The Clays
of
Orange and Riverside Counties
Southern California

A Geologic Thesis

by

J. Clark Sutherland

Presented in partial fulfilment
of a
Degree of Master of Science
California Institute of
Technology
1930

TABLE OF CONTENTS

ABSTRACT

In this paper the author seeks to describe the geological relations and properties of the more important clay producing areas in Riverside and Orange Counties, Southern California. As a result of his work he finds that the clays are found in a particular Tertiary formation, of Martinez age. They were deposited under continental conditions at the edge of a gradually encroaching sea. The clays are invaribly associated with lignitic shales and coals and thus represent deposition in a humid, probably temperate climate under extremely reducing conditions.

INTRODUCTION

The most important clay producing areas in Southern California are confined to three counties, namely, in rapidly decreasing order of importance, Riverside, Orange, and San Diego. Only the occurences in Riverside and Orange county will be dealt with in this paper, as work has not been completed in the San Diego mines. The latter are very similar in type to the deposite immediately to the north.

Location of the deposits

Scope of this paper

Although the deposits have been described by ceramists or mining engineers in many papers in the past, no geologic work has been done on the clays of the Southern California district considered as a unit. The occurence of clay and the associated coal has been discussed in several geologic reports which deal with the material of a particular area, but no attempt at correlation of the clays as to age and conditions of deposition has been recorded.

Extent of previous work

The writer became associated with the Pacific Clay Products Company of Los Angeles in June, 1929, as consulting geologist. In the course of his work it became increasingly apparent that the importance of the geologic relations of the clays had not been recognized by previous workers, either in the ceramic or geologic fields. Work that was done before had been too purely concerned with one or the other particular science and no serious attempt had been made to correlate and substantiate the work of one with the other. The writer's previous training and his connection with one of the most important companies utilizing the clays thus gave him an opportunity to prosecute the problem from both a ceramic and geologic standpoint.

Acknowledgments

The writer wishes to thank the geological staff of the California Institute of Technology, particularly: Dr. J. P. Buwalda, for his general supervision of the work and correction of the geological portions of the manuscript; Rene Engel, for the suggestion of the problem, supervision of the mineralogical portions of the thesis; Dr. W. P. Woodring, for his help in whatever paleontological problems that were encountered and particularly to Mr. B. N. Moore, for his intelligent interest, suggestions and co-operation in the field work. The author also wishes to thank Mr. Robert Linton and the McClintock brothers (William, Charles and Gus) without whose co-operation, the collection of data and presentation of it in this report would be impossible. Acknowledgments are also due to Professor A. O. Woodford and Messrs. William Hill and P. H. Dudley of Pomona College who contributed many valuable suggestions.

Maps

The various clay producing properties described in this paper are located in the areas covered by the Elsinore and Corona topographic maps of the U. S. Geological Survey. The location and names of the principal mines are to be found on these sheets in rear pocket.

Previous literature

A list of the literature which the writer has found valuable is placed at the end of this paper, and is referred to by numbers intercalated in the text. The reader is particularly recommended to the works by Ries, Dietrich, Moore, Linton, Dickerson,and English.

Age of exploitation

Clay, as an easily exploited plastic material which man can shape and then harden by drying or by fire, was probably one of the first weapons employed by the human race in its battle against environment. The clay deposits described in this report have probably been used by men for thousands of years, for the migrating ancestors of the Indians probably worked down the coast, making it one of the earliest of the human inhabited areas of the Americas. Howlong ago the exploitation began is a matter of conjecture but we know that the Indians were using the clays when the Spaniards came. Since then, their use has gradually increased. However, the main impetus to their utilization came with the advent of modern industry in Southern California, when ceramic products were demanded in increasing quantity and diversity.

In the following classification of the types of clay, the writer has abbreviated considerably. For a more complete analysis, see the reports by Linton (11) and Dietrich (4).

Classification of the clays.

Generally speaking, the clays found in the areas described in this report comprise three main groups, namely, fire clays, refractory bond clays, and low vitrification point red burning clays. A brief description of the properties and uses of these clays follows:

The term fire clay, properly speaking, refers to those clays capable of withstanding a high degree of heat. They may or may not possess a high degree of plasticity. Those fire clays which possess good plasticity, and good bonding powers when wet, dry or fired are placed into a separate division-the refractory bond clays. Fireclays, to be used as such in the district, possess a fusing point above cone 27' (1605°c) and a fairly small shrinkage.

Fireclays

Those materials found in the area which belong to the restricted class of fire clays may be divided into three main classes: first, plastic; second, non-plastic; and third, flint fire clays. It will be readily seen that the plastic fire clay group overlaps strongly the refractory bond clays, different manufacturers using the same clay for the two purposes. In general, they possess a smaller shrinkage and a smaller fired strength than the bond clays. They usually are simply bond clays contaminated by a larger amount of sand. They contain a low percentage of fluxing impurities such as ferric oxide, lime, magnesia, and alkalies. They are universally white or grey in color.

Plastic fireclay

"Bone" fireclay

The non-plastic fire clays include for the most part those clays known as "bone" to the western states ceramist. Their distinguishing characteristic, aside from non-plasticity, is their pisolitic structure. This may vary from a few irregularly spaced angular grains included in the clay to a solid mass of rounded pisolites.

The author failed to recognize in thin sections of these materials any crystal which could be definitely identified as one of the alumina hydrate minerals. The concentric structure has been taken in common geological usage to indicate the presence of gibbsite, diaspore or an associated mineral. However, this criterion is apparently not diagnostic and should be applied with some caution, for certain clays high in alumina have been recorded by Shearer as showing pisolitic structure with little evidence of the presence of either of these two minerals. However, it has been noticed by the present author that the higher alumina clays of the district tend to be pisolitic and this tendency becomes more marked with greater percentages of alumina. Obviously the non-plastic clays are mixed with refractory bond clays in order to hold them together either in shaping, drying, or in burned state.

The flint fireclays develop but little plasticity even when ground fine and allowed to age. They are hard and flintlike, with a smooth, conchoidal fracture and possess a very dense texture. It is not known in what specific characters the flint fireclays differ from the ordinary plastic ones. In this district the variation might be accounted for in two ways. First, they may have

Flint fireclay

been deposited as materials which were not the same as other clays in the district and their present characters may thus be due to the fact that different rocks or different proportions of the same rocks, when decomposed gave rise to the clays; or that the materials which later formed the fireclays had gone further in the process of decomposition. Second, the flint fireclays may have gained their present distinguishing characteristics by secondary changes brought about by the decrease of organic colloidal material due to the greater amount of diastrophism that the region in which they are found suffered.

Uses of fireclays

There is almost an endless variety of uses to which refractory wares are subjected. Some must resist heat alone, others changes of temperature, resistance of abrasion or corrasion; many are called upon to resist tangentional or compressive forces while at a high temperature. Consequently, the aim of the manufacturer is to select a mixture of clays which will give a body having the properties best adapted to resist the conditions under which it is used. It is obvious that we cannot here list all of the products in which the fire clays of this district have been used. In general, however, they have been employed as an ingrediant in mixtures used in the manufacture of various shapes of fire brick, locomotive and furnace linings, saggers, etc.

Refractory Bond clays

The refractory bond clays include those clays which in addition to their refractoriness have a strong bonding power. They are all fire clays and the small amount of ball clays found in the district are included in this classification. In general, clays in this class should have a high transverse strength and should be able to bind less strong material together. In the area concerned, the plastic fireclays are in reality bond clays which, by reason of the sand included in the material, cannot be further admixed to any great extent with low strength materials. The qualities described in the plastic fireclays therefore also apply to this class and need not be repeated.

Red burnin[g] clays

The low vitrification point red burning clays include those materials which contain sufficient iron oxide or other fluxes so that they have the properties named. In general, they usually represent insufficiently leached material, either during the course of transportation or in place. In a few cases, the presence of the fluxes is due to solutions bringing in impurities from the outside, and depositing them in the pore spaces of the materials.

The specifications of this type of clay are: good plasticity, dry and burn without warping or cracking, good transverse strength when dry, freedom from soluble salts, as well as from lumpy impurities. The composition should be such as to permit the taking of a salt glaze, if necessary.

Necessary properties

The uses of this type of clay are innumerable, any product in which a red color or low firing temperature are desired being made of this material. Afew of the wares in which this type of material is used are: sewer pipe, bricks, and hollow and roofing tile.

Uses.

According to origin, the clays found in the district, fall into two main classes. These are residual and transported. Under the term residual are included those clays which have been altered to their present condition in place, that is, after deposition. Transported clays are those materials which have been substantially altered to their present condition before or during transportation. Secondary changes, of course, in which minor alterations take place occur in both classes.

Classification as to origin.

Most of the clays in the district and all of the purer types are transported clays. Thus, in terms of the classification according to uses, those clays which are refractory bond or fireclays are transported and the red burning clays may be transported or residual. Examples of transported clays include all of the Goat Ranch, Corona McKnight, Serrano-El Toro and Alberhill type of clay in Temescal Valley. Residual clays are represented by the Wildomar type of deposit.

SUMMARY

The transported clays described in this paper comprise many different types but are classified into three divisions according to their ceramic use. They are fire, refractory bond and red burning clays. All of these clays are found in the non-marine lower portion of the Martinez Eocene formation. They are derived from the weathered products of pre-existant formations, both sedimentary and igneous, whose feldspar minerals were dominantly plagioclase. Coal is found in close association with all sedimentary clay deposits and its presence is supposed to specify one of the conditions under which the clays deposited, namely, a humid moderate climate. On the basis of lithology and paleontology another condition is thought to be estuarine.

Since deposition profound diastrophic movements and erosion have taken place so that succeeding formations have been stripped away, leaving the clays irregularly exposed in various portions of the area concerned.

MINERALOGICAL EXAMINATION OF THE CLAYS

Identification and study of the relationships of the minerals which are found in the clay beds naturally subdivides itself into two main parts: first, examination of the coarse particles, and second, examination of the fine clay matrix. The two methods require an entirely different technique; the first is accomplished by separation of the coarse and fine materials by washing followed by examination of the coarse residue by the binocular microscope suplemented by the intensive study of the type grains under the petrographic microscope. The second requires the preparation and study of thin sections. Inasmuch as each method involves a certain technique which was evolved only after considerable experimentation, it may be helpful to give here a description of the procedures finally adopted.

Two methods of attack

Examination of coarse particles

Preparation

The clays to be washed were allowed to stand under water in large covered bowls a sufficient time to insure the softening preparatory to separation of the coarse and fine material. The flint fire clays were occasionally broken up by grinding the lumps with a pestle. The time required for complete soaking varied from twenty-four hours to a week or more. The bowl was then placed in the sink and a gentle stream of water was allowed to stir the sediments and to carry the lighter clay minerals off over the edge of the recepticle. After the water passing through the material became clear, the residue was examined. If the grains were covered with a foreign coating the material to be analyzed was boiled in a solution of HCL whose concentration varied between ten and five percent, depending upon whether the cement was ferruginous or calcareous.

Method of examination.

Due to the extreme preponderance in percentage of the quartz particles over the heavier minerals, and also the variability of the amount of sand in different specimens in the same bed, it was not thought practical to attempt quantitative analysis of the heavy minerals. The material was simply panned and the residue was examined under the binoculars. The concentrate was spread out on a plate and the various minerals were areally counted. Unfamiliar grains were extracted by a moistened needle and were examined by the conventional methods under the petrographic microscope.

Examination of clay matr[illegible]

The making of thin sections of clays involves long and discouraging practice of the manipulations necessary and the worker should be willing to devote many hours of effort before expecting to obtain thin sections of good size and thickness. A thoroughly dryed chip of the clay should be first ground as thin as possible on the side of an emery wheel, taking care to obtain close parallelism of the sides.

Preparation of thin sections

The chip, which should be slightly smaller than the glass slide, is then impregnated with canada balsam. This is accomplished in two ways. If the material is fairly porous, the chip is merely placed on a hot plate and the canada balsam, dissolved in xylol soon evaporates out of the balsam. This method suffices for the ordinary type of clay but if the material is too compact for this treatment the chip is immersed in a beaker of canada balsam more diluted with xylol than for the first treatment. The xylol is then evaporated off. Care should be exercised in both methods that the plate is not allowed to become too hot, for then the balsam turns a dark brown, or that the balsam is allowed to become hard and brittle. After the balsam is the right consistancy the chip is allowed to thoroughly cool and is then ready to be ground flat on one side. This is done by grinding by hand on a piece of plate class with fine abrasive powder. The mineral oil, Nujol, was found to be the best medium although water, kerosene, lubricating and olive oils were tried. After obtaining as flat a surface as possible, the chip is mounted on a glass slide and ground down on the other side. The entire process should be done by hand, although coarser powders may be used on the preliminary cutting. Care should be taken to avoid the wetting of the material by water during the entire operation, for the clay minerals easily dissolve out of the canada balsam matrix. After the slide is of the desired thickness it should be thoroughly cleaned with mujol. A cover class coated with balsam is then heated, and just before the balsam is of the right consistancy the slide is warmed and then the cover glass is carefully placed over the section, avoiding, if possible, its breaking up and floating off in different directions.

Mineralogical examination of clay material in thin section is very difficult for many reasons. First of all, the individual particles are so small that they cannot be readily distinguished. Portions of these particles do not represent the same chemical composition and grade into one another in birefringence, showing that variable amounts of water and degrees of crystallization are present; second, the literature on all the clay minerals, whether silicates or oxides, is very inconsistent in all the listed properties, whether mineralogical, chemical, or petrographic. Innumerable clay minerals have been described in the literature, at least fifteen new varieties having been added since J. A. Howe listed sixty-one in his "Handbook on Kaolin," which was published in 1914. However, it is extremely doubtful that all these species and varieties are all valid.

Difficulties of distinguishing specific clay minerals.

Ries, in his latest edition on "Clays-Occurence, Properties and Uses", names sixteen minerals as being common in clay andthere are probably very few others which are important enough to warrant consideration in this study.

The most fruitful lines of future investigation of the clay minerals and their classification will probably be in the study of the Xray diffraction pattern photographs and also of thermal analysis.

The writer felt it would be necessary to adopt some standard classification of the minerals in the clay and accordingly chose the system adopted by A. N. Winchell in his three volume publication on the "Elements of Optical Mineralogy" because of the accessibility, recency of the work, (1927) and the critical attitude of the author.

