THE IONE FORMATION OF CALIFORNIA

BY

VICTOR T. ALLEN

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CONTENTS

PLATES

INTRODUCTION

The Ione formation of California lies along the foothills of the Sierra Nevada, where the rolling topography of the Bedrock series changes to the level plain of the Great Valley. It consists of quartz sands and gravels, clays and seams of lignite, extending from Friant northward more than two hundred miles to Oroville; and throughout that distance possesses remarkable uniformity in its mineral composition and mode of occurrence.

After its deposition the Ione formation was covered by younger beds of rhyolitic and andesitic tuff and Pleistocene sediments which have aided largely in its preservation. Erosion has removed this covering at a number of places, leaving the Ione exposed at the surface. The most favorably exposed areas include Friant, Merced Falls, Knights Ferry, Ione, Lincoln, Marysville Buttes, and Oroville Table Mountain. The writer spent several months during the spring and summer of 1926 and 1927 studying the Ione formation in the field. Specimens of the various lithological types were collected and their mineral composition was determined in the laboratory. The conclusions stated in this paper are based on a consideration of the mineral assemblage of the Ione formation and on its field relations.

Several writers have correlated the Ione formation with the auriferous gravels of the Sierra Nevada. The work of the writer lends support to the belief that the Ione is contemporaneous with the white quartz gravels. The character of the Ione sediments, their distribution and composition, indicate delta deposits formed at the mouths of many westward-flowing streams. The presence of marine fossils in the upper part of the Ione formation shows that it accumulated on the shores of an Eocene sea. The fossils of the Ione and of the larger fauna occurring above and below the Ione are regarded by Clark as characteristic of the Meganos division of the Eocene.

Acknowledgments

Investigation of the Ione formation and the problems that it offers was undertaken at the suggestion of Dr. George D. Louderback and the writer gratefully thanks him for his interest and help during the course of the work, for a critical reading of the manuscript, and for his valuable suggestions during a short visit in the field. Professor A. C. Lawson has been long interested in the Ione formation and the auriferous gravels of the Sierra Nevada and the writer has found conversation with him stimulating and helpful. Dr. Bruce L. Clark has determined the invertebrate fossils collected during the investigation, and the writer is indebted to him for the generous way in which he has given help and information. Dr. Ralph W. Chaney has studied the flora of the auriferous gravels and his report is gratefully acknowledged. The writer has freely used the information secured during a visit to Marysville Buttes in the company of Dr. Howel Williams, and in the many fruitful discussions that followed. Thanks are due to the other members of the faculty, to fellow-students, and to the owners and employees of mines, quarries, and plants, who have cooperated and contributed to the progress of the work.

Review of the Literature

The term Ione, as a formational name, was first used by Lindgren in the text of the Sacramento folio submitted in 1892. His published statement[1] is as follows:

> During the Neocene period the auriferous gravels accumulated on the slope of the Sierra Nevada, and at the same time there was deposited in the gulf then occupying the Great Valley a sedimentary series consisting of clays and sands, to which the name Ione formation has been given.
>
> Beds of this age, which probably underlie the larger part of the Pleistocene formations in the valley, are exposed only to a limited extent. At Lincoln there is a succession of white sand and clay beds containing a few seams of inferior lignite. North of Rocklin the same series, fifty to a hundred feet thick, is exposed in places below the andesitic beds. The largest development is found south of American River. The strata form characteristic flat-topped hills and consist of a succession of light-colored clays and white or yellowish white sandstones. . . .
>
> The white clays of the Ione formation are frequently well suited to the manufacture of pottery. This industry is at present extensively carried on near Lincoln, where local conditions permit the clays to be quarried with little expense. In the Cosumnes area of the Ione formation similar clay is found at many places, but it is not utilized at present. In many places there are indications that the clays have been derived from rhyolitic tuffs. A bed of pure quartz sand is also found at Lincoln.

A brief statement of the occurrence of the clays, sands, lignites, and iron ores near the town of Ione was made by Rémond,[2] and in the Reports of the State Mineralogist of California.[3] In 1894 Tur-

[1] Lindgren, W., U. S. Geol. Surv., Sacramento Folio 5, p. 3, 1894.

[2] Rémond, A., Geological Survey of California, Geology, vol. 1, pp. 269–271, 1865.

[3] Eighth Ann. Rept. State Mineralogist Calif., pp. 108–115, 1888.

ner[4-5] mapped and described the Ione formation of the type locality, making the following divisions in ascending order:

(*a*) The white clay and sand beds which contain coal seams.
(*b*) Sandstone, usually white in color, but sometimes red and occasionally passing over into a quartz conglomerate.
(*c*) Clay rock or tuff, overlying the sandstone.

A deposit of impure hematite occurring two miles west of Ione was also considered part of the formation. Lindgren's suggestion that the white clay of the lower beds was formed from rhyolitic tuffs was repeated by Turner without further comment. The clays and sands frequently containing beds of lignite were regarded as brackish-water deposits of Neocene age formed along the shore line of a gulf occupying the Great Valley. The auriferous gravels, which are chiefly composed of white quartz pebbles, were considered contemporaneous stream deposits.

As early as 1887, Diller[6] described a fresh-water Miocene formation consisting of sandstone, shales, lignites, and conglomerates, which are well developed in the Lassen Peak district. In 1894,[7] he designated these sediments as the equivalents of the Ione formation, which he defined as including the beds between the Tuscan tuff and the Chico formation. The clays and sands occupying the same stratigraphic position on the tributaries of Cottonwood Creek, west of Red Bluff, were considered the western extension of the same deposit. The descriptions of the areas mapped as Ione in the Lassen Peak[8] and Redding[9] folios are similar, and these sediments were considered Miocene on the basis of the fossil leaves found in them.

In 1894 Turner[10] recorded the occurrence of the Ione formation in Butte County where it underlies the basalt of Oroville Table Mountain and is said to contain thin seams of a low-grade lignite. He referred the clay of the Miocene Hydraulic Mine, located on the east side of South Table Mountain, to the Ione formation. In the beds overlying the Chico fossiliferous sandstone south of Pentz he found

[4] U. S. Geol. Surv., Jackson Folio 11, p. 4, 1894.

[5] Turner, H. W., Rocks of the Sierra Nevada, U. S. Geol. Surv., Fourteenth Ann. Rept., pt. II, pp. 462–465, 1894.

[6] Diller, J. S., Geology of the Lassen Peak district, U. S. Geol. Surv., Eighth Ann. Rept., pt. I, p. 413, 1887.

[7] Diller, J. S., Topographic revolution on the Pacific Coast, U. S. Geol. Surv., Fourteenth Ann. Rept., pt. II, p. 416, 1894.

[8] U. S. Geol. Surv., Lassen Peak Folio 15, 1895.

[9] U. S. Geol. Surv., Redding Folio 138, 1906.

[10] *Op. cit.*, p. 463, 1894.

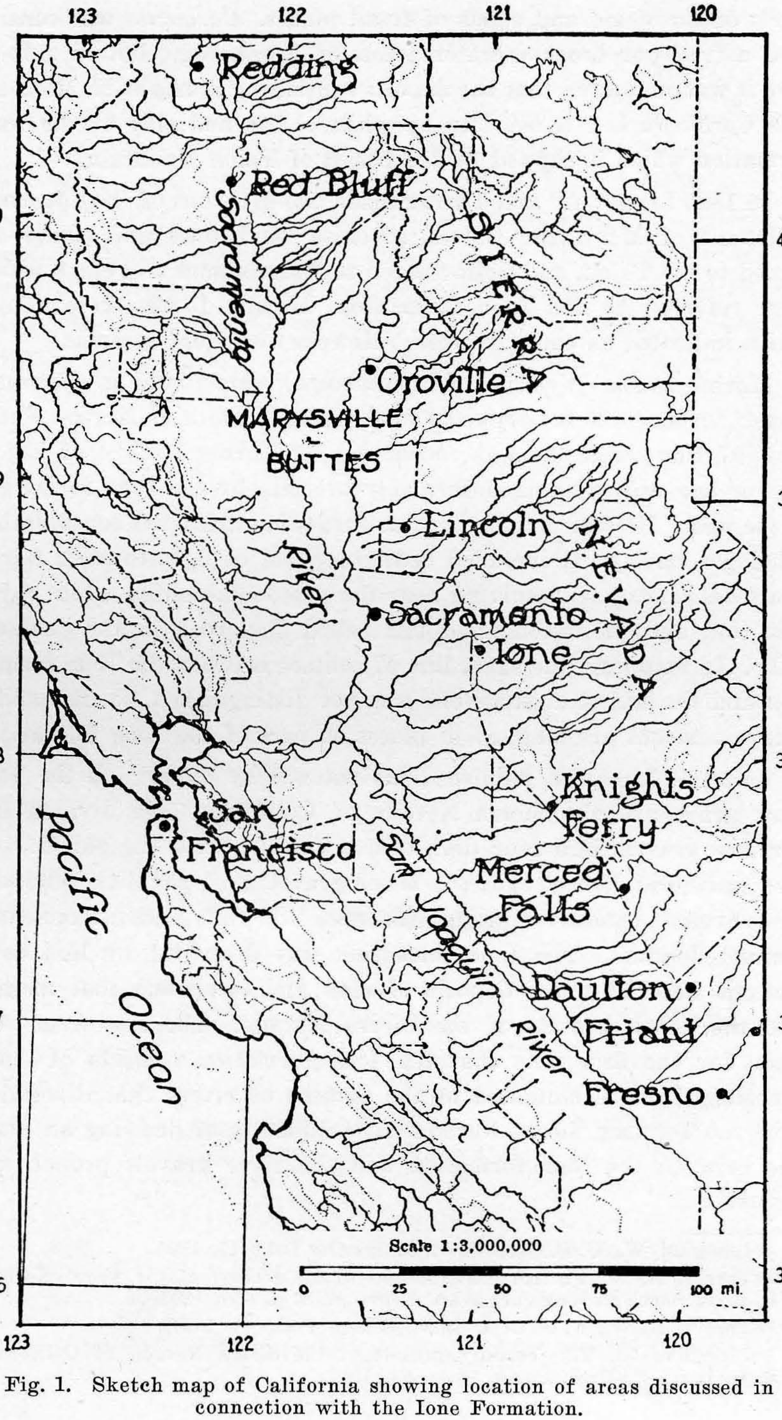

Fig. 1. Sketch map of California showing location of areas discussed in connection with the Ione Formation.

shells of *Corbicula* and stems of fossil plants. *Corbicula* was considered a fresh- or brackish-water genus of Eocene age, but in a footnote it was suggested that the deposit containing it might be Miocene. The *Corbicula* bed is overlain by white shales and clay of the Ione formation which is capped by the basalt of Table Mountain.

In 1895 Lindgren[11] and Turner made two divisions of the upturned sediments of Marysville Buttes, greenish sandstones and shales assigned to the Tejon, and light-colored soft sandstones and clays which were referred to the Ione formation. Marine fossils were found which indicated an early Neocene (Miocene) age for the Ione.

Marine fossils (*Venericardia planicosta*) were found in the sandstone[12] forming the flat-topped buttes one mile south of Merced Falls. In 1897 this sandstone was considered by Turner[13] to be of Tejon Eocene age and to be unconformably overlain by the Ione formation to the west. He stated that the Ione formation exhibited considerable lithologic variety. It included beds composed of light-colored, fairly quartzose sandstone, occurring near the base of the series, white rhyolitic tuff, and the decomposed tuff called clay rock in the Jackson Folio. In mapping, the exact line of contact between the Ione formation and the andesitic sandstone was not distinguished, so that andesitic sandstones are mapped in places as part of the Ione formation.

In 1911, Lindgren published his noteworthy paper[14] on the Tertiary gravels of the Sierra Nevada of California. He divided the Tertiary gravels into four divisions, beginning with the oldest: (*a*) deep gravels of Eocene age; (*b*) bench gravels; (*c*) rhyolitic tuffs and interrhyolitic channel deposits; (*d*) andesitic tuffs and intervolcanic channel deposits. The Ione formation was described by him as a Miocene brackish-water deposit of clay and sandstone that merges into the bench gravels of the Sierra Nevada. The statement was made for the first time that the Ione formation consists of delta deposits which accumulated at the mouths of rivers that descended from the Tertiary Sierra Nevada. The difficulty of drawing an exact line between the Ione formation and the river gravels proper was pointed out.

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11 Lindgren, W., U. S. Geol. Surv., Marysville Folio 17, 1895.

12 Turner, H. W., Further contributions to the geology of the Sierra Nevada. U. S. Geol. Surv., Seventeenth Ann. Rept., pt. I, p. 659, 1895–96.

13 Turner, H. W., U. S. Geol. Surv., Sonora Folio 41, 1897.

14 Lindgren, W., The Tertiary gravels of the Sierra Nevada of California, U. S. Geol. Surv., Prof. Paper 73, p. 24, 1911.

From 1913 to 1916, Dickerson[15] made valuable contributions to our knowledge of the Ione by finding Eocene marine fossils in it. He designated the Ione as the *Siphonalia sutterensis* zone which he considered the uppermost part of the Tejon Eocene. Some of his more important conclusions were: (*a*) the Ione formation is the marine or estuarine equivalent of the auriferous gravels of the Sierra Nevada; (*b*) the lower clay of the Ione formation of the type locality is an altered rhyolitic tuff; (*c*) the clay with interbedded lignite and the overlying red sandstone containing Tejon fossils are equivalent to the rhyolitic and interrhyolitic channels of Lindgren; (*d*) the deep gravels of Lindgren should be correlated with the 500 or 600 feet of sediment below the clays and lignite recorded in a boring near Ione.

In 1921, Clark[16] referred Dickerson's uppermost Eocene *Siphonalia sutterensis* zone to the Meganos Middle Eocene. This reference applied especially to the marine Ione, such as Dickerson described from Oroville Table Mountain and Marysville Buttes, but not to the type section. Perhaps the latter was excluded because of its limited fauna and poor preservation of the forms obtained.

IONE FORMATION DEFINED

The term Ione formation has been employed in a number of different ways and to include a variety of unrelated rock types. Yet there remains no doubt that Lindgren intended it to represent the time interval involved in the section near Ione, Amador County, California. Therefore careful consideration should be given this section in determining just what the Ione formation includes. While mapping the Jackson quadrangle, Turner[17] made three divisions of the type section, which are, in ascending order: (*a*) white clay and sand containing lignite, well exposed around Ione; (*b*) white or red sandstone that occurs to the south; (*c*) clay rock or tuff. In the present paper, it is proposed to restrict the name Ione formation to the beds along the foothills of the Sierra Nevada that have a mineral composition and history similar to the lower two members of the

15 Dickerson, R. E., Fauna of the Eocene at Marysville Buttes, California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 7, p. 257, 1913; Notes on the faunal zones of the Tejon group, *ibid.*, vol. 8, p. 17, 1914; Stratigraphy and fauna of the Tejon Eocene of California, *ibid.*, vol. 9, p. 363, 1916.

16 Clark, B. L., The stratigraphy and faunal relationships of the Meganos group Middle Eocene of California, Jour. Geol., vol. 29, p. 125, 1921.

17 Turner, H. W., Rocks of the Sierra Nevada, U. S. Geol. Surv., Fourteenth Ann. Rept., pt. II, pp. 462–465, 1894.

type locality. Statements have appeared from time to time that the lower clays of the Ione formation were formed from rhyolitic tuffs. The investigation of the nature of these clays lends no support to this notion, but on the contrary shows that both the clays and the associated sands were derived from a surface that had been subjected to a long period of chemical weathering. Turner[18] mentions the occurrence of pearly scales of a hydrous silicate of aluminum that is characteristic of the sandstones. This mineral is anauxite,[19] and with it are associated quartz and a group of minerals that have withstood the intensive chemical weathering. This assemblage composes the lower two members of the type section, and it is so persistent that it has been traced more than two hundred miles. Therefore it is suggested that the name Ione formation be reserved for this lithologic unit, serviceable in mapping and valuable in correlation. The reasons for the separation of the "clay rock" from the lower members will be given later.

In discussing the problem of the Ione formation, its distribution, structures, and mineral composition will be considered first. Subsequently, the surface on which the Ione was deposited will be reconstructed in so far as it has been found possible, and the inference as to climate will be scrutinized. It will be shown that the condition of pre-Ione time favored the development of the minerals now found in the Ione formation, and that large areas of the Tertiary Sierra Nevada were covered with them. Then the relationship of the "auriferous gravels" to the Ione will be taken up. Evidence will be cited that the streams, which filled the channels on the higher slopes with white quartz gravel, were the agents that carried the finer material westward to form the deltas that constitute the Ione formation. Finally, the mineral composition of the clay rock and the rhyolite tuffs, as well as their relation to the Ione formation, will be discussed.

DISTRIBUTION OF THE IONE FORMATION

Jackson and Carbondale Quadrangles

The clays and sands constituting the lower member of the Ione formation are well exposed in the vicinity of the town of Ione, largely because pits have been opened in order to exploit them. Much of the

[18] *Op. cit.*, p. 464.

[19] Allen, V. T., Anauxite from the Ione formation of California. Am. Mineralogist, vol. 13, pp. 145–152, 1928.

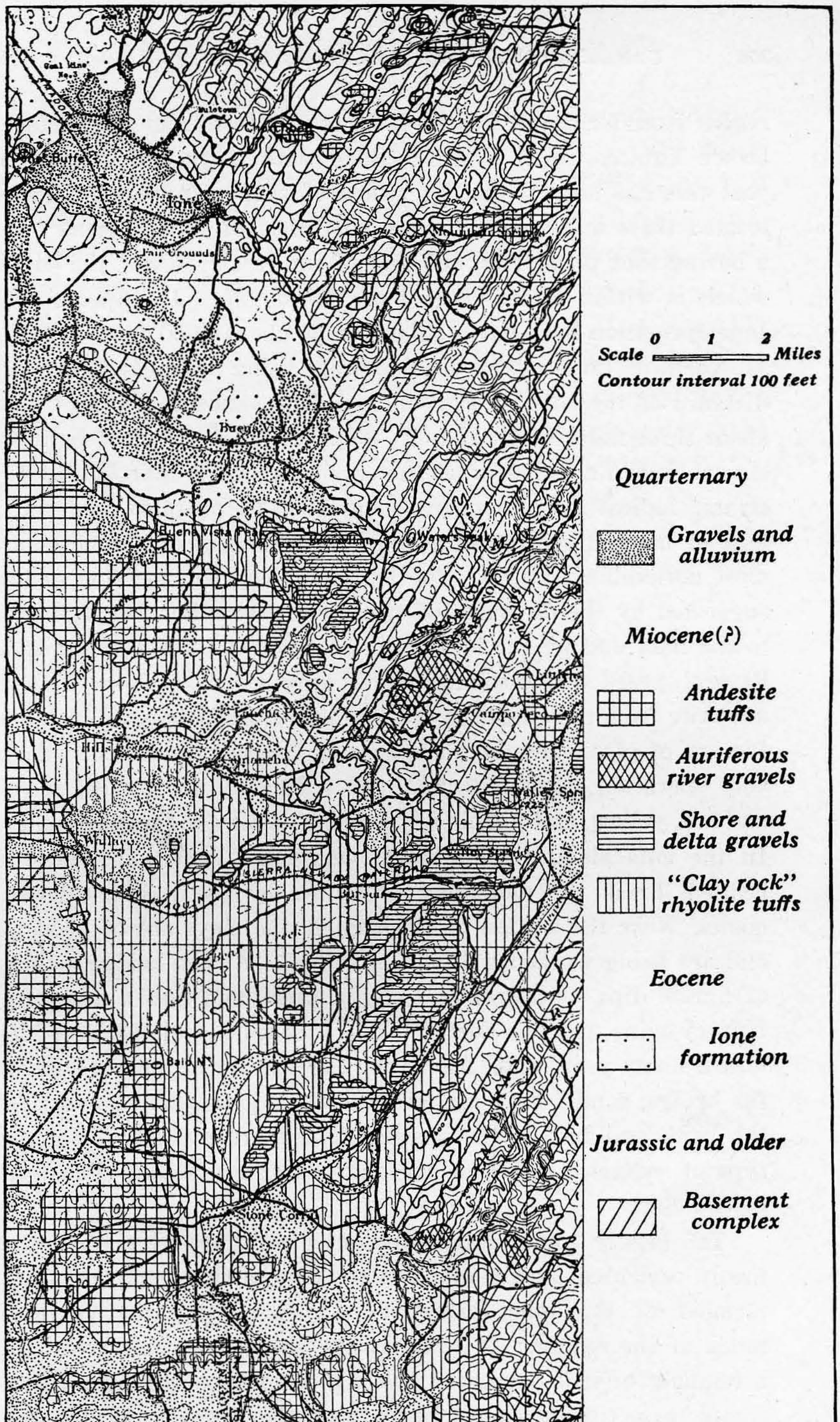

Fig. 2. Geological map of part of the Jackson Quadrangle, California. Modified after H. W. Turner.

region is underlain at depths of 50 to 100 feet from the surface with brown lignite, which is interbedded with clays and sands. In the past this has been mined by means of shafts. At Coal Mine No. 3, located three and one-half miles northwest of Ione, Turner[20] records a boring that penetrated 800 feet of sandy clay below the coal seam, which is within 60 or 70 feet of the surface. It appears that the Ione formation here has a thickness of about 1000 feet.

North of Ione several open pits are being operated within a short distance of the road to Carbondale. The exposure at the Clark Pit, about three miles north of Ione, is typical. Fifty feet of light-colored clay occurs in massive lenses that are practically unbroken by thinner strata, indicating continuous deposition of uniform material. The lack of marked stratification and the whiteness of the clays are the most noticeable features. The lenticular character of the deposits is suggested by the difficulty of tracing a particular clay from one pit to the next and by the local intercalations of quartz anauxite sands. Several years ago washing-plants were established to remove the anauxite from the quartz so that the latter might be used in the manufacture of glass, but the cheapness of Belgian sand has made profitable operation impossible. All the sediments are not light colored, and red, yellow, and purple are common colors for the clays and sands. In the cuts along the highway, variegated sands, in places cross-bedded, break the monotony presented by the lighter-colored sediments. Near the station of Carbondale the clays are of good quality and are being worked with steam shovels. At the bridge a thin seam of lignite dips southwest at a slight angle, and half a mile away the Harvey mine was put down 80 feet into a body of lignite which was mined many years ago. Along the Laguna for a quarter-mile west of the bridge, sandy clays and cross-bedded quartz-anauxite sands form the bank and bed of the stream. These are overlain by a peculiar type of sediment in which angular quartz grains are embedded in a brittle clay.

The loosely consolidated sands and clays are overlain by massive firmly cemented quartz-anauxite sandstones that comprise the upper member of the Ione formation. Erosion has removed this from much of the region. At Jones Butte, three miles northwest of Ione, a remnant of it is preserved below a covering of younger rocks. The complete section at Jones Butte near the property of the Stockton Fire Brick Company is in descending order as follows:

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[20] Turner, H. W., U. S. Geol. Surv., Jackson Folio 11, p. 2, 1894.

