Ringer north property line, 630 feet E of Ringer west property line; 1650 feet WNW of Buena Vista. Elevation 309 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
No core	30		30	
Eocene Ione formation				
Lower Ione member				
Brown lignite containing much clay	4		34	
Buff yellow-stained clay	0	5	34	5
Pale brown, yellow-stained clay	7	7	42	
Light cream-colored clay	3	5	45	5
Dark-gray carbonaceous clay	1	1	46	6
Lignite	0	6	47	
Dark-gray carbonaceous clay	4		51	
Gray-brown clay	1	1	52	1
Lignite	1	11	54	
Brown clay	0	6	54	6
White clay	6	2	60	8
White clay; some sand grains	1	4	62	
White sandy clay	0	8	62	8
Light-gray sandstone and some clay	1	4	64	
Conglomerate; weathered to buff color	0	9	64	9
White argillaceous sandstone containing iron nodules	3	4	68	1
Buff sandstone; very abundant iron nodules	2	11	71	
Light-buff coarse-grained sandstone	2		73	
Buff argillaceous fine-grained sandstone	1		74	
Buff argillaceous medium-grained sandstone	2		76	
Coarse-grained sandstone containing some clay; iron-oxide cement	5		81	
Fine-grained white, argillaceous sandstone, some red stains	3		84	
Buff clay	10		94	
Buff conglomerate	4		98	
Reddish-buff clay	3		101	
Yellow-brown clay	4		105	
Conglomerate	3		108	
Dark gray carbonaceous clay	2		110	
Very light-buff clay, some silty partings, some carbonaceous streaks	4	9	114	9
Purplish clay	0	2	115	11
Very dark-gray clay containing lignite seams	1	6	116	5
Very dark-gray sandy clay	0	7	117	
Conglomeratic sandstone; dark gray, grading to light-brown	7		124	
No core. (One piece of white clay)	10		134	
Fine-grained white argillaceous sandstone	3		137	
Gray-white sandstone with clay cement	1	6	138	6
Conglomeratic gray-white sandstone with clay cement	0	6	139	
Red and buff clay and pebbles	1	6	140	6
Gray-white conglomeratic sandstone	1	6	142	
Lignite	0	3	142	3
Fine-grained gray-white argillaceous sandstone	0	9	143	
Dark gray carbonaceous sandy clay	0	6	143	6
Gray-white silty clay containing pebbles	0	6	144	
Fine-grained gray carbonaceous sandstone	3		147	
Dark-gray, carbonaceous, argillaceous, medium-grained sandstone	0	6	147	6
White clay; some silt	7	6	155	
Conglomeratic white clay; some silt	9		164	
Fine-grained, white, argillaceous sandstone	15		179	
Gray carbonaceous clay	6		185	
Sandy lignite	1		186	
Carbonaceous sandy clay	0	9	186	9
Argillaceous lignite	0	3	187	
Carbonaceous clay	0	9	187	9
Argillaceous lignite	0	3	188	
Gray carbonaceous sandy clay	16		204	
Light-brown clay	1	5	205	5
Highly carbonaceous clay	3	7	209	
Dark-gray carbonaceous clay, sandy lenses	4	6	213	6
Buff silty clay	0	6	214	
Gray carbonaceous clay	1		215	
Buff silty clay; iron nodules	3	9	218	9
Buff silty clay	0	3	219	
Light-buff and red mottled sandy clay	2		221	
Red sandy clay, some buff mottling	7		228	
Red and buff mottled clay	2	2	230	2
Buff clay	1	1	231	3
Eocene (?) unnamed pre-Ione beds				
Gray argillaceous siltstone	4		235	3
Dark-gray carbonaceous argillaceous siltstone	0	6	235	9
Very light-brown argillaceous siltstone	0	6	236	3
Light-brown argillaceous siltstone	1		237	6
Gray carbonaceous argillaceous siltstone	6	6	244	
Dark-gray carbonaceous argillaceous siltstone	12		256	
Dark-gray carbonaceous conglomeratic fine-grained sandstone	3		259	
Quartz pebbles in greenish clay matrix	0	6	259	6
Jurassic Amador group				
Green clay containing some lighter colored areas	2	6	262	
Highly altered greenstone	5		267	
Fresh greenstone	2	3	269	3
Greenstone, partially altered to clay	2	2	271	5
Fresh greenstone	1	7	273	

HOLE 13-1

20 feet E of Fancher west property line, 110 feet N of Fancher south property line. Elevation 244 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
No core	236		236	
Eocene Ione formation				
Lower Ione member				
Ferruginous nodule	1		237	
Yellow-stained clay	0	9	237	9
White clay	2	6	240	3
White sandy clay	0	6	240	9
White clay	1	3	242	
White, yellow-stained clay	1	5	243	5
White sandy clay; yellow stain	0	6	243	11
White clay	0	1	244	
White argillaceous sandstone; yellow stain	1		245	
White clay	0	3	245	3
Light gray clay	8	6	253	9
Pebbles, 2 inches in maximum diameter	0	3	254	
Fine-grained cream colored sandstone	20		274	
Light-gray silty clay	1	6	275	6
Light-gray silty clay; iron nodules	8	6	284	
White clay; iron nodules	10		294	
Eocene (?) unnamed pre-Ione beds				
Green silty clay; iron nodules (siderite)	10		304	
Gray-green silty clay; siderite nodules	9		313	
Buff clay	1		314	

HOLE 13-2

200 feet S. of county road, 30 feet W. of Fancher east property line. Elevation 259 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Quaternary alluvium (?)				
Sand, gravel, and clay *	49		49	
Eocene Ione formation				
Lower Ione member				
Lignite *	1		50	
Sand, gravel, and clay *	40		90	
Lignite *	17		107	
Clay, sand, and gravel *	55		162	
White medium-grained sandstone; some clay	2		164	
White medium-grained sandstone; iron nodules and clay	1		165	
Yellow to red sandy clay	3		168	
Buff to red clay with a little sand	3		171	
White sandy clay heavily stained with red and yellow	1	2	172	2
Mottled red and yellow sandy clay	0	10	173	
White clay	0	6	173	6
Reddish sandy clay	1	6	175	
White sandy clay	0	9	175	9
Pink and dark-red clay	0	3	176	
Pink-stained sandy white clay	0	6	176	6
Coarse, very angular quartz grains cemented with red iron compound	0	6	177	
White clay with red stains	7		184	
Red and yellow banded clay	1	2	185	2
White clay	3	4	188	6
Light-brown clay	0	6	189	
Light-brown fine sandy clay with reddish streaks	1	9	190	9
Light-brown argillaceous sandstone	0	4	191	1
Light-brown clay with some silt and fine sand grains	1	11	193	
Brownish-gray clay	4	9	197	9
Gray clay with scattered sand grains	2	11	200	8
Brownish-gray sandy clay	1	1	201	9
Medium-gray clay with some sand grains; carbonaceous	2	3	204	
Light-gray clay with some sand grains	1		205	
Gray clay	2	9	207	9
Medium-gray clay with pieces of carbonaceous material	2	9	210	6
Light-gray clay	3	6	214	
Sandy clay and silt ranging in color from gray to black *	51		265	
Gray medium-grained sandstone; yellow stain	10		275	
Sandy clay and silt ranging in color from gray to black *	26		301	
Sandy red clay *	3		304	
Deep-red conglomeratic material with white fragments	2		306	
Rust-brown clay containing a few pebbles	2	3	308	3
White clay with red stains and pebbles	0	9	309	
Rust-brown sandy clay with small pebbles	4	6	313	6
Red clay with some sand grains	3	6	317	
Buff-colored, weathered conglomerate	2	6	319	6
Red and buff mottled argillaceous sandstone	1	6	321	
Brown-buff argillaceous sandstone	1	2	322	2
Light-buff, weathered conglomerate	0	10	323	
Yellow, weathered conglomerate	1		324	
Dull-red and yellow, weathered conglomerate	0	6	324	6
Coarse-grained yellow sandstone containing much clay	0	6	325	
Dull-red conglomerate	1		326	
Dull-red and yellow, weathered conglomerate	1	3	327	3
Dark-yellow banded siltstone	0	3	327	6
Fine-grained dark gray rotten siltstone	0	9	328	3
Dark-gray very coarse rotten sandstone	1	9	330	
Rotten, chalky-white conglomerate	1	6	331	6
Rotten, dark-gray conglomerate	1		332	6
Rotten, white conglomerate	1	6	334	
Eocene (?) Unnamed pre-Ione beds (?)				
Green and white weathered conglomerate	1		335	

* No core, description from driller's log.