Divisions of Kaolin Group.

The writer also felt that it would be useless to attempt to classify the clay minerals of the specimens collected more precisely than by broad divisions. He accordingly has differentiated only between the following divisions of the Kaolin group: 1, Kaolinite; 2, Montmorillonite; 3, Halloysite. The distinguishing characters of the types are based mainly on their birefringence and indices, and were set as follows:

Kaolinite has the highest birefringence - about .006 or .007 with an index of about 1.56. Montmorillonite has a much lower birefringence- in the neighborhood of .002 or less and an index of 1.55. Halloysite is completely isotropic - with an index of 1.54. Distinction between Montmorillonite and Halloysite is very difficult because Montmorillonite may be amorphous and thus be isotropic.

Other minerals.

Chlorite is also a fairly common mineral in the clays but the writer was not able to always distinguish to what type it belongs. Hydromica, as used in this paper, is a term applied to those minerals which lie between the various micas and kaolinite in chemical composition and optical properties. In most cases, it has very likely the composition of sericite or damorite and usually occurs in fan shaped bundles or in typical sericitic-like aggregates. The recognition of the other minerals listed in the various sections offers no difficulty for they possess well known and universally recognized characters.

As an interesting comparison the theoretical composition of the clays was calculated whenever chemical analyses of specimens from the various beds were available. This composition was computed according to the procedure outlined by H. S. Washington

Computation of theoretical composition of the clays in terms of standard normative mineralogical molecules.

in 1918 closely following the principles of his classification for igneous rocks from their ultimate analyses, as published in 1917. It simply consists in the calculation of percentages of certain standard minerals present according to the relative proportions of oxides in the ultimate chemical analysis of the clay. Due to the fact that the various percentages of the oxides in the actual minerals present are averaged in the chemical analysis, the theoretical composition should not be taken too seriously, especially with regard to the clay minerals, where a molecular ratio of aluminum-silica-water may fit the description of a particular clay mineral exactly, but which may actually be due to a combination of two or more minerals whose ratios average the theoretical one. In the calculations, the undifferentiated alkali content in the analyses was figured as soda because of the great predominance of plagioclase feldspars over the orthoclase in the basement rocks in the surrounding region. The ferric iron was computed as limonite. The magnesia was put into serpentine, although most of it is undoubtedly contained in the clays as chlorite, whose chemical formula is considered too complex and variable to use conveniently. The remainder of the alumina was computed as present in kaolinite (Al_2O_3 - $2SiO_2$ - $2H_2O$) although halloysite and montmorillonite may be known to be present from microscopic examination. However, it will be noted that only a small percentage of the water lost in the ignition loss is not used up in the computation, and the remainder may well represent incomplete drying. It also will be noted that the percentage of water is always left over at the end, to be called fire water. The fact that some is left is a more favorable sign than the lack of it.

The reader should remember that the theoretical calculated mineralogical composition does not conform with the truth and the results are simply expressed in terms of standard mineralogical molecules.

GENERAL GEOLOGY

Introduction

The clay described in this report are found in the Martinez Paleocene formation. They outcrop discontinuously in a horseshoe shaped zone from Temescal Valley around the northern end of the Santa Ana Mountains and south down the seaward side of that range where the appropriate horizons of the sedimentary series intersect the land surface. Inasmuch as they occur in an area in which considerable crystal deformation has taken place, it is not surprizing that outcrops exhibit great complexity and diversity of structure. Accordingly, only a short survey of the general geological conditions will be attempted in this section, reserving the more detailed discussion of the relations for those portions of the paper describing the individual districts in detail.

Stratigraphy

Practically all of the ranges in Southern California are composed of a great variety of metamorphic and igneous rocks. Until very recently, very little was known about the so-called "basement complex" because scientists had preferred to work on the post-Jurassic sediments that lie on and around the mountain ranges. With the exploitation of petroleum an ever increasing number of geologists began to work in Southern California, and the broader feature of the stratigraphic geology were rapidly recognized. Investigators were compelled to do more and more detailed work and it was gradually realized that more should be known about the ultimate source of the sediments. Of recent years, many men have been devoting attention to the nature and relationships of the rocks making up the "basement" and we are coming to know more about them.

Basement complex

In the vicinity of the clay mines, Rene Engel and Bernard Moore of California Institute of Technology and P. H. Dudley of Pomona College have devoted considerable time mapping and studying the components of this formation as research problems; Dudley in the Gavilan mountains, Engel in Elsinore Valley on both sides of the trough, and Moore in the Central Santa Ana mountains. Both Engel and Moore's work has been in conjunction with the complete deciphering of the geology of the region and in consequence they were also concerned with the sedimentaries found in their districts. Most of the incomplete description of the basement complex here presented was either gained from or verified by these three workers.

According to R. Engel and P. H. Dudley, the east and west sides of Elsinore Valley are made up of schists, slates and basic lavas intruded by rhyolite porphyry which, in turn, are intruded by batholiths and stocks of grano-diorite, quartz-monzonite, and norite. Moore states that the materials making up the basement complex of the Santa Ana is a complex series of slates, tuffs, andesites, granodiorites and many other rocks.

The reader will note that with the exception of the rhyolite porphyry, the rocks of the basement complex of the entire region have, as an average, predominance of plagioclase feldspars over orthoclase. This has a very concrete bearing on the origin of the clays for it has heretofore been considered that most of the clays were derived by the decomposition of orthoclase feldspar from masses being eroded in the region. However, the results of this work seem to show that the clays were mainly derived from plagioclase rather than orthoclase alteration products.

Cretaceou formation

At least part of the metamorphosed rocks are of Triassic age, but the overlying Cretaceous is entirely unaltered. Thus the intrusives are probably to be correlated with Jurassic batholiths of the Sierra Nevada. A great series of Cretaceous sediments unconformably overlie the basement. In the Santa Ana Range, they can be divided into two main groups. First, the Trabuco formation, a red conglomeratic arkosic sandstone, about 200 feet thick, generally considered to be continental in origin because of its red color and lithology; and second, the Chico. The Chico, which is undoubtedly marine, consists of three divisions; a well indurated conglomeratic sandstone, much harder than the Trabuco and much lighter in color, the conglomerate lenses consisting of extremely well rounded pebbles of quartzites, slates and a considerable range of basic igneous rocks, which approximate in appearance the Chico over wide areas in California. They are overlain by considerable thickness of sandstone in turn grading into several hundred feet of finely laminated shales which are blue when fresh and light gray when weathered. These in turn are overlain by sandstones with conglomerate and shale lenses. The total thickness of the Cretaceous is in the neighborhood of 2000 to 3000 feet depending on where the section is measured. The lithology and induration of the Chico is fairly distinctive and it is readily recognized in the field.

Martinez formation

The Cretaceous is unconformably overlain by the Martinez formation, which is continental in its lower part and marine in its upper portion. It differs from the Cretaceous in its lighter color, which is buff or light green, and its comparative lack of induration.

The basal bed of the formation is a coarse conglomerate which has unmistakably derived its materials from the underlying Cretaceous. It consists of well rounded pebbles which are exactly similar to the pebbles of the Chico conglomerates, admixed with infrequent pebbles of conglomerates, sandstones and shales. The sedimentary cobbles exhibit the same lithologic characters as the corresponding units in the Cretaceous, the shales being particularly distinctive. The sources of the materials must have been rather near at hand for it is inconceivable that the shales would resist complete breaking up in such a ball mill as the bottoms of the streams would be in the presence of the well rounded cobbles of the conglomerates.

Basal bed

The basal conglomerate grades upward into a variable thickness of subangular arkosic santstone which in turn gives place to shales. These shales are almost universally lignitic in character. The carbon may be contained in the form of fossil reeds, or may be finely disseminated throughout the bed. Occasional lenses of coal are found which give evidence of being autochthonous by reason of the unbroken character of the fossil reeds present. In the case of the Alberhill coal, upright tree trunks and large pieces of fossil wood are also found. The clays, if present in the section, are immediately associated with the lignitic shales and are always found in the near vicinity of the carbonaceous materials. The presence of coal seems to indicate favorable horizons for end products of the various processes of alteration of silicates to hydrous compounds. Well sorted and bedded sandstones overlie the shales. They are remarkably constant in character, but they may contain thin lenses of conglomerates which resemble the basal bed. They also carry calcareous lenses in which distinctive Martinez invertebrate marine fossils are to be found.

The entire Martinez, both above and below the shales, is characterized by the presence of Chlorite. This may be considered as a distinctive feature of that formation, as it was not found in quantity in any other formation in the district.

Conditions under which deposited.

The writer has already stated that the character of the sediments indicate a gradual change from continental to marine type of deposition. In extreme cases, however, the change from basal conglomerate to fine shale is accomplished within a thickness of seventy-five feet. The frequent presence of coal which contains unbroken remnants of reeds and large pieces of wood indicate that deposition was continental. The writer has found a brackish water fauna in the shales just below the Alberhill clays closely associated with magnificent leaf impressions in the sandstones in the the shales are intercalated. This, coupled with the abundant reeds in the clay beds, indicates estuarine or swamp conditions. No marine fossils were found below the clay and shale zone but they are fairly abundant in the sandstones above.

These facts seemed to the writer to be conclusive evidence of a gradually encroaching sea. A reconstruction of the particular conditions which gave rise to the clays are given in another section of the paper.

The remaining Tertiary formations of the district need not be described here. No commercially important clays are to be found in them in the area described in this report. Good descriptions of the characters of the sediments by other writers are to be found in the papers previously mentioned.

Structure

The Coast Ranges are a series of north-west south-east mountains which form a broad belt along the Pacific Ocean from the Oregon line southward. They are supposed to owe their elevation primarilly to folding rather than to faulting. This generalization seems to accord closely to the truth from the Oregon border southward to the Santa Monica Mountains or to the Puente Hills.

Geographically, the belt continues with the same trend in the mountain ranges southward to the tip of the Lower California Peninsula. Geologically, folding gives place to faulting as the major mode of deformation in the southern province, as contrasted with the northern. Thus grounds for argument exist between the two sciences as to the affinities of this area. However, geologists are not agreed as to how large a preponderance, if any, of fold over fracture is characteristic of Coast Range structure. Of recent years, certain men have advanced the theory that faulting has also played an important if not major factor in the formation of the northern Coast Ranges. Whatever decision the future may give,it is certain that the forces which acted in the formation of the structures of the two units must have had some close relation to each other. The coincidence of magnitude and direction of deformation produced, and contemporanity of time, would indicate that the tremendous forces causing this geographically continuous belt of crustal failure were somehow linked together. Introduction

The Santa Ana, Gavilan and San Jacinto mountains are uplifted blocks, separated by graben valleys. The nature of the forces: compressional, tensional, horizontal or vertical, which produced the deformation is not clearly known but it is certain that we will know more about them when the causes and history of the San Andreas Rift to the east are deciphered.

The Gavilans

The Gavilan mountains are an irregular mass of old crystalline rocks from which all unmetamorphosed sediments have been stripped. The mountains lack the continuity of outline and height that marks the other ranges of the district to the east and west, but they probably also owe their present elevation to the widespread structural readjustment which took place during late Tertiary and Quarternary time in Southern California. They are bounded on the west by a possible fault which separates the mountains from Temescal Canyon.

Elsinore Valley

Temescal Canyon and its continuation, the Elsinore Valley have been aptly termed by Engel (5) a composite graben. The trough is a series of slices lying between the Gavilan and Santa Ana horsts. It is bounded on the western side by a major fault zone along which movement must also have occured in very recent time. The Gavilans rise about 1200 feet above the surrounding valley floors but they shrink into insignificance when they are compared with the towering Santa Ana Range. From the Temescal Valley at its foot, the Santa Anas rise majestically to Santiago Peak, a vertical distance of 4500 feet in three miles. This range represents the eastern edge of a westward tilted block, which is bounded on its eastern edge by a series of step and tear faults, breaking the steep rise of the slopes from the graben floor. The crest of the range is composed of the metamorphosed sediments and the intrusives of the basement complex, upon which the Mesozoic and Cenozoic sediments of the western side of the range lie. These sediments dip under the Irvine Ranch valley and lap up on the side of the mountains with increasing dips. Thus, the most recent formations are to be found at the bottom of the slope and successively older formations are encountered as one moves toward the center of the range. Opinions differ as to the western boundary of the Santa Ana block. They alfo differ as to the manner of uplift. One theory postulates longitudinal warping of the block as well as the undoubted lateral warping so that the sediments gain increasing dip as they swing higher and higher in the range, finally giving way to the basement complex. The other stipulates the continuity of slope between the mountains and the Laguna Hills and advances the idea that the valley between was cut out by continental or marine abrasion and postulates a siiple rigid block which has had broad folds developed in the sediments

Santa Ana Range

on its back. Obviously, this question cannot be settled here, but the fact that the sediments have an ever decreasing dip from the flanks of the range to the bottom of the sycline and then rise in a broad anticline in the Laguna Hills suggests uplift and warp of the Santa Ana block with a broad wrinkle at its base to account for the shortening necessary at the top of a hinge line when the block for which it acts as a fulcrum swings upward.

As was indicated before, block faulting is the main structure in the region. Folding of the sedimentary formations in which the clays are contained is primarily dependent on and caused by the faulting movements. Consequently, in those areas which are not faulted, the geological relations of the clays are rather simple. The sediments of the Temescal Valley in general form a broad northwest-southeast syncline in which the sediments lap up on the sides of the trough. This syncline is warped into folds which have axes perpendicular to the valley depression. This structure is so remarkably constant that the same horizons of the Martinez sediments are exposed again and again.

Summary of structu of various localities described

Clays also outcrop immediately to the northeast of the edge of the Santa Ana block, in the foothills of that range southeast of the town of Corona. Vertical, thrust and possibly horizontal faulting movements along the Chino, Whittier, and Elsinore block faults have here produced very complicated relationships of the beds containing the clays.

The clays of the so-called Goat Ranch at the north end of the Santa Ana Range are considered to belong to the same horizon of the Martinez as the McKnight Corona clays. The sedimentaries in this locality dip towards the Santa Ana River off the Chico Cretaceous formation in a monocline.