	Feet
Brown andesite tuff	20–100
Andesite tuff and conglomerate	20
—disconformity—	
White, biotite rhyolite vitric tuff	45
Massive 3-ft. beds of clay rock	60
—disconformity—	
Massive Ione quartz-anauxite sandstone	12
White to gray plastic Ione clay	16
White brittle halloysite Ione clay	8
—disconformity—	
Buff to red massive laterite, part exposed	6

The Ione formation occupies the area north of Buena Vista Peak at an elevation of one to two hundred feet above Jackson Creek. At the Buena Vista Coal Mine, a shaft penetrated seventy-five feet of sediments to reach the lignite. The section exposed in the shaft is composed of poorly bedded white anauxite-quartz sands and sandy clays arranged in lenses, the texture of which changes suddenly both horizontally and vertically, for drill holes a few hundred feet away encountered pure clay alternating with sands. Less than a mile away a well is said to have been drilled through 300 feet of sediments in order to obtain water. Unfortunately samples from these wells are not available. The exact thickness of the Ione formation here is unknown, but the suggestion is that it is at least 500 feet. The Ione sediments extend eastward where they rest on the Bedrock complex of the Sierra Nevada. Erosion has removed much of the Ione formation in this area and some of it is covered by shore and delta gravels of Miocene (?) age. One and a half miles southwest, a quarry was opened in the quartz-anauxite sandstone of the Ione formation. The nature of the rocks on which the sandstone rests is unknown, as the lower part is covered by talus. The sandstone is higher in elevation than the beds associated with the lignite and is considered higher stratigraphically, comprising part of the upper member of the Ione formation. The lowest beds quarried consist of red and, rarely, purple sandstone. Barrell[21] and others have pointed out the prevalence of these colors in continental sediments, especially mentioning them in connection with fluviatile deposits. At the south end of the quarry the beds curve downward toward the north (pl. 24*a*). About 450 feet to the north, the beds bend toward the south, outlining a channel. The curvature of the upper beds is on a smaller scale, the distance from

[21] Barrell, J., Criteria for recognizing ancient delta deposits, Bull. Geol. Soc. Am., vol. 23, p. 416, 1912.

side to side being only a few feet (pl. 24*b*). The variation in the curvature of the strata, and the manner in which the horizontal layers abut against the sides, indicate the structures formed during deposition. Twenhofel[22] mentions that river channels when being aggraded are filled not infrequently with sediments which arch downward from bank to bank giving a synclinal effect. Also, there is evidence that scour and fill has operated, for some horizontal layers have been cut away and the resulting minor channels filled by beds having a greater curvature than those on which they rest. This stream action undoubtedly took place at the shore line probably in the top-set beds of a delta, for oscillation ripple-marks with the crests striking N 50° E are present on the surface of some of the curved beds. Moreover, the uppermost horizontal layer shown in plate 24*a* contains casts of marine fossils. From this locality Dickerson[23] reported collecting:

Venericardia planicosta merriami Dickerson
Meretrix hornii Gabb
Psammobia cf. *hornii* Gabb
Crassatellites sp.
Turritella merriami Dickerson
Natica sp.
Clavella sp.

These forms are present as poorly preserved casts, but the *Turritella merriami* Dickerson is considered by Clark[24] to be sufficiently complete for accurate determination. He regards it as a marker of the Meganos Eocene, and on this evidence refers the Ione formation at its type locality to the Meganos (Middle Eocene).

Near the north end of the quarry, white Ione sandstone ten or twenty feet thick occurs above the red. The upper surface of the white sandstone is waterworn and on it rests nonconformably a white rhyolite tuff and in other places gravels containing rhyolite pebbles. These gravels are part of Turner's "shore gravels," and farther south they contain andesite pebbles. At Waters Peak, one and a half miles northeast, massive Ione sandstone rests directly on the Bedrock complex. The sandstone is firmly cemented, contains abundant anauxite, and certain layers are made up largely of pebbles of quartz and the older rocks of the Bedrock series.

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22 Twenhofel, W. H., Principles of sedimentation, p. 434, 1926.

23 Dickerson, R. E., Stratigraphy and fauna of the Tejon Eocene of California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, p. 397, 1916.

24 Personal communication.

Massive Ione sandstone firmly cemented with iron oxide and silica forms the banks of the Mokelumne River near Lancha Plana. In places it is 200 feet thick and contains large flakes of anauxite. To the west, at the bridge, it is overlain by the clay rock. From Comanche to Valley Springs, the sandstone and the lower sands are exposed where erosion has removed the overlying rhyolitic series and shore gravels. At Valley Springs, a clay with a high content of iron is being quarried. One mile west of Valley Springs is a small sandstone quarry. The sandstone contains, in addition to anauxite and quartz, altered biotite and more feldspar than is in the usual Ione sandstone. It probably should receive a separate name, as the mineral assemblage is not typical, but the outcrop is small and hardly warrants it. It will be mentioned again in connection with the origin of the Ione sediments.

Knights Ferry

In the southern part of the Jackson and the adjoining Copperopolis quadrangle, outcrops of the Ione formation are limited owing to the overlap of the younger formations on the Bedrock series. At Knights Ferry, erosion by the Stanislaus River has removed the overlying tuffs and gravels and the Ione formation is exposed in the gully north of the village. At several points it rests on a white lithomarge derived from the rocks of the Basement complex. The formation consists of plastic clays, ochres, and sands of various colors. The ochres are yellow and brittle and make up a considerable part of the series. They are the only portion utilized in the district and a number of tunnels have been opened for mining them. In places anauxite sandstones overlie the ochres, and are firmly cemented with iron oxides; they dip west at about 10°. The thickest section lies to the east and can be observed from the road before crossing the bridge over the Stanislaus River. Sixty feet of plastic clays, sands, and ochres rest on the altered bedrock. Seventy feet of cross-bedded sandstone forms the upper part of the section. This sandstone contains biotite and about 30 per cent of orthoclase, and like the standstone at Valley Springs probably should have a separate name, but for the same reason a name has not been given.

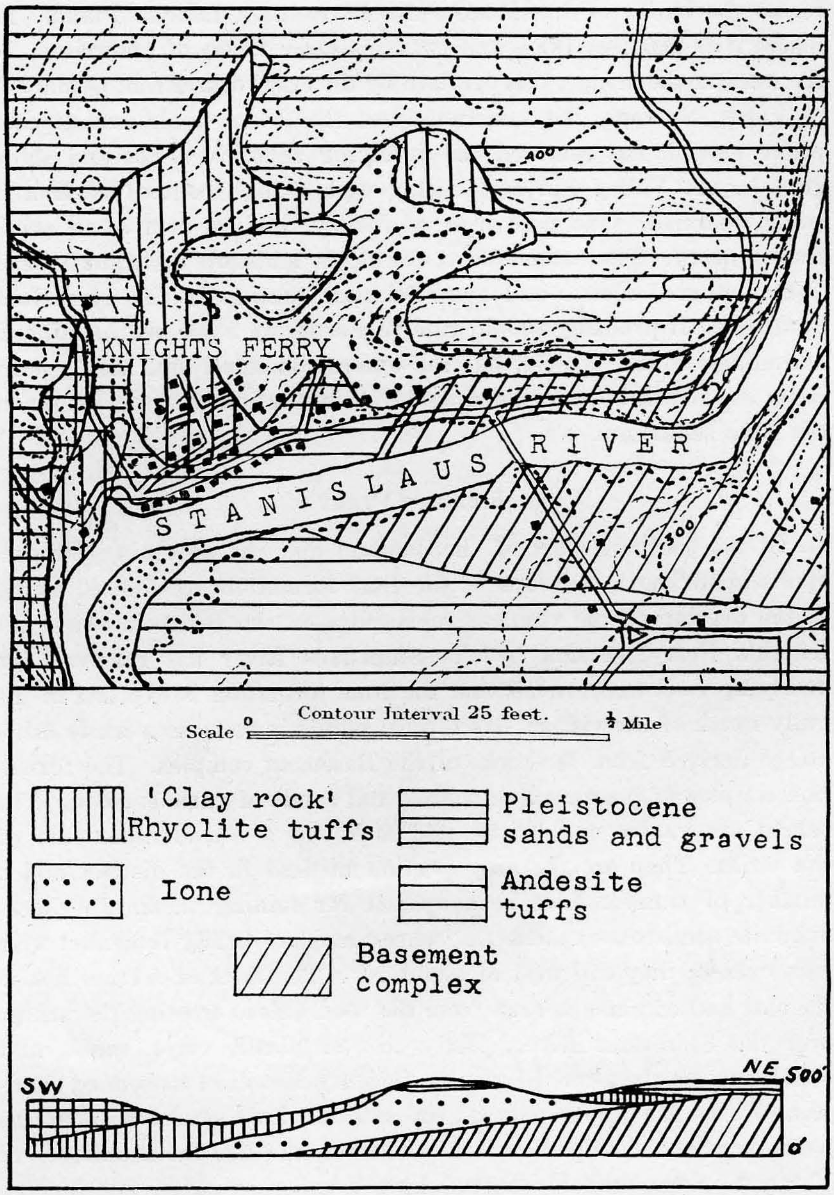

Fig. 3. Geological map and cross-section near Knights Ferry, Copperopolis Quadrangle, California.

MERCED FALLS

The Ione formation is exposed along the Merced River in the Sonora quadrangle near Merced Falls. Massive quartz-anauxite sandstone forms the flat-topped hills south of town. Casts of *Venericardia planicosta* in the sandstone were the basis for its being considered Tejon Eocene by Turner.[25] To the west, thinner anauxite sandstones

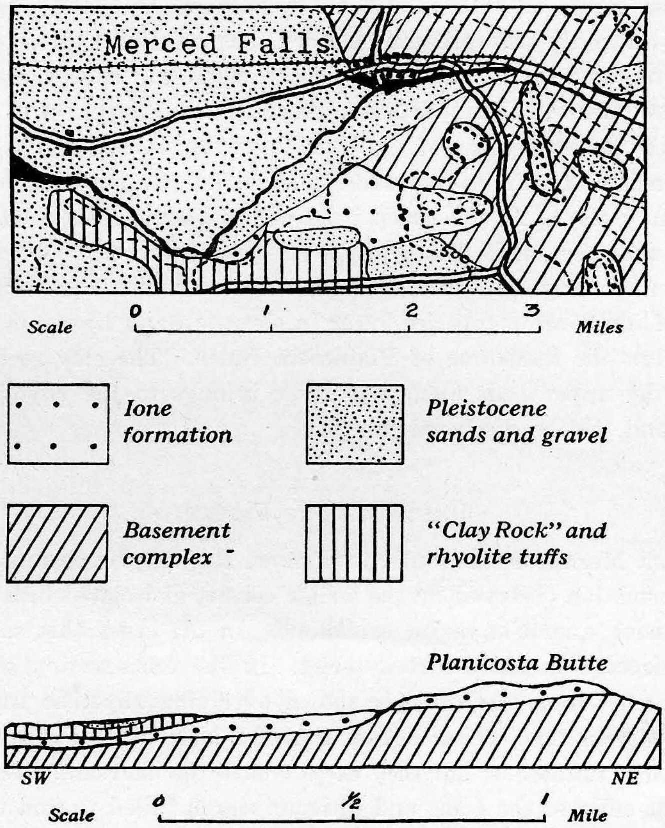

Fig. 4. Geological map and cross-section near Merced Falls. Modified after Sonora Folio, California.

of the same mineral composition (see table 1, p. 375) outcrop at a lower level, and were mapped by him as Ione. The mineral assemblages of the upper and lower sandstones are so much alike and so closely approach parts of the Ione of the type locality that the writer regards

[25] Turner, H. W., and Ransome, F. L., U. S. Geol. Surv., Sonora Folio 41, p. 2, 1897.

both as Ione and of Eocene age. Earlier, Turner had noted this similarity, for he stated:[26]

"Sandstone quite like that of the Ione formation of the Jackson sheet was observed by the writer capping flat-topped hills south of Merced Falls." But the Ione was supposed to be Miocene, and when Eocene fossils were found in this sandstone Turner modified his decision in an effort to explain the situation.

Dickerson[27] correctly interpreted the conditions of Ione deposition when he stated that the sediments were deposited along the shore line of a rapidly transgressing western sea, and that the massive fossiliferous sandstone is the uppermost member. However, certain points require some amplification. About a mile southwest of Merced Falls, the lower member of the Ione formation is exposed in a gully and consists of thin-bedded sandstone resting on uncemented sands and sandy clays. At the sharp bend of the Merced River, 60 feet of quartz-anauxite sands form the lower part of the steep south bank, and contain fragments of slate bleached snow white. As is shown in figure 4, these sediments are lower in elevation and lie stratigraphically below the sandstone of Planicosta Butte. The clay rock which forms the upper beds along the river belongs to the rhyolitic tuff series and will be discussed later.

Bear Creek to Friant

From Merced Falls south to Friant, the only exposures of the Ione formation observed by the writer consist of isolated hills capped by massive quartz-anauxite sandstone. In all cases this sandstone rests directly on the Bedrock series. In the cross-section given by Dickerson,[28] Ione sandstone is shown overlying rhyolitic tuffs near Burns Creek. The writer agrees that the beds so indicated by him are clearly tuffaceous, but they do not have the characteristics of the lower member of the Ione, and diligent search failed to find the Ione sandstone overlying the tuffs. Several hills are capped with the more resistant layers of the tuff series, but none possess the mineral composition of the normal Ione sandstone. The writer considers that all the superjacent beds shown in the western part of Dickerson's section belong to the rhyolitic tuff series.

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[26] Turner, H. W., Rocks of the Sierra Nevada, U. S. Geol. Surv., Fourteenth Ann. Rept., pt. II, p. 465, 1894.

[27] *Op. cit.*, vol. 9, p. 398, 1916.

[28] *Op. cit.*, p. 402.

The massive sandstone resting on the slates, near Burns and Bear Creek, is Ione as is shown by its mineral composition in table 1. It was first described by Blake,[29] and the locality is interesting because of the well developed mud cracks on the surface of some of the blocks, and the occurrence of andalusite crystals in the gravels. The sandstone mentioned by Turner,[30] along the road from Madera to Daulton, is also Ione, but the outcrops are small and poorly exposed. Northwest of Friant on the San Joaquin River, this sandstone, resting on the granodiorite, forms the upper series of flat-topped hills, and can be followed from the road to Coarse Gold for more than two miles in the direction of Lanes Bridge. Its thickness varies from 40 to 80 feet, and it is made up of anauxite sandstone alternating with layers of conglomerate composed of pebbles of porphyritic rocks of the Bedrock series and quartz up to 5 or 6 inches in diameter. The beds are well consolidated, forming exposures with vertical faces, and dip southwest at a low angle. The vicinity of Friant marks the southern limit to which the Ione formation has been traced, and although the region along Kings River and the area to the south were examined, no Ione sediment could be found.

Lincoln

In the Sacramento quadrangle, the Ione formation is best exposed at Lincoln, where clay pits are being operated by the Gladding McBean Co., the Lincoln Clay Products Co., and the Stockton Fire Brick Co. The section at the Gladding McBean pit, beginning with the uppermost bed is as follows:

	Feet
Andesite lithic tuff and boulders	6–15
—disconformity—	
White to gray massive clay of the Rhyolitic period	5
Biotite sands and sandy clays of the Rhyolitic period, laminated and cross-bedded, some gravel interbedded and at the base	20
—disconformity—	
Bedded white and brown Ione clays	10
Massive white Ione clay	35

29 Blake, W. P., Exploration and surveys for a railroad route from the Mississippi to the Pacific Ocean, vol. 5, pt. 2, pp. 12–15, 1853.

30 Turner, H. W., Further contribution to the geology of the Sierra Nevada, U. S. Geol. Surv., Seventeenth Ann. Rept., pt. I, p. 683, 1896.

Prospecting by drilling has been carried on and below the exposed portion blue clays of similar composition pass downward into layers containing lignitic streaks, and finally at about 140 feet from the surface the "Walkup clays" are reached. The Walkup clays are crudely bedded, and yet in some places they become shaly and contain thin lenses of limestone. The color is gray, but where weathered it may be buff or yellowish. Less than half a mile to the east, the Walkup clays appear at the surface at a pit bearing that name. The writer collected poorly preserved casts from this clay, among which is a coral that resembles *Stephanophyllia* (?) *vacavillensis*[31] described from the Meganos Eocene near Vacaville. Some of the other forms might be doubtfully referred to that horizon. The Cretaceous of this quadrangle consists of fossiliferous sandstone containing concretions, so the limited evidence points to an Eocene age for the Walkup clays. Its contact with the Ione is not exposed, but the Ione is known to thicken rapidly to the west and it does not reach so far east as the Walkup. The chemical composition of the Walkup, furnished by the company, is given below:

	Per cent
SiO_2	56.47
Al_2O_3	21.90
Fe_2O_3	7.70
CaO	1.15
MgO	1.26
Alk (by diff.)	.27
H_2O	11.25

It is somewhat different from that of the Ione clays, and there is also a marked difference in ceramic qualities. The Ione clays are used for terra-cotta products; the Walkup clays are not suitable for that purpose and are utilized in making sewer pipe. So, even though no sharp break is known to separate the two formations in the field, it seems desirable to use the name Walkup, already in use locally, to denote this transitional stage to Ione conditions.

The Ione clays at Lincoln are similar in mineral and chemical composition and in field appearance to those of the type section. Light colors predominate, white, gray, pink, salmon, brown, and reddish spotted types being represented. Ordinarily, the bedding is obscure and lenticular, for efforts to correlate the individual beds at the Gladding McBean pit with the clays in the pits to the north has

[31] Palmer, Dorothy Kemper, A fauna from the Middle Eocene shales near Vacaville, California, Univ. Calif. Publ. Bull. Dept. Geol. Sci., vol. 14, p. 289, 1923.

met with little success. The upper ten feet of the Ione at the Gladding McBean pit are composed of alternating brown and white layers which dip west at 4°. Clays derived from rhyolitic tuffs rest on the terra-cotta clays of the Ione, and are separated from them by an erosion interval.

Marysville Buttes

Some 40 miles northwest of Lincoln, in Sutter County, the Marysville Buttes rise above the Sacramento Valley. About 150 feet of Ione sediments are exposed around the central core of the Buttes. The region has been mapped recently by Williams[32] who has followed the writer's usage of the term Ione. The beds here assigned to that formation have a similar mineral assemblage and show evidence of having been deposited under the same conditions as the Ione formation at its type section. The best exposures are on the south and west sides of the Buttes and consist of quartz-gravel that is dominantly white or cream colored, but may be stained yellow, red, or purple with iron oxide. In the outcrop, the absence of fine lamination, the pattern of its cross-bedding, and the lenses of rounded quartz pebbles are features that can be duplicated near Ione. These sediments are today only loosely consolidated and where erosion has sculptured and carved them, miniature Bad Land topography has been produced (pl. 27*a*). Where it is well developed, the combined effect of the topography, color, and character of the sediments is so characteristic that the formation can be recognized at a distance, even though the width of the outcrop is narrow.

The Ione formation rests on buff sands with interbedded gray shales that are locally glauconitic. The contact with the Ione is apparently conformable, as there is no appreciable divergence in dip and strike. However, there is a notable difference in the mineral composition of the two formations. The buff sands carry feldspar, chiefly orthoclase but some soda-lime, that constitutes 60 or 70 per cent of some samples. Much of the feldspar is altered and some is quite fresh. The maximum feldspar content observed in the overlying Ione was 20 per cent, consisting of orthoclase. Biotite and hornblende are common minerals in the buff sands, but are lacking or sparsely present in the Ione. The two formations could not have been produced under the same conditions. During the discussion with

[32] Williams, H., Geology of the Marysville Buttes, Univ. Calif. Publ. Bull. Dept. Geol. Sci., vol. 18, pp. 103–220, 1929.

Williams, of the stratigraphic section at the Marysville Buttes, the name Marysville formation was suggested for these sediments, and it is here proposed that the buff sands and gray shales shall be so designated. From the Marysville formation, Dickerson[33] collected a fauna which he supposed belonged to the *Siphonalia sutterensis* zone of the Tejon Eocene. Clark[34] considers this fauna to belong to the Meganos group of the Middle Eocene.

Above the Ione formation are beds of gravels containing quartz, quartz-porphyry, and siliceous pebbles up to five inches in diameter, which are interbedded with biotite sands and lenses of buff sandstone. According to Williams, this formation locally reaches a thickness of over 1200 feet. In places its contact with the Ione is disconformable and there is evidence of an erosion interval between the two formations. Near the middle of the formation Williams[35] found *Turritella merriami* Dickerson and other species considered by Clark as belonging to the Meganos horizon. The characteristics and the mineral assemblage of these beds are not those of the Ione formation, and the name Butte gravels has been given to them.

The significant point derived from a study of the sediments at the Marysville Buttes is that the Ione formation is a distinct lithologic unit occurring within the range of *Turritella merriami* and other species considered Middle Eocene (Meganos) by Clark.

Oroville Table Mountain

Oroville Table Mountain forms a prominent landmark in the southeast corner of the Chico quadrangle, in Butte County. The sediments below the basalt that caps the surface have been described in the early reports of the State Geological Survey and of the California State Mining Bureau. In 1911, Lindgren[36] mapped and described the area, and summarized the previous literature including the papers of Turner and Diller. In 1916, Dickerson[37] reported a collection of

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33 Dickerson, R. E., Fauna of the Eocene at Marysville Buttes, California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 7, pp. 257, 298, 1913; Stratigraphy and fauna of the Tejon Eocene of California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, p. 409, 1916.

34 Clark, B. L., The stratigraphy and faunal relationships of the Meganos group, Middle Eocene of California, Jour. Geol., vol. 29, p. 125, 1921.

35 Personal communication.

36 Lindgren, W., The Tertiary gravels of the Sierra Nevada of California, U. S. Geol. Surv., Prof. Paper 73, p. 86, 1911.

37 Dickerson, R. E., Stratigraphy and fauna of the Tejon Eocene of California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, p. 388, 1916.

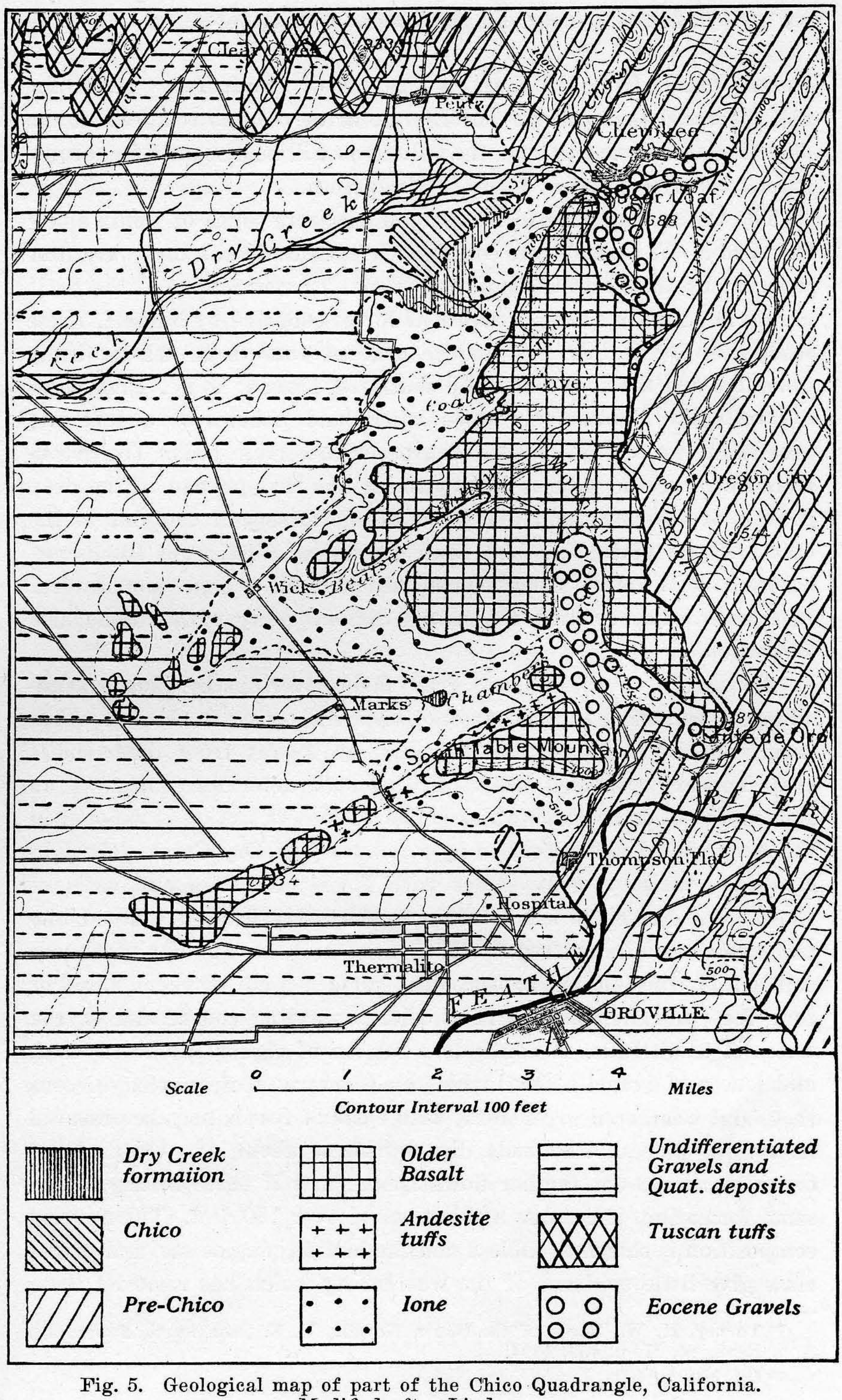

Fig. 5. Geological map of part of the Chico Quadrangle, California. Modified after Lindgren.