HOLE 18-1

Approximately 1215 feet N. 73° E. of top of Chitwood Hill, approximately 50 feet south of Kovacevich north property line. Elevation 254 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Quaternary alluvium				
Caving sand and gravel *	26		26	
Eocene Ione formation (?)				
Upper Ione member (?)				
Green clay *	83		109	
Lower Ione member				
Lignite *	6		115	
Lignite	3		118	
Dark-gray carbonaceous clay	0	3	118	3
Gray clay, some sand	4	9	123	
White clay	3		126	
Pale-brown clay	3	6	129	6
Brown clay	0	6	130	
Lignite	0	3	130	3
Brown clay	0	8	130	11
Lignite	1		131	11
Brown clay	1	4	133	3
Pale-brown clay	6	3	139	6
Light-gray sandy clay	1	6	141	
Gray sandy clay	2		143	
Gray-green argillaceous sandstone	1	6	144	6
White clay with some sand	6	6	151	
Light-gray clay	0	3	151	3
Fine-grained light-gray sandstone with clay cement	1	9	153	
Light-gray clay	2		155	
Dark-gray clay	0	6	155	6
Carbonaceous clay, some lignite	6	6	162	
Carbonaceous clay with some sand	2		164	
Carbonaceous clay	1		165	
Lignite with abundant clay	0	8	165	8
Carbonaceous clay	0	5	166	1
Lignite with abundant clay	0	3	166	4
Carbonaceous clay	0	8	167	
Lignitic clay	1	8	168	8
Slightly silty carbonaceous clay	2	7	171	3
Lignite with a few clay partings	2	6	173	9
Gray argillaceous sandstone	1	9	175	6
White clay	6		181	6
White sand with clay cement	1		182	6
Cream-colored clay	5		187	6
Cream-colored clay with iron nodules	0	6	188	
Cream-colored clay	1		189	
Light-gray clay with some sand grains	3	6	192	6
Light-gray clay	1	6	194	
Light-gray sandy clay	1	2	195	2
Light-gray clay very little sand	2	10	198	
White clay	14		212	
White clay with dark brown specks; 2″ pebble at 213′	3		215	
White clay with a 4″ dark brown fragment of wood at 215′ 6″	2		217	
Gray sandy clay	15	4	232	4
Gray sand with clay cement	0	5	232	9
Light-gray clay and sand	3	3	236	
Light-gray sandy clay with slight yellow stain	1		237	
Light-yellow clay with some sand grains	2		239	
Light-yellow sandy clay	3		242	
Light-yellow clay	5		247	
Buff sandy clay	1		248	
White and buff clay	1		249	
White clay	0	2	249	2
Buff silty clay with red stain	3	4	252	6
Light buff clay	3	6	256	
White sandy clay some buff stain	2	9	258	9
White quartz gravel *	5	3	264	
Carbonaceous argillaceous sandstone	1		265	
White argillaceous sandstone with clay chips and iron nodules	4		269	
White siliceous sandstone, clay cement	2	6	271	6
Gray carbonaceous silty clay with some sand	3	6	275	
Gray sandy clay	0	6	275	6
White clay with some silt and colored pebbles	0	9	276	3
Red sandy clay with buff spots	4	3	280	6
Red and buff clay with some silt	4	6	285	
Red, yellow, and white mottled sandy clay	3	3	288	3
White sandy clay with yellow stains, iron nodules	1	9	290	
Dark-yellow sandy clay with red and white areas	4		294	
Yellow and white argillaceous siltstone	1		295	
Weathered conglomerate; various colored pebbles in pink to brown matrix with transition to white matrix between 297′ and 298′	8		303	
White clay with sand grains, some pale green areas	2	3	305	3
Deep-red clay with quartz pebbles and white patches	5	9	311	
Eocene (?) unnamed pre-Ione beds				
Reddish buff silty clay with some pebbles	2		313	
Yellow-brown clay with some sand grains	1		314	
White clay with sand grains, light buff stains	1		315	
Yellow to reddish-yellow clay with sand grains	2		317	
White sandy clay	0	9	317	9
Yellow to reddish yellow clay with sand grains	2	3	320	
White sandy clay	4		324	
White clay	7		331	
Green clay	4		335	
Greenish clay with scattered sand and pebbles	0	9	335	9
Greenish clay with some sand	2	6	338	3
Greenish sandy silt with iron nodules	20	9	359	
Greenish silty clay	10		369	
Greenish-white sandy clay with yellowish stains	6		375	

* No core, description from driller's log.

HOLE 18-2

190 feet east of Ringer west property line, 400 feet north of Jackson Creek. Elevation 270 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Quaternary alluvium (?)				
Sand and gravel *	51		51	
Eocene Ione formation				
Lower Ione member				
Lignite *	3		54	
Dark-gray carbonaceous clay	0	2	54	2
Lignite	0	2	54	4
Light-brown fine sandy clay	1	4	55	8
Lignite	6		61	8
Transition to pale-brown clay	0	7	62	3
Pale-brown clay	1	9	64	
Very pale-brown clay	15		79	
Lignite	1	2	80	2
Brown clay	1	10	82	
Lignite	0	3	82	3
Pale-brown clay with some silt	1	9	84	
White clay with small red areas	10		94	
White clay	5		99	
Pale-brown argillaceous silt	6		105	
Pale-brown clay	8		113	
Fragments of clay and lignite	1		114	
Lignite with clay	0	3	114	3
Dark-gray carbonaceous clay	0	9	115	
Lignite	1		116	
No core	3		119	
Lignite	2		121	
Brown clay	1		122	
Lignite	1		123	
Brown clay	0	3	123	3
Lignite	5	3	128	6
Dark-brown silty clay	2	3	130	9
Lignite	2	1	132	10
Clay	0	2	133	
Lignite	1		134	
Dark-gray carbonaceous sandy clay	1	5	135	5
Lignite	0	7	136	
Dark-gray carbonaceous sandy clay	0	2	136	2
Lignite	0	2	136	4
Brown carbonaceous sandy clay	1	2	137	6
Lignite	1		138	6
Brown sandy clay	1	5	139	11
Lignite	4	1	144	
White conglomeratic clay	1		145	
Fine-grained white argillaceous sandstone	8	3	153	3
Fine-grained white sandy clay	0	9	154	
Fine-grained white argillaceous sandstone	12		166	
White argillaceous medium-grained sandstone with some buff stains	3	3	169	3
Gray carbonaceous medium-grained sandstone	4	9	174	
Gray carbonaceous medium-grained sandstone with some buff stains	10		184	
Dark-gray micaceous fine-grained sandstone	9		193	
Dark brownish-gray sandstone with clay, some pebbles and some plant remains	1		194	
Light-brown clay with scattered pebbles	0	9	194	9
Light-brown clay with abundant fine sand and plant remains	9	3	204	
Brownish carbonaceous clay with some pebbles	2		206	
Dark-gray carbonaceous siltstone	3		209	
Dark-gray carbonaceous argillaceous sand	1	3	210	3
Dark-red sand with carbonaceous material	0	3	210	6
Dark-gray carbonaceous argillaceous sand	0	2	210	8
Dark-red sand with carbonaceous material	0	4	211	
Dark-gray sandy clay with carbonaceous material	3		214	
Fine-grained dark gray carbonaceous sandstone with much clay	5	4	219	4
Lignite	0	1	219	5
Fine-grained dark-gray carbonaceous sandstone with much clay	4	7	224	
Buff clay with some sand and small iron nodules	1	4	225	4
Gradation to red and buff mottled clay with some sand and iron nodules	0	5	225	9
Red and buff mottled clay with some sand and iron nodules	3	3	229	
Red clay with some mottling and iron nodules	2	3	231	3
White and red mottled clay with iron nodules	1	7	232	10
Red clay with some sand	1	2	234	
Dark-red clay with iron nodules	1		235	
Eocene (?) unnamed pre-Ione beds				
Transition to green unaltered conglomeratic material	0	6	235	6
Green conglomeratic material	3	6	239	
Whitish-green conglomeratic material	5		244	
Buff sandy clay	2	6	246	6
Olive-brown sandy clay, some pebbles	5	6	252	
Grayish buff-brown silty clay	2		254	

