THE GEOLOGY OF THE
CACHE CREEK REGION
KERN COUNTY, CALIFORNIA

Thesis by

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ABSTRACT

Along the north side of Tehachapi Pass, California, lies a basin containing three Tertiary formations resting on crystalline rocks of Sierra Batholith (?) age. The lowermost formation, the Witnet, is approximately 4000 feet thick and consists of coarse arkosic sandstones and conglomerates; the formation contains no fossils. The middle formation, the Kinnick, is 1900 feet thick and consists of massively bedded tuffs, agglomerates, and andesitic lavas; it is of lower Miocene age. The upper formation, the Bopesta, is more than 4000 feet thick and is made up of a fine grain sandstone; it was deposited in upper Miocene time. A Quaternary basalt is also present.

Deformation first occurred in pre-Kinnick (lower Miocene) time as a major thrust fault placing crystalline rocks over Witnet. The motion was toward the north-northwest, or perpendicular to the Garlock Fault. In middle Miocene time, folding and minor thrusting parallel to the Garlock Fault occurred. In post Miocene time, broad folds parallel to the Garlock were formed and uplift on the north side of the fault took place. The writer has concluded that this indicates activity on the Garlock fault in pre-lower Miocene time with less intense but continued activity to the present.

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Fig. 1. Panorama view of the Cache Creek Region. Taken on the south side of Oil Canyon, looking west (left) to north (right).

INTRODUCTION

Location --

The region described in this report is located approximately half way between Tehachapi and Mojave, Kern County, California. It lies about 110 miles by highway north of Los Angeles, 53 miles by highway east of Bakersfield, eight miles east of Tehachapi, four miles east of Monolith, and 12 miles west of Mojave.

United States Highway 466 cuts along the southwest corner of the region, and there is a black surfaced road that runs northward from the main highway into the mapped region and Sand Canyon. A connecting dirt road of fair quality extends half the length of Oil Canyon, and a poor dirt road runs the entire length of Horse Canyon. A number of other fair quality dirt roads branch from the paved road, as shown on the map, affording access to other parts of the region.

The map territory consists essentially of the head-water region of Cache Creek which drains eastward out of Tehachapi Valley. It consists of three main tributaries: Sand Creek in Sand Canyon, upper Cache Creek in Horse Canyon, Oil Canyon Creek in Oil Canyon. These unite approximately in the middle of the map area to form the main stream of Cache Creek in Cache Creek Canyon.

The mountains of this region are known as the southern-most tip of the Sierra Nevada, and by some as the Piute Mountains. (Raisz, 1939). It should be noted, however, that these mountains can be related to the Sierra Nevada only by topographic similarity in the trend; the geology is in no way similar, as will be noted in detail later.

Fig. 2 Location of the area.

Purpose --

The purpose of the investigation was to determine the geologic age and relationships of the structures found within the Cache Creek Region. The report is being submitted in partial fulfillment of the requirements of a Master of Science at the California Institute of Technology, Pasadena, California.

Methods employed --

Two maps were made of the geology of this region. One map was made on a scale of 2000 feet per inch, and covers about 30 square miles in areal extent. The second map was done with a 500-feet-per-inch scale and covers approximately one square mile in the upper part of Oil Canyon (this region is also included on the smaller scale map). The purpose of a large scale map is to portray more accurately the geology of the critical area and to relate these findings to the broader structures of the Tertiary rocks of this region.

For a base map of the territory, the author used the fifteen minute Tehachapi Quadrangle issued by the War Department, Corps of Engineers, U. S. Army. This was published on a scale of 1:62,500. The portion to be included in this report was then enlarged by photostating it on the new scale of 2000 feet per inch, then a tracing was made from this enlargement, and an ozalid print was made from the tracing. The latter was used in the field as a base map. The larger scale map was made by photographically enlarging the desired portion of the tracing. The original topographic map was made by air photograph methods and was excellent in respect to the absolute accuracy, as well as being representative in the detail of the contours. Even after being enlarged to a scale of 500 feet per inch (a little more than ten times), the author found the detail and accuracy still sufficient for precise work.

Field work was carried out for the most part alone, although another student, George Sawyer, of the California Institute of Technology, was working in the region throughout most of the investigation. A total of 33 days was spent in the field; the majority of these being in the months of August and September of 1950, the remainder being in October and November of 1950, and February of 1951.