Eocene fossils from the shaft and tunnel of South Table Mountain, and discussed the geology. In order to bring out the relations of the older formations to the Ione, the sediments will be discussed in chronological order, beginning with the Cretaceous.

The Chico sandstone forms a small exposure south of Pentz along Dry Creek. This sandstone contains Cretaceous fossils that were first reported by the State Geological Survey. Turner reprinted the list[38] giving in addition a large number of forms collected by himself. These sediments are mainly buff biotite arkoses, some soft, others firmly cemented and massive, which dip southwest from 4° to 6°. Fragments of shells are abundant in some layers and pebbles of quartz and greenstone up to eight inches long occur in certain beds. The greenstone forming the pebbles is very much like that present in the deep gravels at Cherokee and like parts of the Basement complex to the east. At one place, soft buff sand containing Cretaceous fossils cut across a fossiliferous conglomerate bed and fill a depression several feet lower. The relation suggests a disconformity within the Chico formation.

Above the Cretaceous are gray shales overlain by biotite sandstones. The actual contact was not observed owing to the soil which forms on the shaly portion. Apparently it was from these shales that Turner[39] collected casts of *Corbicula* determined first as an Eocene fresh- or brackish-water genus. The best section is exposed in the steep-walled valley formed by a tributary of Dry Creek. The lowest beds consist of gray shales with flakes of biotite and casts of Eocene fossils. These are overlain conformably by light-colored biotite sands containing fragments of wood and leaves. The sands are sufficiently consolidated so that the stream has cut a trench three or four feet wide in which it flows with a winding course and over a series of small falls. A continuous section of eighty feet is exposed, and lenses of gravel a few inches thick composed of quartz, siliceous rock, and weathered greenstone, with casts of fossils may be observed in several places. The beds dip southwest about 4°. Gray shales occur at a road-cut farther downstream, and if these belong to the same formation, it reaches a thickness of over 180 feet. The mineral composition is shown in table 2 and the biotite, plagioclase, and orthoclase give little evidence of the weathering which has removed these

[38] Turner, H. W., Rocks of the Sierra Nevada, U. S. Geol. Surv., Fourteenth Ann. Rept., pt. II, p. 459, 1894.

[39] *Op. cit.*, p. 463.

minerals from the Ione assemblage. The name Dry Creek formation is suggested for these beds, from the tributary along which the section is displayed. At Coal Creek the lower three feet of biotite sands that are exposed belong to this formation. At the lower part of Chamber's Ravine four feet of biotite gray shale is overlain by two feet of glauconite-anauxite sandstone containing casts of fossils. Some of these are similar to the forms reported by Dickerson[40] from the Dyer shaft one and one-half miles farther south. Dickerson states that his collection came from "dark gray shales interbedded with lignite containing fossiliferous strata, and thin-bedded fossiliferous sandstone." The matrix attached to some of the fossils from the shaft is very much like parts of the Dry Creek formation. Clark[41] considers the fauna from the Dyer shaft to be Middle Eocene (Meganos) age.

Along the tributary of Dry Creek, the Ione formation consists of white quartz-anauxite sands and clays. Cross-bedding is common and is brought out by streaks of red, due to iron oxide. The beds are for the most part unconsolidated, but occasionally a massive bed is well cemented with limonite. The total section exposed is 400 feet. At Coal Creek, the biotite sands of the Dry Creek formation are conformably overlain by fine thin-bedded anauxite clayey sands containing leaf impressions. Farther upstream is a peculiar type of sediment in which angular quartz grains are embedded in clay. Similar material encases rounded quartz pebbles in the gravel portion. In some respects the hand specimen resembles a tuff, but the texture in thin section is not tuffaceous (pl. 37*a*). Gravels composed largely of white quartz pebbles that are overlain by clays form the upper part of Coal Creek. At Chambers Ravine, there is evidence that the deposition of the Ione followed the Dry Creek formation without a withdrawal of the sea. Anauxite occurs here with glauconite, and the sandstone containing these minerals has the same casts of fossils as the underlying gray shales. The contact is not only conformable, but anauxite was contributed to the sea while the conditions were still favorable for the formation of glauconite. At the next higher exposure near the juncture of the tributaries, coarse Ione sand of the usual composition is present. The upper beds in Chambers Ravine consist of soft sands and clay. The top layer is like the peculiar sandy

[40] *Op. cit.*

[41] Clark, B. L., The stratigraphy and faunal relationships of the Meganos group, Middle Eocene of California, Jour. Geol., vol. 29, p. 125, 1921.

clay at Coal Creek. In general the Ione sediments are finer toward the west. The most western exposure of any consequence is on the west side of the road to Chico, where the Table Mountain Clay Products Company near Wick is using the Ione clay below the isolated hills for brick making.

Dickerson[42] published the following statement regarding the section on the south and west sides of South Table Mountain:

The base of the Eocene strata of South Table Mountain is exposed in the old Miocene Hydraulic Mine, one mile north of Oroville. The basal conglomerate, about twenty feet in thickness, rests upon Chico rocks from which Mr. Ruckman obtained specimens of *Trigonia evansana* and *Cucullaea* sp. Twenty feet of clay strata rest upon this conglomerate. These two lithologic members were recognized in the Rumble Mine, one-half mile northwest of this locality, at the County Hospital Hill, one mile west, and in the Dyer mining shaft, two and one-half miles north of Oroville. A study of the sediments as exposed in the Dyer shaft and on the south face of South Table Mountain gives in descending order the following approximate sequence:

		Feet
(9)	Older basalt	100–150
(8)	Andesitic tuff breccia	10–20
(7)	Alternating sandstone, clay, and carbonaceous shales	100
(6)	Conglomerate	50
(5)	Tuffaceous clay	20
(4)	Yellow, tan sandstone	100
(3)	Dark gray shales interbedded with lignite containing fossiliferous strata, and thin-bedded fossiliferous sandstone	40
(2)	Clay with tuff fragments	20
(1)	Conglomerate resting upon Chico sandstone	20

The remaining sedimentary series on the west side of Oroville Table Mountain and South Table Mountain are composed of similar sediments and are beyond doubt the same as those south of South Table Mountain.

Any doubt as to what Dickerson considered the location of the Miocene Hydraulic Mine and the Chico outcrop is removed by consulting his map,[43] on which a small area southeast of Thompson Flat and a little over a mile north of Oroville is marked "Kc." The sandstone containing casts of *Trigonia* at this locality is nearly vertical and is interbedded with tuffaceous and agglomeratic members usually considered Jurassic. The relations and character of these beds are so different from the gently dipping Chico beds near Pentz, that the writer collected some fossils and sent them to Mr. T. W. Stanton of the United States Geological Survey. His report appears below:

The collection includes at least three species of pelecypods of which two belong to *Trigonia* and the third and most abundant form is a pterioid shell which I have had in two previous collections from the Monte de Oro formation

[42] *Op. cit.*, p. 390. [43] *Op. cit.*, p. 393.

and referred first to *Eumicrotis* ? sp. and afterwards to *Cardium* ? sp. On reexamination of the old material in connection with your somewhat better specimens I will return to my first determination and call the form *Eumicrotis* ?, since it seems to belong to the Pteriidae, a family formerly called Aviculidae. This form is the most abundant invertebrate in the collections from the Monte de Oro formation as well as in your collection, and I consider it sufficient evidence that your new locality, which as you state is about three miles from the type locality of the Monte de Oro formation, is also in that formation.

Each of the two species of *Trigonia* is represented by an excellent imprint, casts from which give a very good idea of the form and sculpture. The smaller specimen belongs to the group Clavellatae and is distantly related to *Trigonia dawsoni* Whiteaves. This I consider a distinctly Jurassic type.

The larger imprint apparently belongs near the Aliformis subgroup of the group Scabrae, which is chiefly a Cretaceous group, but your species departs considerably from the usual form of the group and is certainly distinct from anything that has been described from the Pacific coast. The species is also represented by an internal cast of a small specimen.

Taking into consideration all the invertebrate collections I have seen from the Monte de Oro formation together with the testimony of the plants I think that the formation is of Jurassic age—most probably Upper Jurassic. Whether it is equivalent to part of the Mariposa formation I do not know, but the abundance and excellent preservation of fossils at this new locality makes me hopeful that a sufficient fauna will yet be found to enable us to classify it accurately.

The report which Mr. Stanton has so kindly furnished shows that Lindgren was correct in mapping this area as pre-Cretaceous. The writer also noticed that the gravels at this locality are not those mentioned in Turner's[44] description which appears below:

The Miocene Hydraulic Mine is at the east edge of South Table Mountain. The deposit is largely sand and white clay, containing fossil leaves, with gravelly layers made up chiefly of white quartz pebbles. Professor Knowlton identified one of these leaves as *Juglans Californica* Lx. The bed rock is a greenstone breccia, representing an original augitic surface lava, probably an andesite. The sedimentary beds are perhaps 300 feet in thickness, capped with a basalt sheet about 100 feet thick.

This description fits the hydraulic mine located about two and one-half miles north of Oroville, instead of one mile as given by Dickerson. It thus appears that the name Miocene Hydraulic Mine has been used in the literature for two different localities. Inquiry of the older settlers in the region brought out the following explanation for the conflicting usage. The area mapped as Chico by Dickerson, southeast of Thompson Flat, is known by many people as the Miocene Mine. The water used in the hydraulic mining came from a ditch known as the Miocene ditch that passed close to the east edge of South

[44] Turner, H. W., Further contributions to the geology of the Sierra Nevada, U. S. Geol. Surv., Seventeenth Ann. Rept., pt. I, p. 546, 1896.

Table Mountain. By some people the mine near the ditch was also called the Miocene Mine. In the present case, the important question is, from which locality did *Juglans Californica* Lx. and the other leaves come? The writer visited Mr. Turner, who is certain they came from the mine two and one-half miles north of Oroville that contains white quartz gravels. Lindgren[45] considered that these leaves came from the clays in Morris Ravine. It is in these beds that the present writer would expect the occurrence.

The twenty feet of gravel and twenty feet of biotite sandy clay considered by Dickerson as the base of the Eocene, do not resemble the older pre-volcanic gravels of the Sierra Nevada. Lindgren mapped these beds as bench gravels of late Pliocene or Quaternary age, and Turner[46] agrees with him. The writer observed that similar material can be seen at the Rumble Mine, County Hospital Hill, and the Dyer shaft, for it rests upon benches cut into the Ione, the Dry Creek formation, and older beds. Dickerson neglects to state whether he observed the conglomerate below the gray shales in the Dyer shaft or whether he inferred that it passed below them. The present owner of this land stated that the shaft was abandoned because no coarse gravel was found at the bottom. For some years the Dyer shaft has been filled with water and débris to within twenty feet of the top.

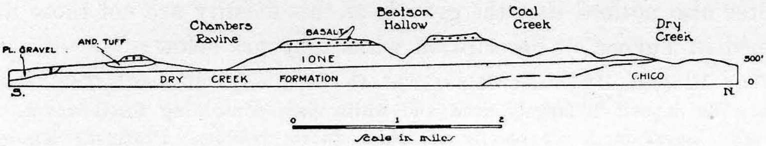

Fig. 6. Section, Dry Creek south to Dyer's Shaft.

Tan biotite sands form the part that can be observed and these belong to the Quaternary bench gravels and sands. The fossiliferous gray shales encountered in the shaft probably belong to the Dry Creek formation, and these shales appear at the surface in Chambers Ravine one and one-half miles to the north. The shaft was put down near the edge of the bench gravels, for white anauxite sandstone occurs a few feet higher on the hillside. The writer's opinion of the general relations here is expressed graphically in figure 6. The south face of South Table Mountain is composed of anauxite clays and sands of the Ione formation. The only tuffs are those which overlie the Ione. These can be seen where the Chico road passes between the basalt of South Table Mountain and the hills to the west. Here the tuff con-

[45] *Op. cit.*, p. 89, 1911. [46] Personal communication.

tains pebbles of hornblende andesite and compact rhyolite tuffs. Similar tuffs are present in Chambers Ravine between the small round hill capped by basalt and South Table Mountain. These tuffs appear to underlie the basalt and show that the older basalt is younger than the hornblende andesite. Turner[47] has described the basalt of Table Mountain and listed chemical analyses, and has traced it into the region to the east where it is overlain by hornblende-pyroxene andesite-breccia at Mount Ingalls.

Oroville Table Mountain marks the northern limit of recognition of the Ione formation. The writer examined a number of sections along Big Butte Creek in the effort to prove its continuity northward, but these reconnaissances were unsuccessful. The Ione formation was probably removed from this area by erosion before the deposition of the Tuscan tuff. This conclusion had been reached by others who have worked in the region. Diller[48] recognized that the Tuscan tuff is extensively developed from Pentz north to Bear Creek, and that few good exposures of what he considered the Ione formation are present. Diller's Ione formation included the beds between the Chico and the Tuscan tuff, and the absence of his larger formation from the district is noteworthy. He affirmed that this was due to removal before the deposition of the tuff. Turner[49] stated that the Chico standstone in the canyons of Butte and Chico creeks is overlain by Tuscan tuff. He considered that the Tuscan tuff came from the vents of Lassen Peak and was very late in the succession of Tertiary volcanics, and he described it as basaltic, in part consisting of coarse doleritic basalt, which overlies the hornblende-pyroxene andesite-breccia at Mount Ingalls. Along Chico Creek, the Tuscan tuff rests on the older basalt (like that of Oroville Table Mountain). At the Welsh Hydraulic Mine, one and one-half miles north of Pentz, angular fragments of older basalt occur in the gravels showing that erosion of the older basalt took place before the deposition of the overlying andesitic tuffs, containing augite, hypersthene, and brown hornblende, that pass upward into basaltic tuffs and breccia. Lindgren[50] appreciated the extent of the erosion that followed immediately after the deposition of the Ione. He remarks that around Oroville Table Mountain the

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[47] Turner, H. W., Rocks of the Sierra Nevada, U. S. Geol Surv., Fourteenth Ann. Rept., pt. II, p. 491, 1894.

[48] Diller, J. S., Topographic revolution on the Pacific Coast, U. S. Geol. Surv., Fourteenth Ann. Rept., pt. II, p. 417, 1894.

[49] Turner, H. W., Rocks of the Sierra Nevada, pp. 492–495, 1894; Further contributions to the geology of the Sierra Nevada, p. 540, 1896.

[50] *Op. cit.*, pp. 25, 91.

andesitic tuffs are in places at least 500 feet below its top member. On the road from Magalia to Oroville, by way of Paradise and Clear Creek, no Chico sandstones, Neocene auriferous gravels, or Ione clays are seen. The andesitic tuff continues almost to the level of the valley, alternating in places with clay beds and volcanic gravels. He concluded that all these relationships strengthen the inference that the Ione formation suffered much erosion between the eruption of the Table Mountain basalt and that of the andesitic tuffs.

In the Redding district, Diller[51] referred certain beds to the Ione formation, which he described as follows:

> Within the Redding Quadrangle the Ione formation is composed of gravel, sand and clay with occasional beds of coaly material and has a thickness not exceeding 50 feet. Sands, often micaceous, are by far the most abundant. The best exposures of the Ione formation are outside the quadrangle along the western border of the Sacramento Valley as well as to the east of Little Cow Creek and about the Great Bend of the Pit River to the head of Kosk Creek, where it certainly is over 1000 feet in thickness.
>
> It crops out around the borders of the valleys and canyons of the Piedmont region in the Redding quadrangle, forming a narrow belt between the Chico below and the Tuscan tuff above. On the one hand, it is difficult to decide in some places whether the non-fossiliferous beds overlying those well characterized by Chico fossils are Cretaceous or Ione, and on the other, the tuffs of the Tuscan formation and the gravels of the Ione appear to be interstratified, and therefore the upper boundary is not always evident. In general, however, where the Ione is best developed there is little difficulty in recognizing it.

From Diller's description of these sediments, it is evident that the typical mineral assemblage of the Ione was not recognized here. The writer visited the area near Oakrun where several prospect tunnels have been opened in the coals. The sandstones overlying the coal are biotite arkoses and contain sandstone concretions such as are found in the Cretaceous to the south. The writer searched the outcrops for fossils, but did not find them and direct evidence of their age is wanting at present. In 1885, Diller[52] reported Chico fossils from the coal-bearing strata south of the Great Bend of the Pit River and it is possible that he referred to these beds. The writer examined the shales and standstones with coaly material near the Great Bend of the Pit River and for a distance of five miles along Kosk Creek. Although the imperfect fossil leaves found here appeared to be Cretaceous,[53] Diller considered the strata as part of the Ione. Lithologically these sedi-

[51] Diller, J. S., U. S. Geol. Surv., Redding Folio 138, p. 6, 1906.

[52] Diller, J. S., Coal in the Chico group of California, Science, vol. 5, p. 43, 1885.

[53] Diller, J. S., Topographic revolution on the Pacific Coast, U. S. Geol. Surv., Fourteenth Ann. Rept., pt. II, p. 416, 1894.

ments bear little resemblance to the anauxite clays and sands to which the writer has proposed that the term be restricted and the limited evidence is more suggestive of a Cretaceous rather than any other age. If the Ione assemblage was deposited here, the extensive erosion during the long interval from Chico to Tuscan time, recognized farther south, may have been largely responsible for its absence in this district.

MINERAL COMPOSITION OF IONE SEDIMENTS

In table 1, there is listed the mineral composition of representative sands of the Ione formation from widely separated localities. The uniformity of mineral composition shown by these sands is their most striking feature. In the samples examined, the percentage of minerals heavier than bromoform (2.9) varied from 0.1 per cent to 1 per cent.

TABLE 1

MINERALS OF THE IONE SANDS

MINERALS SP. GR. >2.9: B = Abundant C = Very Common D = Common E = Rare F = Present MINERALS SP. GR. <2.9: A = Present	Ilmenite	Magnetite	Epidote	Zircon	Tourmaline (brown)	Tourmaline (blue)	Andalusite	Sillimanite	Hornblende (green)	Rutile	Garnet	Anauxite	Quartz	Feldspar
Near Friant	B	E	E	C	D	......	E	......	......	E	......	A	A	A
Near Daulton	B	E	D	C	C	......	D	D	......	D	......	A	A	A
Bear Creek	B	F	D	C	C	......	C	D	F	D	......	A	A	A
Merced Falls, fossil layer	B	F	D	C	C	......	C	D	F	D	......	A	A	A
Merced Falls, mapped Ione by Turner	B	E	D	C	C	......	C	D	F	D	F	A	A	A
Near Ione, Buena Vista Quarry	B	F	E	C	C	......	C	D	......	E	......	A	A	......
Near Ione, Water's Peak	B	E	D	C	C	......	C	D	F	E	......	A	A	A
Ione, Preston School	B	F	E	C	C	E	C	D	......	E	......	A	A	......
Marysville Buttes	B	F	D	C	C	......	D	E	F	E	F	A	A	A
Oroville Table Mountain	B	F	E	C	C	E	E	E	E	D	F	A	A	A

TABLE 2

HEAVY MINERALS OF THE PRE-IONE SEDIMENTS

B = Abundant
C = Very Common
D = Common
E = Rare
F = Present

	Ilmenite	Magnetite	Epidote	Zoisite	Zircon	Tourmaline (brown)	Andalusite	Sillimanite	Hornblende (green)	Hornblende (brown)	Titanite	Biotite	Rutile	Garnet
Massive Chico Sandstone, 2 mi. S. of Pentz	D	B	B	C	E	D	......	......	B	D	D	C	E	C
Dry Creek Sandstone, Eocene, 2 mi. S. of Pentz	B	D	D	E	D	D	F	F	C	......	F	C	E	D
Massive Chico Sandstone, Marysville Buttes	D	C	C	D	E	F	......	......	B	E	E	C	E	D
Marysville Sandstone, Eocene, Marysville Buttes	C	D	C	F	E	C	......	......	C	D	F	C	E	D
Concretion in Marysville form.	C	C	C	E	E	D	......	......	C	E	E	C	E	D
Chico Sandstone, near Folsom	C	C	B	E	F	F	......	......	B	D	......	C	F	D
Diller's Ione, Oakrun	C	F	C	F	C	D	......	......	C	D	......	C	E	D
Chico Sandstone, near Rumsey	D	C	C	......	D	......	......	......	B	......	D	B	......	D

Among the heavy minerals, the presence of andalusite is noteworthy, for it has been described by Turner[54] as a contact mineral, produced by the granitic intrusions into the Mariposa slates. Lindgren[55] has recorded its occurrence in the Pyramid Peak and Truckee quadrangles. This implies that the detrital andalusite in the Ione formation came from the east, and its non-occurrence, so far as the writer is aware, in the Coast Range, adds strength to the inference. The other detrital minerals might well have come from the Sierra Nevada, for magnetite and zircon are known in the granodiorite, ilmenite in the basic rocks, tourmaline in the pegmatites and schists, and epidote and garnet in certain metamorphic types. Among the light minerals, anauxite is the most characteristic mineral of the assemblage, being nearly always present and in exceptional cases constituting more than half the

[54] Turner, H. W., Further contributions to the geology of the Sierra Nevada, U. S. Geol. Surv., Seventeenth Ann. Rept., pt. I, p. 688 ff., 1896.

[55] Lindgren, W., U. S. Geol. Surv., Truckee Folio 39, p. 3, 1897; U. S. Geol. Surv., Pyramid Peak Folio 31, p. 4, 1896.

sample. The observance of it as an alteration product of biotite in the granodiorite is further evidence of a Sierran source for the assemblage. Quartz is usually the most abundant mineral, and grains of it are exceedingly angular. Granules over 2 mm. have a greater tendency to be rounded, but there is much angular material mixed with particles that vary from those with the corners slightly rounded to those approaching spherical. In the lower beds, near Ione, feldspar is rare and often entirely absent. In general the percentage of orthoclase increases toward the top of the formation where it attains 10 to 25 per cent. One familiar with the composition of the Cretaceous and Tertiary sediments of California cannot help but be impressed by the absence or paucity of certain minerals usually present in considerable quantities. For example, let us compare the Chico sandstone from some of the same localities. Orthoclase with subordinate plagioclase often constitutes more than 50 per cent of the minerals present. The yield of heavy minerals may be 3 or 4 per cent and biotite, hornblende, and titanite are abundant. These minerals are also plentiful in the rocks of the Sierra Nevada, and if that source furnished the Ione sediments, they must have been partly or totally removed by some agency. The marked angularity of some grains and the euhedralism of others such as zircon prohibits the possibility of long-distance transportation or reworking, because rounding of the surviving minerals would take place as the more easily abraded ones would be worn away. There remains the possibility that the scarcity or absence of these minerals in the Ione sands is due to their disintegration by chemical weathering. The Ione assemblage is characterized by minerals that are resistant to chemical decay and the evidence is strongly suggestive that chemical weathering has been largely responsible for the individuality attained by the Ione sediments.