* No core, description from driller's log.

HOLE 18-3

200 feet N. of county road and 190 feet E. of Hart west property line. Elevation 321 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Quaternary terrace gravel				
Sand and gravel *	15		15	
Eocene Ione formation				
Upper Ione member				
White to gray-green clay *	52		67	
Lower Ione member (?)				
Sand *	8		75	
Clay *	3		78	
Lower Ione member				
Lignite *	11		89	
Clay, sandy clay, and silt *	27		116	
Clay, silt, and gravel beds *	18		134	
Brown ironstone, extremely hard; many quartz grains *	9		143	
Rust-colored medium-grained sandstone cemented with iron oxide and clay	20		163	
Coarse-grained sandstone with heavy iron-oxide cement	2	8	165	8
White clay with some silt	2	1	167	9
White clay with a few sand grains; heavy yellow stain	2	3	170	
Buff silty clay with purple stain	2		172	
Light-buff silty clay with red stains	1	6	173	6
Red and white clay	6	6	180	
Very light buff clay with red stains	3		183	
Light-buff clay with red stains	1		184	
Light-buff clay with sand grains, red stains	1		185	
Red, white, and buff mottled clay	2	1	187	1
Light-buff clay with sand grains, red stains	0	11	188	
Light-buff clay with red and dark buff strains	2	1	190	1
Very light-buff sandstone, very little clay cement	6	4	196	5
White clay	1	5	197	9
Sand parting	0	1	197	10
White clay	2	2	200	
Light-buff clay with some sand grains	1	6	201	6
Light-buff argillaceous sandstone	0	6	202	
White silty clay	1		203	
Cream-colored silty clay	0	9	203	9
Cream-colored fine-grained sandy clay	1	6	205	3
Cream-colored coarse-grained sandy clay	1	5	206	8
Cream-colored clay	0	7	207	3
Cream-colored clay with red stain	0	9	208	
Cream-colored clay with sand grains and red stain	0	5	208	5
Light-buff sandstone with clay cement and red stains	0	7	209	
Fine-grained white argillaceous sandstone	20	5	229	5
Lignite with sand parting at 229′ 10″	0	9	230	2
Gray medium-grained sand with lignite seams at 231′ 2″ and 231′ 5″	3	4	233	6
Light-gray argillaceous siltstone	2	6	236	
Fine-grained dark-gray carbonaceous argillaceous sandstone	8		244	
Lignite and dark-gray clay alternating	3	9	247	9
Gray argillaceous sandstone alternating with lignite seams	0	9	248	6
Gray medium-grained sandstone with yellow stain	2		250	6
Fine-grained gray standstone with lignite as thin partings	3	6	254	
Fine-grained gray carbonaceous sandstone	4		258	
Dark-gray carbonaceous sandy clay	6		264	
Dark-gray carbonaceous silty clay with numerous lignite partings	3	8	267	8
Highly carbonaceous sandy clay with lignite partings	6	4	274	
Jurassic Mariposa slate				
Pinkish-stained clay grading to gray clay	3	6	277	6
Gray clay red-stained in places	1		278	6
Olive-colored clay with red stain	1	6	280	
Pinkish-clay with iron specks	4		284	
Olive-colored clay	7	6	291	6
Olive-colored clay, some sand grains	1	6	293	
Pinkish clay, some sand	1		294	
Olive-colored clay, some sand	10		304	

* No core, description from driller's log.

HOLE 18-4

50 feet E. of range line between R. 9 E. and R. 10 E. (projected); 240 feet N. of north side of sec. 19, T. 5 N., R. 10 E. Elevation 258 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
No core	180		180	
Eocene Ione formation				
Lower Ione member				
Clay *	14		194	
Dirty white clay with one 3-inch pebble	4		198	
White clay with abundant iron nodules	3		201	
White clay	3		204	
White clay with fine to coarse sand grains	6		210	
White clay	0	10	210	10
White clay with iron veinlets	1		211	10
White clay with some sand grains	1	11	213	9
Jurassic Amador group				
Residual clay; mostly white; some green	0	6	214	3

* No core, description from driller's log.

HOLE 19-1

60 feet E. of Ringer west property line, 100 feet S. of south boundary of Buena Vista Grant. Elevation 327 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Eocene Ione formation				
Upper Ione member (?)				
Sand and gravel *	16		16	
Sand and clay *	74		90	
Lower Ione member				
Lignite *	5		95	
Sand and clay *	24		119	
Lignite *	14		133	
Clay *	15		148	
Lignite *	6		154	
Clay *	21		175	
Sand and clay *	60		235	
Sand and pebbles, increasing in coarseness downward. Very coarse at 265' *	30		265	
Eocene (?) unnamed pre-Ione beds				
Gray medium-grained sandstone with pebbles	0	9	265	9
Fine-grained olive buff micaceous sandstone	4	3	270	
Buff sand with lenses of biotite	5		275	
Sand and pebbles *	9		284	
Glauconitic green sand grading downward into a gray plastic clay *	30		314	
Gray plastic clay *	11		325	
Green and brown dense siltstone	11		336	
Gray plastic clay *	54		390	
Jurassic Amador group				
Greenstone	6		396	

* No core, description from driller's log.

HOLE 24-1

2810 feet S. 40° W. from hole 18-1. Approximately 95 feet W. of Hart east property line. Elevation 269 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Eocene Ione formation (?)				
Upper Ione member (?)				
Sand and gravel *	82		82	
Lower Ione member (?)				
Red clay *	4	6	86	6
Jurassic Amador group (?)				
Bed rock *	1	6	88	

* No core, description from driller's log.