Acknowledgments --

The investigation was carried out under the direction of Dr. John P. Buwalda, to whom the author is greatly indebted for his assistance and encouragement in the field as well as his suggestions and criticisms in the preparation of this paper. The writer would also like to thank his field partner, George Sawyer, for his help and assistance in the mechanical problems of field work, as well as for his tracing used in the preparation of the base map. He would also like to thank Mr. Walter Eiseman of Tehachapi, and Mr. Roland Eiseman and Mr. Kline of the Tehachapi branch of the U. S. Soil Conservation Service for the use of their facilities and suggestions related to the field problems.

GEOGRAPHY

The mapped area lies between elevations of 4000 feet and 6200 feet, and thus has a relief of 2200 feet. It consists of a long alluviated valley bordered by steep hills of crystalline and tertiary rocks, the slopes of which are "steep" and range between 20° and 35°. In the southeast sector, the hillsides are made of weathered remains of the underlying granite which lie at the angle of repose of about 32°. In the southwest, the hills are predominantly of cliff forming tuffs, that overlie less resistant arkosic sandstone. In the northern portion of the territory, the exposed rocks are of a softer nature and thus result in a more gently rolling topography.

The drainage, as was mentioned above, consists of three main streams uniting to form one in the middle of the map area. Of these, Sand Creek in Sand Canyon and Cache Creek in Horse Canyon are the larger and both drain approximately equal areas (see drainage map), while Oil Canyon Stream in Oil Canyon drains a much smaller territory. Although all of the streams were dry in the period during which the mapping was done, in "wet years" there is a continuous flow in Cache Creek and in Oil Canyon Creek, and in the event of a heavy rain, the three canyons have contributed enough water to cause serious damage from flood. In Sand Canyon, several earth-filled dams have been constructed to help control this situation.

In general, the vegetation is that of a semi-arid region. However, on the higher parts (above 5500 feet) larger conifer trees replace the smaller bush-like plants of the canyon floors. In the "lower" assemblage, there are many yucca, rabbit bush, and tumbleweed, and in the "higher" regions are found pines and juniper trees of mature proportions.

Exposures are in general good enough for surficial mapping, although in many cases, the details of the structures could not be determined with the certainty desired for this scale of work. The best exposures were those of the Kinnick formation, while the underlying Witnet Formation, the overlying Bopesta Formation, and the Quarternary basalt, weathered in general, to a soft non-resistant powder that gives no indication of the details and structure of the underlying rock. By interpreting the available information however, a reasonably complete structural map could be made.

STRATIGRAPHY

Regional --

In the Sierra Nevada there are two series of rocks, designated by many as the "subjacent" and the "superjacent" series. The former consists of strongly metamorphosed Paleozoic and lower Mesozoic sedimentary rocks; the latter consists of semi-consolidated Tertiary volcanic lavas and sedimentary rocks. Dividing the two series is the igneous Sierra Batholith of upper-Jurassic age. This general division can be made in the vicinity of the mapped area also. In the Mojave Desert region to the south, granitic rocks (Sierra Batholith age (?)) and upper Tertiary volcanic flows and continental deposits (superjacent series (?)) make up the bulk of known outcrops. To the north of the map limits, the outcrops are predominantly of igneous granitic rocks (Sierra Batholith age) and metamorphosed pre-Cretaceous rocks (subjacent series). (See fig. 12).

Northeast, some 25 miles, lie the Rosamond (lower Tertiary), Barstow (middle Miocene), and Ricardo (lower Pliocene) formations. The first of these consists mainly of volcanic lavas and pyroclastics amounting to a mile or more in thickness, which are strongly deformed by folding and faulting. The second, the Barstow, is also about a mile thick, and consists of fanglomerates and other land-laid deposits which yield numerous vertebrate fossils. This too has been deformed to a moderate degree. The uppermost formation, the Ricardo, is also approximately a mile thick and consists of volcanics in the lower part and terrestrial clastics in the upper part; this also can be dated by good fossil records. (Buwalda, oral communication). This series of beds is not connected in any place to the Tertiary rocks exposed in the Cache Creek region. The lowermost series of each set might be correlative, but there is no similarity in lithology or any fossil record in either to affirm this. The remaining beds of each group straddle the age represented by the other, as the Barstow and Ricardo represent middle-Miocene and lower-Pliocene, and the Kinnick and Bopesta are of lower and upper Miocene age. Since all four are dated by fairly reliable means, any possible connection between them seems precluded.