The beds lapping up on the range swing southward from that point. In the central Santa Anas the formations regularly dip off the granitic core toward the edge of the block to the wouthwest. The Martinez is thus exposed in a broad belt which roughly parallels the basement sedimentary contact of the Cretaceous to the east. A bed called the Serrano-El Toro clay, which belongs to a slightly higher horizon than the Goat Ranch-Corona, but may represent the equivalent of the Alberhill clays, outcrops continuously except by minor displacements over a distance of about eight miles. In general, the beds dip southwest very steeply, 60° or more, throughout this belt, but flatten rapidly down the slope.

Thus the clays,occur in beds which vary in all positions from horizontal to vertical and strike in all directions, depending upon local structure.

TEMESCAL VALLEY CLAYS

Importance of this district.

The clays found in Temescal Valley make it one of the three most important clay producing areas in the state of California in point of quality, variety and tonnage mined. Production from this area has increased from year to year so that now about 100,000 tons a year of over thirty distinct varieties of clay are mined from the various clay producing properties by the five major operators. This wide variety of clays is being largely produced from only three localities, but numberless pits, scattered throughout the valley, attest the activity of the property owners, and the potential resources of the Canyon for the future.

That portion of Temescal Valley from which clays have been taken comprises an area thirteen miles long and two miles wide, running from the town of Corona on the north to a point a few miles below Elsinore Lake on the south. Although the clays outcrop among the sandstones and shales with which they are intercalated only in irregular patches over this wide area, and they vary widely in each outcrop, a surprising regularity and continuity of type is found in the materials from one pit to the next.

On account of the conformity to type, the writer has deemed it advisable to give a full description of only one of the districts and to mention in what particulars the other diverge from this locality. Inasmuch as by far the greatest percentage of the tonnage mined comes from the Alberhill district, and the greatest diversity of types of clay is produced from that locality, he has felt that on account of its economic importance this should be the section described.

Stratigraphy in the valle

The only formations which outcrop in the Valley are metamorphic shists and quartzites and their intrusives, the Martinez and Quarternary fan and terrace deposits. As has already been stated, at least a part of the metamorphosed sediments are Triassic in age. They consist mainly of thinly laminated siliceous phyllites which usually strike parallel to the valley with a very steep dip. Massive quartzite beds are intercalated in these schists. The schists are extremely fissile and weather into thin flakes which may be easily dug out with the geologist's pick. It resembles to a remarkable degree in appearance the siliceous shale found in the Modelo or Monterey formations. Due to its cleavability, it does not resist erosion as well as the quartzite lenses and thus the metamorphosed sandstones stand out as reefs above the swales of schist.

No Cretaceous sediments were seen in the valley. According to Rene Engel, it is extremely doubtful that the Cretaceous sea extended that far inward. At Alberhill, the only place the writer has clearly seen sediments lying with depositional contact on the "basement," the clastics are Martinez in age.

Martinez formation

Very little difference is to be observed between the Martinez of the Santa Ana Mountains and that of Elsinore Valley. Only the sandstones of the middle portion of the formation were seen. The basal conglomerate does not outcrop in any portion of the valley studied by the writer and no sediments which resemble the overlying formations of the Santa Ana Mountains were noticed. The sandstones appear to be somewhat better sorted, the individual beds of shales, sandstones, and very infrequent conglomerates being better defined. The lower section of the Martinez, which is thought to be continental in origin, is very much softer than the upper marine portion by reason of its lack of calcerous cement. The sandstones below the clays are very soft and may be easily dug out by an ordinary shovel. They consist of well sorted and bedded arkosic sandstones containing considerable amounts of chlorite, muscovite and biotite, the chlorite being by far the most frequent of the micaceous minerals.. Frequently, thin lenses of shale are found intercalated in the sandstones below the clays. They consist of very fine thinly laminated argillaceous beds which contain considerable organic matter. As a result, they usually are colored a dark gray or black. Upon weathering the dark color fades and the shales become a light grey. They are extremely fissile but they are much more indurated than the sandstones above and below.

Upon breaking, they emit harsh and shrill crackling sound, and give forth a strong odor of crude oil. Most of the shales yield oil upon destructive distillation. Some of the material is reported to have given up as much as twenty gallons to the ton to a now defunct company located at San Bernardino. Property owners have firmly convinced themselves that great quantities of oil underlie the valley. Consequently, wildcat companies find no difficulty in financing drilling projects and numerous oil wells, many more than the structure or probability of paying quantities of oil would justify, have been drilled. Any person coming into the valley who admits possessing geological knowledge is immediately besieged with favors in return for which donors expect and ask for information concerning possibilities of oil on particular pieces of property.

Fossils

The non-marine horizons of the Martinez occasionally contain a fauna and flora which establish thei continental origin beyond all doubt. Brackish water pelecypods were found in a bed of shale at the abandoned brick plant at Terra Cotta in the bottom of an old well. They probably are to be referred to the genus Corbicula, although this is uncertain. They lie about forty feet stratigraphically below remarkably fine leaf impressions along the bedding in the sandstones. These may be collected in a pit immediately to the north of the home of Charles McClintock at Terra Cotta. The leaf impression horizon does not lie more than, and probably less than, 150 feet stratigraphically below the clay beds.

The sandstones above the clays have a tendency to be slightly more reddish in color. They contain calcareous lenses which may carry marine invertebrate faunas characteristic of the Martinez. Such fossils were found on the end of the spur running down to the Atcheson and Sante Fe railroad track immediately south of the gas station at Lee Lake about 5 miles northwest of Alberhill. The particular reef in which the fauna is found is a very fine grained calcareous sandstone which, when fresh, is very tough and hard. It lies about 300 feet above the clays exposed in the Pacific Clay Products Company's pit at Twin Springs. Fossils found there include giant Venericardias, which cannot be referred to any definite species, and Turritella pechecoensis Stanton.

The Martinez both above and below the clays, marine or non-marine, is characterized by the presence of chlorite. It occurs in greater or less extent throughout the clays, shales, sandstones or conglomerates. It constitutes a distinctive litholgic characteristic which is of great value in mapping.

Quaternary deposits

The Martinez is unconformably overlain by a variable thickness of fan and alluvial material. At sometime during the uplift of the Santa Ana Mountains, the streams that normally flowed westward to the sea were unable to maintain their courses across the more rapidly rising central portion of the range. They were diverted and sought new outlets by flowing along the base of the scapp. Remnants of the deposits of this river are to be found beveling the Martinez at almost every place where the Eocene formation is exposed. They consist mainly of coarse conglomerate composed of well rounded boulders of the igneous rocks of the region predominating in monzonites, imbedded in a matrix of very arkosic coarse sandstone containing weathered feldspar, quartz, muscovite, and biotite. The boulders average about four inches in diameter although they may occasionally contain cobbles up to two feet or more in thickness. Intercalated in these conglomerates are to be found lenses of sandstone which resembles the above described matrix of the conglomerate. They are easily distinguished from the Martinez by their unsorted character, lack of induration, the extremely arkosic nature of the material, and the sharp unconformable contact at their base. That considerable deformation has occurred since their deposition is proven by the present irregularity of the dips of the beds of the material from locality to locality, by the fact that they have been deeply dissected, and by the fact that no corresponding stream can now be found, present topography not being favorable to such a stream.

Structure

As was indicated in the section on general geology, structure in the valley as in the entire district is primarily due to faulting rather than to folding. The Temescal and Elsinore trough is a complex graben lying between the Santa Ana Range and the Gavilans. It is broken up into slices which follow the longitudinal axis of the depression. Ordinarily, in the clay district, only the bottom slice is topped by unmetamorphosed sediments. However, occasional further longitudinal faulting is observable in this unit. The beds within it ordinarily dip away from its edges, forming a cyncline rises and plunges so that the clay beds are exposed in a variable position in the various portions of the slice both laterally and longitudinally, that is, outcrops of the clays swing out on a plunging syncline and vice versa. This structure is so constant that the clays are irregularly exposed over a considerable distance. At Alberhill the clays dip about five to twelve degrees to the southwest down the clope of the hill and come up on the other side of the valley. This syncline plunges at a rate of about 125 feet to the mile for a distance of about two miles to the northwest.

In a series of beds competent to withstand stresses that the sandstones, shales and conglomerates possess in relation to interbedded clay members, it is natural that any deformation in the more resistant beds by diastrophism or loading is reflected manyfold in the incompetant clay strata. While the structure of Temescal valley is, in general, rather simple, considerable movement has occurred along the fractures bounding and included in the trough block.

These movements are merely adjustments of the crust in response to powerful vertical and horizontal forces. The thickness of the clay member varies widely from locality to locality as a result of yielding to different modifications of these stresses. Individual clay strata thin and thicken as a reflection of the larger variance, they also vary so widely in character that correlations of the individual beds between different pits is difficult or impossible. On account of this multiplicity of detail, it would be futile to describe at great length the character, thickness and uses of the individual strata in each pit.

Alberhill District

Because of its importance in the ceramic field, Hill, Burchfiel and Dietrich have already given a full account of those aspects of the Alberhill district which are of interest to that profession; namely, by the quantities and qualities of the various materials present. Thus, for a detailed ceramic survey the reader is referred to their publications.

Generalizations as to the average thickness of the clay stratum are rather dangerous. Only a portion of the section is present or exposed at each pit. Stratigraphic relations of the individual beds seen are difficult to discern. However, the writer has been able to measure several sections and the clays are very close to 100 feet in thickness.

In each complete section in this district three main types of clay may be distinguished, namely:

1. Refractory bond clays and white or buff burning fire clays, possessing a good plasticity, fairly high fusion point and usually have good bonding power when wet and burned. Like the fireclays, they are usually associated with carbonaceous clay or coal. Types of clay

2. Refractory bone clays having a very high fusion point, are white or buff burning, and possess a poor plasticity. They contain a high percentage of alumina and are usually pisolitic.

3. Red burning clays which fuse at a lower temperature and are used for products in which a lower vitrification point is desired. On account of their containing ferric iron they are usually pink or red, although when the ferrous variety is present they are green.

A description of a representative section of the clays as found in the main pits of the locality follows:

1. Yellow top clay--a slightly gritty tough blocky clay possessing good plasticity. It has had a good deal of limonite and vegetable acid staining. It finds its main use in sewer pipe mixes. About 20 feet of it is exposed at the main pit at Alberhill. Yellow top clay

2. Main Tunnel Clay--A gray white blocky clay possessing semi-conchoidal fracture. It contains considerable fairly coarse sand in irregular patches, particularly in the upper portion of the beds, the lower portion being finer and slightly carbonaceous. Main Tunnel Clay

The heavy minerals found in this clay include in order of importance: magnetite, ilmanite, apatite, zircon, and tourmaline. A thin section of the clay reveals that the coarse sand particles are quite angular. Their matrix is a fine grained clay material in which kaolinite and a brown fibrous mineral are by far the largest of the grains seen. Halloysite and the ordinary montmorillonite are also present, the matrix, in general showing very great change in light passed through under ordinary and crossed nicols. An estimation of the percentages of the materials gives Quartz 10%, Kaolinite 25%, Halloysite 25%, Montmorillonite 20%. The brown fibrous mineral which constitutes about 20% of the area, is probably replacement of cellulose.

Chemical analysis of a speciman of the bed furnished by the Pacific Clay Products Co. is given on the following page:

CLAY	Ig.Loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Alk.
Sandy Main Tunnel	6.97	72.56	18.73	.63	.54	.22	.30
Fine Main Tunnel	12.34	59.32	25.67	1.67	.58	.26	.10

Computation of the mineral analysis by H. S. Washington's method gives the following results:

SandyMain Tunnel	Quartz 49.5	Kaolimite 44.	Serpentine .8	
	Limonite .7	Orthoclase 1.67	Anorthite 2.50	Ig.Loss .63
Fine Main Tunnel	Quartz 28.6	Kaolimite 60.5	Serpentine .6	
	Limonite 2.8	Orthoclase .56	Anorthite 2.78	Ig.Loss 3.4

The ignition loss in the first instance is probably represented by excess free water, in the second by included carbonaceous material. A very large quantity of this type of clay is mined. At the main pit at Alberhill it is about thirty-five feet in thickness. The material possesses a good working plasticity but the amount of sand within the clay cuts down its plastic strength. It has a high fusion point cone 30 (1650° C). It is very widely used for firebrick, terra cotta, art tile, and for similar purposes.

3. Coal stratum--As was indicated above, the clays become finer towards the base of the Main Tunnel. This clay is floored by an impure coal bed, portions of which are pure enough to justify mining in the past for lignitic coal. Other portions of the bed contains enough clay so that the material can be used as such.

Coal bed

A chemical analysis of an argillaceous specimen follows:

	Ig.Loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Alk.
Coal Crop	33.84	35.35	20.74	2.52	.90	.15	1.18

Computation by H. S. Washington's method of the theoretical mineral content gives the following results: Carbonaceous materials, of course, is lost in ignition. This accounts for its high percentage in the first set of figures. The second set of figures represents the results obtained by eliminating the ignition loss and redalculating to 100%.

	Ig.Loss	Quartz	Kaolinite	Serpentine	Limonite
C.C.	30.1	5.84	48.8	.67	2.84
		8.3	81.00	1.	4.05

Orthoclase	Amorthite
7.00	4.45
10.00	7.45

In common with the other beds the coal stratum is subject to considerable variations in thickness. However, the more purely lignitic portions of the bed are much more constant in this respect than the more incompetant orgillaceous parts. However, the average thickness as exposed in the main pit at Albehill is about six feet.

The mines at Alberhill were originally opened by the combined families of Alber & Hill for the purpose of exploiting the coal. Inasmuch as eight feet of lignitic coal is present in some places, the project enjoyed some success, in spite of the high ash content of the material. The lack of heating materials in the valley and also the lack of a railroad to transport those materials made coal valuable. The clay was simply thrown aside. Of lateryears, only the mexican laborers mine the coal for their own use. The argillaceous portion of the bed possesses an excellent smooth plasticity, medium high dry strength, and when fired, a white or buff color. It softens at cone 30 (1650°C) On account of its smooth texture its excellent working and fired properties, it is widely employed in dry pressed brick, art tile and saggar mixtures.