HOLE 24-2

Approximately 1660 feet S. 12° E., from the top of Chitwood Hill. Elevation 275 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Eocene Ione formation (?)				
Upper Ione member (?)				
Sand and gravel *	32		32	
Greenish silty clay *	12		44	
Pale-buff clay	1	6	45	6
Yellow-brown clay with some silt	2		47	6
Yellow-brown argillaceous sandstone	0	7	48	1
Olive-brown silty clay	4	11	53	
Eocene Ione formation				
Lower Ione member				
Fine-grained gray argillaceous sandstone	1		54	
Gray medium-grained sandstone with clay cement	1		55	
Light-gray silty clay	0	6	55	6
Light gray clay with pieces of lignite	2	6	58	
Lignite	0	8	58	8
Light-gray carbonaceous clay	4		62	8
Light-gray silty clay	1	4	64	
Light-gray argillaceous medium-grained sandstone	10		74	
Fine-grained light-gray argillaceous sandstone	5		79	
Light-gray argillaceous medium-grained sandstone	5		84	
Light-gray clay	0	2	84	2
Fine-grained light gray argillaceous sandstone	3	10	88	
Fine-grained gray argillaceous sandstone	9		97	
Light-gray carbonaceous clay with some silt	1	8	98	8
Lignite	0	2	98	10
Light-gray carbonaceous clay with a little fine silt	3	2	102	
Light-gray carbonaceous clay	2		104	
Light-brown clay	0	4	104	4
Lignite	4	8	109	
Dark-brown clay	0	5	109	5
Lignite	3		112	5
Brown clay	0	7	113	
Lignite	1	3	114	3
Dark-brown clay	0	2	114	5
Lignite	4	6	118	11
Dark-brown carbonaceous clay	0	6	119	5
Light-brown clay	3	7	123	
Pale-brown sandy clay	6		129	
Very light gray silty clay with iron specks	9		138	
White sandy clay with iron nodules	8		146	
White sandy clay with red clay fragments and iron nodules	2		148	
White clay with red stain and iron nodules	4		152	
White sandy clay with iron nodules	2		154	
White clay	2		156	
White clay with some silt	2	6	158	6
Very light buff silty clay	0	8	159	2
White clay with some silt	1	4	160	6
White clay with some silt and some iron nodules	1	4	161	10
Very light buff silty clay	2	2	164	
White clay, conchoidal fracture	1		165	
White clay with some silt	7	2	172	2
Jurassic Amador group				
Altered greenstone	0	7	172	9
Fresh greenstone	2	1	174	10

* No core, description from driller's log.

HOLE 24-3

50 feet W. of county road and 100 feet S. of Kidd north property line. Elevation 273 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Eocene Ione formation				
Upper Ione member				
Light-buff sandy clay *	14		14	
Red ferruginous conglomeratic sandstone	0	9	14	9
White, iron-stained, coarse sandstone	0	9	15	6
White, iron-stained, sandy clay, sand grains becoming coarser and more abundant after 19′ 6″	5		20	6
White, iron-stained, argillaceous sandstone	1		21	6
Greenish-tan silty clay with almost no sand grains	0	7	22	1
Ferruginous sandstone	1		23	1
Olive-brown clay	0	11	24	
White, iron-stained, argillaceous fine-grained sandstone	6		30	
Light-brown silty clay	0	7	30	7
Light olive-brown clay with some silt	1	7	32	2
Reddish-brown ferruginous sandy clay	1		33	2
Dark-buff sandy clay	0	10	34	
Fine-grained greenish argillaceous sandstone with yellow stain	2		36	
Fine-grained greenish argillaceous sandstone	7	7	43	7
Greenish medium-grained sandstone	0	5	44	
Greenish coarse-grained angular sandstone, poorly cemented with clay	6		50	
Buff medium-grained sandstone with a little clay cement	4		54	
Fragments of buff coarse-grained sandstone with a little clay cement (poor core recovery)	10		64	
Buff medium-grained argillaceous sandstone with yellow stains	3		67	
Buff clay with a few sand grains	2		69	
Olive-buff clay with some sand grains	2	2	71	2
Greenish-buff fine-grained argillaceous sandstone	1	8	72	10
Clay with abundant sand grains	1	2	74	
Medium-grained argillaceous sandstone	1	1	75	1
Coarse-grained sandstone with brown stain	1	3	76	4
Gray-buff sandy clay	0	8	77	
Coarse-grained sandstone with brown stain	0	10	77	10
Gray-buff sandy clay with sand grains more abundant after 79′ 3″	3	2	81	
Sand and clay fragments (poor core recovery)	3		84	
Dark-buff sandy clay	3		87	
Dark-buff clay	1		88	
Light-buff clay with small red areas	2	6	90	6
Silty clay	0	6	91	
Fine sandy clay	1		92	
Clayey sandstone	1		93	
Buff clay with some silt	0	6	93	6
Dark-buff medium-grained sandy clay	0	6	94	
Hard, gray, medium-grained sandstone with buff stains	0	4	94	4
Soft, dark-buff medium-grained sandstone	0	4	94	8
Dark-buff clay	0	8	95	4
White clay	1	6	96	10
White clay with sand grains	0	2	97	
Greenish-gray sand with clay cement, grades from fine- to coarse-grained	7		104	
Lower Ione member				
Gray coarse-grained quartz sandstone with clay grains that resemble weathered feldspar grains	6		110	
Fine-grained white sand with buff stains and a few partings of coarse sand	4		114	
Gray-brown carbonaceous clay	3	5	117	5
Carbonaceous brown clay	0	1	117	6
Gray-brown carbonaceous clay	0	8	118	2
Lignite	0	8	118	10
Brown clay grading downward to white clay	5	2	124	
White clay with some sand grains	3		127	
White silty clay with some yellow stains	4	3	131	3
Light-brown clay	1	9	133	
White clay with some sand grains	3		136	
White clay	2		138	
White clay with iron nodules	3	7	141	7
White clay with a few large iron nodules	2	5	144	
Reddish buff and gray mottled clay, some iron nodules (reworked laterite)	3		147	
Red and white clay with specks of iron oxides (reworked laterite)	10		157	
Red and white mottled clay with abundant iron nodules (reworked laterite)	11		168	
Red with some white areas (reworked laterite)	6		174	
White clay mottled with some red clay (reworked laterite)	3	8	177	8
Red, gray, and cream clay (reworked laterite)	0	5	178	1
Yellow and red clay	1	1	179	2
Brown clay	0	6	179	8
Red smooth clay with conchoidal fracture	0	5	180	1
Dark-buff and purple mottled clay	13	11	194	
Yellowish clay with red stain and white spots	10		204	
Red and white clay	10		214	
Claylike material with pebbles of greenstone and quartz	6		220	
Jurassic Amador group				
Greenstone	2		222	

* No core, description from driller's log.