In the western part of Tehachapi Valley, there are some outcrops of sedimentary rocks that represent two ages. The lower is of a pyroclastic character, and shows light gray beds of tuffaceous sandstone throughout most of the section. In the lowermost part of the section, near Cable, there is a flow of basaltic volcanic rock further indicating that volcanism was present in the period of deposition. The younger section lies with a mild unconformity over this, and is made up of coarse fanglomerates and conglomerates that show only crude stratification. Neither of these formations has yielded any fossils, so the date of deposition remains unknown. The older beds may be corelative with the Kinnick formation as the lithology is similar to the extent of representing local volcanic activity, but the characteristic green color of the Kinnick is not present. If they are the same, this would mean it was of lower Miocene age. The upper beds appear to be comparatively young, as they are poorly consolidated, thus Pliocene or Pleistocene would appear to be a plausible guess, and the mild deformation represented would be after these dates. Again, however, this dating is hypothetical, and no reliance should be placed upon it.

Stratigraphy of the Cache Creek Region --

Within the territory mapped, there are the pre-Cretaceous crystalline rocks, three sedimentary formations, and a Quaternary olivine basalt. The sedimentary rocks are the Witnet formation of lower Tertiary age, the Kinnick formation of lower Miocene age, and the Bopesta formation of upper Miocene age.

Pre-Cretaceous Crystalline rocks --

The pre-Cretaceous rocks of the Cache Creek Region are of two types: 1) the metamorphosed sedimentary rocks, and 2) the igneous rocks tentatively assigned to the Sierra Batholith series.

The metamorphosed rocks are generally limestones, or phyllites. Garnet, chlorite, sericite, epidote, tremolite and actinolite, talc, serpentine, and graphite, have been found by the author and others are certainly present. The limestones are entirely metamorphosed to marble with crystals up to one inch across.

The igneous rocks were not studied in detail, and no thin sections were made. Megascopic identifications of the minerals show that quartz is present in most instances, both orthoclase and plagioclase are represented in most rocks, and biotite is often found constituting up to 5% of the total. Compositions range from granite to granodiorite, and the mean is probably adamellite (quartz-monzonite).

Much of the exposed igneous rock is badly shattered by the deformation of the region. As a consequence, many of the exposures are silicified by later percolating waters thus giving a false impression of the texture. When the rocks were relatively unbrecciated, the texture was found to range from coarse to medium (i.e., crystals from 2 to 10 mm in diameter). A second result of this crushing was the transformation of the mica to chlorite in almost all instances.

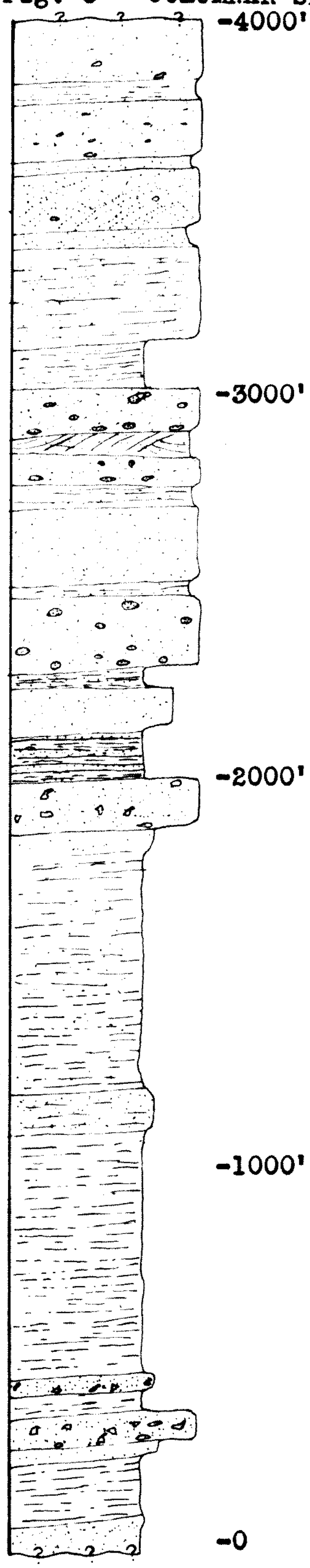
A total of eight different rock types were counted by the author in the southeast portion of the mapped region, and many others certainly exist. No sequence of intrusion was attempted.

Witnet Formation --

About 4,000 feet of this formation is found within the mapped region. This maximum thickness is between the southeast side of Oil Canyon and the north side, near the junction of the three canyons. Although the major part of this section is concealed by alluvium, the extrapolation is reasonably safe in the light of the known structure. The columnar section was obtained on the west side of Cache Creek Canyon.