4. Bone Clay--The coal is underlain by a high alumina bed which may or may not be pisolitic in character. When it is not pisolitic it is a plastic clay used as a ball or refractory bond material. "Bone" Clay When pisolitic, it is non-plastic and is termed "bone". Its oolitic character may vary from a few sparsely distributed angular oolites to large round pisolites. Heavy mineral separation of the very scanty coarse particles was not attempted. A thin section of the plastic material locally termed S.H.4, reveals that practically all of the minerals in the clay are isotropic or nearly so. The mass is so extremely fine grained that distinction and identification of the individual minerals is very difficult, even for the largest grains. A small amount of hydromica and chlorite was seen. Estimation of the per-

centages of the minerals present is necessarily based on poor evidence. The author estimates that about 85% halloysite, 3% quartz, 10% carbon and about 2% of hydromica are present. Apatite, zircon and rutile also appear in the section. A thin section of the bone clays shows, rather unexpectedly, about the same birefringence as the plastic clay. However, a very weakly anisotropic mineral is present which has about the right amount of birefringence for montmorrillonite. The pisolites seem to be composed of rings of ferruginous material. Percentages of the minerals present are about 80% halloysite, 10% montmorrillonite, 5% goethite, and 5% quartz.

The uses of this type of clay have already been discussed. That called soft bone is ground and used refractory wares, the hard bone is calcined and used as grog in the same materials. At the main pit bed is about four feet thick.

5. Red Burning Clays--Below the bone clay red burning clays are found. They are usually termed pink mottle, due to the appearance given them by irregular patches of ferruginous staining. In general, this type of clay was laid down under conditions in which they were not as well leached, either before or after deposition, as the materials above. They

Red burning clays.

were deposited inmuch coarser form and may grade into conglomerates which show a great deal of alteration. The character of the material in the field and under the microscope suggested to the author that they have received considerable alteration in place by secondary changes. Clear evidence of this fact is found in the material when examined under the microscope. A thin section shows that it is composed of coarse rounded pebbles which appear originally to be made up of every sort of material but they predominate in acid volcanic material which probably, by reason of its quartz phenocrysts, represents a rhyolite or similar rock. Deposition, then, was in the form of an altered conglomerate arkosic sand or silt and considerable decomposition must have occurred after deposition. The abundant presence of humic acid in the coal above the pink mottle probably indicates the agency. The minerals as estimated from thin section are present in the following proportions: Quartz 60%, kaolinite 20%, colloidal iron 15%, halloysite 5%. Apatite, zircon, tourmaline and rutile were observed in the section.

Field evidence found of these secondary changes is described in the discussion of the "Pink Mottle Pit" clays immediately below.

In practically all the pits, the red burning clays form the base of the producing horizon. They vary widely in thickness usually constituting the most abundant type of clay present. They have to compete with the much more easily accessible clays in the Los Angeles District, which are all of this type. As their main market is in that portion of Southern California, transportation either in their raw or burned state is one of their biggest handicaps. However, with the rapidly approaching exhaustion of the closer materials, they will come into more popularity.

The clays immediately across the valley from Alberhill are exposed in several pits mined by two companies. In the stratigraphically lower "Pink Mottle" pit at the Los Angeles Brick Co. property the section is composed going downward of bone, pink mottle, very ferruginous red plastic clay, white burning clay and a large thickness of arenaceous red clay. In this particular pit, the pink mottle bed grades into an altered conglomerate bed. The pebbles and granules of the conglomerates show a big preponderance in acid volcanic flow material, probably a rhyolite. Quartzites, schists, shales and a variety of other rocks are present in minor quantities. Considerable quartz sand is also present which is very angular in form. The granules of

Pink Mottl pit.

the material vary from angular to well rounded, the preponderance being sub-angular. While the material unquestionably has been transported some distance, the preponderance of the rhyolitic material would seem to indicate that a flow was one of the largest componets in the distributive province which gave rise to the deposits being laid down in that particular locality at that time. This would also seem to postulate a large mass of that type of rock being eroded close by, indicating either exhumation or somewhere nearly contemporaneous volcanic activity.

The presence of such mass contributing in so large a part to beds immediately below the clays suggests the fact that the more leached, transported clays which overlie it probably have also received a larger portion of clay derived from this type of material than previously had been supposed. However, the utter lack of structures in the white clays which are characteristic of the pink mottle would seem to indicate more complete alteration before deposition.

The Morton Pit lies in the Arroyo Del Toro to the east of North Elsinore, The stratigraphic succession, as far down as they have mined, is the same in ceramic and physical properties as Morton Pit the Alberhill mines. Yellow clay is followed by white plastic clay which in turn lies on top of coal. The section appears to be perfectly analogous. Mining in this property started very recently but is being pushed forward rapidly by the owner, whose pit bears his name. The clays are sold to the various manufacturers.

Closely to be correlated in type of clay as the Pink Mottle Pit and possibly as to horizon are clays in the Harrington Pit in the upper end of the valley. The same succession is present, that is, bone, pink mottle, highly ferruginous plastic, white burning refractory plastic and a huge thickness of arenaceous red clay. The ceramic properties are closely akin to the Alberhill district clays. Harrington Pit

This completes the list of the principle transported clay pits in Temescal Valley.

The only pit south of the town of Elsinore that produces clays, as far as the writer knows, is a small mine which is called the "Wildomar Kaolin Deposit" in ceramic literature. It would not deserve mention in this report except for the fact that it represents a different origin than the clays further to the north, the clays being residual. Wildomar Pit

The deposit lies 2.6 miles southwest of the town of Wildomar on the main highway to Murrieta about one-fourth mile east of a prominent and the only bend in the road between the two towns. Considerable stripping of the deposit has been done in the development and mining, so that good exposures are to be found. Location

The beds strike N 37° W and dip 26° to the south. They plunge under the alluvium of the valley but were not observed coming up on the other side. At the top they are terminated by a very sharp line which has a very distinct topographic expression in sharp breaks in slopes of the spurs running out from the hill into the valley. These notches possess a good alighment which when measured proved to have the same strike as the beds (N 37° W). The accordant height and alighment of the notches at the contact would physiographically indicate a fault. However, it seemed to the writer the two directions of strike would, under the laws of probability, only coincide if the faulting, if any, should be the main cause of the present attitude of the beds. The material of the hills to the back of the beds is basement complex and is clearly older than the clays. Uplift of the hill with respect to the valley block would conform with the relationships shown and Structure would also produce drag in the materials along the fault, which would presumably conform to the strike of the plane of movement. This last explanation seemed to the writer to best fit the field relations.

Derivation

The clays themselves are clearly derived from very acid lava flows. These lavas have been very little altered and the original structure of the igneous material is clearly to be seen. The beds consist of rhyolites and rhyolitic tuffs which are pumaceous and agglomeratic. Several flows make up the total section, the various members being indicated by a glassy and cooling cracked base and brecciated lava cemented top. The beds break very easily along the bedding planes of the flows and also along lines of flow structure.

Minerals

A thin section of a specimen taken across the flow structure of this material shows characteristic rhyolitic texture. Under ordinary light, typical stringers of material enclosing bubbles and phenocrysts are to be seen. Under polorized light only corroded and somewhat oriented quartz phenocrysts can be observed, the matrix being istropic glass. The extremely acid nature of the rock is shown by the presence of this type of phenocryst, and by the following ultimate chemical analysis from the laboratory records of the Pacific Clay Products Company of Los Angeles.

Clay	Ig.Loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Alk.
Wildomar	7.78	70.14	14.97	1.61	1.58	.09	3.94

The materials comparative lack of alteration is brought out by its extremely high alkalic content. It is even better shown in the results of Computation by H. S. Washington's method of obtaining mineralogical content of clay from the ultimate analysis.

Quartz	Kaolinite	Limonite	Serpentine	Orthoclase
42.48	19.7	2.16	2.22	23.2
		Anorthite	Freewater	
		7.9	4.7	

The very high free water content probably indicates that a good deal of it has combined with the alumina silicate of the feldspars but leaching of the alkalies and calcium oxides has as yet been incomplete.

Properties and uses.

The clay is non-plastic and is used as a filler in various mixes. It burns brown at a rather low temperature but possesses a very low shrinkage. Considerable quantities have been mined in the past by stripping and hand loading methods and also by a shaft sunk to follow the bed beneath the valley floor. However, very little use has been made of the deposit in recent months.

Residual clays are also found immediately to the north east of Alberhill across the canyon. They represent alteration of an rhyolite intruded between the grano-diorites and schists of the basement complex.

PLATE I

Figure 1. Elsinore Valley from the Douglas Pit at Alberhill, looking northwest. The Santa Ana Mountains are on the left, the graben valley of Temescal Canyon in the center and the Gavilans on the right.

Figure 2. Alberhill district looking east from across the valley. Hill in the middle distance is the one in which the Alberhill mines are located. The large pit in the center is the Main Pit, the one at the north side (left) the Douglas Pit. The pit in right foreground is the Pink Mottle Pit of the Los Angeles Brick Co.

PLATE II

Figure 3. Close up of Main Pit at Alberhill. This is the largest clay mine in California. The beds exposed that have been mined comprise a total thickness of over fifty feet.

Figure 4. Character of clay bed illustrates vertical variation in beds, which nedessitates hand mining methods. Plastic fire clay above and below thin bed of coal. Taken at Douglas Pit.

PLATE III

Figure 5. Panorama of Douglas Pit taken southeast to west. Showing character of clays, methods of mining and a representative section. Main Tunnel, the coal bed and a clay stained by ferruginous matter locally called "Lower Douglas" are the principal beds to be seen in the photograph.

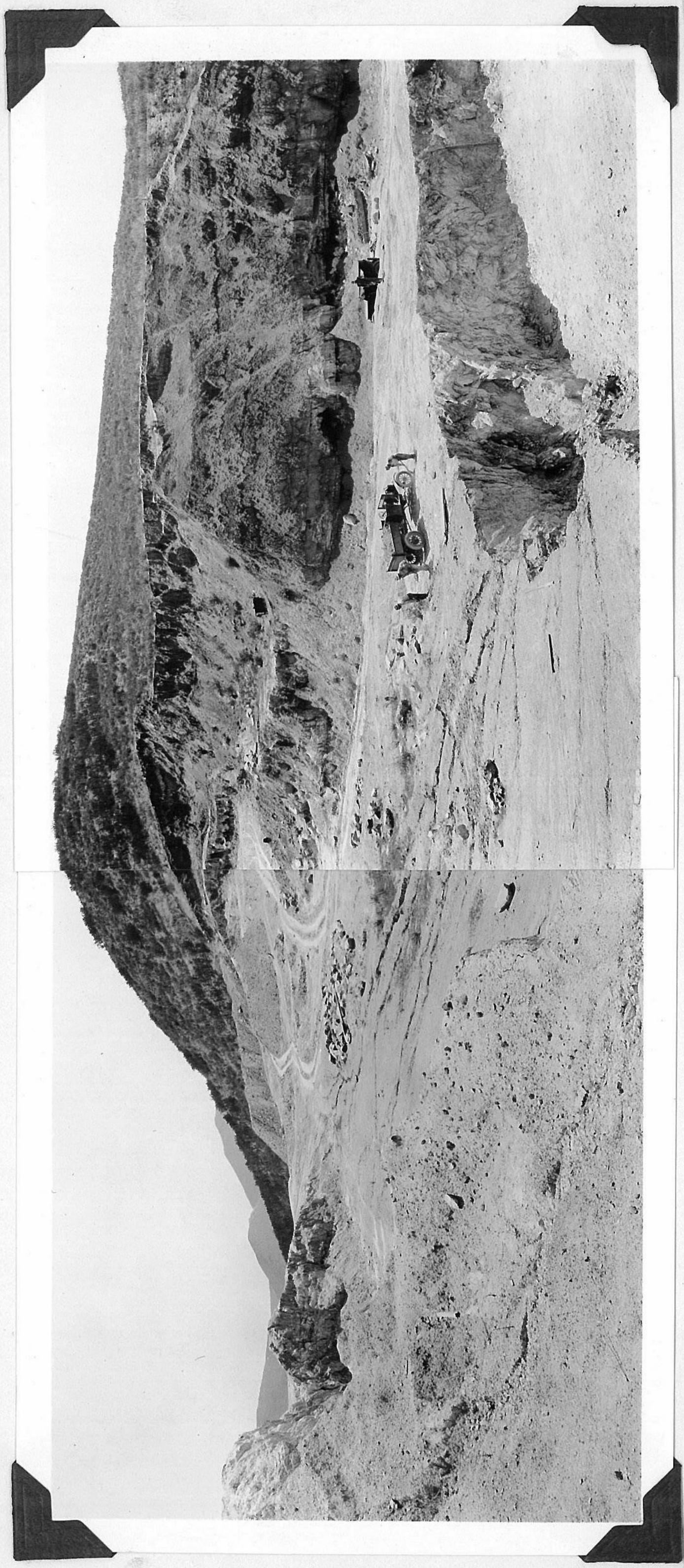
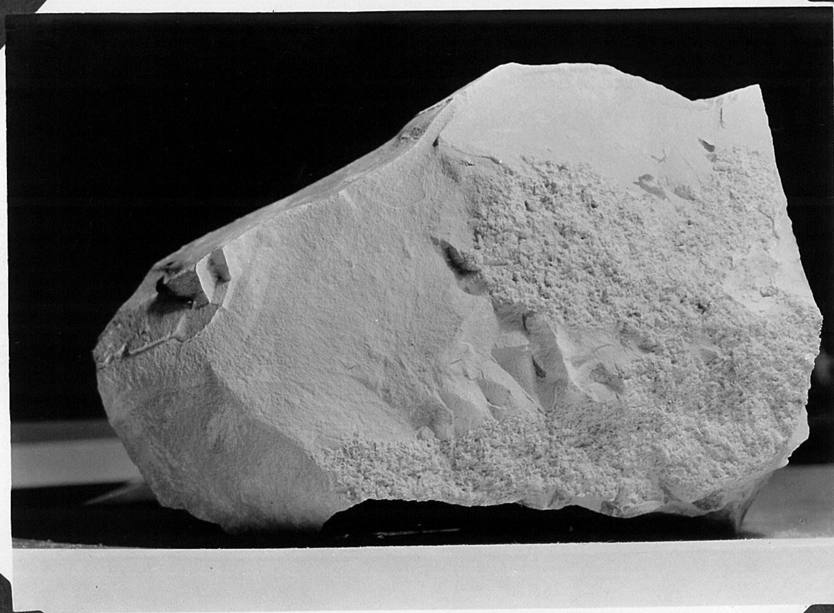


PLATE IV

Figure 6. Main Tunnel Clay-Megascopic appearance, showing blocky character and irregular patches of sand within bed. Taken from upper portion of stratum. Natural size.