The low content of alkalies, calcium, magnesium, and iron in certain types could have been produced only by intensive leaching of these constituents during some stage of their formation. The sand at the Newman pit, one mile south of Ione, has such a small percentage of these elements that it is used for making fire brick and is sold under the name of "Ione sand" for that purpose. Through the courtesy of the Stockton Fire Brick Co., five analyses of this sand as it comes from the pit are given in table 3.

The Ione sand is fine grained, all grains passing through a sieve with round holes ¼ mm. in diameter. In thin section it consists of angular quartz grains surrounded by plates of anauxite (pl. 29*a*).

TABLE 3

ANALYSES OF IONE SAND, NEWMAN PIT

<table>
<tr><th></th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th></tr>
<tr><td>SiO_2</td><td>65.20</td><td>71.98</td><td>72.24</td><td>72.88</td><td>75.80</td><td>48.40</td></tr>
<tr><td>Al_2O_3</td><td rowspan="2">19.00</td><td>18.38</td><td rowspan="2">20.02</td><td>17.77</td><td>16.70</td><td>35.58</td></tr>
<tr><td>TiO_2</td><td>.56</td><td>.47</td><td>.20</td><td>.61</td></tr>
<tr><td>Fe_2O_3</td><td>1.60</td><td>.72</td><td>1.10</td><td>.78</td><td>.40</td><td>1.24</td></tr>
<tr><td>CaO</td><td>.33</td><td>.27</td><td>Tr</td><td>.30</td><td>.70</td><td>.22</td></tr>
<tr><td>MgO</td><td>.27</td><td>.42</td><td>.27</td><td>.30</td><td>.40</td><td></td></tr>
<tr><td>Na_2O</td><td rowspan="2">.60</td><td rowspan="2">.67</td><td rowspan="2">.00</td><td rowspan="2">.97</td><td rowspan="2">.90</td><td>.25</td></tr>
<tr><td>K_2O</td><td>.40</td></tr>
<tr><td>$-H_2O$</td><td>8.00</td><td>.85</td><td>.29</td><td>.40</td><td rowspan="2">4.90</td><td rowspan="2">14.26</td></tr>
<tr><td>$+H_2O$</td><td>5.00</td><td>6.15</td><td>6.22</td><td>6.13</td></tr>
</table>

1, 2, 3, 4, 5, Ione sand, Newman Pit. Alkalies by difference.

6, anauxite from the Ione sand, Newman Pit. Separated by C. S. Ross and analyzed by Mr. Fairchild.

The optical properties and occurrence of the anauxite are similar to those described by the writer from the Ione sandstone along the Mokelumne River.[56] Dr. P. F. Kerr,[57] of Columbia University, has compared the X-ray patterns of material from these two localities with that of anauxite from the type locality at Bilin, and the patterns are identical. The close similarity in the optical properties and X-ray patterns, and at the same time a variation in the silica-alumina ratio, are best explained by assuming an isomorphous mixture of two members, the properties of which vary only slightly. The proportion of anauxite to quartz in the sand varies. The average of measurements on four thin sections was 72 per cent anauxite and 28 per cent quartz. If one attempts to calculate the relative amounts of these minerals from the chemical analyses, using Fairchild's figures for the composition of the anauxite, the proportion of anauxite is about 55 per cent. This possibly indicates that the amount of anauxite in different parts of the pit is variable. The minerals heavier than bromoform make up about .1 of 1 per cent, and these were concentrated and determined. The list, in the order of their abundance includes ilmenite, zircon, brown tourmaline, rutile, andalusite, and sillimanite. The standstones of the Ione formation have a similar appearance in thin section to that of the Ione sand, and differ from it only in the size and proportion

[56] Allen, V. T., Anauxite from the Ione formation of California, Am. Mineralogist, vol. 13, pp. 145–152, 1928.

[57] Personal communication.

of these minerals. Alunite, mentioned by Dickerson,[58] occurring in scales in the white and red coarse-grained sandstone was not detected, and he probably mistook anauxite for it.

Ione Clays.—In the literature, the statement has been made repeatedly that the Ione clays were formed from rhyolitic tuffs. It is not definitely known who originated the idea. The first expression of it was made by Lindgren[59] in one sentence stating: "In many places there are indications that the clays have been derived from rhyolitic tuffs." Turner apparently accepted this explanation, for he repeated it without any objection. Several times Dickerson[60] rather emphatically expressed his opinion that the clays are altered rhyolitic tuffs. Logan[61] considered that the white clay is of rhyolitic origin and apparently came from the rhyolitic ash flows that overlie the older gold-bearing channels in the Sierra Nevada. During the investigation of these clays, evidence supporting a tuffaceous origin was sought for but was not found. Typical analyses are given below; the low content of sodium, potash, calcium, and magnesium has made these clays valuable for ceramic uses. The usual type of Ione clay is a plastic, even-textured clay.

TABLE 4

TYPICAL ANALYSES OF IONE CLAYS

<table>
<tr><th>No.</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th></tr>
<tr><td>SiO_2</td><td>48.00</td><td>55.72</td><td>51.64</td><td>50.38</td><td>55.65</td><td>52.85</td><td>52.72</td></tr>
<tr><td>Al_2O_3</td><td>34.56</td><td rowspan="2">24.56</td><td rowspan="2">23.84</td><td>32.11</td><td rowspan="2">28.89</td><td rowspan="2">33.50</td><td rowspan="2">32.39</td></tr>
<tr><td>TiO_2</td><td>1.00</td><td>.38</td></tr>
<tr><td>Fe_2O_3</td><td>1.54</td><td>4.02</td><td>9.78</td><td>2.99</td><td>2.61</td><td>2.46</td><td>2.45</td></tr>
<tr><td>CaO</td><td>.23</td><td>.45</td><td>.67</td><td>1.15</td><td>1.28</td><td>.55</td><td>.90</td></tr>
<tr><td>MgO</td><td>.35</td><td>1.15</td><td>1.24</td><td>1.07</td><td>.89</td><td>.33</td><td>.39</td></tr>
<tr><td>K_2O</td><td>.59</td><td rowspan="4">12.92</td><td></td><td></td><td>.20</td><td>.20</td><td>.12</td></tr>
<tr><td>Na_2O</td><td>.51</td><td></td><td></td><td>.72</td><td>.49</td><td>.20</td></tr>
<tr><td>$-H_2O$</td><td>1.30</td><td rowspan="2">11.92</td><td rowspan="2">11.29</td><td rowspan="2">9.83</td><td rowspan="2">10.03</td><td rowspan="2">10.70</td></tr>
<tr><td>$+H_2O$</td><td>12.30</td></tr>
<tr><td>Mn_2O_3</td><td></td><td></td><td></td><td>.56</td><td></td><td></td><td></td></tr>
</table>

1. Plastic Ione clay. Jones Butte. Analysis furnished by the Stockton Fire Brick Co.
2 and 3. Ione clays. Valley Springs. Analyses through the courtesy of W. F. Dietrich.
4. Ione clay. Gladding McBean Pit. Analysis through the courtesy of the company.
5, 6, 7. Ione clays. Lincoln Clay Products Co. Analyses by W. F. Dietrich.

58 Dickerson, R. E., Stratigraphy and fauna of the Tejon Eocene of California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, p. 412, 1916.

59 Lindgren, W., U. S. Geol. Surv., Sacramento Folio 5, p. 3, 1894.

60 *Op. cit.*

61 Logan, C. A., Amador County. Report 23 of the State Mineralogist, Calif. State Mining Bureau, p. 135, 1927.

In thin section, the clays are composed largely of small crystal plates without any definite arrangement (pl. 29*c*, *d*), and there is no evidence of tuffaceous texture. Some of the larger particles have been identified as anauxite and generally the index of refraction of these clays is close to $1.560 \pm .005$. The chief constituents are micaceous minerals, double-refracting, with the size of particles within the range of visibility of the petrographic microscope, so they cannot be rightfully regarded as colloidal. Because the proportion of alumina to silica is not 1:2 is no evidence that a clay is a mixture of gels, as has been argued by some writers. A number of hydrous aluminum silicates, not to mention other minerals, present in one clay, may be the cause of the variation. This is not intended to mean that colloidal material may be totally wanting. There is still ample room for the 3 per cent of colloidal[62] matter that has been reported as being separable from clays, and which may be present as a film covering the mineral particles.

At the meeting of the Mineralogical Society of America at Cleveland in December 1927, a paper was given by Ross and Kerr on "Optical and X-ray Research of Clay Minerals." In this paper, the scope of which is far-reaching, three groups were made of the clay minerals.

Kaolin Group

Kaolinite, Al_2O_3, 2 SiO_2, 2 H_2O
Leverrierite, Al_2O_3, 2 SiO_2, $2 \pm H_2O$
Anauxite, Al_2O_3, 3 SiO_2, $2 \pm H_2O$
Halloysite, Al_2O_3, 2 SiO_2, $3 \pm H_2O$

Montmorillonite Group

Montmorillonite, (Mg, Ca)O, Al_2O_3, 5 SiO_2, $5 \pm H_2O$
Beidellite, Al_2O_3, 3 SiO_2, $5 \pm H_2O$
Nontronite, Fe_2O_3, 3SiO_2, $5 \pm H_2O$

Hydro Mica Group

Potash bentonite, K_2O, Al_2O_3, 5 SiO_2, $3 \pm H_2O$
Potash gouge clay, K_2O, Al_2O_3, 2–4 SiO_2, $3 \pm H_2O$

In the kaolin group, kaolinite can be distinguished from the other members by its optical character and by its X-ray pattern. An isomorphous series is considered by Ross to exist with anauxite as one end-member and leverrierite-halloysite as the other. Kerr states that it is not possible at present to distinguish anauxite from leverrierite by X-ray patterns. In the case of halloysite, as the colloidal state is reached, separate and distinct lines in anauxite-leverrierite may be represented by one broad line.

[62] Searle, A. B., Clays and clay products. Third report on colloidal chemistry and its general and industrial application, Rept. British. Assoc. Adv. Sci., p. 116, 1920.

Dr. Kerr has kindly made X-ray patterns of the plastic clay at Jones Butte (analyses, table 4), the clay at the Clark pit, and Ione clays at Lincoln and Valley Springs, and reports that all show the anauxite-leverrierite pattern. The minerals of the Montmorillonite group have different patterns, and none of them were detected in any of these clays.

The suggestion of an isomorphous series, with Al_2O_3, 3 $SiO_2 + H_2O$ as one member and Al_2O_3, 2 $SiO_2 + H_2O$ as the other, offers a possible explanation of the composition of the Ione clays. The aluminum content of the plastic type has not been known to reach the 39.5 per cent required by the formula of kaolinite. The low aluminum content cannot be explained by assuming that the surplus silica is there as quartz. In the plastic clay at Jones Butte quartz may reach 0.5 per cent but that is not sufficient. The composition of all the plastic clays falls within a range that can be produced by mixing anauxite with leverrierite or some intermediate member of the series. This possibility is in keeping with the optical and X-ray data. The plastic clays contain a small fraction of 1 per cent of other minerals. By washing large samples of the clays at Lincoln, the following were concentrated: ilmenite, brown tourmaline, epidote, rutile, and zircon. All these minerals have been reported from the Ione sands at the type locality and elsewhere.

At Jones Butte is another type of clay which might be regarded as a further stage of decomposition. A white brittle clay, locally known as the "Edwin clay" forms the lowest eight feet of the deposit. Its plasticity is lower than the usual Ione clay and it breaks with a conchoidal or irregular fracture. Three analyses furnished by the Stockton Fire Brick Company are listed below:

TABLE 5

ANALYSES OF "EDWIN CLAY"

No.	1	2	3	4
SiO_2	43.60	42.54	43.48	43.5
Al_2O_3	37.80	39.48	40.14	36.9
TiO_2	1.90	1.32		
Fe_2O_3	1.10	2.00	.92	
CaO	.40	.49	.32	
MgO	.18	.24	.20	
K_2O	.12	.00	.24	
Na_2O	.23			
$-H_2O$	1.20	1.28	1.10	19.6
$+H_2O$	13.70	13.60	13.60	

1, 2, 3. Edwin Clay, Jones Butte. In 2 and 3, alkalies by difference.
4. Theoretical composition of halloysite.

In thin section, the clay is isotropic and this in addition to its chemical composition suggested halloysite. X-ray patterns made at the University of Wisconsin through the kindness of Professor W. J. Mead verify this. Its index of refraction is 1.570 ± .005, which is somewhat higher than that usually given for halloysite, but Splichal[63] has shown that the index of refraction increases to 1.57 as the water decreases. In all the analyses of the Edwin clay the water content is below the theoretical for halloysite. Angular quartz grains, making up about 1.2 per cent are scattered through the clay. Ilmenite, zircon, and brown tourmaline are also present, but do not exceed 0.2 per cent. Irregular small plates or patches of a mineral with higher birefringence and index of refraction are present and may be gibbsite, but its presence could not be established with certainty. The amount present is estimated at about 1 per cent. The aluminum content is always slightly higher than indicated by the formula of halloysite, which might be considered a further indication of its presence. The total amount of fluxing impurities recorded in the analyses is small and with the low silica content it is a type that could be produced only by efficient chemical sorting.

Conclusions

1. The source of the Ione sediments was to the east.
2. The sediments are not tuffaceous.
3. The sediments afford evidence of extreme decomposition that produced uniform types.

SURFACE ON WHICH THE IONE RESTS

Very little can be ascertained concerning the topography of the surface on which the Ione sediments were deposited. West of Ione, some idea of the relief is afforded by the hills of porphyrite and diabase that have been partly stripped of their covering of Ione sediments. From Lancha Plana, a greenstone ridge trends northwest in the general direction of the structures of the Sierra Nevada, and appears at intervals flanked by the Ione sediments. At Jones Butte, its elevation above sea level reaches 500 feet, and about a mile distant, where Turner shows the location of Coal Mine No. 3, the elevation of the Ione sediments at the surface is 300 feet. At this mine, 800 feet

[63] Splichal, I., Mineral Abst., I, p. 288, 1922.

of sands and clays were penetrated in a drill hole, and the depression here must be at least that deep. Using these figures, the bedrock surface from Jones Butte to Coal Mine No. 3 has a minimum slope of about 11°. Whether this is characteristic of much of the area covered by the Ione formation is not known, for there is little opportunity to judge. There is also some doubt as to the origin of this ridge, but it is most likely the result of erosion along structural lines by subsequent streams that developed in the softer rocks at an angle to main, westward-flowing streams.

CLIMATIC CONDITIONS OF PRE-IONE TIMES

The most noteworthy feature of the pre-Ione surface is the extent to which it has been weathered. At Jones Butte, the Ione clays rest unconformably on argillaceous laterite derived *in situ* from the older rocks of the Sierra Nevada. The laterite is compact, red or buff in color, and in places oolitic or pisolitic. The outcrops are massive, with a strong tendency to show vertical structure (pl. 30*b*). In this respect it is similar to the porphyrite area a short distance west, mapped by Turner, and it is not unlikely that it was developed from similar rocks. The best exposures at the surface are found on the next small hill south of the tunnels operated by the Stockton Fire Brick Company. The iron ore containing 44.59 per cent metallic iron, reported by Turner[64] two miles south of this area as a part of the Ione formation, is an extension of the laterite. In the tunnels at Jones Butte, the rolling nature of this surface is displayed and its contact with the Ione clay is sharply defined. Knolls or mounds of the reddish rock extend from one to three feet up into the white clay. The Stockton Fire Brick Company was able to furnish analyses of the lateritic material forming the floor, which are given in the following table:

TABLE 6

ANALYSES OF PRE-IONE LATERITE

	H_2O-	H_2O+	SiO_2	Al_2O_3	Fe_2O_3
Lithomargic laterite	(*a*)	(*a*)	29.64	27.90	24.30
Lithomargic laterite	(*a*)	(*a*)	33.56	34.72	16.14
Lithomargic laterite	1.50	12.60	38.30	41.50	6.00

(*a*) not determined.

64 Turner, H. W., U. S. Geol. Surv., Jackson Folio 11, p. 6, 1894.

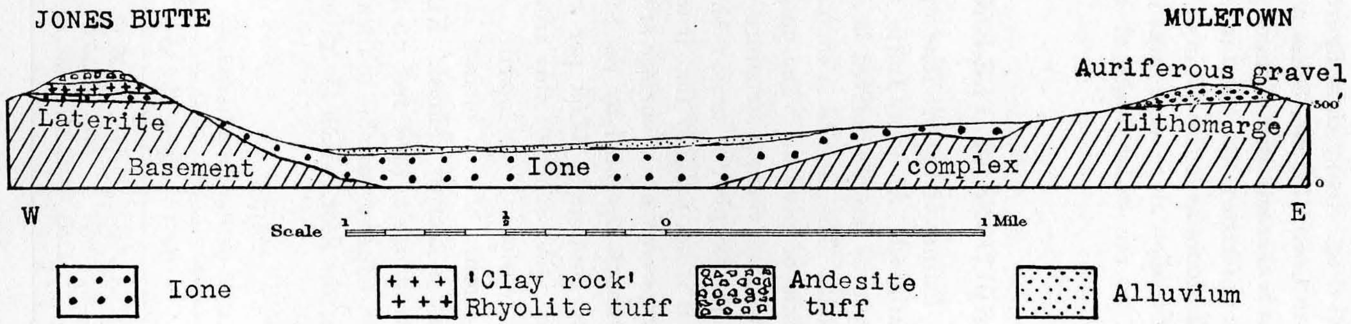

Fig. 7. Cross-section two miles north of Ione.

Hill[65] published these analyses in 1923 and called the material laterite, but did not attempt to explain its origin or its relationship to the Ione formation. On the basis of this announcement and his wide experience with other deposits, Harrassowitz[66] suggested a Tertiary age for the laterite, as he realized that conditions in the region at present are not favorable for its formation. In Lacroix's classification[67] the material is a lithomargic laterite, since the percentage of lateritic constitutents is between 50 and 90 per cent.

Before continuing with other localities, it seems appropriate here to insert a brief description of the parts of a laterite deposit in order to bring out the relationship of the different types of material. Many writers, including Lacroix,[68] Fox,[69] and Harrassowitz,[70] consider that a typical lateritic profile consists of four parts:

1. Iron crust 1 to 8 feet thick forms the surface.
2. Zone of concretion, 3 to 70 feet thick, made up chiefly of a porous mass of aluminum-iron hydrates, in which oolitic or pisolitic structure is extensively developed.
3. Bleached zone, 15 to 80 feet in thickness, is composed of white or light-colored hydrous aluminum silicates. The name lithomarge has been applied to this part of the profile. Its most notable feature is the retention of the structure of the original rock, even when marked changes in chemical composition have taken place. Inclusions, quartz veins, and often details of texture are preserved.
4. Fresh rock is reached by gradual transitions.

According to Fox,[71] who has investigated hundreds of occurrences in India, the complete section is seldom seen, but occasionally excellent exposures are available. However, scores of outcrops of white to pink lithomarge have been examined by him, and in places it is as intimately related to the bauxite as to the lower mass of kaolinized basalt, indicating that it is formed by the same process as the bauxite.

The lithomarges, belonging to the bleached zones, form the part of the profile most commonly observed below the Ione sediments, but all parts of a typical profile are represented to some extent. In 1927, a

[65] Hill, J. M., Bauxite and aluminum in 1923, Mineral resources of the United States, pt. I, 3, p. 27, 1923.

[66] Harrassowitz, H., Laterit, Fortschritte der Geologie und Palaeontologie, p. 487, 1926.

[67] Lacroix, A., Les latérites de la Guinée, Nouv. Archives du Museum d'Histoire Naturelle, ser. 5, vol. 5, p. 260, 1913.

[68] Lacroix, A., *op. cit.*, p. 272.

[69] Fox, C. S., Geol. Surv. India, Memoirs, vol. 49, 1913.

[70] *Op. cit.*, p. 321.

[71] *Op. cit.*, pp. 10–12.

number of drill holes were put down a few miles north and south of Jones Butte to determine the thickness of the Ione lignite. Some of these penetrated two hundred feet of sediments before passing into bedrock. The writer had the opportunity of examining a number of the cores, and in some a light-colored lithomarge ten to fifteen feet thick was encountered below white Ione clays. This lithomarge had a decided vertical structure and became more firm and more greenish until it passed into the rock termed porphyrite in the United States Geological Survey folios. The slates exposed along the road a mile north of Ione are bleached white or yellowish, but not to the extent of those observed in the drill cores to the west. At Muletown, two miles north of Ione, are gravels and sands with interbedded clays, which Turner mapped as Ione, but with two symbols indicating that gold gravel mining had been carried on in the area. The sediments are similar to the Ione and were probably deposited contemporaneously with the Ione to the west. At a number of places, the gravels rest on a white to yellow lithomarge with vertical structure.

Two and one-half miles southeast of Buena Vista, a small hydraulic gravel mine may be seen along the east side of the road to Lancha Plana. The gravel is composed mostly of white quartz pebbles and rests on a white clay showing relic schistosity. A hole was bored five feet into it and no apparent change in composition was noted in that depth. The clay contains doubly terminated quartz crystals and was probably derived from the quartz porphyrites which occur as dikes in the bedrock, having the same strike as the lithomarge. A partial analysis of the clay from which the quartz grains were removed is given below (table 7, no. 1).

TABLE 7

ANALYSES OF LITHOMARGE AND HALLOYSITE

	1	2	3
SiO_2	56.49	41.09	40.90
Al_2O_3	30.69	34.33	34.66
Fe_2O_3	2.38	1.00	
CaO	.34	.20	
MgO	.56	.60	
Alk. (by diff.)	3.17	.83	
$H_2O-110°C$	.92	9.79	12.22
$H_2O+110°C$	5.45	12.16	12.22

1. Lithomarge near Buena Vista. A. Pabst, analyst.
2. Micaceous halloysite from feldspar near Nevada City. W. S. Morley, analyst.
3. Theoretic composition for Al_2O_3, $2SiO_2$, $2H_2O$, $2H_2O$.

Half a mile from Valley Springs, along the road to Burson, an area mapped as amphibolite schist has been altered to a white lithomarge. To the north, massive Ione sandstone occupies the top of the hill and the weathered surface probably continues beneath the sandstone. This is substantiated by observations made when passing along a ditch, dug in connection with Mokelumne water project, that crosses the road from Campo Seco to Comanche, several miles to the west. In parts of this excavation, Ione clays and sands rest on red to white clays that have retained either the massive or the schistose structure of the rocks from which they were formed.

The nearest approach to a complete profile at one locality is between Valley Springs and Campo Seco. Here a number of outcrops of iron oxides have been mapped in the Jackson folio as Ione. Plate 31*b* shows a typical exposure and even in the photograph the almost vertical structure can be easily made out. In the hand specimen can be observed many details of the schistosity, the strike and dip of which in the field have the same trend as the less altered parts of the Bedrock series. In one place the outcrop is cut by a four-inch quartz vein, the cracks in which are filled with iron oxides. As one descends from the crest of the hill, gullies are passed which have been cut a hundred feet into the surface and which expose white to yellow lithomarge. It is clear that these deposits have been derived *in situ* from rocks subjected to the strong compressional movements at the close of the Jurassic.