HOLE 24-4

140 feet W. of Churchman east property line and 380 feet N. of Churchman south property line. Elevation 290 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Miocene (?) Valley Springs formation				
Bright blue-green clays, silts, and sands *	100		100	
Eocene Ione formation (?)				
Upper Ione member (?)				
Green sand, silt, and siliceous clay and some gravel beds *	26		126	
Olive-buff fine-grained sandstone with some well-rounded pebbles	4	6	130	6
Olive-buff sandstone with a very few small pebbles, some pebbles weathered to clay	0	8	131	2
Olive-buff siltstone and some pebbles	3		134	2
Conglomerate with buff silty matrix, dark-colored siliceous pebbles less than 3" in diameter	6	10	141	
Olive-buff fine-grained sandstone	0	3	141	3
Conglomerate with buff-colored silty matrix, dark-colored siliceous pebbles	2	6	143	9
Yellowish fine-grained sandstone with brown stains	1	3	145	
Cream-colored silty clay with buff stains	4		149	
Cream-colored silty clay with buff stains and some pebbles	5		154	
Light-brown conglomerate	4		158	
Light-brown silty clay; color grades downward to brown	4		162	
Mixed fragments of olive-brown silt and clay	2		164	
Olive-colored silty clay	10		174	
Light olive-brown argillaceous sandstone	8	6	182	6
Conglomerate with olive-colored matrix	1	6	184	
Green-gray fine-grained argillaceous sandstone with some black carbonaceous matter	7		191	
Green-gray silty clay	2	10	193	10
Green-gray silty clay with sand grains	2	2	196	
Light olive-buff siltstone	8		204	
Light olive-buff fine-grained sandstone	3	6	207	6
Gray-brown fine-grained argillaceous sandstone	16	6	224	
Light olive-gray fine-grained sandy clay	3	3	227	3
Light olive-gray fine-grained silty clay with finely disseminated pyrite	3	9	231	
Light olive-gray fine-grained silty clay	5	6	236	6
Olive-brown clay with some silt	2	6	239	
Olive-brown finer-grained argillaceous sandstone	3	6	242	6
Olive-brown coarse-grained sandstone	0	6	243	
Olive-colored fine-grained sandy clay	1	6	244	6
Eocene Ione formation				
Lower Ione member (?)				
Light buff argillaceous sandstone, coarsest at top of bed	2	6	247	
Light-buff clay	0	9	247	9
Light-buff argillaceous sandstone, coarser toward the base	4	3	252	
Light-buff clay	2		254	
Lower Ione member				
Purple-brown carbonaceous clay with some lignite	3		257	
Light gray clay	0	6	257	6
Lignite with some clay	3	3	260	9
Gray clay; some plant fragments	1		261	9
Light-gray clay	2	3	264	
Light-gray sandy clay	0	7	264	7
Gray sandy clay with plant fragments	0	8	265	3
Lignite	0	3	265	6
Light-gray clay	1	4	266	10
Light-gray argillaceous sandstone	3	7	270	5
Olive-brown sandy clay	0	3	270	8
Light-gray argillaceous sandstone	3	3	273	11
Brown carbonaceous clay	1	2	275	1
Light-gray silty clay	3	8	278	9
Brown carbonaceous clay with lignite partings	1	10	280	7
Black highly carbonaceous clay	0	6	281	1
Light-gray sandy clay	2	11	284	
Light-gray clay with coarse sand	4	6	288	6
Light-gray clay with iron nodules and sand	1		289	6
Light-gray sandy clay	1	2	290	8
Tan argillaceous medium-grained sandstone	3	3	293	11
Lignite	1	2	295	1
Brown medium-grained sandstone with clay cement	6	11	302	
Medium-grained brownish-gray argillaceous sandstone	3		305	
Highly carbonaceous coarse-grained sandstone	0	6	305	6
No core	6	6	312	
Brownish-gray medium-grained sandstone with much carbonaceous material	1	7	313	7
Dark-brown highly carbonaceous shale and lignite	0	8	314	3
Brownish-gray coarse-grained sandstone with carbonaceous material	0	9	315	
Fragments of coarse-grained, pebbly sandstone, dark carbonaceous clay, and sandstone (poor core recovery)	10		325	
Brown carbonaceous clay	0	9	325	9
Light-brown clay with some sand and many plant fragments	1	8	327	5
Gray sandy clay with many plant fragments	1	7	329	
Gray argillaceous sandstone with plant fragments	1	8	330	8
Light-gray conglomerate	0	4	331	
Light-gray argillaceous sandstone	2	5	333	5
Light-gray argillaceous sandstone with rust-brown stain	0	7	334	
Medium-grained argillaceous sandstone	5		339	
Jurassic Amador group				
Green, gray, red, and yellow weathered agglomerate; some pyrite	5		344	

* No core, description from driller's log.

HOLE 24-5

180 feet E. of county road and 80 feet S. of north side of sec. 24, T. 5 N., R. 9 E., Elevation 260 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Eocene Ione formation				
Lower Ione member				
Laterite (reworked) *	4		4	
Red and buff mottled clay (reworked laterite)	8		12	
Red, buff, and purple mottled clay (reworked laterite)	8		20	
Red and buff mottled clay (reworked laterite)	10		30	
Red clay with some mottling (reworked laterite)	10		40	
Red, yellow, and purple mottled clay with some sand grains (reworked laterite)	14		54	
Red and buff mottled clay (reworked laterite)	4		58	
Jurassic Amador group				
Red and buff mottled clay (laterite)	5		63	
Fresh greenstone	1		64	

* No core, description from driller's log.

HOLE 24-6

30 feet W. of Churchman east property line, 158 feet S. of Churchman north property line. Elevation 277 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Quaternary soil				
Surface sand and gravel *	6		6	
Miocene (?) Valley Springs formation				
Green clays, silts, and sands *	57		63	
Olive-brown fine-grained sandstone with clay cement	21		84	
Olive-brown coarse-grained sandstone with clay cement	1		85	
Olive-brown conglomeratic fine-grained sandstone	5		90	
Olive-brown silty clay	7		97	
Olive-buff silty clay	7		104	
Light olive-buff silty clay with clay fragments	4		108	
Eocene Ione formation (?)				
Upper Ione member (?)				
Light-buff coarse-grained sandstone with some clay cement	1		109	
Greenish-buff coarse-grained sandstone with much biotite	1	7	110	7
Buff argillaceous fine-grained sandstone	0	10	111	5
Greenish-buff silty clay	4	7	116	
Light-greenish-white clay sand	1	6	117	6
Light-olive-buff mixed sand and clay	2	5	119	11
Light-olive-buff silty clay	1	3	121	2
Light-olive-buff sandy clay	2	10	124	
Grey biotitic sandstone with a little clay cement and disseminated pyrite	9	1	133	1
Light-buff clay with disseminated pyrite	0	11	134	
Light-olive-buff silty clay with patches of disseminated pyrite	4		138	
Light-olive-buff sandy clay with occasional siliceous and clay pebbles. Patches of disseminated pyrite	6		144	
Olive-brown silty clay with biotite	12		156	
Light-brown silty clay	1	1	157	1
Light-brownish-buff clay with biotite	4	11	162	
Light-brown fine-grained sandy clay	2	6	164	6
Fine-grained olive-buff argillaceous biotitic sandstone	2	3	166	9
Olive-buff conglomerate with clay and sand matrix. Weathered and siliceous pebbles up to 2″ in diameter	7	3	174	
Olive-brown conglomeratic clay	0	7	174	7
Red and white mottled clay with occasional pebbles	0	3	174	10
Olive-buff medium-grained sandstone with biotite	0	7	175	5
Clay-pebble conglomerate	0	6	175	11
Lower Ione member				
Red, white, and buff coarsely mottled clay (reworked laterite)	8	1	184	
Red and buff mottled clay (reworked laterite). A 1″ pebble at 193′	10		194	
Red, white, and buff mottled clay (reworked laterite)	5		199	
Red clay with small white patches (reworked laterite). A 1½″ water worn pebble at 214′	22		221	
Jurassic Amador group				
Highly weathered greenstone	0	6	221	6
Fresh greenstone	0	6	222	

* No core, description from driller's log.