Figure 7. Main Tunnel Clay Microscopic appearance showing its texture. Specimen taken from bottom portion of bed, which is less sandy and more carbonaceous than top part. Taken with a magnification of ordinary light, 100 diameters.



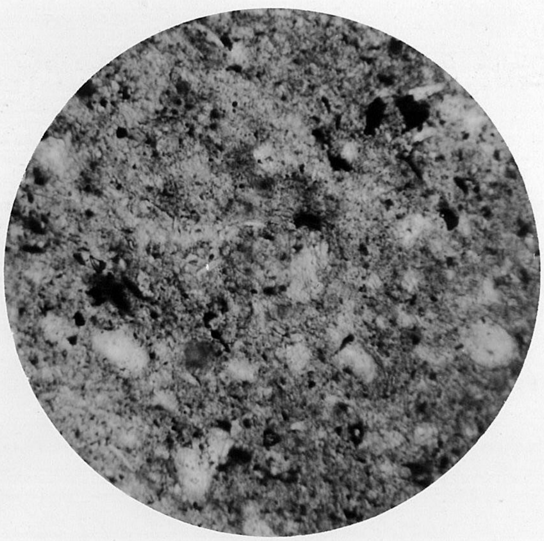


PLATE V

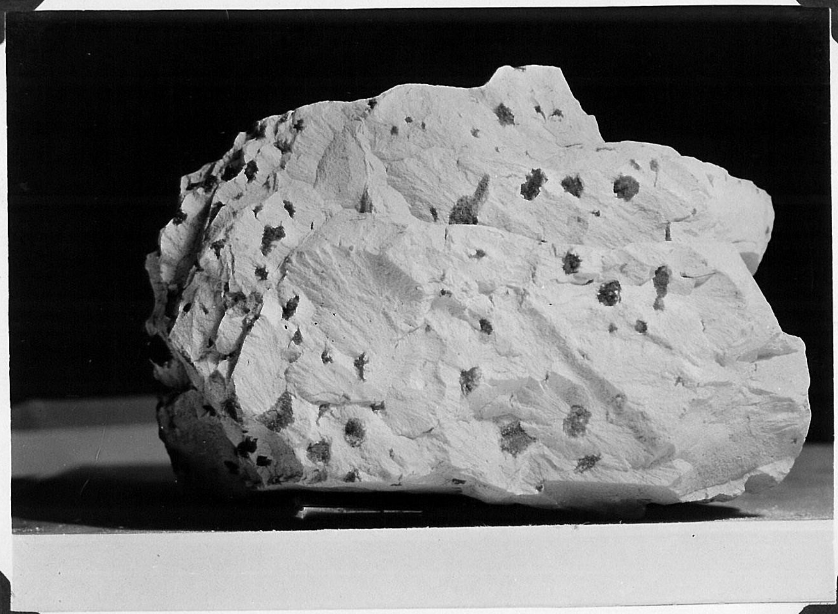
Figure 8. External appearance of coal bed showing its well bedded character. Upright trunks of trees are found in the mass.

Figure 9. Close up of a hand specimen of carbonaceous clay which represents the same horizon as the coal. Shows variations in the amount of finely disseminated carbonaceous material. Natural size.

PLATE VI

Figure 10. Mon-plastic "Bone" clay. Megascopic appearance showing angular, irregularly spaced segragations of darker ferruginous material. Natural size.

Figure 11. "Bone" clay. Microscopic appearance, showing fine texture. Taken with ordinary light with a magnification of 100 diameters.



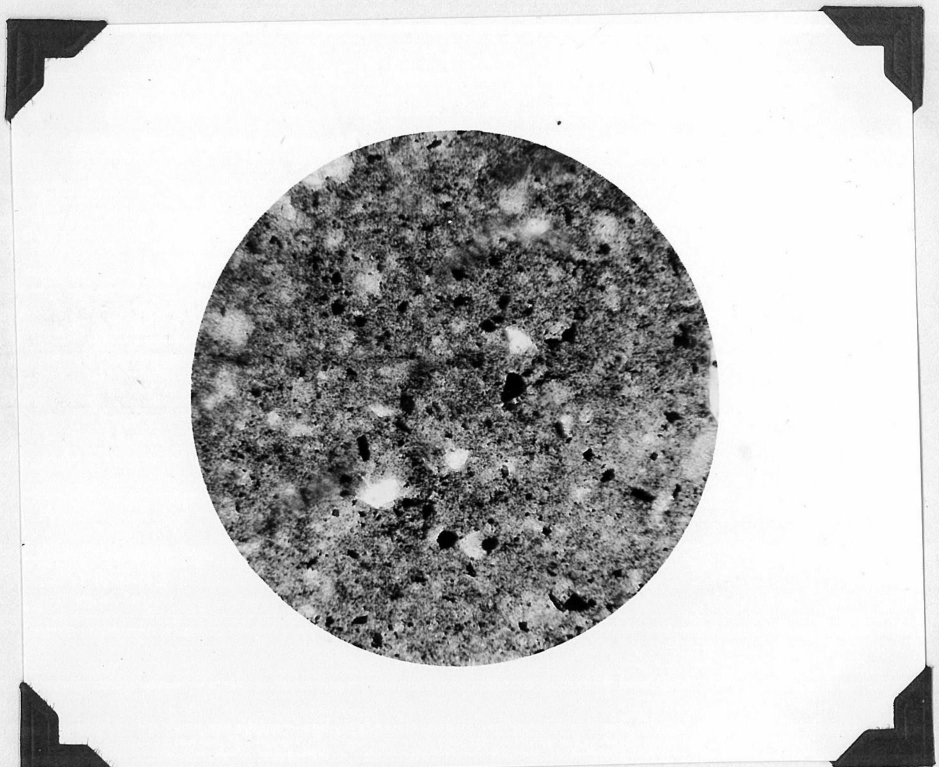
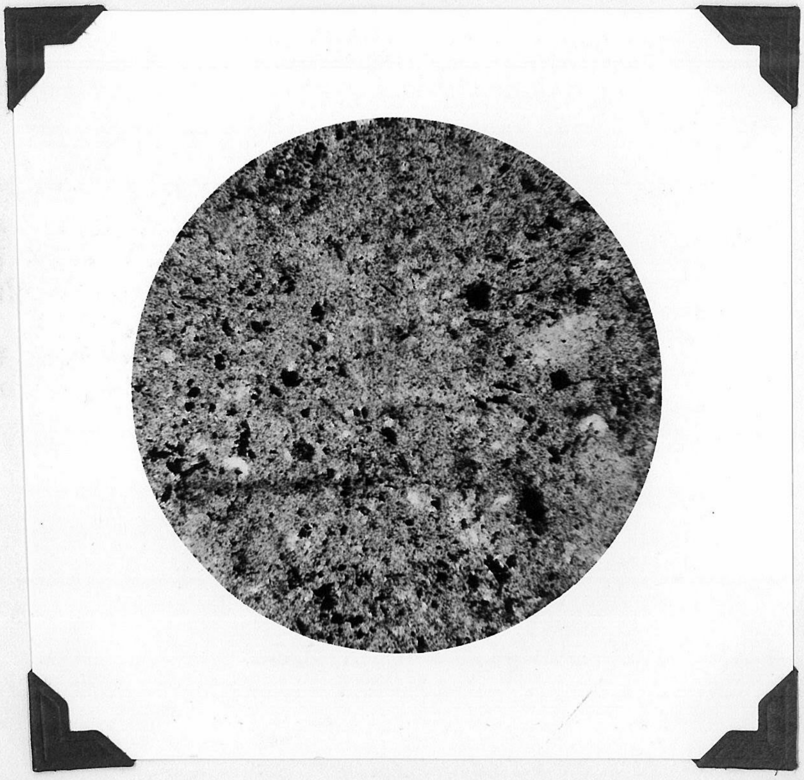


PLATE VII

Figure 12-A. Photomicrograph of plastic "SH 4 Clay" which is a variation of the "bone" clay bed. Compare with Figure 11 for differences in texture. Taken with ordinary light and with a magnification of 100 diameters.

Figure 12-B. Photmicrograph of "Pink Mottle" clay showing residual structures. The rounded lighter portion represents an completely altered particle which was laid down as a granule of partially altered material and since then decomposed to its present condition by secondary changes. Picture taken with ordinary light with a magnification of nineteen diameters.



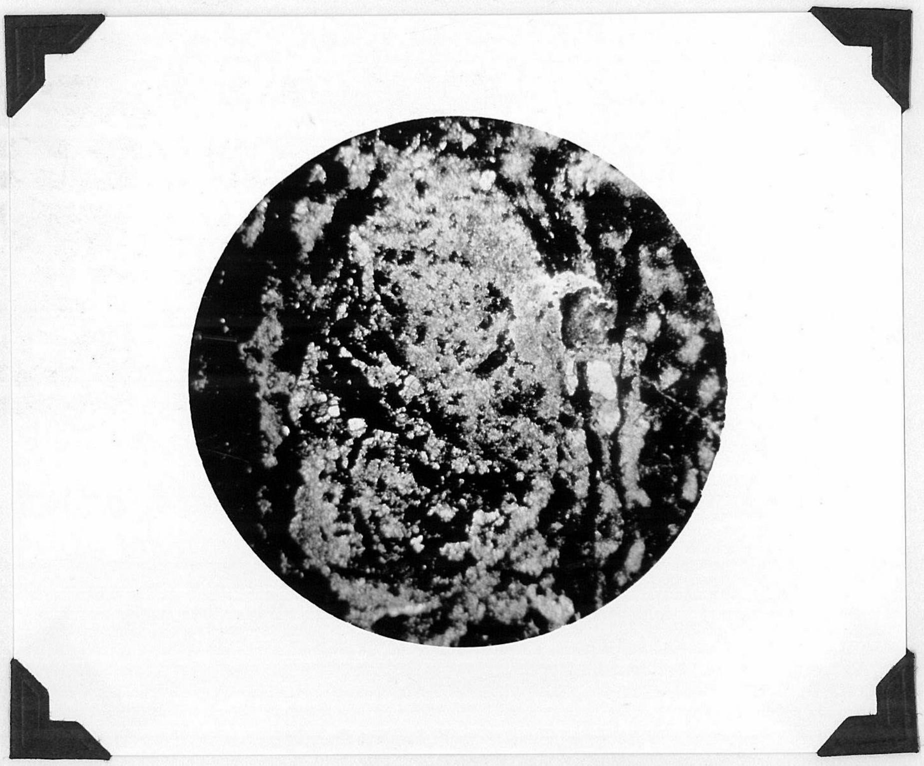


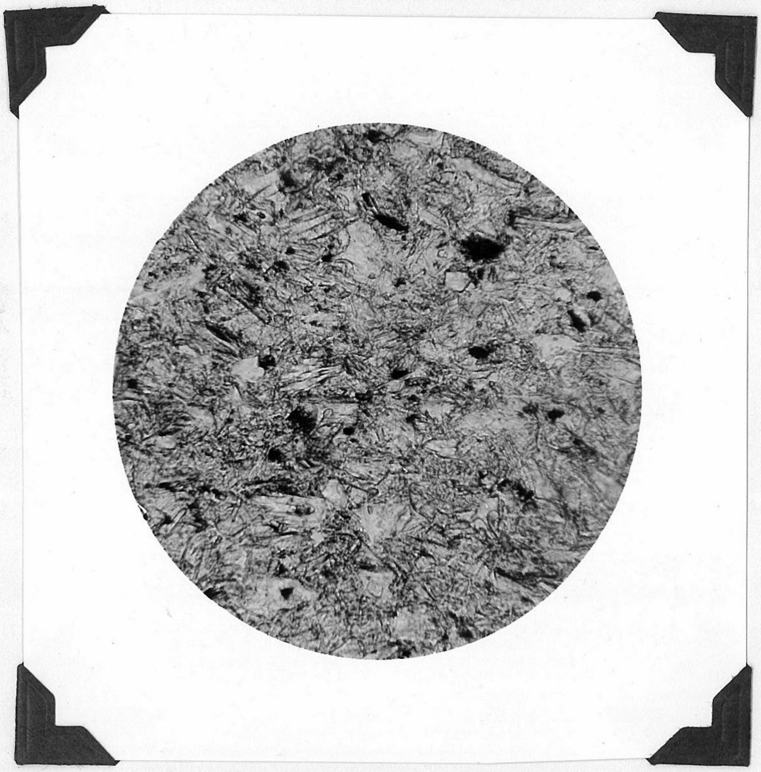
PLATE VIII

Figure 13. Photograph of Wildomar Pit from the north-west, showing remarkably well developed parting within the successive flows.

Figure 14. Wildomar clay. Megascopic appearance, showing agglomeratic nature and finer, cooling cracked, more glassy portion of base of the next flow at top of hand specimen. Natural size.

PLATE IX

Figure 15. Photomicrograph of Wildomar Clay showing remarkably well developed tuffaceous structures, such as stringers of glass, broken shells of bubbles, etc. Taken with ordinary light with a magnification of 100 diameters.



McKNIGHT CORONA CLAYS

No account of the geological relations of the sediments exposed in an elongated triangle which lies between the margin of the valley floor, the basement complex of the Santa Ana Range and the Santa Ana river canyon, has been published. Therefore, it is thought desirable to give here the results of a very brief reconaissance survey by the author along the Skyline Drive from Corona Valley to the crest.

General structure in vicinity of outcrop

Structure in the triangle is very complicated and increases in complexity as one approaches the apex of the triangle. It is here that the Chino and Whittier faults merge and join into the Elsinore fault. The section along the road is some four or five miles from the gore of these three major fault systems but nevertheless it probably owes its imbrication mainly to the compensation necessary in the crust in the vicinity of their intersection.

The trace of the Whittier fault bounds the south side of the Puente Hills, crosses Santa Ana Canyon and turns southeastward. The fault which bounds the main block of the Range is almost certainly the continuation of this fault.

Structure of the Puente Hills to the north.

One of the lower northwest-southeast faults in the triangle a continuation of the Chino fault which also bounds the Puente Hills, but on the east side. Both of these faults in the vicinity of Santa Ana Canyon are reverse in character, the most consistant dip of the Whittier fault being about 45° toward the hills, while the Chino fault has similar dips in a westward direction. Thus the Puente Hills are bounded on two sides by reverse vaults which dip under that block.