Granitic rocks occupy large areas in the higher parts of the Sierra Nevada, and these, too, show the same type of alteration. One of the places where remnants may be studied is near Nevada City in the Colfax quadrangle. The bedrock of the Manzanita Hydraulic Mine is a biotite-hornblende granodiorite with titanite, zircon, and magnetite as minor accessory minerals. In places below the quartz gravels it is altered to a light-colored rock in which the angular quartz grains retain the same position as in the fresh rock. Filling the space between the quartz grains are plates of a pearly mineral having the properties of anauxite,[72] and masses of fine white earthy kaolin. Under the microscope, some of the anauxite flakes contain small rutile needles and a few have hexagonal outline, two features observed in the anauxite of the Ione sands. It seems fairly certain these were derived from biotite. Others without rutile needles may have formed from

[72] Allen, V. T., Anauxite from the Ione formation of California, Am. Mineralogist, vol. 13, p. 150, 1928.

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hornblende. The size, shape, and distribution of the small masses of white kaolin suggest that they take the place of the feldspars in the fresh rock. The largest of these were selected and purified by handpicking under a binocular microscope and by using solutions of suitable density. The analysis of this material is given in table 7, and the aluminum-silica ratio is 1:2 with small amounts of calcium, magnesium, iron, and alkalies present as impurities. Kerr has made X-ray patterns of it and reports a very close similarity to the anauxite-leverrierite pattern. Under the microscope it consists of very small plates with an index of refraction of $1.561 \pm .005$ and a birefringence estimated at .01. The large amount of water given off below 110° C and retention of 12.16 per cent above 110° is analogous to the behavior of halloysite, which has been observed with a crystalline structure and slightly lower index of refraction,[73] and has been termed micaceous halloysite. At present, this seems the most appropriate name for this hydrous aluminum silicate. In order to determine if the alteration had also affected the minor accessory minerals, large samples of the weathered rock were washed and the heavier minerals concentrated and separated with bromoform. This treatment yielded euhedral zircon, pellets of reddish iron oxide, and a brown clay with forms approaching those of titanite. The reddish iron oxide probably represents the magnetite of the fresh rock, and the yellow clay, the titanite. The places where this lithomarge has escaped removal by erosion or hydraulic mining are few, but where present it stands out in marked contrast to the residual soils forming on the granodiorite today. The latter consist of reddish colored sandy clays, containing golden colored micas which testify that the present conditions in this region are not those that produced the white alteration products of the granodiorite lying below the white quartz gravels.

The regolith on which the Ione sediments rest has been observed at widely separated localities. At Knights Ferry, snowy white lithomarge derived from the Bedrock series appears below the ochres and clays of the Ione formation. North of Oroville along the road to Cherokee that crosses Table Mountain, red argillaceous laterite with pisolitic texture can be seen forming a small exposure before crossing the lava top. At Morris and Saw Mill ravines, the surface below the white quartz gravel is weathered to a white or yellow lithomarge that locally is many feet thick. No doubt many other cases could be cited,

[73] Ross, C. S., and Shannon, E. V., The minerals of bentonite and related clays and their physical properties, Jour. Am. Ceramic Soc., vol. 9, p. 96, 1926.

for the writings of Whitney, LeConte, and other observers record deeply weathered surfaces below the auriferous gravels of the Sierra Nevada. The association of the white residual clays with laterites offers the possibility that the voluminous literature on laterites that has accumulated in recent years, may give some suggestion of the conditions of pre-Ione time. It is with this intention in mind that certain references have been selected.

Most authorities are convinced that laterites are the products of surface weathering requiring special topographic and climatic conditions. Maclaren[74] concluded that laterite deposits are restricted geographically because they require for their formation: (*a*) "Tropical heat and rain with concomitant abundant vegetation; (*b*) alternating wet and dry seasons."

Simpson,[75] Holmes,[76] Fermor, [77] and Fox[78] lay great stress on the alternation of wet and dry seasons, like those that exist in the tropics. Fox[79] gives a splendid bibliography and summarizes the general conditions under which laterites form from rocks *in situ,* as recorded by various observers under the following heads:

1. A tropical climate subject to alternations of dry and wet seasons, or monsoons.

2. Elevated level or very gently sloping land surfaces, which are not subject to appreciable erosion.

3. Exposed rocks of suitable chemical and mineral composition and of a porous or finely jointed texture.

4. Infiltrating water to remain for long periods of time in contact with the rock. During the wet season, the interspaces of the upper part of the profile are kept filled with water but these are practically dry during the dry season. The percolating waters remove certain substances in solution, while others are brought to the surface by capillarity and deposited during the evaporation of the water.

Lacroix[80] in his excellent treatise on the laterite of Guinea states that laterization is everywhere intense where the slope of the ground is low enough to permit the infiltration of water and to allow it to

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[74] Maclaren, Malcolm, The origin of certain laterite, Geol. Mag., vol. 3, p. 546, 1906.

[75] Simpson, E. S., Laterites in West Australia, Geol. Mag., n.s., Dec. V, vol. 9, p. 399, 1912.

[76] Holmes, A., Laterite deposits of Mozambique, Geol. Mag., n.s., Dec. VI, vol. 1, p. 529, 1914.

[77] Fermor, L. L., Geol. Mag., n.s., Dec. VII, vol. 2, p. 126, 1915.

[78] Fox, C. S., The bauxite and aluminous laterite occurrence of India, Geol. Surv. India, Memoirs, vol. 49, 1923.

[79] *Op. cit.*, p. 38.

[80] *Op. cit.*, p. 306.

remain for a long time in contact with the rocks. He places great emphasis on the action of vegetation, which develops with extreme rapidity under such conditions. As the zone of concretion progresses, the conditions become more unfavorable for the existence of vegetation, which finally disappears. The absence of a forest cover from the surface of the laterite does not exclude the possibility that laterization commenced under a cover of vegetation. The association of laterite with areas where superficial débris is clean and free from organic matter is thus easily explained, but the absence of laterite at the surface below thick forest and undergrowth, as reported by Holmes,[81] is not in harmony with the idea.

Holland[82] considers that laterite is characteristic of the tropical belt, and that it forms through the action of some lowly organism having the power of separating alumina. Thiel[83] has shown that the presence of microorganisms aids in liberating alumina. Fox[84] reports that bacterial action has not been detected in connection with the Indian deposits.

The majority of writers recognize that laterites are most generally formed in the tropics, and some regard them as diagnostic of tropical or subtropical conditions. Mead[85] writes:

> The formation of bauxite as a residual product of weathering has been observed for the most part in tropical or subtropical regions. . . . . Laterization has been so generally correlated with tropical conditions that it seems quite probable that the Arkansas bauxite was developed under a tropical or subtropical climate.

A statement by Fox[86] is of interest in this connection.

> It is also a remarkable fact that, as new deposits are found or old deposits carefully reexamined, the evidence regarding the mode of formation of each deposit favours a similar sub-aerial origin for all laterites and lateritic bauxites. These deposits have evidently been formed in a tropical climate subject to monsoon conditions.

Harrassowitz[87] has recently published a valuable work in which he considers the laterite deposits of past geological periods as well as those of the present. He has done much to show that laterites belong to the domain of the tropical or subtropical forest.

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[81] *Op. cit.*, p. 532.

[82] Holland, Sir T. H., On the constitution, origin and dehydration of laterite, Geol. Mag., vol. 40, p. 63, 1903.

[83] Thiel, G. A., The enrichment of bauxite deposits through the activity of microorganisms, Econ. Geol., vol. 22, p. 480, 1927.

[84] *Op. cit.*, p. 40.

[85] Mead, W. J., Bauxite deposits of Arkansas, Econ. Geol., vol. 10, p. 52, 1915.

[86] *Op. cit.*, p. 188.

[87] *Op. cit.*

The preponderance of evidence accumulated by modern investigators of laterites emphasizes the adequacy of surface weathering under tropical or subtropical climate to produce the type of alteration observed below the Ione sediments. The suggestion that the climate was tropical or subtropical prior to the deposition of the Ione is supported by the fauna. The laterized rocks include the Upper Jurassic slates and are overlain unconformably by the Ione formation of Middle Eocene (Meganos) age. The period of laterization must be confined to these limits. Smith[88] believes the climate of the Cretaceous was tropical, but a study of the Chico sandstones at Pentz, Marysville Buttes, and near Folsom shows that no extensive weathered surface existed to contribute to these sediments. In fact, the abundant feldspars and the smaller amounts of biotite, hornblende, and titanite indicate rapid erosion without the chemical sorting noted in the laterite profile. Dickerson[89] considers that distinct climatic zones, varying from temperate to tropical, were outlined during the Martinez. Accordingly, a statement concerning the climate of this part of the Eocene is of value only when it refers to a specific district, and the absence of a Martinez fauna from this region renders this impossible. At the same time the absence of Martinez sediments from this region may indicate that it was a land area throughout that interval. The fauna from the Marysville formation at Marysville Buttes has more direct bearing on the present problem for it is nearer to the area under discussion, and it applies to the climatic conditions just before the deposition of the Ione, an event that terminated the formation of the lateritic profile. Dickerson[90] reports that the fauna from this horizon contains many tropical forms and that the climate during the deposition of the Eocene was tropical or subtropical. Stipp[91] has studied the foraminifera from these beds and the presence of tropical species led him to the same conclusions regarding the climate. It seems very likely that these forms inhabited a tropical Eocene sea that bordered on a land area favorable for the formation of laterite. The sediments of the Marysville formation do not contain notable amounts of lateritic

[88] Smith, J. P., Salient events in the geologic history of California, Science n.s., vol. 30, p. 346, 1909; Ancient climates of the West Coast, Pop. Sci. Mo., vol. 76, pp. 476–486, 1910.

[89] Dickerson, R. E., Climatic zones of the Martinez Eocene time, Calif. Acad. Sci., Proc. (4) 7, 193–196, 1917.

[90] Dickerson, R. E., Fauna of the Eocene at Marysville Buttes, California. Univ. Calif. Publ. Bull. Dept. Geol., vol. 7, pp. 257, 298, 1913.

[91] Stipp, T. F., The Eocene foraminifera of the Marysville Buttes. Thesis submitted for the degree of M.A. at Leland Stanford University, 1926.

material. Is it possible that another source furnished these sediments, which are fine-grained and suitable for long-distance transportation? If the presence of glauconite in these beds indicates slow[92] accumulation, the source might be at a great distance, and even in a different direction from which the potash, iron, and silica came to form glauconite. It is hardly necessary to point out that the elements required to form glauconite are some of those which are removed in solution during the formation of laterite from granitic rocks. It is possible that the glauconite of the Martinez, the Marysville, and the Dry Creek formations was forming in the sea as a result of the contribution of the required substances which were being leached simultaneously from the rocks of the Sierra Nevada. None of the detrital minerals of the Marysville sands are characteristic of the Franciscan areas of the Coast Range, but this is also true of the Cretaceous sandstones near Rumsey on the west side of the Marysville Buttes. There are many points of similarity between the Cretaceous at this locality and the Marysville sands, including mineral composition. The problem is made more difficult because the length of time necessary to produce a lateritic surface is not known. Fox reasons that the formation of laterite in India began in the Eocene with the establishment of monsoon conditions and continues at present because these conditions still persist. It is his experience that it is most difficult to distinguish the older from the newer deposits, which may have developed at any time subsequent to the commencement of the Tertiary. The best of the Sierran laterites do not compare favorably with the more advanced stages of the Indian deposits, and possibly the time interval involved in their formation may not be nearly so great. Even so, with much of the feldspars, biotite, and hornblende of the Marysville sands coming from the west, the early part of the Eocene would be free for the physical-chemical changes of laterite formation to take place—a much more reasonable arrangement.

Tropical species of plants have been described from the older Tertiary auriferous gravels of the Sierra Nevada. Knowlton[93] records the following genera as distinctly tropical or subtropical in their distribution: *Laurus* (4 species), *Persea* (3 species), *Cinnamomum* (2 species), and *Areodaphne* (2 species), all belonging to the Lauraceae. To these he adds *Artocarpus* and *Zizyphus,* each with 2 species, *Ficus* with 6 species, and *Sabalites* with 1 species, or 22 species in all,

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92 Thompson and Murray, Challenger report, Deep sea deposits, p. 382, 1891.

93 Knowlton, F. H., quoted by Diller, J. S., Topographic revolution on the Pacific Coast, U. S. Geol. Surv., Fourteenth Ann. Rept., pt. II, p. 421, 1894.

representing at least 20 of the entire present flora. This list is not complete and it may not be representative; it is reproduced to show that it has long been recognized that tropical or subtropical plants grew in this region during the Tertiary. To acknowledge more than this does not seem advisable, for the indications are that there is need for restudy of the flora based upon new collections in which the localities are kept separate for possible variation with altitude, with lithology, and with stratigraphic position. At Saw Mill Ravine, near Oroville, are clays containing fossil leaves that the writer considers the same age as the Ione. Chaney has furnished the following preliminary statement based on five Eocene species from these clays: "No certain inferences can be drawn on the basis of so small a flora, but the indications of the material now available are that the climate was warm-temperate or subtropical, with a rainfall sufficient to permit a luxuriant growth of vegetation."

Both the fauna and the flora are in agreement and furnish satisfactory evidence that the climate of the pre-Ione Eocene was tropical or subtropical. The natural outcome of this would be the formation of laterite, which is a common soil in such a climate. What other limiting factors operated to make the Sierra Nevada the site of this type of alteration is not easy to decide, for there is much variation of opinion among those who have studied modern deposits. It is difficult not to believe that some erosion was connected with slopes like those at Jones Butte, or that mentioned by Lindgren near San Andreas, where within a distance of three miles, the greenstone ridges rose 2000 feet above the Tertiary Calaveras River. Lindgren's[94] picture of the Sierra Nevada, at the time when the oldest gravels, probably of Eocene age, began to accumulate, may be summarized by his statement that it was "a mountain range as distinct, if not as high, as at present." The level or gently sloping land surface demanded by some is not in evidence here. Our knowledge of the flora of the time is not sufficient to determine whether wet seasons alternated with dry. Perhaps future study will answer this question. But with a mountain range rising from a coast washed by the warm waters of the sea it is possible the rainfall was seasonal as well as abundant. The firm compact nature of the rocks of the Basement complex may have played no small part in the alteration, for the world's important laterite deposits are formed from igneous and metamorphic types. Sandstones covering other areas might be deprived of their cementing materials, resolved into their

[94] Lindgren, W., The Tertiary gravels of the Sierra Nevada of California, U. S. Geol. Surv., Prof. Paper 73, p. 37, 1911.

component grains, and washed away without much alteration taking place. In the Basement complex of the Sierra Nevada, the depth and the extent of the alteration is most irregular. Is this to be connected with the ease of access and movement of ground-water producing the change? Roa[95] has conducted experiments to determine the effect of solutions of sulphuric acid, humic acid, alkali carbonates, and carbonic acid on basalt. He considers that tropical temperatures are necessary for laterization, so the temperature during the experiment was controlled by a water bath between 32° and 52° C for nine months. Unfortunately he did not try some samples at a lower temperature. The sample treated with alkali carbonates showed the greatest loss of silica and greatest increase of aluminum. He describes the process in nature thus:

> The carbon dioxide present in rainwater combines with the alkalies present in rocks and soils forming alkali carbonates. Aqueous solutions of these carbonates react on the feldspars and other aluminum silicate minerals present in rocks, giving rise to alkali silicates and hydrated aluminum carbonates; the former are removed in solution and the latter, being unstable, are decomposed into carbon dioxide and hydrated aluminum oxide, which is deposited in the form of bauxite. . . . . Some of the liberated carbon dioxide may help in the removal of magnesia as bicarbonate.

Glinka[96] declares that carbonated water and high temperature are apparently the predominant factors in lateritic weathering. Under these conditions the hydrolysis of the silicates and the aluminum silicates takes place rapidly, resulting in the splitting off of important amounts of the mineral bases which are found in the soil solutions as carbonates. It is possible that the alkaline carbonates take part in the solution of the aluminum which is deposited rather abundantly in the soils of this group as concretions of hydrargillite.

Both of these statements leave out the work performed by vegetation, which might be threefold, increasing the amount of CO_2 to produce the above changes, aiding in the removal from the rocks of the elements required by plants, and protecting the surface, up to a certain stage, from denudation. Whatever the causes may be, they appear to be connected with tropical climatic conditions, and the deposits themselves remain as testimonials that the same minerals found in the Ione sediments were produced from the rocks of the Sierra Nevada, and that others not found in the Ione were removed by the same selective process.

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95 Roa, T. V. M., A study of bauxite, Min. Mag., vol. 21, p. 407, 1928.

96 Glinka, K. D., The great soil groups of the world and their development (translated by C. F. Marburt, Edwards Bros., Ann Arbor, Mich., 1927).

RELATIONS OF THE AURIFEROUS GRAVELS TO THE IONE FORMATION

In this attempt to correlate the Ione formation with the auriferous gravels of the Sierra Nevada, special attention was given to lithology and mineral composition in order to determine whether the sedimentary types of the Ione could be traced to the higher slopes where recognized stream deposits have yielded gold. Not only have the Ione types been duplicated among the finer sediments of the white quartz gravels, but pebbles similar to those in the gravels have been found interbedded in the Ione, suggesting continuity that is supported by the field relations.

At Muletown, two miles north of Ione, are gold-bearing sediments that were mapped as Ione by Turner. During the early days of the settlement of Amador County, Muletown was a busy camp of several hundred inhabitants, whose chief source of income was mining the auriferous gravels in the vicinity. All their buildings have disappeared, but the stone foundations remain, and these and the hills partly stripped of gravel testify to the activity of the early miners. The lowest part of the deposit consists of pebbles and boulders of milky white vein-quartz up to eight inches or so in diameter and rests in a poorly defined channel. Layers of angular quartz-anauxite sands, well rounded pebbles of quartz and siliceous rocks alternate with clays in making up the remaining part of the deposit. Fluviatile cross-bedding in the sands and gravels indicates a westward flow of the waters that formed the deposit.

To the west, there is a small area where only metamorphic rocks are present. At the rear of the Preston school grounds is a sand pit, the sediments of which resemble the finer parts of the Muletown deposits. Fluviatile stratification, converging westward, is well brought out by the light-colored clay streaks which are not stained red to the same extent as the sands (pl. 32*a*).

On the west side of the road is a much larger pit where the Ione sands can be followed for many feet with only horizontal structure. The similarity in the heavy mineral assemblages of these localities is shown in table 8. If continued westward, the gradient of the Muletown channel, would bring the auriferous gravels (fig. 7) below the uppermost Ione sediments at Jones Butte. The mineral composition, the sedimentary structures, and the slope of the bedrock floor indicate that the Ione sediments were once continuous with the auriferous gravels at Muletown and were deposited by streams flowing from the east. Turner expressed a similar opinion when he mapped both as Ione, and stated that the Ione is contemporaneous with the auriferous gravels composed largely of white quartz pebbles. Dickerson emphasized the close relation of the gravels at Muletown to the Ione farther west.

TABLE 8

Showing Similarity of Mineral Composition of Auriferous Gravel to the Ione

B = Abundant C = Very Common D = Common E = Rare F = Present	Ilmenite	Magnetite	Epidote	Zoisite	Zircon	Tourmaline (brown)	Andalusite	Sillimanite	Hornblende (green)	Titanite	Biotite	Anauxite	Rutile	Garnet
Dry Creek Sandstone, Eocene, 2 mi. S. of Pentz	B	D	D	E	D	D	F	F	C	F	C	......	E	D
Deep Gravel, Cherokee Pit	C	D	C	E	D	D	......	......	C	E	C	......	D	C
Ione Sandstone, 2½ mi. S. of Pentz	B	D	E	......	C	C	D	E	F	......	......	C	E	......
Bench Gravel, Morris Ravine	B	C	D	......	C	C	F	......	......	......	......	C	E	......
Bench Gravel, Laport	B	D	E	......	C	C	......	......	......	......	......	C	E	......
Ione Sand, 1 mi. NW. of Ione	B	F	E	......	C	C	E	E	......	......	......	C	......	......
Cross-bedded Sand, N. of Preston School	B	F	E	......	C	C	D	F	......	......	......	C	......	......
Auriferous Gravel, Muletown	B	F	E	......	C	C	D	......	......	......	......	C	......	......
Auriferous Gravel, Chili Gulch	B	F	F	......	C	C	......	......	......	......	......	C	......	......

At Newman's Pit, about a mile south of Ione, is a large exposure where the Ione sand has been quarried for making fire brick. At the east side of the pit, the upper 20 or 30 feet is composed of sands with lenses of quartz gravels, which dip west at about 10°. The lower 40 feet is the part mined, and consists of snow white quartz-anauxite sands, in which rounded pebbles occur as lenses that are thickest to the east, and die out to the west. Plate 33*b* shows the western end of one of the lenses. Shallow pits and drill holes have been put down and show that the same conditions prevail to a depth of 30 feet. Although almost continuous sections can be followed in the adjacent pits for 300 feet to the west, no lenses have been observed in that direction, and the sandy layers rest on more clayey beds. Partly carbonized logs of wood and leaves have been found in the sands during the operation of the pit. Lenses of gravel and carbonaceous material have been observed in the deltas of modern streams such as the Po,[97] and the evidence here is suggestive that these are delta deposits brought by streams from the east.

To the east of the pit, along the railroad cut near the road to Jackson, fine quartz gravel rests directly on the slates, and the contact slopes as if to form one side of a channel. Perhaps it was on this evidence that an old prospector put down a shaft a few hundred feet to the west, and brought up gravels similar to those at Muletown. The miner met with little success because of the small scale of his operation and the caving of the soft sediments, due to lack of proper precautions. The pebbles along the dump are similar to those in the sands at Newman's Pit, except that many are larger, and it is not unlikely that these were deposited by the same stream that carried the finer material westward and deposited it as a delta.

North of Waters Peak on the east side of the road to Lancha Plana is a small hydraulic mine, which has already been mentioned. The white quartz gravels resting on the lithomarge have yielded gold, and their mineral composition closely approaches the Ione sediments near Buena Vista Peak. The irregular surface on which these gravels were laid down lies below the upper part of the Ione, and this furnishes another instance of the close relationship of the Ione formation and the auriferous gravels.

The excellent work of Lindgren[98] shows that four divisions can be made of the Tertiary gravels of the Sierra Nevada. Beginning with the oldest, these are: (*a*) deep gravels of Eocene age; (*b*) bench gravels; (*c*) rhyolitic tuffs and interrhyolitic channel deposits; (*d*) andesitic tuffs and intervolcanic channel deposits. The deep gravels frequently contain feldspars, biotite, and other minerals along with large boulders of greenstone, granite, and other rocks of the Basement complex. The bench gravels are composed of finer pebbles, chiefly quartz, and the mineral composition is generally similar to the Ione formation. However, the white quartz gravels are not limited to

[97] Grabau, A. W., Principles of stratigraphy, p. 613, 1913.

[98] *Op. cit.*, p. 29.

benches, and in places they fill poorly defined channels. Lindgren realized this for he stated that the distinction between the deep gravels and the bench gravels is much more marked at some localities than at others. For this reason, the gravels will be referred to on the basis of their mineral and rock composition.

Twelve miles north of Oroville is the well-known Cherokee hydraulic mine. Lindgren's[99] description of it is the most complete, and includes the following section, beginning from the top:

(*h*) Massive basalt, 50 to 75 feet thick.

(*g*) Yellowish white sandy clay, 200 feet thick, nearly without structure; in places with horizontal beds.