HOLE 24-7

Approximately 50 feet W. of county road and 1400 feet S. of hole 24-3. Elevation 300 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Quaternary terrace gravel				
Gravel with boulders *	8		8	
Miocene (?) Valley Springs formation				
Yellow clayey silt *	7		15	
Gray siliceous clay *	10		25	
Eocene Ione formation (?)				
Upper Ione member (?)				
Buff siliceous clay *	10		35	
Buff clay *	10		45	
Greenish-gray clay and silt *	10		55	
Gray sandy silt *	10		65	
Greenish silty clay *	10		75	
Greenish-gray silt grading downward into sand *	20		95	
Clay and sand *	98		193	
Lower Ione member				
Lignite *	6		199	
Clay *	16		215	
Gray medium-grained micaceous sandstone with carbonized plant fragments	10		225	
Gray clay with carbonaceous material	2		227	
Lignite	1	2	228	2
Gray clay with carbonaceous material	1	11	230	1
Light gray fine-grained sandstone	2	11	233	
Light-gray argillaceous medium-grained sandstone	3		236	
Light-gray medium-grained sandstone with some clay	4		240	
Light-gray argillaceous medium-grained sandstone	1		241	
Light-gray medium-grained sandstone with some clay	1	5	242	5
Light-gray clay with red stains and some sand	0	7	243	
Light-buff clay with red and purple spots (weathered conglomerate)	4	10	247	10
Light-buff coarse-grained argillaceous sandstone with some red stain	2	1	249	11
White medium-grained argillaceous sandstone with some red stains	2	1	252	
White sandy clay	3		255	
Brown silty clay with white and yellow areas	0	5	255	5
No core	5	7	261	
White sandy clay	1	2	262	2
Greenish-gray clay with coarse sand grains	2	4	264	6
White clay with coarse sand grains	0	6	265	
Brown clay	1	5	266	5
Green-brown conglomerate with clay matrix	2	1	268	6
Chalky white conglomerate and clay mixture	2	6	271	
Brown clay with some red stain	1	10	272	10
Gray argillaceous sandstone	1	2	274	
Yellow-brown clay	0	5	274	5
Coarse-grained angular quartzose sandstone with red cementing mineral	0	3	274	8
Red and yellow brown silty clay	0	4	275	
Gray weathered conglomerate	0	4	275	4
Olive buff silty clay with iron nodules, fewer iron nodules below 277′ 7″.	4	6	280	
White sandy clay with red and yellow stains and a few iron nodules	0	8	280	8
White sandy clay with red stains	2	5	283	1
Purple, red, and buff mottled clay (reworked (?) laterite)	1	11	285	
Red-buff clay (reworked (?) laterite)	4		289	
Jurassic Amador group				
Greenstone	1		290	

* No core, description from driller's log.

HOLE 24-8

900 feet due S. of Hole 24-2. Elevation 273 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Eocene Ione formation				
Upper Ione member				
Green sands and clay *	235		235	
Buff clay	0	10	235	10
Gray clay	0	11	236	9
Gray clayey silt with biotite	4	2	240	11
No core	1	6	242	5
Jurassic Amador group				
Fresh greenstone	0	7	243	

* No core, description from driller's log.

HOLE 24-9

50 feet W. of Hart east property line, 1050 feet N. of Hart south property line, and 1000 feet S. of hole 24-1. Elevation 273 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Eocene Ione formation				
Upper Ione member				
Sand *	26		26	
Green clay *	19		45	
Lower Ione member				
Gray clay gradually becoming lighter in color *	30		75	
Gray clay *	6		81	
White clay with some sand and buff stains. (Pebble bed at 81′ 4″.)	4		85	
White clay with some sand and red stains	4		89	
Red and white banded clay with some silt	2		91	
Pink and white silty clay	0	10	91	10
Pink silty clay with red spots	3	7	95	5
Pink sandy clay	1	7	97	
White argillaceous siltstone with iron nodules	1		98	
White argillaceous fine-grained sandstone	3		101	
Buff argillaceous fine-grained sandstone	1		102	
White argillaceous siltstone with some yellow stains	6	1	108	1
Buff argillaceous siltstone	0	10	108	11
White argillaceous fine-grained sandstone	2	1	111	
Pinkish buff clay	1		112	
Banded red, yellow, and white clay	3		115	
Reddish clay	2	5	117	5
Red and white sandy clay	1	3	118	8
Yellowish argillaceous sandstone	1	10	120	6
Yellow argillaceous sandstone with iron nodules	0	6	121	
Pink silty clay with white spots	1		122	
Jurassic Amador group				
Pink to red gritty clay (residual)	2		124	
Green gritty clay (residual)	1		125	
Weathered greenstone	0	2	125	2
Fresh greenstone	1	10	127	

* No core, description from driller's log.

HOLE B.V. 1

Approximately 900 feet S. 73° W. of the power plant at the Buena Vista wax plant. Elevation 362 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Recent soil				
Red soil with cobbles	2		2	
Eocene Ione formation				
Upper Ione member				
Pale-green clay	13	6	15	6
Gray to greenish-gray loose sand	8		23	6
Yellowish-gray sand	1		24	6
Gray-white sand	2		26	6
Buff sand	1	6	28	
Greenish-gray clayey sand	8		36	
Greenish-gray clay	4		40	
Greenish-gray clayey sand	4		44	
Light-gray loose sand	15		59	
Tan coarse-grained loose sand	2		61	
Buff coarse-grained loose sand	0	6	61	6
Tan clayey sand	2	6	64	
Blue-gray clayey sand	1		65	

HOLE B.V. 2

On top of small hill approximately 1800 feet S. 75° W. of the power plant at the Buena Vista wax plant. Elevation 392 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Eocene Ione formation				
Upper Ione member				
Not cored but included gray siltstone, chocolate-colored clay, and some buff-stained white sand	44	6	44	6
Tan to white clayey sand	4	11	49	5
Loose grayish sand	6	7	56	
Grayish white clayey sand	3		59	
Loose grayish sand	6		65	
Grayish-white clayey sand	1		66	
Loose grayish sand	4		70	
Tan sand with some clay	7		77	
Tan sand with pebbles and some clay	1		78	
Buff sandy clay to clay	2		80	

HOLE B.V. 3

On crest of ridge about 900 feet S. 33° W. of the power plant at the Buena Vista wax plant. Elevation 420 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Eocene Ione formation				
Upper Ione member				
Buff, brown, and tan clays and sands	20		20	
Buff, greenish-tan, and lavender clays and sands	50		70	
Ferruginous sand	1		71	
Light-gray sand with some pebbles	29		100	
Light-gray quartz conglomerate	1		101	
Greenish-gray clay	9		110	

HOLE B.V. 4-A

On top of small hill about 2400 feet W. of the power plant at the Buena Vista wax plant. Elevation 341 feet.

	Approximate thickness feet	Approximate thickness inches	Approximate depth feet	Approximate depth inches
Eocene Ione formation				
Upper Ione member				
Grayish-white sand	30		30	
Brown sand	1		31	
Buff to greenish silty clay	39		70	

HOLE B.V. 4-B

On crest of ridge about 650 feet S. 7° W. of the power plant at the Buena Vista wax plant. Elevation 380 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Quaternary terrace gravel				
Brown conglomerate, large cobbles	5		5	
Eocene Ione formation				
Upper Ione member				
Greenish-buff sandy clay	3	10	8	10
Light-gray sand	11	2	20	
Limonite-stained sand	0	6	20	6
Light greenish-gray sand	9		29	6
Greenish-gray to greenish-buff clay	10	6	40	
Light greenish-gray sand with some clay	6		46	
Light grayish-tan sand	3		49	
Light gray quartz conglomerate with pebbles less than 1 inch in diameter	2		51	
Hard limonite-rich streak	0	2	51	2
Greenish-gray clay	7	3	58	5
Greenish-brown clay	1	1	59	6
Gray-green clay	4	6	64	
Greenish-gray clay with rust-colored stains	2		66	

HOLE B.V. 5

In low saddle on crest of same ridge as Hole B.V. 1 about 1500 feet S. 53° W. of the power house at the Buena Vista wax plant. Elevation 417 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Eocene Ione formation				
Upper Ione member				
Buff, greenish-buff, and brown sand and silt	19	4	19	4
Greenish-white sand	5	8	25	
Buff-brown clayey sand	3		28	
Buff, brown, and light-gray clay with some sand lenses	6		34	
Light-brown clay	3		37	
Brown clay	1		38	
Light blue-gray clay	4		42	
Hard light-brown sandy clay	1	6	43	6
Hard light-gray sandy clay	2	6	46	
White clayey sand	4		50	
Buff sand	0	3	50	3
White clayey sand	4	5	54	8
White sand	11	4	66	
Fine-grained conglomerate with many black pebbles and white sand matrix	14	9	80	9
Tan sandy clay with limonite concretions, a lense of fine-grained conglomerate at about 83 feet	4	3	85	
Buff and tan sandy clay grading to greenish color toward the base	13		98	
Light gray-green clay	2		100	
Gray-green clay	2	8	102	8

HOLE K-10

At present site of Kaolin-Fye clay pit about 125 feet northeast of Calaveras Cement Company southwest property line and 250 feet northwest of stream. Elevation 358 feet.