Compressional forces producing thrust movements along reverse faults in sediments normally result in folding and faulting structures in either the lower or upper block which parallels the reverse faults. However, an examination of the folds and faults of the Puente Hills and its continuation shows that those structures which show evidences of shortening are, in the main, perpendicular to the axis of Y. These folds bend to the southward in the close vicinity of the Chino fault, indicating that the Chino-Corona block was moving southward with respect to the Puente Hills, corresponding to direction of movement in the San Andreas Rift. This and their location with respect to the San Andreas Rift would indicate that the Chino-Cornoa and Santa Ana Range blocks were moving northward with respect to the Puente Hills, although drag in the folds in the vicinity of the Chino fault block indicates that they too may have had differential movement corresponding to Rift displacement. Thus the Puente Hills block may be acting as an incompetant mass between compe-tant east-west blocks bounding the north side of the Los Angeles Basin and the blocks to the south.

Compressional forces are known to have played a prominant role in the formation of the structures of the east-west ranges to the north and this locality may represent one of the crucial points in the solution of the perplexing problems of structural geology in Southern Califor-nia.

Viewed from the Corona valley, the steep rise of the land surface from the head of the fans to Sierra Peak appears to be quite regular. However, closer examination shows that the spurs have the form of steps with almost flat treads alternating with the steep breaks of the raises. These features on one spur are fairly well matched in height and alignment on spurs to the north and south.

Four main blocks may be distinguished. This is a matter of degree only, for each of the blocks is cut by longitudinal faults running parallel to the axes which differ only in slight degree in size from the boundary faults. They are bounded by five faults which are fairly continuous throughout the triangle although some tear faulting is present.

Slice faulting in the triangle

The step faulting theory postulated by physiographic evidence is strengthened by the structural relationships. Each of the four blocks is topped by successively older formations according to their position relative to the core of the range. The bottom block, which by reason of the alignment of the truncated bottoms of the spurs, is probably to be classed as a slice with a fault also at its eastern side, separating it from the valley, contains sandstone and conglomerate beds which are Martinez in age. They are separated by a fault from the Cretaceous sandstones and shales of the next block by a fault which coincides with the bottom of the rise to the next prominant step. The Cretaceous sandstones and conglomerates of the second block abutt on the west side into the granodiorites and metamorphics of the basement complex. To the westward of this belt of crystallines, the

Formations topping the blocks.

Cretaceous again outcrops. While no exposure of this contact between the sediments and the basement was seen, the writer believes that the most logical explanation of the relations would be postulated by a depositional contact of the sandstones and conglomerates on the basement, with the present westward dip of the sediments carrying them against the crystallines of the main block which forms the crest of the range.

Cross Faulting

In addition to the major and minor northwest-southeast slice faulting, the steps are further mosaiced by innumerable cross fractures which are roughly perpendicular to the longitudinal faults. While the individual cross faults are not, as a rule, as conspicuous a feature as the slice faults due to the fact that they have neither the continuity nor the magnitude of movement that the others have had, nevertheless they are an important factor in the deformation of the block.

Compressional forces dominating north-south

All of the cross faults absberved by the writer were predominantly reverse in character, and very often had dips as low as 20°or less. While movement along the individual fractures would be measured as a few feet or yards, the total shortening along the vast number of these faults would aggregate a very large amount.

Axes in the folds of the sediments in the triangle also trend northeast-southwest. The orientation of this compressive phenomena gives strong support to the theory regarding the direction and nature of the forces acting in the triangle. The clays lie between relatively competant beds of sandstone and conglomerate and form a very favorable plane for slippage, along which major or minor movements have taken place when the attitude of the beds was favorable. This relationship is so universal that the writer first thought that the clays were merely a zone of intensive alteration along faults. At the McKnight mine just south of Tin Mine Canyon the strike of the bed averages about N65°E and the dips about 25° to the south. This attitude places it in a very favorable position for thrust slippage and it has suffered this type of movement. However, pockets of the fire clay on either side of the fault prove that the zone is really a bed.

Claybed a zone of slippage.

The McKnight clay beds are intercalated in the sandstones and conglomerates of the Martinez formation exposed on the first or lower block. They represent the end product of a process of deposition of increasingly fine material. The clays grade downward in the section to arkosic sandstones which in turn pass into coarser and coarser conglomerates.

Character of the formation in which the clays are found

The conglomerates are composed of well rounded pebbles of quartzites, fine grained intrusives intermediate in composition schists and infrequent conglomerates, sandstones and shales. The matrix is a coarse arkosic sandstone containing considerable amounts of chlorite, biotite and muscovite. The graduation into sandstones and shales above is an insensible one, the mineral content remaining about the same except for elimination of the more easily weathered minerals. The occurance of the well rounded quartzite and dacite boulders with much softer sandstones and shale pebbles probably indicates that most of the material was derived from the Cretaceous sediments below, which contain all of the above materials in the same lithologic assemblage. The source of the materials could not have been very far away for the conglomerate, shale and sandstone pebbles could not have withstood long continued abrasion by the heavy quartzite and dacite members.

Age of the form tion

Abundantly fossilliferous massive sandstones lie immediately above the zone of shales and clays. The invertebrate fauna found there include such forms as giant as venericardias and Turritella pachecoensis Stanton. Giant venericardias are characteristic of the Eocene but the turritella form has only been described from the Martinez and is regarded as an unquestionable marker of that division of the Eocene.

The fossils were found almost immediately on top of the zone of more or less plastic material. There was no evidence found which indicated the possibility of the two horizons belonging to different formations.

Character of the clay

As previously indicated, the clays lie within a more or less plastic zone. The transition from sandstone to fire clay to sandstone is not an abrupt one and the contacts are more of the nature of belts than of planes. The sandstones below are green or buff in color but as they approach the clays they become darker going into light and then into dark grays. Immediately below the black flint fire clay occasional lenses of pisolitic "bone" clay are found, particularly in those vicinities where there is an increased amount of carbonaceous material present in the clay stratum. The clay bed is overlain by argillaceous shales which are universally stained a red or pink by iron oxide. Part of the iron may have been deposited with the sediments or derived from the immediate beds but the main portion is supposed to represent material leached from the overlying sediments and deposited on top of the impermeable membrane of clays.

The flint fire clay is a more or less sandy, very well indurated material which contains a variable amount of finely disseminated carbon giving it a grey or black color. The carbonaceous material may be as concentrated as to give rise to lenses and pockets of lignitic coal within the clay. Lenticular bodies of clay may contain practically none of the material and are thus almost white in color.

Association with coal

The white or light gray clays do not have the toughness of the darker portions of the bed and break into small roughly cubical blocks with conchoidaly fractured sides when exposed to the air. The writer lenses of the bed also contain considerable less quartz sand than the remainder. The content of sand particles varies within wide limits in the black clay, lenses of almost all coarse material running through the clay bed.

Qualitative mineral analysis of the coarse material showed it is almost entirely made up of clear quartz which is fairly well rounded and shows much abrasion. The infrequent feldspar minerals were so badly altered that mineral identification is impossible. Other minerals found in order of frequency are:

Heavy Minerals

	Mineral	Characteristics
1.	Ilmanite	Frequently shows traces of trirhombohedral forms
2.	Magnetite	Silver grey in color.
3.	Tourmaline	Light brown but only slightly pleochroic
4.	Sphalerite (?)	Good cleavage-black in color-opaque-resinous

A thin section of an average sample shows that the fire clay is extremely fine grained, with quartz particles, as usual, considerably the larger. An approximate estimate of the divisions of the Kaolin group is as follows: kaolinite 30%, montmorillonite 30%, halloysite 4$. About 30% of the slide was quartz and the trace of chlorite that was present would amount to about 1% of the area. The relative percentages of the various constituants in the matrix is exceptionally difficult to determine for the slide is extremely fine grained. Thus the observer estimating percentages on the amount of birefringence has very little upon which to base his judgment.

The following chemical analyses were obtained from the laboratory records of the Pacific Clay Products Co. of Los Angeles, who own and operate the McKnight Mine:

Clay	Ig. Loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Alk
McKnight (fire) clay	10.62	57.38	27.62	2.06	1.90	.11	.13
Red McKnight	8.73	63.86	21.52	4.12	.24	.09	.83

Calculation by H. S. Washington's method of the mineral content from the ultimate analyses shows the clay would have the following theoretical composition:

Clay	Quartz	Hydrous Aluminum Silicate	Serpentine	Limonite
McKnight fire clay	23.2	60.10	2.50	2.43
McKnight red clay	33.15	52.50	.19	4.20

Table of theoretical mineral constituants continued from last page:

Clay	Albite	Anorthite	Freewater
McKnight fire clay	1.25	9.45	1.7
McKnight red clay	7.20	1.20	.70

It will be seen that the calculation of the hydrous aluminum silicate as kaolinite does not use up all of the water, particularly in the fire clay. This may be due to two factors, either the hydrous aluminum silicate contains more water than the 1-2-2 ratio or lack of porosity of the clay prevented loss of all water in the drying process.

Ceramic properties and uses.

An investigation of the ceramic properties shows that the fire clay has a fair plasticity, a medium low dry strength, and is granular and friable when dry. Steel hardness is developed very high and its softening point is cone 33 (1745°C). It has a low shrinkage as would be suspected from the amount of sand contained in it, and is usually mixed with more plastic fire clay to give strength to fire bricks. However, when so mixed, it possesses good hand molding qualities.

The Red McKnight clay is a buff burning clay which was used as an ingrediant in sewer pipe and face brick mixes. It has a better plasticity than the fire clay although the large amount of sand weakens this. Fingernail hardness developes at cone 010 and steel hardness at cone 7. Its softening point is cone 28, and it has not been mined for several years, although a great tonnage has been taken out in the past.

The McKnight mine itself is one of the oldest clay producing properties in Southern California. Operations are supposed to have begun as early as 1890. Mining carried on then, as now, was by underground tunnel and stope methods, similar to practice in coal producing districts today. Tunnels driven by early miners were never mapped and portions of them are occasionally encountered today which are caved in at both ends, and which are timbered with eucalyptus tree trunks. Old time miners in the district whose experience runs back 25 or 30 years with the mine do not remember these old tunnels and it may be that mining was carried on much earlier. Open pit mining was carried on quite a number of years ago and a great tonnage of clay was taken out, principally by hand methods. The red clays are not being mined at the present time but they represent a large potential supply of this type in event of a change in economic conditions with regard to the more easily accessible clays in the Alberhill District.

Earliness of mining operations.

PLATE X

Figure 16. Whittier Fault looking along its strike towards the west. Puente shales overlie in reverse fault contact vertical Fernando sandstones and conglomerates. The dip of the fault is about 45°. Photo by B. N. Moore.

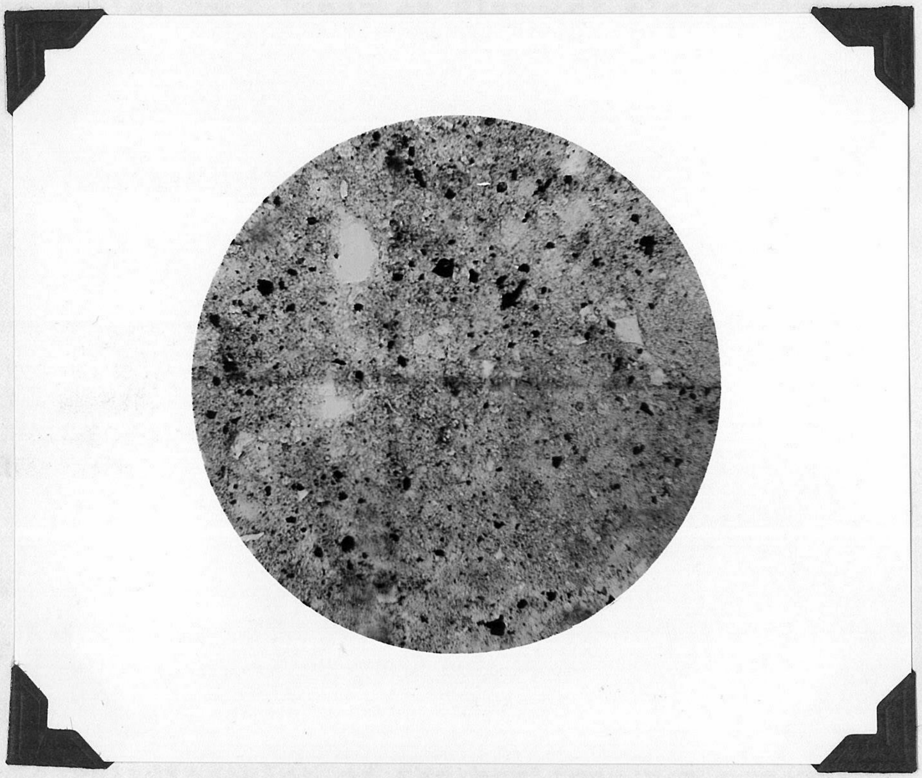
Figure 17. Chino Fault looking along its strike towards the north. Chocolate colored Puente shales are above the contact, vertical Fernando conglomerates below. The dip of the fault is about 45° to the east. Mr. B. N. Moore is standing on the contact.

PLATE XI

Figure 18. McKnight Pit, now fallen into disuse. The picture is taken towards the west. The mine lies at the base of the steep scarp of the Santa Ana Range, which can be seen in the background. The beds dip to the south (left) and are imbricated by numerous faults.

PLATE XII

Figure 19. Photomicrograph of the McKnight flint fire clay showing its texture. Taken with ordinary light with a magnification of 100 diameters.



GOAT RANCH OR CLAYMONT CLAYS

The commercial clays of the Santa Ana mountains are confined to two general localities:-- the so-called Goat Ranch or Claymont clays which outcrop at the extreme northern end of the range and the Serrano clays which are exposed from Trabuco Creek northwestward through Modjeska Grade Pass to Silverado Creek.

Clays in the vicinity of the Goat Ranch have been mapped by English as Cretaceous in age and subsequent writers have assumed that they all belong to that period. However, English was probably referring to some long since abandoned pits. Thus, contrary to many published reports, the clays now mined are of an entirely different era. Stratigraphic relationships of the horizons now producing indicate that the clays in reality belong to the Martinez Eocene in age, and not to the earlier period. Age of cla

The lignitic shales in which the flint fire clay bed is intercalated grade downward into a sandstone member which in turn grades into a thick bed of coarse conglomerate. This overlies a finely laminated reddish black shale aggregating at least 1000 feet in thickness.