(*f*) White sand and quartzose gravel, 50 feet thick, mostly very fine, some a little coarser, cobbles on bedrock of (*e*). Lower part yields 25 cents to the cubic yard in fine gold. Fluviatile stratification very distinct.

(*e*) A few feet of rotten boulders, simply the decomposed gravels of (*d*), acting as bedrock for stream depositing fine gravel.

(*d*) Partly cemented, very coarse, fresh blue gravel, 20 to 30 feet thick, with large blocks of greenstone, partly rounded. . . . . Surface almost level.

(*c*) Small blocks of basaltic lava, probably a local intrusion.

(*b*) Local small streaks of black clay with wood and bark.

(*a*) Hard cemented greenstone gravel, 5 to 10 feet thick, part angular, very poor in gold. Some quartz cobbles.

The greenstone gravel (*a*) fills the lowest part of the channel and rests upon water-worn bedrock of greenstone, showing no signs of decay. About 500 feet to the south in Saw Mill Ravine, white quartz gravel (*f*) rests directly upon a red lateritic surface, which continues for some distance south. White or yellow lithomarges are the most common, and often the surface is coated with a crust of limonite upon which the quartz gravels rest. In plate 34*b*, this surface, which slopes west, is shown, as well as the residual lithomarge which is here 30 feet thick. The weathered surface is so generally present beneath the quartz gravels that the absence of any sign of it below the greenstone gravel requires an explanation. Since the bedrock of the region is chiefly greenstone, striking in the general direction of Saw Mill Ravine, there was probably little difference in the original composition of the rocks to account for it. There remain two possibilities: the weathered layer has been removed by erosion, or it was never formed. The greenstone gravel (*a*) and (*d*) is hard and fresh, but (*e*) is composed of boulders so decayed and soft that they could not have been

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[99] *Op. cit.*, p. 87.

transported without disintegrating. Moreover, if (*e*) represents fragments of the weathered surface rounded by water action, which does not seem possible in their softened condition, a few such pebbles would be expected in the lower beds (*a*) and (*d*). These are not present, and the decayed boulders are confined to one bed. The elevation of this bed is about the same as that of the residual lithomarge below the quartz gravel. From these observations it seems that both developed during that stage of the stream history when the lower part of the channel was filled with 30 or 40 feet of coarse boulders which protected it from weathering. The boulders were kept in position partly by their size, but mostly as a result of the deposition of silica that was removed during the laterization of the "rims" of the valley. It has been shown that streams and springs in regions of lateritic weathering carry silica, which would furnish a sufficient supply for cementation. The lower gravels are so firmly cemented that in mining it was necessary to blast them loose before the washing could be carried on.

The closest approach to the conditions at Cherokee have been reported by Holmes[100] in Portuguese East Africa, where laterite deposits occur along the sides of small streams, the majority of which dry up during several months of the year. In a cross-section of the streams no laterite was shown on the floor of the channel, but the sides are mantled with deposits of laterite, varying in thickness. The deposits are most extensively developed when the dip of the foliation of the gneiss is toward the stream, as this permits the upper surface to drain. Holmes considers that vegetation plays no part in the formation of laterite. The process is due to the lateritic constituents being dissolved in ground-water during the wet season, and as the stream dries up, some of the water is drawn from below toward the surface by capillarity and evaporation. Ferruginous nodules about the size of a pea, with a nucleus of sand, are found on the lower part of large river beds that seasonally shrink to a succession of stagnant pools and such nodules also form a hill below the quartz gravels at Saw Mill Ravine. Holmes attributes their formation to precipitation by oxidation of the solutions concentrated during the dry season. The evidence suggests that wet seasons alternated with dry during the period of gravel formation in the Sierra Nevada.

Where last seen, the Cherokee channel appears to turn southwest below the basalt of Table Mountain. An attempt to correlate the section at Cherokee with that exposed at Dry Creek is shown in

[100] Holmes, A., Laterite deposits of Mozambique, Geol. Mag., vol. 1, p. 531, 1914.

figure 8. Attention has already been called to the similarity of the pebbles of the Chico conglomerate to the greenstone pebbles at Cherokee, and it is possible that both were deposited during the same period. Lindgren[101] has suggested that some of the deep gravels along the Tertiary Yuba River may be as old as Cretaceous. Turner[102] reports that the lower part of the Chico near Helltown contains much gravel and some gold, but not enough to be worked. The evidence for the disconformity shown between the Dry Creek formation and the Chico is weak, as the actual contact was not observed, and it is based upon a single outcrop which appears to be lower than the top of the Chico. During the accumulation of the Dry Creek formation, only finer gravel was deposited, and this is mostly quartz with some weathered greenstone. This may represent the deposits formed while the weathering of the coarse boulders (*e*) and the slopes of the valley took place. Some of the feldspars and biotite of the Dry Creek formation may have come from the Chico beds to the north, but probably there were also areas in the Sierra Nevada where alteration had not progressed sufficiently at this time to remove all of these minerals.

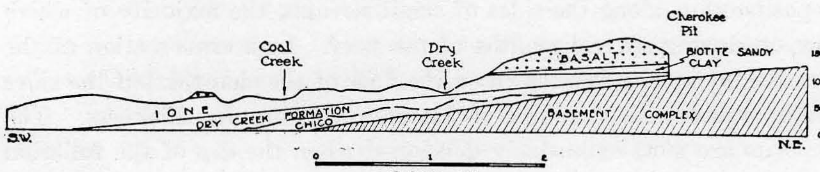

Fig. 8. Section from Cherokee southwest towards Wick.

The lack of much-altered minerals, such as anauxite, in the Dry Creek formation, makes the transitional conditions to the Ione difficult to understand. But when the mineral composition of the quartz gravels (*f*) is compared with that of the Ione, the similarity is at once apparent. Both are composed of quartz, anauxite, and minerals resistant to chemical weathering, many stages of their history are identical and it is more than likely they were deposited contemporaneously. That the quartz gravels are of Eocene age is substantiated by a flora collected from the anauxite clays interbedded in these gravels at Saw Mill Ravine. Chaney has furnished the following preliminary statement regarding it:

The shales at the Cherokee Pit contain abundant remains of plants in the form of leaf impressions. Due to the highly fractured nature of the shale it

[101] *Op. cit.*, p. 29.

[102] Turner, H. W., Further contributions to the geology of the Sierra Nevada, U. S. Geol. Surv., Seventeenth Ann. Rept., pt. I, p. 547, 1896.

is difficult to collect complete specimens, and most of the material so far studied is fragmentary. The following species have been recognized:

Apocynophyllum wilcoxensis
Ficus cf. pseudopopulus
Magnolia magnifolia
Platanus nobilis

In addition there are fragments of palm leaves which may be referable to *Geonomites tenuirachis.*

All the above species are typical Eocene forms, occurring in the Paleocene of the Great Plains and the Lower Eocene (Raton) of the Southwest.

A single specimen from Coal Creek near Oroville is referred to *Lygodium kaulfussii,* which is also a typical Eocene species.

No certain inferences can be drawn on the basis of so small a flora, but the indications of the material now available are that the climate was warm—temperate or sub-tropical, with a rainfall sufficient to permit a luxuriant growth of vegetation.

The yellow sandy clay (*g*) at Cherokee contains biotite and rests upon an irregular surface that is formed in the quartz gravels and crusted with limonite (pl. 34*a*). The texture in thin section indicates that some of the material is an altered tuff (pl. 35*a*). It probably belongs to the Rhyolitic tuff period. The closest resemblance to this material on the west side is afforded by the uppermost layer at Dry Creek and at Coal Creek. Outcrops of it are limited, for talus composed of large blocks of the overlying basalt conceals the beds forming the upper parts of these valleys.

At Morris Ravine, the white quartz gravels fill a poorly defined channel cut in lithomarge. The gravel in the surface mines contains little or no greenstone. The slope of the floor and the cross-bedding indicate that the streams were following west. The sands have the same minerals as the Ione at Chambers Ravine to the west. There is little doubt that the sediments to the west represent a delta deposit formed by the streams that have been recognized to the east. At Chambers Ravine are biotitic gray shales of the Dry Creek formation and between these and the normal Ione sand are three feet of glauconitic sand containing anauxite. At Dry Creek there are also gray shales, but between them and the Ione are eighty feet of biotitic sands. If the gray shale at the two localities is the same horizon, deposition to the north has been more active than farther south. This appears to have been the case for the thick greenstone gravels at Cherokee are missing at Morris Ravine. Perhaps this was caused by slight tilting which slowly and gradually took place, giving the southwest dip to the sediments and exposing the Chico at the north side, while it is still covered to the south.

The Butte gravels, which overlie the Ione gravels and sands at the Marysville Buttes, have been mentioned. These contain a fauna regarded by Clark as Meganos Eocene, and on this evidence the period of white quartz gravel deposition is also of that age. In the Sierra Nevada the white quartz gravels are followed by rhyolitic tuffs and gravels, and in the exposures examined by the writer there is nothing between them that corresponds to the Butte gravels. The lack of andalusite and anauxite in the sands indicates that they were not derived from the Ione or from the east. The sand grains are much better rounded than those of the Ione, and this suggests either reworking or transportation for a longer distance. Among the pebbles are quartz porphyries that resemble those described from the Downieville and Taylorsville region. There is some indication that the northern part of Oroville Table Mountain has been uplifted more than the southern and that extensive erosion to the north followed the deposition of the Ione and removed both the Ione and the auriferous gravels. As the streams cut back, there would be available large areas of gravels which, as Diller has stated, do not have the characteristics of those farther south. It is possible that material from this northern source reached the site of the Marysville Buttes to form the Butte gravels. Notable contributions from the Chico on the west, to form the sands, are not denied by this inference.

Conclusions

The mineral composition of the white quartz gravels is similar to the Ione, and the gravels were deposited by the same streams which laid down the delta deposits of the Ione.

ORIGIN OF IONE SEDIMENTS

Following the preceding discussion, the events concerned with the origin of the Ione sediments can be briefly summarized. These begin with the occupation of what is now the Great Valley of California by an Eocene sea, which left its record in the fossils and sediments of Oroville Table Mountain and the Marysville Buttes. Its extension southward is indicated by the fossils in the gray shales at Lincoln. Near Clements, about twenty miles southwest of Ione, gray shales were encountered in a well 1900 feet below the surface and have yielded an Eocene form of *Exilia*. The fauna of this period is reported as tropical or subtropical, and as belonging to the Meganos division of the Eocene. The sediments are fine grained, mostly gray shales and fine sands, showing that erosion was only moderately active. On the Sierra Nevada land mass bordering this sea, the conditions were favorable for the formation of laterite. A tropical or subtropical climate, with abundant seasonal rainfall, aided by the resulting vegetation, produced the changes described in connection with lateritic profiles. Potash, soda, calcium, magnesium, and some iron were removed as carbonates or bicarbonates. The feldspars and ferromagnesian minerals were

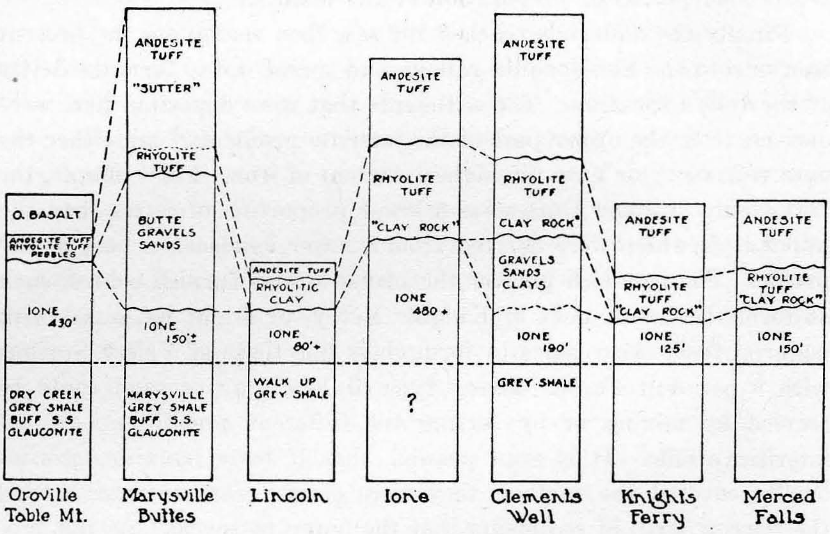

Fig. 9. Showing probable correlation of the Ione Formation and associated sediments.

broken down to form hydrous aluminum silicates, and only those minerals resistant to chemical weathering remained intact. At some unfavorable places the alteration may have been less effective, but these areas apparently were small, and the rocks nearly everywhere were mantled by a residual lithomarge, which was many feet in thickness where conditions were ideal, and locally iron and aluminum hydrates capped the surface. It is considered by the writer that the major part of the alteration producing the component units of the Ione clays and sands took place while they were a part of this residual covering, for no greater amount of fluxing impurities remains in the micaceous halloysite derived from feldspar than is present in the Ione clays.

Before the process of laterization was completed, it was interrupted by uplift and erosion, which commenced to strip off the products of

Carbondale. The apparent lack of bedding in much of the clay is due to the settling of a quite uniform product brought down by the streams under only slightly varying conditions. The Ione clays and sands, as one sees them today, are the result of the deposition of material prepared by chemical processes that have made it a lithologically distinctive horizon. These sediments are thicker near the foothills than farther out under the valley. At least, the sections at Marysville Buttes and in the well near Clements are thinner than those at Ione or Oroville. The uniformity of the Ione mineral assemblage shows that the same conditions prevailed at least from Friant to Oroville, more than 200 miles along the foothills of the Sierra Nevada. The occurrence of *Turritella merriami* Dickerson and *Venericardia planicosta* in the sandstones composed of the typical mineral assemblage indicates that the Ione formation was deposited during the Eocene period and probably within the Meganos division.

As the deltas grew in size, the lower parts of the streams began to aggrade their channels headward, and the deposition of the white quartz gravels took place contemporaneously with the Ione. The gold occurring in the quartz veins cutting the slates had been liberated as the weathered surface was gradually lowered by erosion. This gold was concentrated by the removal of the fine material, largely clay that formed at the expense of the feldspathic and ferromagnesian minerals, and it was deposited along with the gravels composed of quartz and the resistant minor minerals. The history of an effective chemical sorting that preceded the mechanical concentration is clearly written in the auriferous gravels of this period. The streams at this stage became overloaded in their lower stretches, for even slight uplift of the weathered surface would furnish more material than they could transport. When deposition began, all the energy was being expended in the unsuccessful effort to transport the great load, and none remained to erode even the weathered parts of the channels. The deposition of the gravels on the weathered surface has preserved remnants of it to the present day. In an early paper, Lindgren[103] pointed out that deposition began along the lower course, as the streams became charged with more detritus than they could carry. Diller[104] considered that northern California had remained comparatively stationary for a long period, during which the surface weathered. Changes in slope took

[103] Lindgren, W., Two Neocene rivers of California, Bull. Geol. Soc. Am., vol. 4, p. 265, 1893.

[104] Diller, J. S., Topographic revolution on the Pacific Coast, U. S. Geol. Surv., Fourteenth Ann. Rept., pt. II, p. 426, 1894.

place gradually, rejuvenating the streams, and invigorating erosion. The streams soon became overloaded and deposited gravels along their channels. LeConte[105] has stressed the idea that any current, however swift, will deposit material if only its load be sufficient. He cites as an example the Yuba River which fifteen miles above Marysville filled up 115 feet in thirty years, to be accounted for in the large increase of transported material produced by hydraulic mining. According to him, the pre-volcanic gravels were deposited in a geologically short time by very swift, shifting, overloaded currents. Furthermore, he thought the conditions shown by the deposits required a rapid melting of extensive snow or ice. This, however, is in direct conflict with the evidence of the fauna and flora of the pre-volcanic period. The overloaded condition of these streams may be partly related to alternation of periods of great rainfall with those of scanty precipitation. The swollen streams of the rainy season would have enormous transporting power which would decrease as the volume dwindled during the dry season. When the rainy season again commenced, fresh material would be washed from the slopes and a steadily increasing surplus over what could be carried would accumulate in the channels.

The Ione formation is a delta deposit that accumulated simultaneously with the channel deposits and in places it is difficult to decide just where the line of division between them should come. While sedimentation continued the sea advanced eastward, and the sediments overlapped at higher levels as progressive submergence took place. During the closing stages of the Ione, the streams had cut through the weathered mantle and conditions were no longer suitable for the development of the typical lateritic assemblage. The uppermost parts of the Ione contain more feldspars, and at Valley Springs and Knights Ferry biotite and feldspars were secured from the less altered part of the profile.

The explanation herein advanced for the origin of the Ione clays is similar to that put forward for the massive white clay of Georgia. This was considered by Veatch[106] to be a delta deposit formed at the mouths of streams which carried the soil derived from the Piedmont through a long period of weathering. It is Neumann's[107] opinion that the Cretaceous white clays of South Carolina were deposited as deltas

[105] LeConte, J., Old river beds of California, Am. Jour. Sci., vol. 19, p. 182, 1880.

[106] Veatch, O., The kaolins of the Dry Branch region, Georgia, Econ., Geol., vol. 3, p. 109, 1908.

[107] Neumann, F. R., Origin of the Cretaceous white clays of South Carolina, Econ. Geol., vol. 22, p. 374, 1927.

by streams flowing from the Piedmont. The clays occur in massive lenticular beds and are associated with cross-bedded sands. Their whiteness is explained by him as due to residual weathering of granitic rocks under a dense vegetable covering developed in a favorable moist mild climate. The explanation of the Ione clays has the advantage that it is supported by remnants of the residual lithomarge that furnished the material and that the streams which transported it can be located with some certainty.

LIGNITE OF THE IONE FORMATION

While no special study of the lignites has been carried on, because of their present inaccessibility, some observations were made during the investigation of the Ione sediments and are here recorded. Their distribution is their most striking feature, extending from south of Buena Vista Peak to Carbondale. The workable deposits have been limited to the east side of the porphyrite ridge already described. The conditions within this basin, at the mouths of streams flowing from the east, the area being protected on the west, seem to have favored their maximum development.

Adjacent to Carbondale, several holes have been drilled to determine the thickness of the lignite. Seams up to twenty feet thick are known that dip to the west at a low angle. They are associated with sand and gravels dominantly quartz that give one the impression of stream deposits.

The following statements are quoted or abstracted from the reports of the State Mineralogist, for it is many years since the mines have been worked, and it is either impossible or unsafe to enter them.

At Coal Mine No. 3[108] located 3½ miles northwest of Ione, a shaft 160 feet on the slope reached a vertical depth of 80 feet, exposing the following section:

Surface soil	1 foot 6 in.
Surface clay	5 feet 6 in.
Compact white sand	10 feet 0 in.
Bluish clay	10 feet 6 in.
Brown lignite	2 feet 6 in.
White clay slightly sandy	11 feet 6 in.
Brown lignite	4 feet 0 in.
Sandy clay	2 feet 0 in.
Very fine white sand	12 feet 0 in.
White clay with little sand	8 feet 0 in.
Brown lignite	13 feet 0 in.
	80 feet 6 in.
Blue clay under lignite	

[108] Eighth Ann Rept. State Mineralogist, Calif. State Mining Bur., p. 111, 1888.

The lowest stratum has been penetrated in two places by boring to a depth of 600 feet and the deepest material was a mixture of dry clay and sand without reaching the bed rock proper. The best stratum of coal is invariably the lowest of the three parallel strata, and is usually from nine to twelve feet thick, overlain with a few feet of white clay. It lies nearly horizontally, but conforms quite closely to the surface of the ground. The coal appears to have filled extensive potholes, following the general course of a channel or belt a little west of north. Previous to working Shaft No. 3, this company worked a bed in Ione Valley, about one and a half miles from Ione. Its superficial area was about twenty-three acres. It was shaped like a basin, or at least the better coal was found to assume such a shape, while coal too soft to be profitably extracted occupied the basin's rim, defining it, and the thickness also becoming less. For this reason it was unprofitable to longer continue extracting in this immediate vicinity. The body of coal varied from 25 to 50 feet from the surface. In ''Coal Mine No. 3,'' the ''rim of the basin'' has not been touched at any point, and the extent of the bed is consequently undetermined. This vein has been explored by underground galleries, for one-half mile. Borings have been made in various places for three miles from the present shaft, in a northern direction, for three-quarters of a mile in a southerly, one-half mile in an easterly, and thirteen hundred feet in a westerly direction. Each penetration revealed the full thickness of coal, and no ''rim,'' so called, of the basin has so far been discovered.

The Sacramento Ione Coal Company operated a mine about a mile west of Ione, where two seams of lignite occur. The upper one, three feet above the lower one, has an average thickness of eight inches. The lower one, varying from 6 feet to 24 feet, is separated from the upper by about 3 feet of brownish-white clay. The lower stratum is about 54 feet from the surface and is underlain by white clay.

The Buena Vista Coal Mine, located about a mile south of Buena Vista, is the only mine being worked at present, and the writer visited it in 1927. The lignite seam is about seventy-five feet from the surface, and the overlying sediments consist of clay and sandy clay. The bed is about twelve feet thick and is separated near the middle by a four-inch layer of white clay, which can be traced throughout the thousand feet of mine workings. The clay and lignite dip southwest at an angle of five or six degrees. The lignite bed is somewhat thinner to the east and north, as is shown by boring. An analysis of the lignite, furnished by the company and made by the C. A. Luckhardt Company on material dried for ten hours at 105° C to drive off 28 per cent excess moisture, is as follows:

Volatile carbon	31.60
Fixed carbon	55.28
Ash	11.36
Sulphur	1.20
Calories 6366 B. T. U. 11460	99.44%

The four-inch clay layer is nowhere cut by vertical carbon streaks that once might have been roots, but on the contrary it is better stratified than the usual Ione clay and very thin horizontal layers of carbonaceous material alternate with clay. The clay at the base of the lignite shows no evidence of being an old soil, nor has anything comparable to the Stigmaria clays of the Paleozoic coal fields been observed in any of the mines.

The volatile content of parts of the lignite is so high that it can be ignited with a match, and it burns with a smoky flame. Brown coal is perhaps a better name for this material, and it probably consists largely of spores. In thin section are a number of rounded forms that may be spores (pl. 37*b*). Jeffrey[109] and others consider that coal containing a large quantity of spores has formed in the open water, not on land as in the case of peat. Other parts of the lignite appear to have formed from wood, for these are black and fibrous as if retaining the grain of the wood. There is little evidence either from the nature of the deposits or in the structure of the brown coal to support the idea of growth *in situ*. Whether the plant material represented in the lignite accumulated under swamp conditions developed on the fertile mud flats of the delta, or whether it was washed from the higher slopes, is not easy to answer. In these deposits are present all the elements of the transport theory made famous by Fayol[110] and de Lapparent.[111] The writer regards the alteration of the bedrock series to have been partly aided by a dense vegetable growth which covered the surface. As erosion progressed, this plant material had to be disposed of. The observance of altered logs and leaves by Browne, Whitney, Lindgren, and others, testifies that material found its way into the streams and sometimes was caught while being transported and buried with the sediments. The occurrence of logs and leaves at the Newman's Pit shows that some of it reached the margin of the delta. Further, according to the theory, the greater part of the spores, logs, and leaves would be washed out to the quiet waters, but the sediments because they are heavier would settle near the margin. The coals near the edge would be thinner and less pure, and this is the condition described in the reports of the State

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[109] Jeffrey, E. C., The mode of origin of coal, Jour. Geol., vol. 23, p. 218, 1915.

[110] Fayol, H., Résumé de la theorie des deltas et histoire du bassin Commetry, Bull. Geol. Soc. France, sér. 3, vol. 16, pp. 968–978.