Generally, the Witnet is a coarse arkosic sandstone formation, with scattered beds of conglomerate and dark siltstone. In the columnar section, the lower third is generally of a siltstone with fine angular quartz and feldspar fragments totaling less than 10% of the rock. Interspersed in this part of the column are a few beds of more resistant arkose-conglomerates. These are constituted of angular feldspar fragments (plus small amounts of quartz and biotite) as the matrix, and contains larger fragments of either extremely well-rounded quartzitic pebbles to cobbles ($\frac{1}{2}$" to 6"), or angular granitic and metamorphic fragments ($\frac{1}{2}$" to 4"); the two types of coarser fragments were seldom coexistent. These resistant beds make up only about 5% of the lower part of the column. The upper 2/c of the columnar section is of more homogeneous material,

Fig. 3 COLUMNAR SECTION OF THE WITNET FORMATION



Coarse angular feldspar fragments, scattered fragments of granitic rock. Interbedded with non-resistant siltstones.

Extremely coarse feldspar grains, smaller amounts of biotite and quartz. Cross bedded by carbonaceous layers. Tan to red.

Light green and pink siltstone, lenses of coarser arkosic sandstones and granitic fragments.

Thick beds of angular arkosic sandstones, large well rounded boulders of quartzite. Interbedded with finer cross-bedded arkosic sandstones.

Massive, well sorted arkosic sandstones, angular to sub-angular. Lenses of siltstone.

Tan angular arkosic sandstone, contains well rounded quartzitic boulders. Weathers to a deep red.

Alternating beds of coarse arkose and black shales. Arkose is coarse and angular; black shales micaceous, fissile.

Resistant beds of arkosic conglomerate; angular granitic fragments in a matrix of coarse arkose.

Tan, non-resistant siltstone. Thick bedded, contains some coarser material.

Resistant arkosic sandstones, thick bedded, a few conglomeratic lenses.

Non-resistant siltstone. Weathers to a light tan or gray.

Thin beds of arkosic breccia; angular granitic fragments of various sizes in a matrix of angular arkosic sand.

Pink and green siltstones, thick bedded.

being made up for the most part of arkosic sandstone although thin beds of black shale are found interbedded with the arkose in many parts of the section. The ratio of quartz to feldspar in these beds is approximately 50-50, and coarser fragments are found only in small lenses. Near the upper contact, two beds of resistant arkosic conglomerate are found, and these are similar in most respects to those described for the lower part of the section.

Bedding is characteristically between three and ten feet thick, although minor interbedding may be as thin as one inch. Cross bedding, defined by carbonaceous layers in the arkose, is very common and provides the only criterion in many cases to determine which direction is toward the top of the section.

In the part of the section exposed to the east, in the upper parts of Oil Canyon, the Witnet formation consists almost entirely of arkose, with only minor amounts of biotite, quartz, and other constituents. The large cobbles and boulders of well rounded quartzite found in the type section are here present in much larger quantities and sizes (up to one foot diameter) and the angular granitic fragments are virtually non-existent. Black shales and siltstones are found in much smaller percentages, making up less than 2% of the total section.

Since the lower contact of this formation is never exposed, no inferences can be drawn about the initial conditions of deposition.

The source of the sediments that formed the Witnet formation appears to be the granitic highlands to the east or northeast, if the gradation in size and character of the sediments could be trusted as a true criterion. The paucity of information about the facies changes to the north and south, though prevents one from reaching a conclusion that can be regarded as sound. More evidence can be brought to bear on the problem of environment of deposition: the suggestion of cross bedding by the thin laminae of carbonaceous material; the small-scale stratification of different fragment sizes; the generally well-sorted character of the arkosic fragments; the interbedded black shales; and the even width of the beds -- all indicate a lacustrine or fluviatile mode of deposition. The character of the sediments -- easily altered feldspars and micas -- indicates that the deposition was rapid enough to protect the preceeding sediments from destruction by weathering; the angularity of the feldspars and fragments also upholds this supposition of rapid sedimentation. Two features that oppose this proposed environment are: 1) the presence of black shales interlayered with the arkose; and 2) the well rounded quartzite boulders that are found in certain parts of the section. The first item (black shales) is such a minor feature, quantitatively, that it presents no serious objection, and probably is the result of periods of quiescence and flourishing plant growth (thus the carbon) as a result of the vagaries of weather. The second anomaly -- the quartzite boulders -- appears to be a result of second-cycle deposition; apparently they were buried as well-rounded boulders, and were later exhumed and redeposited in the Witnet formation.

The climate at time of the deposition of the Witnet formation was apparently an arid to semi-arid type, with periods of heavy precipitation alternating with dry. By the conventional standards of rock weathering theory, feldspars and, especially, biotite, are among the first minerals to succumb to the weather of a humid climate, and are, therefore, almost always found as sediments in arid regions where physical processes of rock disintegration are predominant over the chemical ways. At present, in the Cache Creek Region, the granitic rocks are seen to be transformed into an arkosic detritus that will in the future form a rock almost identical with the arkose now seen in the Witnet.