No good exposure of the actual plane of the conglomerate-shale contact was seen, but the attitudes of the two beds are usually closely alike, except just below the mine, where the shales appear to have a slightly greater dip. However, a very strong lithologic change occurs between the coarse conglomerate bed and the thin, finely laminated shales below.

Lithologic correlation.

Although no fossils were found in either the upper or lower member there is no doubt that the shales are Cretaceous in age, for the middle portion of that formation is unique in character in the district, but the character of the material above it strongly resembles the Martinez of other portions of the Santa Ana Mountains.

The basal conglomerate of the Martinez formation as exposed in Silvarado Canyon is exactly like this bed in material, appearance and induration, but an analogous bed in the Cretaceous is not to be found. The shale and sandstone pebbles included in the conglomerate bed at the two localities are undistinguishable from one another and the assemblage of the materials differ only in proportion, the bed at Silvarado Canyon having more sedimentary pebbles in its composition. It also possesses a striking resemblance to the conglomerate bed which underlies the McKnight fire clay. As far as the writer can see, material from the three localities is undistinguishable on a lithologic basis. Two of these localities are unquestionably Martinez.

English (6 Page 12) states that the presence of glauconite is characteristic of the Martinez of the north end of the Santa Ana mountains. No glauconite was observed but the writer found a great deal of chlorite, which seems to be confined when abundant to the Martinez. Probably English's hasty determination of the mineral was in error. Chlorite is found in the upper beds but is not found below the conglomerate shale contact.

Considerable doubt would naturally be cast on English's mapping of this particular region by reason of the fact than an obvious continuation of the conglomerate bed is to be found to the south-west across the Cretaceo-Eocene contact as mapped by him.

On the basis of the above evidence the writer feels justified in placing the age of the clays as Martinez-Eocene rather than the Cretaceous as they have heretofore been considered. This hypothesis is strengthened by the remarkable similarity between the Corona McKnight clays and the Goat Ranch clays in manner of occurance, mineral assemblage, and ceramic properties.

If this assumption is true then a strong un-conformity must exist below the conglomerate member.

A normal section of the Cretaceous of the northern Santa Ana mountains shows that the formation is composed of three broadmembers—first a top layer of sandstones and conglomerates which is about 700 feet thick; second, a section of dark colored, finely laminated shales about 1500 feet thick and third, another layer of sandstones and conglomerates, which aggregate about 800 feet in thickness. Inasmuch as the top sandstone member is completely missing a hiatus sufficient for uplift and erosion of at least 700 feet of material is indicated.

Structure

A northerly dipping momocline forms the principle structure in the central portion of the extreme northern end of the Santa Ana range, in which the Cretaceous and Martinez sediments dip steeply off the igneous and metamorphic rocks of the basement complex. In the vicinity of the Goat Ranch the beds dip very little more than the surface of the long slope which runs down towards Santa Ana Canyon. This slope is topped by the prominent ridge which runs from the top of Sierra Peak westward to Santiago Creek. On the south end of the Ranch a hard resistant bed of "bone" clay forms the capping of the spur for a distance of fully one half mile. The dip of the beds carries the clay below the surface at a variable distance from the divide. The Gladding-McBean Co. mine the clay at the head of a canyon which cuts into this long slope, and drops it by means of a chute into trucks which haul it away.

Type of clay

Two types of clay occur on the property. By far the most valuable is a seam of flint fire clay, and, accordingly, from it the most tonnage has been taken, but some use has been made of the shales in which fire clay is found.

Description

The flint fire clay is a persistant bed of black hard clay which contains considerable amounts of carbonaceous material. Like the McKnight clay bed, it represents the end product of a process of deposition of increasingly fine material. Its average thickness varies from four to seven feet. Lignite coal lenses occur above the clay bed and the clay bed itself occasionally takes on a lignitic character. This character may vary to the other extreme for above the mine at the top of the ridge the clay contains practically no carbon and is a light grey in color. The material may contain a good deal of quartz sand both disseminated throughout the clay and also concentrated in lenses. These lenses may contain so large a proportion of the coarse material that they cannot be used and one thrown aside. Below the clay, an extremely pisolitic "bone" clay is found which, as far as the writer knows, has not been mined.

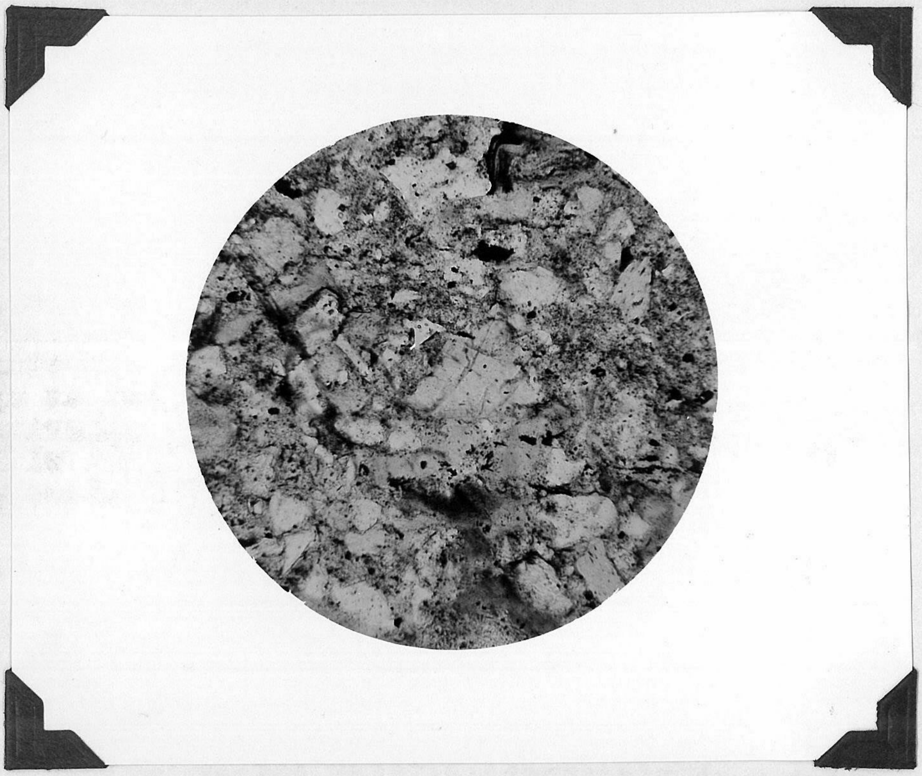
Due to the variation of the proportion of the coarse particles to the finer matrix, estimations of percentages of the materials as seen in thin section are only true for that particular sample. However, they do give a picture of the order of magnitude of the various proportions. The proportions of the clay minerals in the matrix vary much less than to the coarser particles.

A thin section of an average sample of the flint fire clay shows that this clay is composed of about 45% quartz, 40% kaolinite, 12% chlorite and 3% halloysite. The grains of quartz are by far the largest mineral in the section. The chlorite, which is light brown and distinctly pleochroic is in the form of long thin fibrous masses, but the particular species of chlorites present were not determined. It has a yellowish interference color in a standard thickness thin section which would indicate that it has a birefringence of about .015. Very little isotropic halloysite was observed. Mineralogy

The clays of this deposit and of the McKnight-Corona are used for similar purposes. Due to its high fusion temperature (Cone 34-1755°C) the flint fire clay finds its chief use in making high refractory firebrick. Some of the shales which by reason of their high iron content burn red and vitrify at a low temperature have been used for common brick Uses and tile but they cannot be mined in competition with the more easily accessible clay of Temescal Canyon. As stated above, the exploiting company run tunnels up the dip of the bed from the head of the canyon, cart the clay to chutes which carry the material to loading bunkers at the canyon bottom. As far as the writer knows, no figures are available as to the yearly tonnage mined. Practically all of the clays are used at the Alberhill plant of the Company.

PLATE XIII

Figure 20. Photomicrograph of the Goat Ranch flint fireclay, showing comparitively coarser structure. Fibrous chlorite mineral at upper edge may be clino-chlorite. Taken with ordinary light with a magnification of 100 diameters.



THE SERRANO OR EL TORO CLAYS

The Serrano clay bed outcrops in the west central portion of the Santa Ana mountains from Trabuco to Silvarado Creeks and just east of the Orange County Park--Modjeska road. The nearest town is El Toro which is about ten to fifteen miles distant from the various mines scattered along the clay bed. As the principal producing mine along this entire belt at the present time is on the Serrano Ranch property the clays represented will be called Serrano, or El Toro clays. **Location of clays**

The sandstones in which the Serrano clay beds are intercalated have been mapped as Miocene Vaqueros by previous workers (2) in the field. However, in the course of a detailed geological examination of the clays at the Serrano mine, the writer was struck by the resemblance of the formation to the Martinez in other portions of the Santa Ana Range. The abundant presence of chlorite and the general appearance and induration of the material certainly do not resemble the Vaqueros of other portions of that district. Proof of the writer's suspicions was obtained when, in August 1929, in the course of mapping the areal extent of the clay bed, Mr. Bernard Moore, who was working in the area preparing an, as yet, unpublished thesis (12), and the writer were able to trace the clays, with only one short break in **Age** continuity, into a series of beds which were established as Martinez on the basis of invertebrate fauna found very close to the clay exposure in Silvarado Canyon.

Character of the Martinez

The Martinez of the Santa Ana Mountains is, in the main, made up of sandstones which when fresh are white or green, depending on amount of chlorite present, Strangely enough, the chlorite is contained in greater amount in the fine sandstones, in which, by reason of greater weathering and washing, and sorting one would expect elimination of the soft and light chloritic minerals.

Weathering with sufficient leaching reduces the contrasting colors of the fresh sandstones to a uniform buff. The white sandstones take on this color due to the minute amounts of iron present within the formation which is concentrated by evaporation of water on the surfaces exposed to air. The resulting limonite imparts to the sandstones a buff color. The chlorites of the green sandstones break down to hydrous compounds of iron which ultimately result also in limonite. Thus the weathered color of the Martinez is almost uniform, the beds originally green being somewhat the browner. The occasional Chloritic shades do not leach in this manner and result in intensely red colored strata.

The Martinez sediments overlie a conglomerate basal bed. This is overlain by a series of sandstones which varies widely in thickness due to overlap. At Trabuco Creek, for example, the section below the clay bed, although it was not measured, must be nearly 2000 feet in thickness, while at the Santiago-Aliso Divide there is but 50 feet between the two horizons. The conglomerate bed at Silvarado Canyon is made up of quartzite, dacite, slate, shale and sandstone pebbles, which apparently have been derived from the sandstones, shales and conglomerates of the underlying Cretaceous. They average about one to two inches in diameter and the harder materials are very well rounded. The matrix is an arkosic sand in which considerable amounts of chlorite are to be seen. The general character of the sandstones have already been described.

Basal conglomerate

As was indicated above, English states that the presence of glauconite is characteristic of the Martinez of the Santa Ana Mountains; he seems to err in the determination of the green mineral which is in reality chlorite. The amount of chlorite included within the sandstones, shales and conglomerate varies widely, some thick beds having been observed which contain practically no observable chlorite particles, other beds having a dark green color by reason of the abundance of the mineral present.

The material of the clay bed can be readily distinguished from the remainder of the Martinez; the bed constitutes an easily mappable unit. It may be readily discriminated from the remainder of the section by reason of its plasticity, white or pink color and in ease of erosion from the harder buff sandstones. The writer was readily able to trace the bed about eight miles along its strike. Its outcrop is almost a continuous line. It has had a few minor displacements which give some trouble in mining but its one major displacement is by the fault which runs northwest-southeast and intersects the bed just to the north of the Serrano mine. The trace on the north side of the fault is easily found about one-fourth mile back from the trucation of the southern portion of the bed, and continues northward to Silvarado Canyon. The writer has not traced it northward from the point.

Clay bed a mappable unit.

The horizontal displacement of the trace of the bed by the fault referred to is not due to a corresponding relative movement of the two blocks on either side of the fault. The beds in the vicinity of the fault have a dip of 75° to the south and a strike of N65°W. The fault plane is very close to vertical and it has a strike of N75°W. Vertical movement along the fault by which the northeast block moved up followed by erosion would therefore bring about the existing areal relations.

Structure along cla beds.

The clay bed itself lies about 2200 feet above the base of the Martinez at Trabuco Creek, about 200 feet above the base of the Santiago Aliso divide and about 250 feet above the base in Silvarado Canyon. A considerable and constant interval separates it from the basal conglomerate which, in Silvarado Canyon, is immediately topped by lignitic shales and clays resembling strongly the character of the shales
resembling strongly the character of the shales
at the Goat Ranch. The Serrano bed lies about 150 feet above this bed. It will be remembered that the Goat Ranch materials lay immediately above the conglomerate. For the above reasons, the writer thinks that the clay beds probably are not continuous nor do they belong to the same horizon. However, they approach each other closely and probably were laid down under approximately the same conditions.

Goat Ranch horizon below the Serrano horizon.

The main mass of the bed of fine white sandstone of which the clay forms the base contains little alteration products and is composed mainly of quartz. The top of the bed is very arenaccaus but towards its base it contains more and more clay material. A sharp increase in the amount of clay matrix in the sandstones may be detected at the upper contact of the clay bed. Immediately below

Character of clay bed.

the bed lies a fine dark green shale which owes its color to a considerable percentage of chlorite. When weathered, it is a dark red. This bed may contain or closely overlie lenses of lignitic shales, which may be associated with the slate or the sandstones below. These lenses vary widely in size and content of carbonaceous material. In one place--Silvarado Canyon--a lense was pure enough to warrant the Southern Pacific Railway in mining it for coal before the discovery of oil. A sharp contact exists between the green shale and the overlying white clay bed. Only small amounts of chlorite are found within the clay bed itself.

Association with coal.

Almost universally the upper portion of the clay stratum is stained various shades of pink and red, apparently by leaching of iron from the sandstones above, and deposition of it in the form of iron oxide within the upper portion of the impermeable membrane. The main part of the clay bed is usually an intense gray-white but it may rapidly become much darker along the strike due to the inclusion of carbonaceous material.