	Thickness feet	Thickness inches	Depth feet	Depth inches
Quaternary terrace gravel and alluvium				
Coarse reddish-brown conglomerate	10		10	
Eocene Ione formation				
Lower Ione member				
White clayey sand stained yellow for about 2 feet at bottom	22	6	32	6
Dark-gray clayey sand and lignite below	32	6		

HOLE K-11

About 150 feet E. of K-10. Elevation 345 feet.

	Thickness feet inches	Depth feet inches
Eocene Ione formation		
Lower Ione member		
White clayey sand with yellow stain for about 2 feet at bottom	25	25
Dark-gray clayey sand and lignite	below 25	

HOLE K-12

About 300 feet E. of K-10. Elevation 360 feet.

	Thickness feet inches	Depth feet inches
Quaternary terrace gravel and alluvium		
Reddish-brown conglomerate	18	18
Eocene Ione formation		
Lower Ione member		
White clayey sand, stained yellow for about 2 feet at bottom	16	34
Dark-gray clayey sand and lignite	below 34	

Chemical analyses *

* Analyses released for publication on condition that name of analyst remain confidential.

Formation	Analysis number	Hole number	Depth in feet	Analysis: Al_2O_3	Fe_2O_3	SiO_2	TiO_2	Loss on ignition	Free SiO_2	Lithologic description
Greenstone	7-1-0	7-1	263-264	33.30	11.60	45.80	.79	8.51	1.29	Highly altered greenstone.
"	24-1A	24-1	88	20.80	17.00	39.00	.84	8.1	--------	Greenstone.
Pre-Ione Eocene (?) sediment	7-1-M	7-1	232-233	24.93	5.00	61.88	1.02	7.17	6.57	Gray argillaceous siltstone.
"	7-1-N	7-1	235-236	27.43	3.55	59.51	1.10	8.41	2.74	235′-235′ 3″ Gray argillaceous siltstone. 235′ 3″-235′ 9″ Dark-gray carbonaceous argillaceous siltstone. 235′ 9″-236′ Very light-brown argillaceous siltstone.
"	18-1-L1	18-1	311-313	22.58	5.45	65.91	.34	5.72	2.76	Reddish-buff silty clay with some pebbles.
"	18-1-01	18-1	373-374	24.34	3.80	65.37	.47	6.02	4.26	Greenish-white sandy clay with yellow stains.
"	18-2-F	18-2	253-254	26.18	7.15	55.71	1.18	9.78	4.91	Buff-brown silty clay.
Ione formation, Lower Ione member	7-1-A	7-1	35-36	23.37	1.80	64.99	1.81	8.03	3.34	Pale-brown clay with yellow stains.
"	7-1-B	7-1	41-42	24.26	1.75	63.90	1.66	8.43	1.92	Pale-brown clay with yellow stains.
"	7-1-D	7-1	139-140	28.17	6.00	56.15	1.22	8.46	3.90	Red and buff clay with pebbles.
"	7-1-E	7-1	215-216	27.34	7.90	52.09	1.16	11.51	4.42	Buff silty clay with siderite nodules.
"	7-1-F	7-1	220-221	24.03	13.40	48.34	1.20	13.03	3.11	Light-buff and red mottled sandy clay.
"	7-1-G	7-1	222-223	25.97	10.80	51.51	1.14	10.58	5.36	Red sandy clay, some buff mottling.
"	7-1-H	7-1	224-225	25.77	14.55	46.35	1.26	12.07	5.41	Red sandy clay, some buff mottling.
"	7-1-J	7-1	226-227	24.45	21.30	38.41	1.22	14.62	1.68	Red sandy clay, some buff mottling.
"	7-1-K	7-1	228-229	27.79	12.35	47.04	1.20	11.62	.91	Red and buff mottled clay.
"	7-1-L	7-1	230-231	29.54	5.15	55.01	1.22	9.08	3.16	Buff clay.
"	13-2-A	13-2	169-169.5	31.95	18.55	34.52	2.45	12.53	--------	Buff to red clay with a little sand.
"	18-1-A	18-1	276-277	27.48	6.40	56.86	.85	8.41	3.95	Red sandy clay with buff spots.
"	18-1-B	18-1	277-278	29.62	6.70	55.13	.79	7.76	9.10	Red sandy clay with buff spots.
"	18-1-C	18-1	278-279	24.73	4.10	64.64	.67	5.86	8.42	Red sandy clay with buff spots.
"	18-1-D	18-1	279-280	29.30	5.40	57.86	.64	6.80	11.10	Red sandy clay with buff spots.
"	18-1-E	18-1	280-281	27.20	6.10	58.09	.67	7.94	6.10	280′-280′ 5″ Red sandy clay with buff spots. 280′ 5″-281′ Red and buff clay with some silt.
"	18-1-F	18-1	281-282	27.55	7.15	56.29	.67	8.34	6.21	Red and buff clay with some silt.
"	18-1-G	18-1	282-283	26.54	7.40	56.49	.75	8.82	4.73	Red and buff clay with some silt.
"	18-1-H	18-1	283-284	29.09	6.50	55.82	.64	7.95	6.93	Red and buff clay with some silt.
"	18-1-J	18-1	284-285	30.15	5.05	57.78	.53	6.49	11.93	Red and buff clay with some silt.
"	18-1-K	18-1	285-286	24.62	9.05	57.57	.83	7.93	3.45	Red, yellow, and white mottled sandy clay.
"	18-1-L	18-1	286-287	25.42	6.70	59.51	.67	7.70	4.14	Red, yellow, and white mottled sandy clay.
"	18-1-M	18-1	287-288	26.27	5.70	59.85	.56	7.62	5.74	Red, yellow, and white mottled sandy clay.
"	18-1-N	18-1	288-289	26.95	7.70	55.92	.53	8.90	7.96	288′-288′ 2″ Red, yellow, and white mottled sandy clay. 288′ 2″-289′ White sandy clay with yellow stains and iron nodules.
"	18-1-O	18-1	289-290	26.06	5.35	60.63	.45	7.51	5.23	White sandy clay with yellow stains and iron nodules.
"	18-1-P	18-1	290-291	21.32	9.75	61.56	.60	6.77	4.16	Dark-yellow sandy clay with red and white areas.
"	18-1-Q	18-1	291-292	23.69	10.70	57.70	.64	7.27	5.06	Dark-yellow sandy clay with red and white areas.
"	18-1-R	18-1	292-293	24.62	9.45	58.47	.60	6.86	6.64	Dark-yellow sandy clay with red and white areas.
"	18-1-S	18-1	293-294	25.66	6.95	59.15	.56	7.68	5.54	Dark-yellow sandy clay with red and white areas.
"	18-1-T	18-1	294-295	27.79	3.30	63.03	.49	5.39	11.97	Yellow and white argillaceous siltstone.
"	18-1-U	18-1	295-296	26.53	1.70	64.96	.53	6.28	7.75	Weathered conglomerate; various colored pebbles in pink to brown matrix.
"	18-1-V	18-1	296-297	27.81	1.25	64.18	.51	6.25	8.61	Weathered conglomerate; various colored pebbles in pink to brown matrix.
"	18-1-W	18-1	297-298	29.96	2.05	58.99	.51	8.49	5.23	Weathered conglomerate; various colored pebbles in pink to white matrix.
"	18-1-X	18-1	298-299	30.83	2.65	56.75	.89	8.88	5.55	Weathered conglomerate; various colored pebbles in white matrix.
"	18-1-Y	18-1	299-300	30.20	2.15	58.31	.73	8.61	5.10	Weathered conglomerate; various colored pebbles in white matrix.
"	18-1-Z	18-1	300-301	31.47	1.60	58.28	.71	7.94	8.77	Weathered conglomerate; various colored pebbles in white matrix.