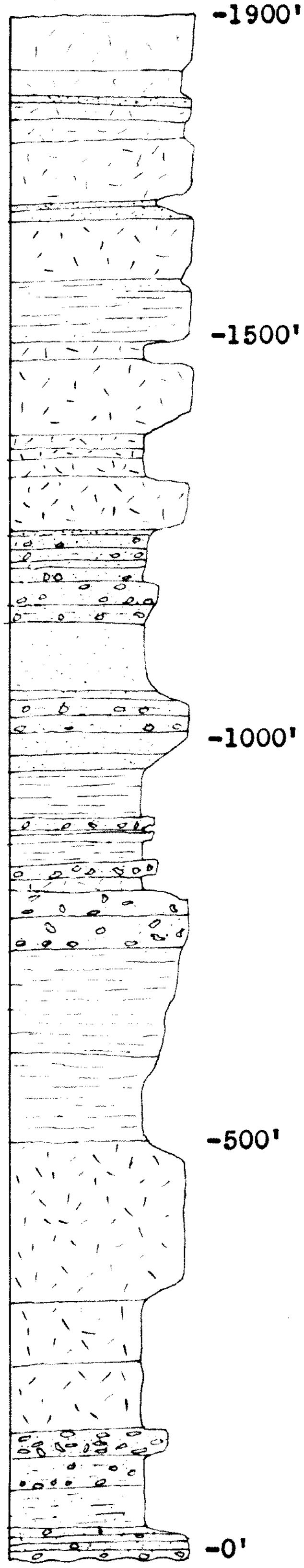
Kinnick formation --

A maximum of about 1,900 feet of Kinnick is found within the mapped region, this being in the syncline between Horse and Sand Canyons. This may represent the maximum thickness deposited, but it is more likely that part has been eroded away. The columnar section was obtained in part at this location, working upward from the contact at the canyon junctions, and the remainder was taken on the west side of Horse canyon, in the vicinity of the cabin.

Generally, the Kinnick is a section of lenticular tuffs and volcanic agglomerates, with the upper part consisting of some extrusive lavas interbedded with the clastic rocks. The most striking single characteristic of this formation is the green color that is present in almost all sedimentary parts of the section; this color varies from light green, to yellow-green or blue-green, with a few scattered beds of tan, red, or brown interspersed at random. The lower 4/5 of the columnar section consists essentially of tuffs and agglomerates, the upper 1/5 is mainly extrusive lavas, averaging andesite in composition.

The clastic part of the section may be characterized as consisting of angular fragments (½" to 1' in diameter) of volcanic rock forming up to 30% of the total rock volume, the matrix consisting of angular fragments

Fig.4 COLUMNAR SECTION OF THE KINNICK FORMATION



Andesitic extrusive rocks in flows 3' to 20' thick. Range is from rhyolite to basalts with the average falling in the andesite range. Base of flows often includes much foreign rock and fragments from previous flows. Contains phenocrysts of amphiboles or pyroxenes (the rhyolites contain quartz). Very few flows are non-porphyritic. Deposits of green pyroclastics and sandstones lie between many of the flows.

Andesitic extrusive lavas. Usually resistant.

Coarse, poorly sorted tuffs and breccias. Green to brown. Beds poorly defined, poorly sorted.

Brown non-resistant tuffaceous sandstone.

Thin bedded green to brown tuffs. Contains quartz and angular fragments of andesitic lavas.

Olive brown siltstone with thin beds of more resistant agglomerates and pyroclastics.

Thick beds of poorly sorted pyroclastics. Green to blue-green; weathers to a brown color.

Greenish-brown tuffaceous mudstone in upper part, light green siltstone in lower part.

Vesicular volcanic flow, weathers to a deep red-brown. Lenticular. Contains many fragments of a a basalt. Average composition is andesitic.

More vesicular than flow above, composition approximately the same. Weathers to a soft dust.

Greenish-brown tuff. Thin bedded in upper part, massive in the lower part.

Thin bedded blue-green tuffaceous agglomerate.

of quartz, lavas, and feldspars (in decreasing order), of all shapes and sizes averaging perhaps 1 millimeter in diameter. In some beds, shards of volcanic glass may be found interspersed with the usual assemblage of clastic fragments. In almost all, a fine volcanic ash appears to make up the finer part of the matrix.