Staining

The material of the bed consists of coarse grains of slightly impure sand, which is imbedded in a much finer matrix of hydrous oxides and silicates of iron and alumina. Microscopic examination of the coarse particles yielded the fact that practically all of them are crystal clear quartz, which may be rounded, sub-angular or infrequently, angular. A few small perfect crystals of the same mineral were seen. Altered feldspar grains, recognized by form, cleavage and alteration are present. They were too much kaolinized for exact determination. The examination proved that more chlorite was present than would be suspected from a megoscopic analysis. Small amounts of biotite and muscovite complete the light mineral list of the coarse material. Qualitative panning methods of the washed partdcles yielded the following heavy minerals in order of frequency:

Mineralogical analysis of the clay.

Mineral	Characteristics
Ilmenite	Irregular grains partially pocketed and coated by leucoxene.
Tourmaline	Yellowish irregular grains and prisms.
Staurolite	Light brown irregular grains.
Magnetite	Somewhat altered
Almandite	Light brown irregular in shape.
Pyrite	Badly altered but frequently with some suggestion of isometric form.

Heavy Minerals.

Thin sections of the Serrano clay show that aside from quartz, the clay is composed of about 25% kaolinite, 15% montmorillonite, 10% halloysite, and 5% chlorite. The kaolinite appears in its usual form of plates and also in elongated stringers due to inclined cutting of the fine plates. It is distinguished by its index

Clay Minerals

(1.561), lack of pleochroism and its irregular extinction. The chlorite has a very slightly lower index, is distinctly pleochroic and is in general considerable larger than the masses of kaolinite. Montmorillonite differs from it only in birefringence. Halloysite resembles the kaolinite except it has less of a regular form and, of course, is isotropic.

The following chemical analysis were obtained from the laboratory records of the Pacific Clay Products Co. of Los Angeles, who operate the Serrano Mine:

Clay	Ig. Loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Alk
Serrano Plastic	11.57	54.08	30.00	2.57	.26	.45	.23
Serrano, 1st car load	8.42	65.94	22.65	1.41	.10	.26	.21
Serrano Washed	14.02	47.44	36.06	2.40	None	None	.14

The Serrano Plastic was a selected specimen from a lense containing more clay and less quartz than the average of the bed. Serrano first carload is ordinary run of the mill material. Washed Serrano clay is the material after most of the quartz has been removed by washing.

Computation of the minerals of the clay from the ultimate analyses by Washington's method gives the following as the calculated mineralogical composition of the clays:

Name	Quartz	Kaolinite	Serpentine	Limonite	Albite	Anorthite	Free Water
Serrano Plastic	18.00	73.1	1.0	3.	1.25	4.19	.60
Serrano 1st C.L.	38.40	59.1	.57	1.68	1.12	1.05	.23
Serrano Washed	4.83	90.5		2.9	.77		1.3

The lack of the magnesia in the washed clay analyses shows that the chlorite and serpentine is in large enough grains to be removed in the washing process. The alkalies were computed as Na_2O and lumped into albite, because of the preponderance of the plagioclase over the orthoclase feldspars in the igneous rocks of the surrounding region. It will be noted that the amount of free water remaining is low and may represent a small residue left after drying.

Exploitatio of the clay

The most consistantly good clay was found at the Serrano mine. Northward along the strike the clay becomes more sandy, more arkosic and contains considerable amounts of biotite, muscovite and chlorite. Southward, the clays contain more iron, becoming reddish in color. As far as the writer knows no attempt has been made to exploit the bed north of the Serrano Ranch but several attempts have been made to do so by Harris, Hunter, Mole and Robinson as it continues to the south through their respective properties.

The white clays are used in face and low grade fire brick mixtures in the natural state. When washed they may be used for china and slip clays. Partially washed and ground they are used for white stone ware products. The natural clay burns buff at cone 10 (1260°C) and has a moderate shrinkage at that temperature. The washed clay burns white at high temperature but when cone 20-26 (1530-1595°C) reached it becomes darker. As would be suspected it has a high shrinkage and the tendency to warp.

Uses of white clay

As indicated above a variable portion of the bed is stained by iron oxide solutions. The contaminated portion usually constitutes the upper third to half of the clay stratum, although this amount may vary to both limits. When the iron oxide is contained in sufficient amounts to visibly stain the clay it so lowers the fusion point and colors the burned ware so that the material can be used only for cheaper products. Due to their inaccessibility, this type of clay cannot compete with the clays from Alberhill.

Uses of red clay

The amounts of material mined varies considerably from year to year. In 1928, about 10,000 tons were mined but this is the highest tonnage recorded. The cost of mining is high because the clay must be hauled by truck to El Toro which is about seven to ten miles from the mines. It is then loaded onto railway cars and shipped to the Los Angeles District.

Amount mined

PLATE XIV

Figure 21. Back slope of Santa Ana Mountains block. Picture taken looking southeast from the top pit at the Serrano Mine to show gently dipping west side of the Santa Ana Mountains. The eastern side was illustrated in Plate I, Figure 1. Photo by B. N. Moore.

PLATE XV

Figure 22. Martinez-Cretaceous contact on north side of Silvarado Canyon. The prominant ridge in the foreground is topped by the resistant bed of the basal conglomerate of Martinez lying on the softer Cretaceous shales below. The angular discordance between the two can be seen best at the extreme right of the picture. A closeup of the relation exposed on the hill to the left is shown in the next plate.

PLATE XVI

Figure 23. North side of Silvarado Canyon. Basal conglomerate outcrop at extreme right on east side of hill overlain by clay (shown in bare patch on hill) of the Goat Ranch horizon. Serrano horizon is slightly to the left off of the picture. Coal has been mined between the two horizons at this place.

Figure 24. North side of Trabuco Creel, showing relations between clay horizon and associated Martinez. Prominant ridge in foregound is topped by sandstone, dark bed at top of the exposure is red clay stained by infilteration of iron, white bed just below is the clay stratum, which is floored by chloritic dark green shale which weathers red on the surface. The sandstones below shown in the extreme right of the picture contain lenses of lignite.

PLATE XVII

Figure 25. Looking northwest on Serrano Ranch, showing typical clay bed exposures. Camera stands on outcrop, and the pit in bottom of canyon, the white spot on spur, the pit at top of next spur are all on the bed. Road in extreme distance is the Modjeska Grade.

Figure 26. Close up of top Serrano pit looking in the same direction. The beds at this point are almost vertical. Dark green shale lies at the base of the bed to the right and a locally resistant bed of sandstone is on the upper side. Modjeska Grade in distance.

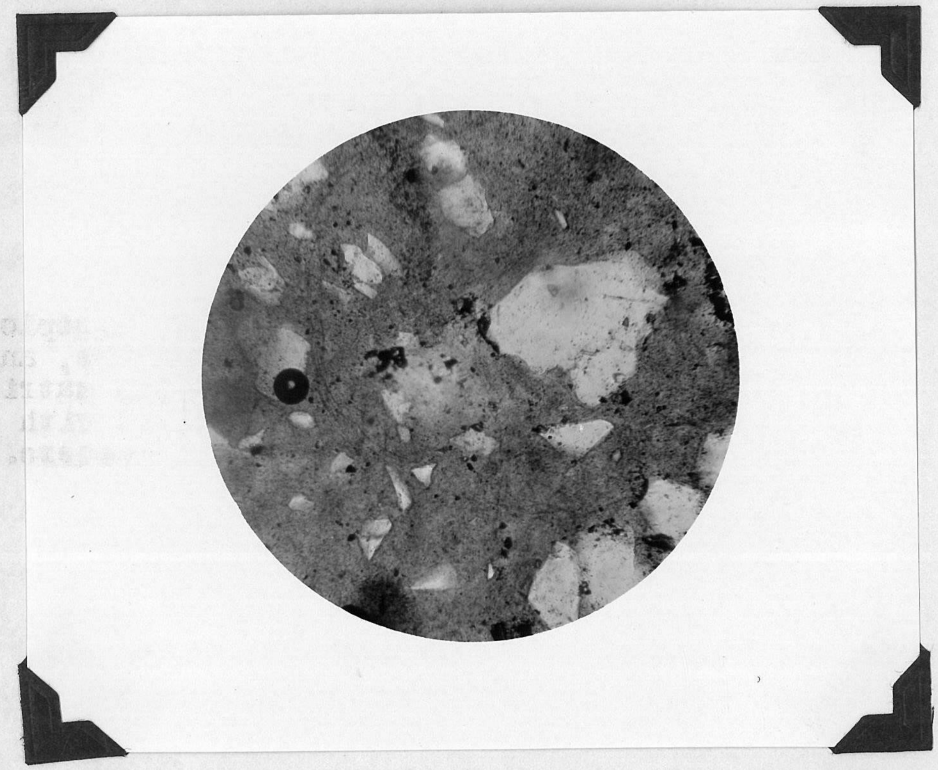
PLATE XVIII

Figure 27. Picture of bottom pit showing massiveness of clay bed. The bed is dipping about 75°away from the observer.

Figure 28. Serrano Clay. Megascopic appearance, showing comparatively coarse sand particles irregularly imbedded in matrix of fine clay. Natural size.

PLATE XIX

Figure 29. Serrano Clay. Microscopic appearance, showing texture, and relation of quartz to its matrix. Taken with ordinary light with a magnification of 100 diameters.



ORIGIN OF CLAYS

Condition of deposits

The Epi-Mesozoic interval on the Pacific Coast was not the time of a rigorous diastrophism as it was in the remainder of the western province. In general, profound conformity does not separate the Cretaceous and Eocene formations of southern California. However, in the Santa Ana Mountains not only an angular discordance is present but clear evidence is found in the deposits of the Martinez Paleocene that the Cretaceous as well as the older rocks was actively contributing its materials to that formation. Mention of the character of the rocks of the basement complex, Triassic, and Cretaceous sediments has already been made and it will not be necessary to redescribe the formations. However, it will be remembered by the reader that the components of the basement complex, as being the ultimate source of the succeeding formations, were primarily such rocks as granodiorites, monzonites and rhyolites.

Clays non-marine sediments

The base of the Martinez is continental in origin. After the initial basal conglomerates were laid down, fairly uniform conditions prevailed. The materials deposited are well sorted and stratified for this type of deposition. As time went on the sea encroached upon the gradually sinking coast. It was only a short time prior to this event that the deposition of the clays took place.

In California, Tertiary coal is almost exclusively confined to Eocene formations and this is particularly true of the southern portion of the state. In that district the presence of coal within a formation can be and has been used as a chronological criteria of the sediments.

Climate

Incomplete oxidation and preservation of vegetable material is more generally found in sub-tropical to temperate climates in which there is sufficient rainfall to produce abundant vegetation on the earth today and uniformitarianism would appear to thus exclude a tropical climate as a dondition of Eocene coal deposition. Thus the clays were probably laid down under humid temperate conditions. We know that the type of climate is very favorable for kaolinization of aluminum silicate minerals in the materials exposed to weathering and also that humic acids present from an abundance of decaying vegetable matter favor alteration and leaching.

Clay probably estuarine

The presence of autochtouous coal, with brackish water fauna in the shales and leaf impressions in the sandstones below the clays, all suggest shallow estuarine conditions, as does the succession of marine beds above, for the deposition of the Alberhill clays.

Profound alteration of the materials laid down either as clay or as partially decomposed materials during this time is indicated by the character of the materials throughout the entire district. In the case of those clays which have suffered secondary changes, it is of course, difficult to postulate just when the alteration took place, but it is the writer's opinion on the basis of their uniformity that they were altered before deep burial, that is substantially that they gained their present form during and immediately following deposition. The silts were deposited in the quieter portions of the basin, the conglomerates in the more rapidly flowing water. Sedondary changes.

This description of processes and events seems only to demand slight modification for the Serrano El Torro and Goat Ranch-McKnight clays. In these, the material was probably in deeper brackish water or very shallow quiet marine conditions.

Thus to sum up, materials composing the clays were derived from land masses which varied considerably in composition. They probably were laid down in estuaries under brackish water conditions under a humid temperate climate in which extremely reducing conditions prevailed.

Summary

BIBLIOGRAPHY

1. Burchfiel, B. M. 1923. Refractory Clays of the Alberhill, Calif. Deposits. Jour. Amer. Ceram. Soc. Vol. 6, p 1167

2. Dickerson, R. E. The Martinez and Tejon Eocene and Associated Formations of the Santa Ana Mountains. U. of Cal. Pub. in Geol. Vol. 8, No. 11.

3. Dietrich, W. F. 1928. Clay Prospecting and Mining in California. Trans. A.I.M. & M. E. Vol. 76, p 413.

4. Dietrich, W. F. 1928. Clay Resources and the Ceramic Industry of California. Cal. State Div. of Mines and Mining. Bul. 99.

5. Engel, R. 1928. Preliminary notes on the Geology of Elsinore Valley. Bull. G.S.A. Vol. 39, p 267.

6. English, W. A. 1926. Geology and Oil Resources of the Puente Hills Region, Southern Cal. U.S.G.S. Bul. [illegible]

7. Galpin, S. L. 1912. Studies of Flint Clays and Their Associates. Trans. Amer. Ceram. Soc. Vol. 14, p 301.

8. Hill, J. H. 1923. Clay Deposits of Alberhill Coal and Clay Company. State Mineralogists Report XIX, pp 185-210.

9. Howe, J. A. 1914. Handbook to Collection of Kaolin, China Clay, & China Stone in the Museum of of Practical Geology, London.

10. Larsen, E. S. 1921. U.S.G.S.Bull. 679.

11. Linton, Robert 1928. Tertiary Clays of Southern Calif. Jour. Am. Ceram. Soc. Vol. 11, No. 10.

12. Moore, B. N. 1930. Unpublished thesis to California Institute.

13.	Ries, H.	1927.	Clays, Their Occurrence, Properties and Uses. 3rd Edition. John Wiley & Sons N.Y. pp613.
14.	Ross, C. S.	1926.	Econ. Geo. XXI, p 454.
15.	Ross, C.S. & Shannon, E.V.	1925.	Jour. Wash. Acad. Sci. XV p 476.
16.	Ross & Shannon	1926.	Jour. Am. Cer. Soc. 9, p 77.
17.	Chearer, H. K.	1917.	Ga. Geol. Survey, Bull 31.
18.	Washington, H.S.	1917.	U.S.G.S. Prof. Paper. 99.
19.	Winchell, N.H. & A. N.	1927.	Elements of Optical Mineralogy Part II. John Wiley & Sons. N.Y. pp 424