*Chemical analyses *—continued*

Formation	Analysis number	Hole number	Depth in feet	Analysis						Lithologic description
				Al_2O_3	Fe_2O_3	SiO_2	TiO_2	Loss on ignition	Free SiO_2	
Lower Ione member—cont.	18-1-A1	18-1	301-302	26.44	1.25	65.03	.51	6.77	6.04	Weathered conglomerate; various colored pebbles in white matrix.
"	18-1-B1	18-1	302-303	26.50	1.20	64.49	.58	7.23	5.96	White conglomerate with spots of carbonaceous material.
"	18-1-C1	18-1	303-304	25.54	1.40	66.07	.53	6.46	6.49	White clay with sand grains, some pale-green areas.
"	18-1-D1	18-1	304-305	24.91	1.40	66.89	.44	6.36	5.66	White clay with sand grains, some pale-green areas.
"	18-1-E1	18-1	305-306	26.52	3.90	62.45	.51	6.62	6.22	305'-305' 3'' White clay with sand grains, some pale green areas. 305' 3''-306' Deep red clay with quartz pebbles, white patches.
"	18-1-F1	18-1	306-307	23.72	4.95	64.58	.56	6.19	5.55	Deep red clay with quartz pebbles, white patches.
"	18-1-G1	18-1	307-308	23.06	4.70	65.91	.56	5.77	4.35	Deep red clay with quartz pebbles, white patches.
"	18-1-H1	18-1	308-309	24.23	4.65	65.15	.58	5.39	6.95	Deep red clay with quartz pebbles, white patches.
"	18-1-J1	18-1	309-310	22.28	4.30	67.65	.49	5.28	5.57	Deep red clay with quartz pebbles, white patches.
"	18-1-K1	18-1	310-311	23.31	4.50	66.03	.34	5.82	4.28	Deep red clay with quartz pebbles, white patches.
"	18-1-M1	18-1	154-155	36.06	2.60	45.77	2.05	13.52	--------	Light-gray clay.
"	18-1-N1	18-1	187-188	28.93	8.75	47.67	1.72	12.93	--------	Cream-colored clay with siderite pellets.
"	18-2-A	18-2	228-229	25.76	14.25	47.37	1.18	11.44	2.23	Red and buff mottled clay with some sand and iron nodules.
"	18-2-B	18-2	234-235	23.19	18.50	45.58	1.24	11.49	1.89	Dark-red clay with iron nodules.
"	24-2-A	24-2	164-165	31.52	1.60	54.81	.42	11.65	--------	White clay, conchoidal fracture.
"	24-2-B	24-2	167-168	22.63	3.75	64.40	.91	8.31	--------	White clay with some silt.
"	24-3-A	24-3	124-125	38.83	1.60	43.34	2.71	13.52	1.35	White clay with some sand grains.
"	24-3-B	24-3	129-130	39.05	1.90	42.70	2.54	13.81	1.21	White silty clay with some yellow stain.
"	24-3-C	24-3	144-145	34.85	10.45	37.31	2.59	14.80	1.02	Reddish-buff and gray mottled clay, some iron nodules (siderite?) (reworked laterite).
"	24-3-D	24-3	145-146	32.90	13.85	35.31	2.57	15.37	--------	Reddish-buff and gray mottled clay, some iron nodules (siderite?) (reworked laterite).
"	24-3-E	24-3	156-157	32.66	14.95	35.15	3.03	14.21	--------	Red and white mottled clay with specks of iron oxides. (reworked laterite).
"	24-3-F	24-3	159-160	27.60	27.85	27.46	2.45	14.64	--------	Red and white mottled clay with abundant iron nodules (siderite?) (reworked laterite).
"	24-3-G	24-3	174-175	32.98	14.70	39.76	1.62	10.94	4.25	White clay with some red clay, mottled, (reworked laterite).
"	24-3-H	24-3	178-179	30.16	18.75	37.82	1.95	11.32	.85	Yellow and red clay (reworked laterite).
"	24-3-J	24-3	180-181	27.80	19.30	40.86	1.45	10.59	--------	Dark buff and purple mottled clay (reworked laterite).
"	24-3-K	24-3	202-203	27.28	21.10	38.14	1.38	12.10	--------	Yellowish claylike material with red stain, white spots. (reworked laterite).
"	24-3-L	24-3	210-211	26.88	20.20	40.08	1.38	11.46	--------	Red and white claylike material (reworked laterite).
"	24-5-A	24-5	5-6	28.05	24.05	33.05	2.19	12.66	.64	Red and buff mottled clay (reworked laterite).
"	24-5-B	24-5	10-11	31.23	17.85	36.00	2.00	12.92	--------	Red and buff mottled clay (reworked laterite).
"	24-5-C	24-5	15-16	32.05	14.85	37.52	1.66	13.92	--------	Red, buff, and purple mottled clay (reworked laterite).
"	24-5-D	24-5	20-21	34.97	11.25	39.10	.98	13.70	--------	Red and buff mottled clay (reworked laterite).
"	24-5-E	24-5	31-32	31.67	17.50	35.93	1.60	13.30	.64	Red clay with some mottling (reworked laterite).
"	24-5-F	24-5	40-41	29.39	21.75	34.95	1.51	12.40	--------	Red, yellow, and purple mottled clay with some sand grains (reworked laterite).
"	24-5-G	24-5	45-46	28.71	12.45	46.56	1.12	11.16	.63	Red, yellow, and purple mottled clay with some sand grains. (reworked laterite).
"	24-6-C	24-6	176-177	28.00	21.80	36.13	2.37	11.70	--------	Red, white, and buff coarsely mottled clay (reworked laterite).
"	24-6-D	24-6	178-179	28.73	22.75	34.68	2.45	11.39	--------	Red, white, and buff coarsely mottled clay (reworked laterite).
"	24-6-E	24-6	180-181	30.14	17.55	36.98	1.81	13.52	--------	Red, white, and buff coarsely mottled clay (reworked laterite).
"	24-6-F	24-6	182-183	23.91	25.75	32.18	1.62	16.54	--------	Red, white, and buff coarsely mottled clay (reworked laterite).
"	24-6-G	24-6	184-194	25.76	26.30	30.82	2.42	14.70	--------	Red and buff mottled clay (reworked laterite).
"	24-6-H	24-6	196-197	30.53	17.50	37.12	1.38	13.47	--------	Red, white, and buff mottled clay (reworked laterite).
"	24-6-J	24-6	199-200	29.72	19.10	37.39	1.54	12.25	--------	Red clay with small white patches (reworked laterite).
"	24-6-K	24-6	201-202	27.44	23.75	34.92	2.19	11.70	--------	Red clay with small white patches (reworked laterite).
"	24-6-L	24-6	204-214	30.10	16.20	39.88	1.84	11.98	--------	Red clay with small white patches (reworked laterite).
" (?)	24-6-M	24-6	218-219	27.55	20.65	37.85	2.12	11.83	--------	Red clay with small white patches (reworked or residual laterite).
Upper Ione member (?)	24-6-A	24-6	114-115	29.49	3.75	56.76	.85	9.15	--------	Greenish-buff silty clay.
" (?)	24-6-B	24-6	157-158	29.10	10.15	51.53	1.20	8.02	--------	Light brownish-buff clay with biotite.

* Analyses released for publication on condition that name of analyst remain confidential.

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