The Kinnick formation is generally resistant to weathering. Cliffs and badlands are characteristic of the regions in which it is exposed, although to the north, the topography formed in this formation is much less rugged. This is due either to a general change in the resistance of the formation, or to the change in the erosive power of the streams that incise it; although the former may be partly responsible, the latter is probably more important in view of the fact that the uplift in recent time has, in all likelihood been more intense in the southern portion of the region than the north.

Bedding is very lenticular throughout most of the formation. In many sectors, the strata are defined only by changes in coloring that have followed a particular time line to the exclusion of others. In parts of the section exposed on the north side of Oil Canyon, no stratification is present at all; other exposures of this same horizon are well-bedded and show excellent sorting. No segment of the columnar section can be characterized as being well-bedded or poorly-bedded throughout the entire section; lateral variation is extreme. In regions where beds are discernible, however, they are 3 feet thick at the minimum, and range up to 50 feet in the extreme cases.

Lateral variation of the clastic horizons is extremely rapid as mentioned above. Although marker beds can be traced along a given outcrop,

Fig. 5. View showing the unconformable relations between the Kinnick and Witnet formations. On the north side of Oil Canyon near the mouth. Looking north-northeast.

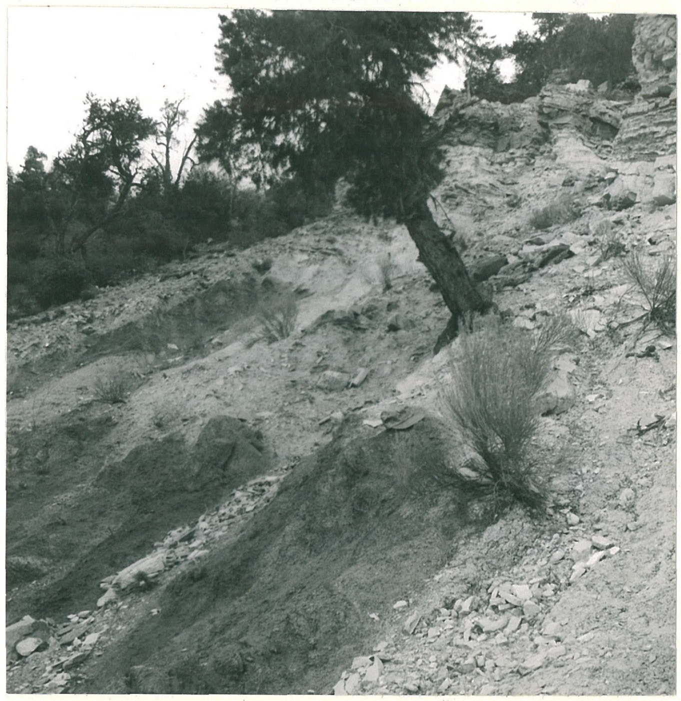


Fig. 6. View showing the irregular lower contact of the Kinnick on the Crystalline Complex. Taken on the south side of Oil Canyon looking south.

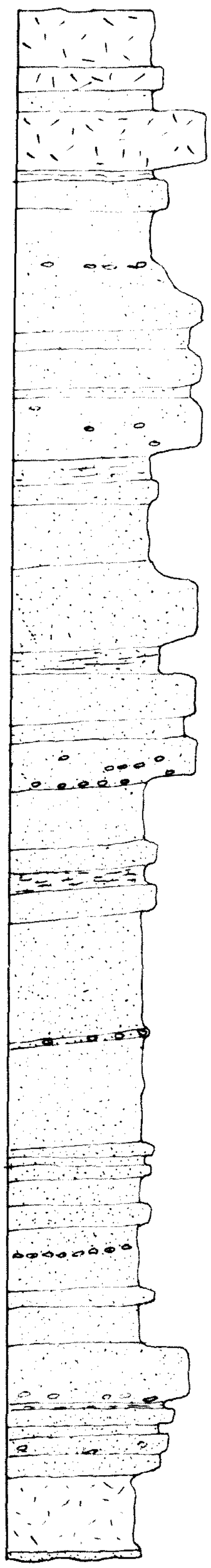
the writer has no success in trying to correlate between unconnected outcrops. Generally, the bedding becomes more massive to the east of the columnar section (i.e., in Oil Canyon), and to the north. In Sand Canyon a few isolated beds of coarse sand-stone are found that have no equivalent in the rest of the section.

Attempts to determine the direction of the sediment-source are futile, owing to the type of sediments involved, and the conflicting evidence at hand. Apparently, the deposition was in a lake or fluviatile environment, as cross bedding is found in a number of places. Marine deposition is virtually excluded because: 1) the character of sedimentation is not of the type found in marine-deposited beds, 2) the presence of plant leaves in the tuffs at the Philips Ranch Fauna locality, and 3) the presence of vertebrate fossils at this location (see paleontology). Thus, the probable environment of deposition was in a playa lake or enclosed continental basin. Since the faunal assemblage is that of a plains environment, and the plant leaves are of a typically arid plant life, we can conclude with reasonable safety that the locality was a semi-desert, similar in most respects to the Mojave Desert at present.