[111] de Lapparent, A., L'Origine de la houille, Assoc. Franc. Avanc. Sci., Conference de Paris, 1892.

Mineralogist. The greater bulk of the plant material would be prevented from floating too far out to sea by the presence of the porphyrite barrier to the west, and would remain until water-logged and then sink to the bottom. Slightly stronger currents and changes of level would carry the clays farther out to be deposited on the coal. The association of the coal with sediments known to be transported and showing the structures of deltas led Fayol to his conclusions regarding the transport theory.

The actual conditions regarding these deposits must await the time when they are opened up and more detailed study can be made. It is tempting to speculate concerning their origin, but the limited evidence at hand does not allow a positive conclusion.

"CLAY ROCK" AND RHYOLITIC TUFFS

The "clay rock" considered by Turner the uppermost division of the Ione formation is separated from the lower two divisions by a disconformity, and differs from them chemically, mineralogically, and in mode of origin. Turner[112] and Dickerson[113] considered the clay rock to be an altered rhyolitic tuff, and the present writer agrees with them. In many respects the clay rock is less closely related to the underlying Ione sediments than to the overlying rhyolite tuffs. Turner did not include some rhyolite tuffs in the Ione formation, but mapped them separately. In so doing, he recognized that the rhyolite tuffs were different from the lower Ione sediments, but the line of division selected by him was certainly not the best. The writer believes that the disconformity observed at several places constitutes the only satisfactory line of demarcation, for it separates the anauxite clays and sands that occur near the town of Ione from the clay rock and the overlying tuffs. Because of the difference in age and in composition, the clay rock should no longer be considered a part of the Ione formation, but should be assigned to the rhyolitic tuff period.

The clay rock is described by Turner as a light gray, but often discolored rock, with an irregular fracture and containing tubular passages, and is composed of fine particles of feldspar, fine discolored

[112] Turner, H. W., Rocks of the Sierra Nevada, U. S. Geol. Surv., Fourteenth Ann. Rept., pt. II, p. 464, 1894.

[113] Dickerson, R. E., Stratigraphy and fauna of the Tejon Eocene, California, Univ. Calif. Publ. Dept. Geol., vol. 9, p. 397, 1916.

sediment, and occasional quartz grains. He also mentions that the relationship of the Ione sandstone to the clay rock is apparent on the south side of the Mokelumne River by the bridge north of Comanche. At this locality a rock answering the above description may be collected and it constitutes the type to which the writer refers when he uses the term clay rock. Here, as Turner has correctly observed, the clay rock overlies the sandstone and rises gently eastward toward Valley Springs. At several places along the way, the clay rock is exposed and grades upward into types which, as Turner admitted, are difficult to distinguish from some of the rhyolite tuffs.

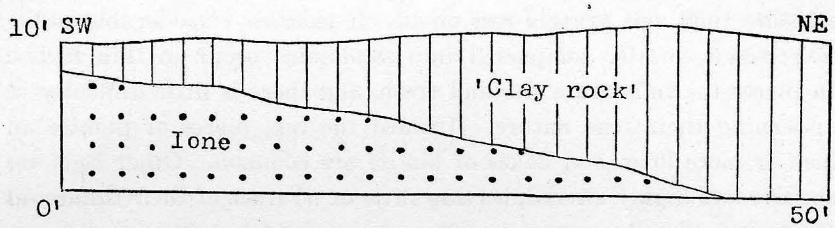

Fig. 10. Cross-section exposed in the ditch of the Mokelumne water project.

An additional point regarding the relationship of the clay rock is brought out on the north side of Buena Vista Peak, about one hundred feet above and a short distance to the west of the coal mine. Here, as along the Mokelumne River, the clay rock forms an exposure with a vertical north face a few feet high. This can be followed eastward where it passes below Turner's shore gravels, and westward below rhyolitic tuffs. As one ascends a hundred feet higher and a little to the south, white anauxite sandstones are met, and the mineral composition of these is similar to the sand associated with the lignite. The clay rock here appears to have been deposited on a surface cut more than one hundred feet into the anauxite sandstone, which forms an erosion remnant below the rhyolite tuff of Buena Vista Peak. Further evidence of this disconformity was found five miles to the southeast in a ditch excavated in connection with the Mokelumne River project. The contact between the anauxite sandstone and the overlying clay rock is irregular, and slopes, so that in fifty feet along the strike, the Ione sandstone is cut away and the clay rock forms the sides of the ditch to a depth of ten feet.

A quarter-mile west of the bridge near the station of Carbondale, a flat-topped hill composed of clay rock strikes a little west of north and stands twenty feet higher because of its superior resistance to erosion. Along the Laguna, the clay rock rests on a peculiar type of Ione sediment in which angular quartz grains are embedded in clay. The contact is exposed for several feet and undulates (pl. 32*b*). Rounded pebbles of quartz, siliceous rock, and rarely a compact rhyolite tuff, are present in the clay rock. The upper part of the sandy clay appears to have been altered by solutions coming from the clay rock or along the contact. Yet it has a decidedly different appearance from the clay rock, both in the outcrop and in the hand specimen. The rhyolite tuff series forms the banks of the Laguna westward to one and one-half miles southwest of the Buckeye school, where andesite tuffs and gravels rest on it. It exhibits considerable variation; sands, locally compacted into sandstone, occur in thin layers. In places the tuffs are white and fresh, and there is little difficulty in discerning their true nature. Toward the top, pieces of pumice an inch or more long, and flakes of biotite are common. Other beds are massive and highly altered, leaving little or no trace of their tuffaceous character. Small caverns or holes one to four feet in diameter are locally characteristic.

In the southern part of the Jackson quadrangle, the area formerly mapped as Ione consists of clay rock and other parts of the rhyolite tuff series. In many places this series overlaps on the older metamorphic rocks of the Sierra Nevada without a trace of Ione sediments. In exceptional cases, a few feet of Ione lies below the tuffs and above the Bedrock series. Examples of these are along the road east of Milton and in the gullies north of Jenny Lind. On account of the scale of the map, it is impossible to represent these accurately and they are omitted. Fragments of pumice an inch or more long are abundant in the tuffs near Milton. Examination of thin sections of these tuffs shows that the pumice is recrystallized and changed to montmorillonite with the retention of texture. Such altered pumice is common in the upper part of the rhyolite tuff series, and may be also noted west and south of Valley Springs. The layer at Milton is well up in the series, for it underlies the andesite tuffs a short distance to the west.

Southward to Fresno, the rhyolitic tuff series increases in importance because of its extensive areal distribution. At Knights Ferry there is evidence of erosion of the Ione formation before the deposition of the clay rock and the rhyolitic tuffs. The clay rock occupies depressions cut below the top of the Ione formation, and the main exposures are to the west and along the river where andesite tuffs unconformably overlie the series. At the sharp bend of the Merced River southwest of Merced Falls, massive layers of clay rock form the upper twenty feet of the exposure and rest on Ione sands. In places, its contact with the Ione is irregular and sharp (pl. 25*b*) but farther west the base locally contains much sand and a few fragments of clay rock and these alone make the distinction from the Ione possible. A short distance downstream the clay rock thickens to forty feet at the expense of the Ione, and less than half a mile farther west it appears at stream level and forms the entire bank. Some of the massive layers dip southwest 12° to 18°, and in some the tuffaceous character can be easily made out. Gravels form a small fraction of the series. The clay rock and tuffs can be followed eastward toward the upper fossiliferous sandstone forming the buttes, but they end before it is reached. It would appear that the upper Ione sandstone was eroded from the area along the river before the clay rock was deposited, and that erosion was caused by uplift which prevented the rhyolitic tuff series from reaching as far east or to the same elevation as the Ione. This would require a lapse of time and suggests that here, as in the Jackson quadrangle, the clay rock is younger than superposition alone would indicate. Dickerson[114] has described the field appearance near Burns Creek of several types that belong to the rhyolitic series, and these, he considered, underlie most of the valley border for a distance of six miles from the old Fort Miller road. The writer is indebted to Professor A. C. Lawson for calling attention to the excellent section exposed along the San Joaquin River. From Herndon to Friant the banks are composed of rhyolitic tuffs, and near Friant a very fine tuff almost free from crystals is being quarried for use in the cement industry.

Below the andesite breccia at Lincoln are clays that were derived from rhyolitic tuffs. No doubt it was the texture of these clays that led to the suggestion that the Ione clays were formed from rhyolitic tuffs. The relationship of the rhyolitic clays to the terra-cotta clays of the Ione is most evident near the east side of the Gladding McBean Pit (pl. 26*b*). Here the gently dipping layers of the Ione are terminated abruptly by a disconformity. On this erosion surface, gravels were deposited in the lowest depressions and these grade upward into

[114] *Op. cit.*, p. 403, 1916.

sands, often with much biotite, or into clays. An analysis furnished by the Gladding McBean Company and given below shows the chemical composition of a sandy phase.

SiO_2	69.20
Al_2O_3	7.03
TiO_2	.44
Fe_2O_3	8.74
CaO	1.23
MgO	1.11
Alk.	.97
H_2O-	3.89
H_2O+	7.78
	100.39

Formerly, brick was made by mixing one-third of this material with two-thirds of Ione clay, but it is so variable that now it is stripped off and discarded as waste. A mineral with an index 1.530 ± .005, presumably montmorillonite, forms an essential part of the deposit. In thin section, shreds of pumice can be easily discerned, even though altered to this doubly refracting mineral. Other minerals present are quartz, biotite, plagioclase and orthoclase feldspars, and smaller amounts of andalusite, zircon, epidote, brown hornblende, and green hornblende. It is obvious that these clays were formed from tuffaceous material that was mixed with the products of erosion of the period, and that they differ from those below the disconformity in texture and in composition. The recognition of two clay formations separated by a disconformity makes it possible to harmonize what appear to be contradictory views concerning the origin of the clay at Lincoln and the Cosumnes region. The clays in this area that show indications of being formed from rhyolitic tuffs are above the disconformity and belong to the rhyolitic tuff period; those below are the Ione clays, the origin and history of which has been outlined.

On the west side of the Sacramento Valley Diller[115] reported the occurrence of the Ione formation at the Cold Fork of Cottonwood Creek and neighboring streams. The beds here are made up of clays, sands, and gravels, thirty feet thick at one place and sixty-four feet at another. The evidence for their reference to the Ione is that they occupy a position between the Chico and the Tuscan tuff. This interval is much longer than Diller realized, including the rhyolitic tuff period and several periods of andestic tuff eruptions separated by erosion

[115] Diller, J. S., Topographic revolution on the Pacific Coast, U. S. Geol. Surv., Fourteenth Ann. Rept., pt. II, p. 455, 1894.

intervals. Ransome[116] has stated that the evidence that these beds are Ione is little more than a guess. The writer collected samples of the clay below the Tuscan tuff at several places, and in thin section it is tuffaceous (pl. 35*b*). It does not resemble the Ione clays, but it is very much like the clays of the rhyolitic tuff period. At several places in the Redding district, Diller mapped such altered tuffs as the Ione formation. This is true near Bellavista, south of the Big Bend of the Pit, and above Phillips Saw Mill.

During the microscopic study of the rhyolitic tuff series, some interesting features were observed. In thin section the clay rock consists of angular quartz grains that are embedded in a clay that is anisotropic. Here and there are a few patches that look as if they were formed from pieces of pumice (pl. 36*a*). These are now crystalline and the plates of the double-refracting mineral are arranged parallel to the sides of the fragment. The index of refraction of the clay rock varies. Some parts are less than 1.537, others are below 1.551, and the remainder below 1.561. This suggests that it is composed of several minerals, probably montmorillonite, potash-bearing montmorillonite, and some anauxite. By washing and separating, epidote, zircon, brown tourmaline, and andalusite were found to be present in small amounts. Pebbles composed of rhyolite tuff and quartz have already been mentioned as making up part of the clay rock. The clay rock probably accumulated in water, in which were deposited pumice fragments and minerals eroded from the Ione and the Bedrock series. These were thoroughly mixed and are now altered to a brittle massive rock that forms a characteristic type differing from those above or below it. Turner[117] gives the silica and alkalies of two samples, one with 59 per cent SiO_2 and 4.8 per cent alkalies, and the other with 72 per cent SiO_2 and 1.6 per cent alkalies.

Along the hilltops north of Jenny Lind is another type mapped as Ione in the Jackson Folio. This is much more sandy, and in thin section quartz and soda-lime feldspars are abundant. Epidote, zircon, and brown tourmaline are among the heavy minerals. The numerous shards leave no doubt that it is a tuff; some of the glass fragments are altered and recrystallized and some are still isotropic (pl. 36*c*).

In the upper part of the series, some biotite is present and the texture even in the hand specimen is more characteristically tuffaceous. In many places, the pumice fragments are larger but for the most part

116 Ransome, F. L., The Great Valley of California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 1, p. 377, 1896.

117 Turner, H. W., U. S. Geol. Surv., Jackson Folio 11, p. 6, 1894.

are recrystallized. Plate 36*b* shows layers of montmorillonite replaceing volcanic glass in a tuff from Milton.

From Buena Vista Peak, Turner[118] described a rhyolite tuff in which phenocrysts of plagioclase, sanidine, and small amounts of quartz and brown biotite occur in glass. In thin section, this rock is a vitric tuff with practically none of the glass altered or recrystallized. Such tuffs were mapped separate from the Ione but differ from parts of the clay rock only in the amount of volcanic glass and the degree of alteration (pl. 36*d*; analyses, table 9).

The cause of the alteration and recrystallization of volcanic glass is not thoroughly understood. The fact that some of the glass in a thin section has been altered while that alongside is isotropic suggests that the chemical composition is the controlling factor. Ross and Shannon[119] have avoided broad generalizations but consider that a glass with 68 or 70 per cent SiO_2 is not likely to alter to bentonite. Turner lists an analysis of the Buena Vista rhyolite tuff, the SiO_2 content of which is 73 per cent, and it has remained unaltered. One partial analysis of the clay rock records 59 per cent SiO_2 and 4.8 per cent alkalies, and that apparently is low enough to be unstable. The other clay rock analysis with 72 per cent SiO_2 and only 1.6 per cent alkalies may contain quartz sand mixed with it, but Turner's statement does not make this clear, even though the low alkali content suggests it. The writer has no suggestions to make at this time as to the kind of solutions or the conditions that might bring about the alteration.

The source of the rhyolite tuffs apparently was outside the foothill belt for no adequate vents have been observed in that area. Turner considered their source to be to the eastward in the higher parts of the Sierra. Even at higher elevations these tuffs often contain detrital minerals such as sillimanite, indicating reworking. At Chili Gulch are such rhyolite tuffs, resting on white quartz gravels and covered by andesitic tuffs. Throughout the Sierra Nevada the rhyolite tuffs are quite uniform in composition, as is shown in the following table listing widely separated occurrences, and Turner[120] considered them all to be about the same age.

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[118] Turner, H. W., Rocks of the Sierra Nevada, U. S. Geol. Surv., Fourteenth Ann. Rept., pt. II, p. 485, 1894.

[119] Ross, C. S., and Shannon, E. V., The minerals of bentonite and related clays and their physical properties, Jour. Am. Ceramic Soc., vol. 9, p. 84, 1926.

[120] Turner, H. W., Rocks of the Sierra Nevada, U. S. Geol. Surv., Fourteenth Ann. Rept., pt. II, p. 485, 1894.

TABLE 9

ANALYSES OF RHYOLITE TUFFS

	126	365	111	133	136	8 N. C.	7
SiO_2	73.23	72.70	71.21	69.45	71.85	69.06	70.01
TiO_2	.09						
Al_2O_3	12.73					15.97	12.61
Fe_2O_3	.99						1.47
FeO	.16						.50
CaO	.61	1.15				1.03	1.06
MgO	.22						.72
K_2O	5.17	4.81	4.16	5.25	5.11	5.00	5.12
Na_2O	1.91	3.46	1.82	.80	1.48	1.38	1.94
$-H_2O$	.53						2.37
$+H_2O$	4.51						4.68
P_2O_5	.02						.04

No. 126. Rhyolite tuff. Butte south of Buena Vista Peak. Jackson quadrangle. Hillebrand, analyst, U. S. Geol. Surv., Seventeenth Ann. Rept., pt. I, p. 721, 1896.

No. 365. Rhyolite tuff. Plumas County. Hillebrand, analyst, U. S. Geol. Surv., Fourteenth Ann. Rept., pt. II, p. 487, 1894.

Nos. 111, 133, 136. Rhyolite tuff. Amador County. Hillebrand, analyst, U. S. Geol. Surv., Fourteenth Ann. Rept., pt. II, p. 487, 1894.

No. 8 N. C. Rhyolite tuff. Near West Harmony incline. Colfax quadrangle. H. N. Stokes, analyst, U. S. Geol. Surv., Seventeenth Ann. Rept. pt. II, p. 99, 1896.

No. 7. Rhyolite tuff. Willards Creek near Susanville. George Steiger, analyst, U. S. Geol. Surv., Bull. 228, p. 211, 1904.

Lindgren[121] has described flows of rhyolite, with phenocrysts of quartz, sanidine, and a little brown mica, which filled a valley near Soda Springs to a depth of one thousand feet. Other exposures are reported northwest of English Mountain and Sugarpine Flat. Northwest of Towle in the Colfax quadrangle, massive light-colored rhyolite outcrops, and below this, in the direction of Alta, rhyolite tuffs are well developed. In thin section these tuffs are much like those over the Ione. The rhyolite tuffs of the foothills may have come from the higher parts of the Sierra for extrusive material of suitable composition had its source there. These tuffs have been traced along the old stream courses and rest upon white quartz gravels even to the margin of the foothills. There is little reason to believe they stopped there; they undoubtedly continued into the Great Valley where they overlie the Ione.

The age of the rhyolite tuffs is not a settled question. The rhyolite tuffs of the foothills are post-Ione (Middle Eocene), since they overlie

[121] U. S. Geol. Surv., Truckee Folio 39, p. 3, 1897; Colfax Folio 66, p. 6, 1900.

the fossiliferous sandstone nonconformably. Allowing time for the erosion that took place after the Ione and before the deposition of the tuffs, the age might be Oligocene or Lower Miocene. Both along the valley and continuing higher into the Sierra, the rhyolite tuffs are overlain by andesitic tuffs and breccia. The age of the Sierran andesites has been ably discussed by Louderback[122] who concludes they represent "the Lower Pliocene or Upper Miocene, perhaps bridging the gap between these two epochs." The greater part of the rhyolitic tuffs at Independence Hill overlie a flora considered Miocene by Knowlton.[123] Above Phillips Saw Mill, Diller collected plants considered Miocene. The best preserved plant materials observed by the writer at this locality were in a rhyolite tuff, and it is possible that Diller's collection came from the rhyolite tuffs. Erosion between the rhyolite tuffs and the andesites has been reported at several localities, and, making allowance for it, a lower Miocene age for the rhyolite tuffs seems the most likely from the present available evidence.

The shore gravels in the Jackson quadrangle, described by Turner,[124] offer further evidence of the erosion that followed the Ione. These gravels contain pebbles of quartzite, mica-schist, quartz-porphyrite, granitoid rocks, andesite, and rhyolite. At the red sandstone quarry they rest disconformably on Ione sandstone and at a number of places they overlie the clay rock; rhyolitic pebbles are so abundant as to be characteristic. North of the red-sandstone quarry are massive sandstones; the upper parts contain pebbles and were mapped as shore gravels. The writer considers the massive sandstone to be later than the Ione, for the following reasons:

1. It contains blocks of white Ione sandstone (pl. 37*c*) and much material derived from the Ione.

2. It rests upon sands containing tuff pebbles up to five or six inches across that do not occur in the Ione.

3. Thin layers of tuff are interbedded with the sandstone (pl. 35*d*).

4. The massive sandstones and overlying conglomerate with rhyolitic pebbles can be traced to the north side of Buena Vista Peak, where it rests on the clay rock.

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122 Louderback, G. D., Period of scarp production in the Great Basin, Univ. Calif. Publ. Bull. Dept. Geol. Sci., vol. 15, p. 19, 1924.

123 Knowlton, F. H., Flora of the auriferous gravels of California, U. S. Geol. Surv., Prof. Paper 73, pp. 57–63, 1911.

124 Turner, H. W., Rocks of the Sierra Nevada, U. S. Geol. Surv., Fourteenth Ann. Rept., pt. II, p. 468, 1894.

Conclusion

Extensive erosion followed the Ione, and during the Oligocene or lower Miocene, rhyolite tuffs were erupted from vents along the crests of the Sierra Nevada. The first eruptions were of slightly less acidic composition and were more susceptible to alteration and recrystallization; and these were followed by biotite-quartz-sanidine vitric tuffs. These tuffs fell or were washed into the streams and have been deposited partly on the Ione and partly over the older stream gravels along the slopes to the east. A long period of erosion followed, and then great volcanic activity took place resulting in the deposition of andesitic tuffs and breccia. The coextension of the andesitic detritus of the foothills, with the andesites overlying the rhyolitic tuffs of the higher parts of the Sierra, can be demonstrated by the similarity of the petrographic types of those regions.