Bopesta Formation --

Approximately 2,000 feet of the Bopesta formation is found within the territory mapped by the author. To the east of the map limits, a large additional thickness can be seen -- in fact this forms all of Cache Peak (6708') and an unknown portion of the region beyond. If the region outside were included in the total thickness, probably 4,000 feet of Bopesta could be measured. The columnar section was taken along the

Fig. 7 COLUMNAR SECTION OF THE BOPESTA FORMATION



-2000' Andesitic lavas with thin beds of tan sandstone between flows.

Alternating beds of resistant and non-resistant sandstones. Lenses of conglomerate or siltstone occasionally found as partings. Tan to gray.

-1500'

Tan sandstone in beds 1' to 5' thick, lenses of conglomerate. Sandstone fragments of quartz with minor amounts of volcanic fragments, feldspars, and micas.

-1000'

Tan sandstone, more thinly bedded than above. Occasional lenses of green sandstone (similar to the Kinnick formation).

Massive sandstone beds, thin interlayers of conglomerate. Generally non-resistant. Tan to gray.

-500' Thin bedded sandstones alternating with partings of siltstone. Tan to buff.

Soft tan sandstones, with scattered beds of more resistant rock.

Vesicular basalt, weathers to brown dust.

-0'

easternmost structural cross section, starting at the contact on the north side of Oil Canyon, and progressing north into the syncline.

The formation as a whole is a well-sorted, well-bedded, yellow sandstone. Generally it is non-resistant and with the exception of a number of isolated resistant strata, is non-cliff forming. Many of the hills that are made up on this formation can be described most adequately as "piles of sand."

The detritus is in most instances well-rounded, and consists of quartz and volcanic rock fragments in about equal proportions with minor amounts of feldspar (up to 10%), and biotite (up to 25%). Lenses of conglomerates are found interspersed throughout, well-rounded cobbles consisting of rhyolitic and andesitic lavas almost exclusively. The matrix varies from a fine sand to a coarse sand, although in one bed the size is very uniform; part of the cementation has been by calcium carbonate, and part by silica.

Along the base of the formation is a thin bed of buff sandstone (averaging 2 feet) that is overlain by a thick bed of vesicular basaltic lava (averaging 50 feet) which weathers to a dark gray-brown; this marker is the best criterion to locate the base of the formation in regions that do not show the angular relations satisfactorily.

In the upper part of the section measured, there are a few blue-green beds that are impossible to distinguish from the Kinnick formation in the hand specimen; also in this area are some beds containing a few shards of volcanic tuff that manifest themselves as white specks in the outcrops and at first might be confused with the lighter portions of the underlying volcanic formation.

The top of the section measured is made of vesicular andesitic lavas, that form a resistant layer thus producing a bench in the topography. In the first part of the investigation, the author assumed these to be a normal part of the section. More recent work, however, has made the alternate hypotheses seem very plausible, i.e., that the lavas are more recent than the Bopesta, and are deposited on the eroded surface of the Bopesta formation. The lack of time, plus the paucity of good exposures in that region, has prevented this problem from being resolved, and the volcanics have been delegated to their original place in the section; if further work is done in the sector, the solution of the problem should be attempted.*

Although the Bopesta formation is poorly cemented for the most part, there are a few beds -- totaling about 20% -- of very resistant rock. These are scattered throughout the section and serve to give the formation many of the characteristics of a resistant section, such as the formation of highlands and cliff-sided canyons. This can be best attributed to the protective action of the resistant beds and also to the stable character of the mineral assemblage. Thus we find the anomalous combination of a formation that weathers for the most part to a soft "sand-pile", but forms high hills and mountains at the same time.

Bedding is in most places well developed, and can be traced laterally for long distances. The bed-width ranges from a few inches to four feet, with the average being approximately two feet. Cross bedding and ripple marks can be seen in many instances, and minor channeling is

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* The lavas seen in the plateau between Sand Canyon and Horse Canyon may also be of this age.

also found. Lateral variation is not rapid. The only change that can be cited is the gradual increase in the percentage of resistant beds toward the east of the mapped region. Exposures are not good enough to determine variation on a small scale, so no attempt has been made to do this.