EXPLANATION OF PLATES

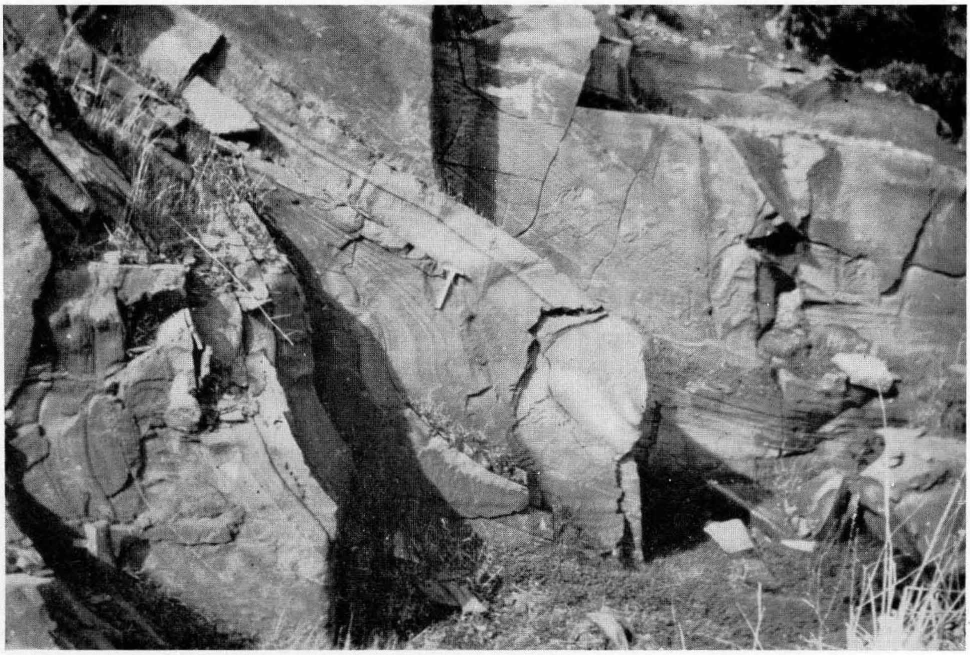
EXPLANATION OF PLATE 24

a

a. Channel-filling in the Ione formation. Shows original curvature of bedding near south end of quarry. Upper flat-lying beds at the right contain fossils. Red Sandstone quarry. Three miles southeast of Buena Vista.

b

b. Showing character of bedding at the top and near the center of the channel. Position is to the right of the above picture.



a

b

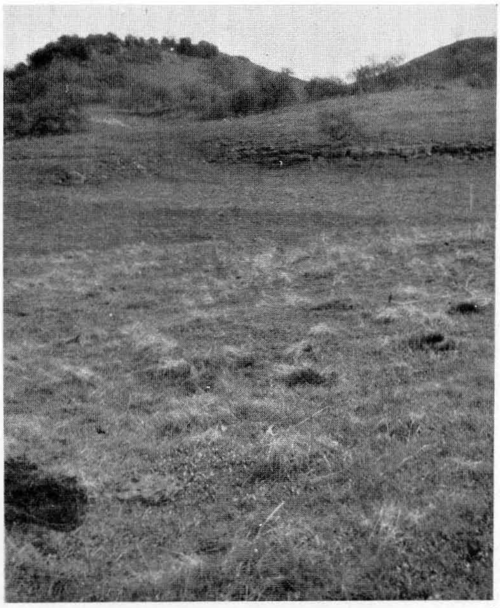
EXPLANATION OF PLATE 25

a

a. Sandstones mapped as Ione by Turner in the foreground. Fossiliferous anauxite sandstone capping buttes in the background. Merced Falls.

b

b. Ione sands disconformably overlain by ''clay rock.'' Bend of the Merced River. Merced Falls.



a

b

EXPLANATION OF PLATE 26

a

a. Andesite breccia, rhyolitic clays, and Ione clays. Gladding McBean Pit, Lincoln.

b

b. Disconformity between rhyolitic clays and Ione clays. East end of Gladding McBean Pit, Lincoln.

a

b

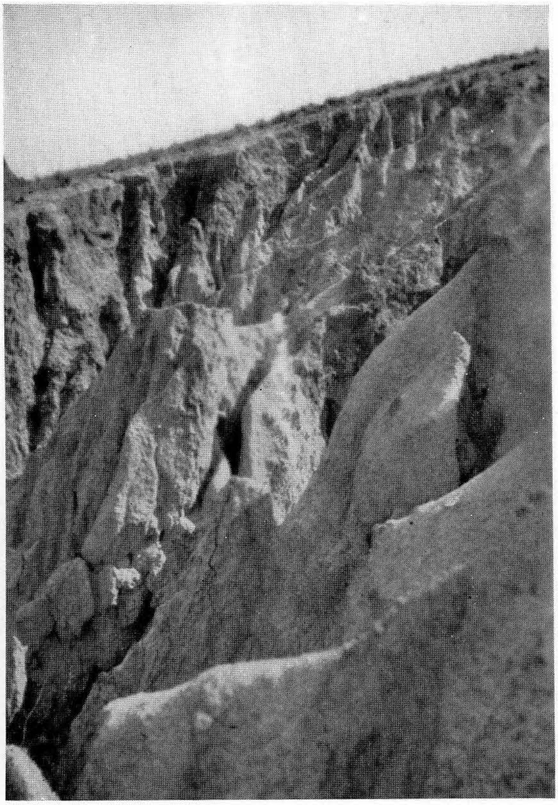
EXPLANATION OF PLATE 27

a

a. Ione sands and gravels. Marysville Buttes.

b

b. Disconformable contact of Butte gravels on the Ione formation. Marysville Buttes.



a

b

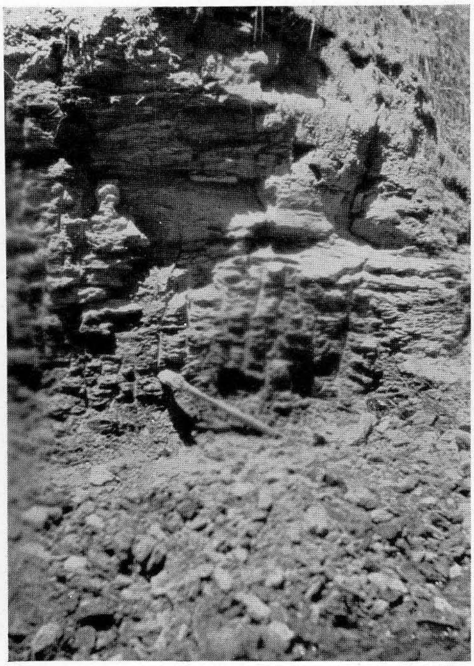
EXPLANATION OF PLATE 28

a

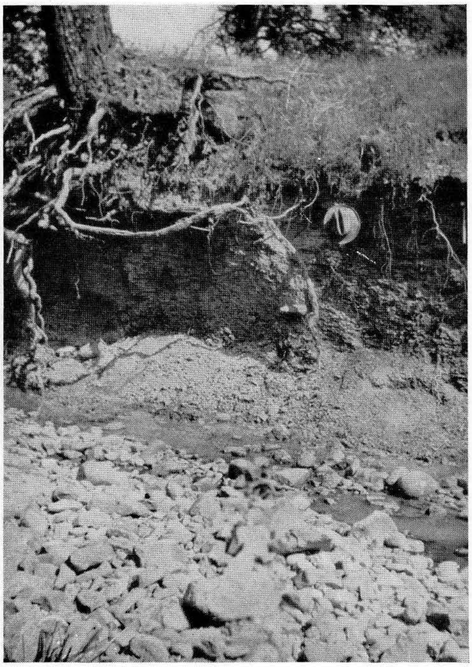
a. Dry Creek formation. Biotite sands resting on gray shales. Dry Creek, Chico quadrangle.

b

b. Dry Creek formation. Anauxite-glauconite sands overlying gray shales. Chambers Ravine, Chico quadrangle.



a



b

EXPLANATION OF PLATE 29

a

a. Ione sand, showing plates of anauxite. Newman Pit, Ione. × 30.

b

b. Ione clay with large plates of anauxite. Gladding McBean Pit, Lincoln. × 40.

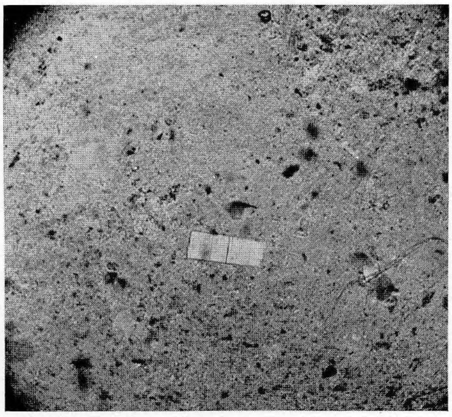
c

c. Ione clay. Clark Pit, Ione. × 40.

d

d. Plastic Ione clay. Jones Butte. × 40.

a



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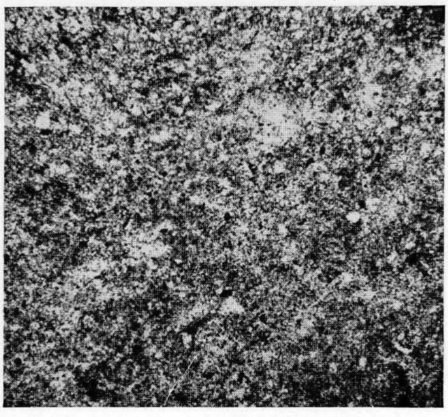
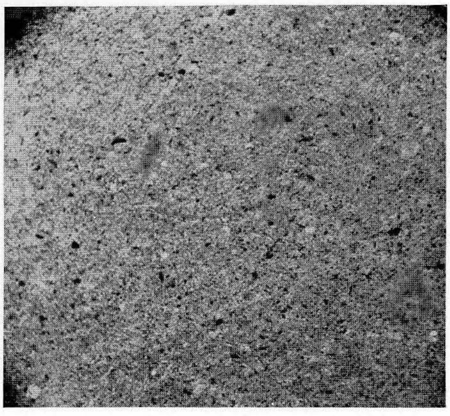


c



d

EXPLANATION OF PLATE 30

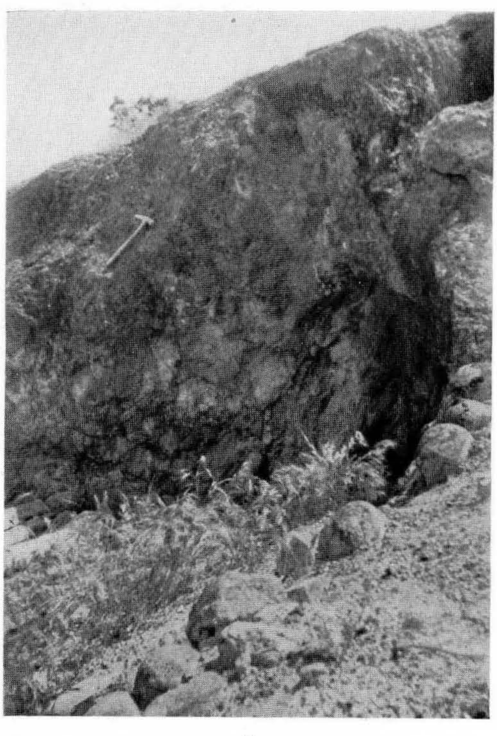
a

a. Laterite surface near pit of Stockton Fire Brick Co., Jones Butte, three miles northwest of Ione.

b

b. Laterite surface, showing spotted appearance. Jones Butte.

a



b

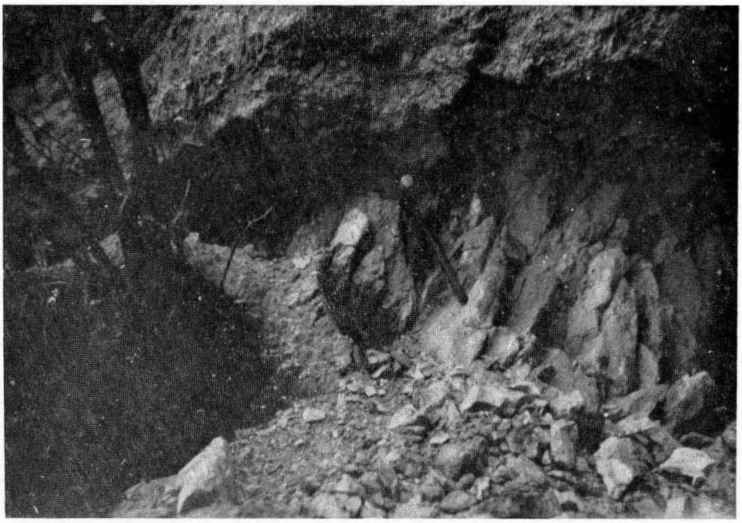
EXPLANATION OF PLATE 31

a

a. Residual lithomarge below auriferous gravel. Muletown, two miles north of Ione.

b

b. Iron deposit mapped as Ione, showing schistosity near the base. North of Valley Springs.



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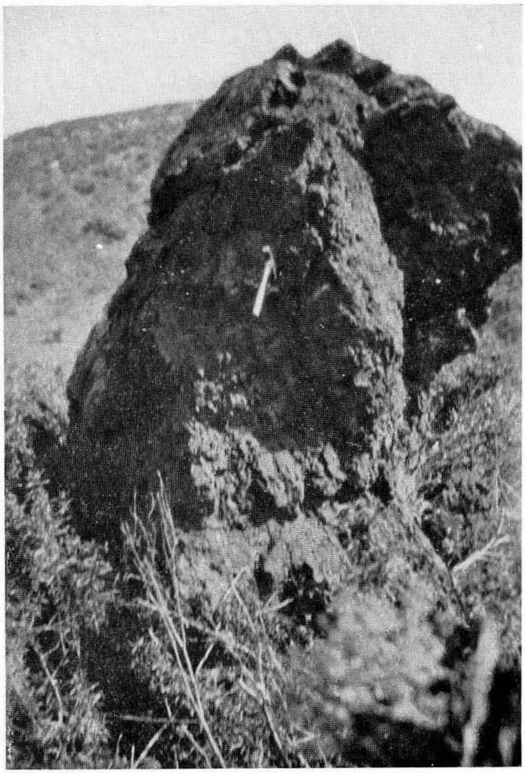


b

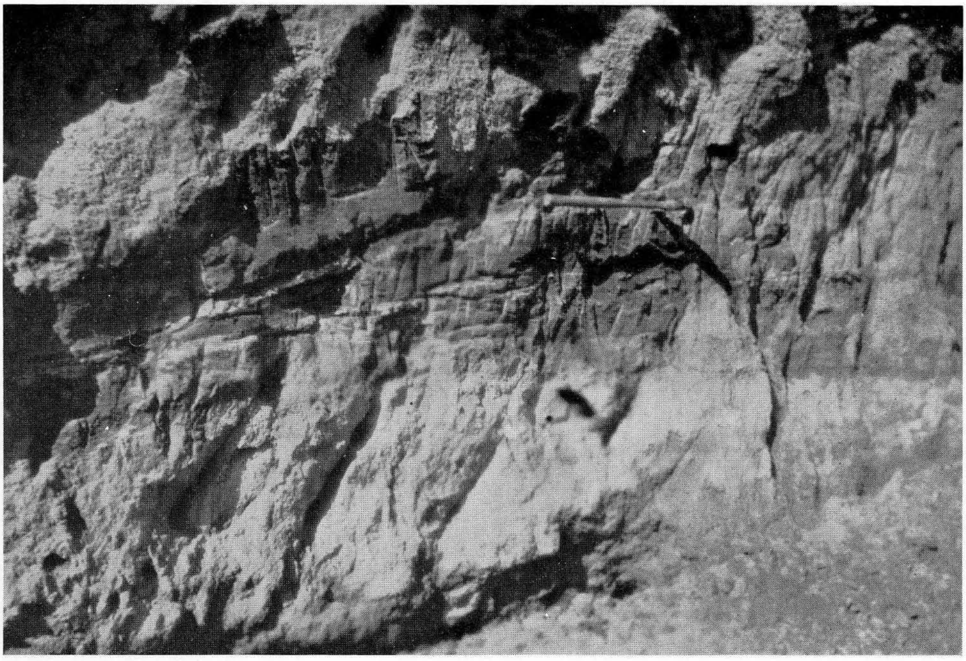
EXPLANATION OF PLATE 32

a

a. Fluviatile cross-bedding in Ione sand. Preston school grounds, Ione.

b

b. Contact of Ione sandy clay, and ''clay rock'' near Carbondale.



a

b

EXPLANATION OF PLATE 33

a

a. Ione sand covered by white quartz gravel. Newman Pit, south of Ione.

b

b. Ione sand, Newman Pit, showing gravel lens which disappears to the west.

a

b

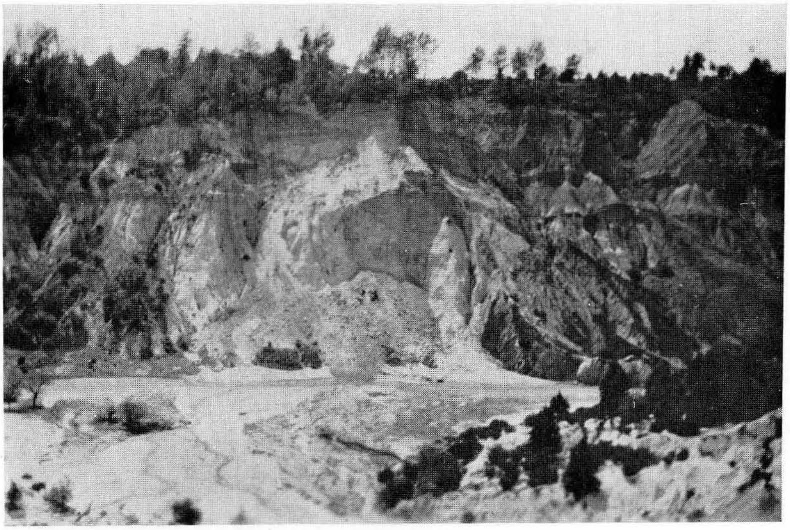
EXPLANATION OF PLATE 34

a

a. Contact of biotite sandy clay with white quartz gravels. Saw Mill Ravine.

b

b. Lithomarge surface crusted with iron oxide on which white quartz gravels rest. Surface slopes west. Lithomarge thirty feet thick at this point. Saw Mill Ravine.



a

b

EXPLANATION OF PLATE 35

a

a. Biotite sandy clay (rhyolitic) over quartz gravels. Saw Mill Ravine. × 40.

b

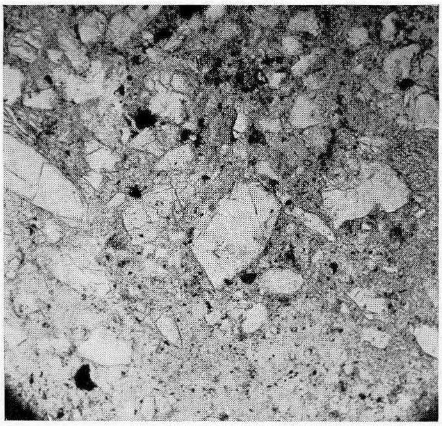
b. Rhyolitic tuff. Diller's Ione. Salt Creek, northwest of Red Bluff. × 40.

c

c. Clay containing tuff fragments. In the upper part a small pumice shred may be seen, in the lower part a large fragment, both recrystallized to montmorillonite. Gladding McBean Pit, Lincoln. × 40.

d

d. Tuff band in massive sandstone. Part of the rhyolitic "Shore gravels." Two and one-half miles southeast of Buena Vista. × 40.



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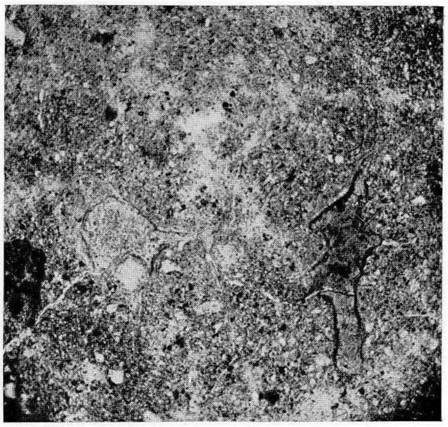

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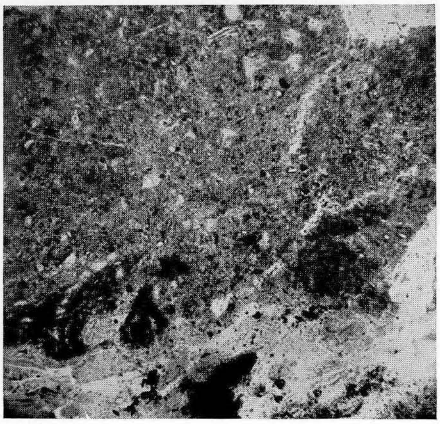

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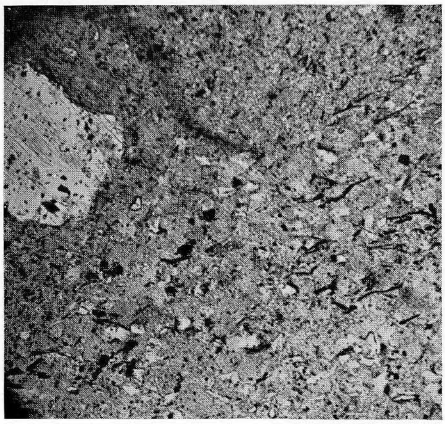


d

EXPLANATION OF PLATE 36

a

a. Lowest part of "clay rock." Valley Springs. × 30.

b

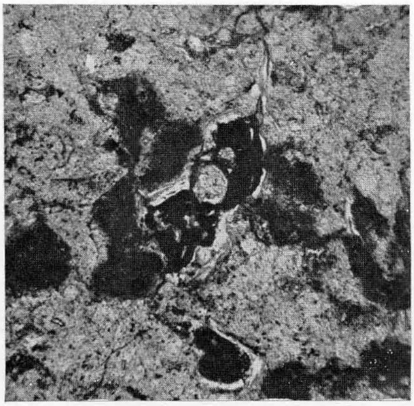
b. Pumice fragment replaced by montmorillonite. Milton. × 40.

c

c. Tuff north of Jenny Lind. Some shards recrystallized, others isotropic. × 30.

d

d. Rhyolite tuff. Buena Vista Peak. × 40.



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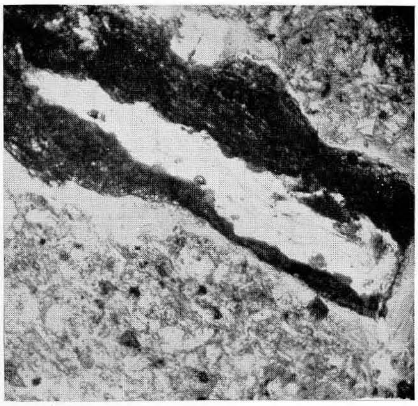

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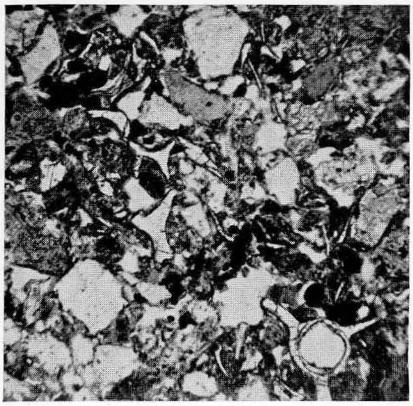

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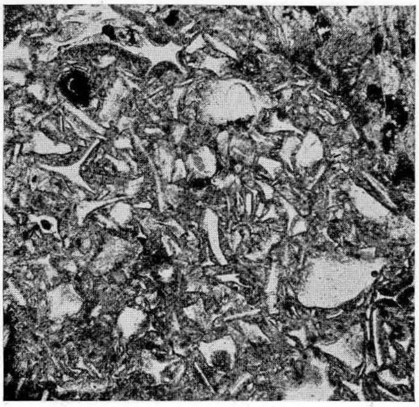


d

EXPLANATION OF PLATE 37

a

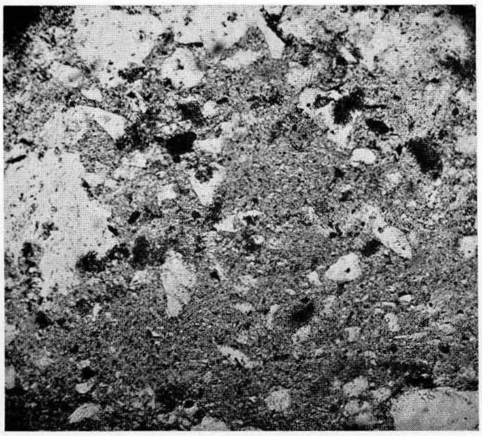
a. Quartz grains embedded in clay. Coal Creek, Chico quadrangle. × 40.

b

b. Lignite from Buena Vista Mine. Small round structures may be spores. × 40.

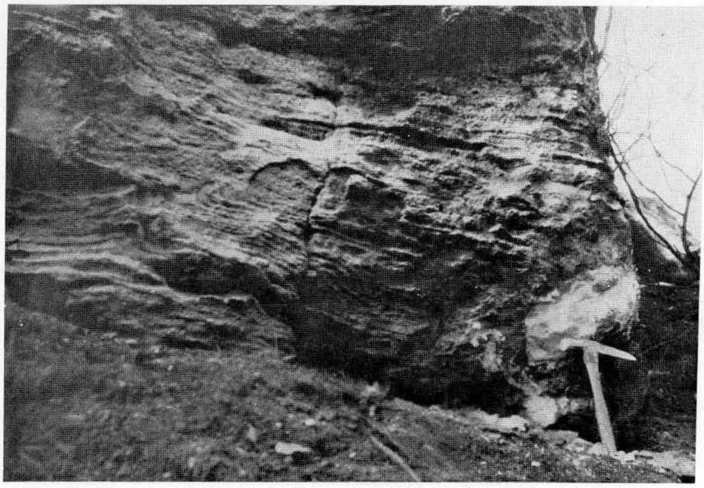
c

c. Block of Ione sandstone in the massive sandstone of the Rhyolitic period. Two and one-half miles southeast of Buena Vista, Jackson quadrangle.



a

b



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