The source of the contributing sediments is not clearly defined, partly because of the homogeneity of the strata involved, as well as the fact that the bulk of the surficial extent of the formation is beyond the limits of the mapped region. It is clear that the source was mainly rhyolitic and volcanic extrusive rocks and quartzitic rocks. No region of pre-Bopesta age is known to the writer that will fit these specifications, so the source also must be delegated to the list of unknown quantities. It is reasonably safe, however, to assume that the deposition was in a basin that contained water part if not most of the year, and that this basin was continental (since numerous vertebrate fauna were found in this formation). If the evidence of faunal habitata may be accepted, the environment was similar to that of the Kinnick -- a plains habitat, probably semi-arid. Thus, a plausible guess for the environment of deposition would be a playa lake or basin.

Olivine basalt --

This extrusive rock covers a large portion of the southwest corner of the mapped region as well as a number of isolated patches. It weathers characteristically to a brown fine dust and well-preserved outcrops are rare.

Fig. 8. View of the unconformity between the Kinnick and the Bopesta. Taken in upper Oil Canyon looking toward the south.

Fig. 9. View of the Quaternary basalt flow in the west of the region. View looking toward the west. Volcanics in the foreground are in the Kinnick.

The minerals that make up this rock, as well as their approximate percentages are:

plagioclase: 70%, calcic-andesine or labradorite, twinned, strongly zoned, euhedral.

olivine: 10%, euhedral to subhedral, crystals equant.

augite (?): 20%, anhedral.

magnetite: trace

The texture is equigranular, holocrystalline. Feldspar crystals are almost decussate in a matrix of augite and, to a lesser extent, olivine. This might almost be described as micro-diabasic texture.

Formation of this rock probably was the result of a rapid extrusion and flowing over the land forms. The fluidity is best demonstrated by the way it followed the microtopography that underlay it, and by the coarseness of the texture (for a basic extrusive rock) which must have been the result of ample mineralizer content.

As far as could be determined, none of the other volcanic lavas found in the region contained olivine, thus making this mineral a good means of identifying the flow.

Location of unconformities

Sierra Batholith - Witnet --

There is no exposure of this relationship; the stratigraphic relationship has been assumed on the basis of the relative degree of metamorphosis of the Witnet when compared to that of the sedimentary rocks known to be pre-intrusive.

Witnet-Kinnick --

The best example of the unconformity that exists between the Witnet and Kinnick formations, is on the north side of the mouth of Oil Canyon. Here the flat-lying Kinnick truncates the top of the Witnet, forming an angle of almost 75°, and in many other locations, they juxtapose at 90°. This angular relationship can be observed at almost any point along the mapped contact, so that there is no possible doubt as to its existence.

Kinnick-Bopesta --

A strong angular unconformity between these two beds can be seen only in one place, viz., the north side of the upper part of Oil Canyon. Here the exposures are excellent, and they show an angular unconformity of some 30° or less. Most of the other examples of the contacts are too badly concealed by weathered debris to serve as good evidence.

The olivine basalt depositional relationships can be seen almost everywhere, especially on the west side of Sand Canyon.

PALEONTOLOGY

The paleontological evidence found in this region has been fully treated in a paper by Buwalda (Buwalda, 1916). The present paper will only present the briefest summary of the data presented in his publication.

No fossils have been found within the Witnet formation. The present writer has prepared a number of samples of the fine sediments to be sent to Mr. Kenneth Loman of the U.S.G.S., and Mr. Merle Israelsky of the California Institute of Technology. At this time, no results have been returned.

In the Kinnick formation, the following forms were found by Buwalda:

Merychippus n. sp.	Mericodus? sp.
Camelid, large	Carnivore, indet.
Camelid, small	Canid, indet.
Moropus, sp.	Felid, indet.

These are known as the Phillips Ranch Fauna, named after the ranch (now the Garrison Ranch) in the uppermost part of Sand Canyon portrayed on the large map; the location of collection is marked by a cross about a mile to the northeast of the house. No additional specimens were found.

In the Bopesta formation the following specimens were found by Buwalda:

Merychippus, n. sp. a	Merychochoerus (?), sp.
Merychippus, n. sp. b	Dromomeryx, sp.
Hypohippus, sp.	Merycodus, sp.
Camelid, sp. a	Felid, sp.
Camelid, sp. b	

These are known as the Cache Peak Fauna, after the peak to the northeast of the mapped region. The collecting locality is along the entire east side of the amphitheater part of Horse Canyon, as well as to the east of the mapped region.

As a result of these collections, Buwalda designated the Kinnick formation as being of lower-Miocene age, and the Bopesta as being upper-Miocene in age. These age designations have been incorporated in this paper.

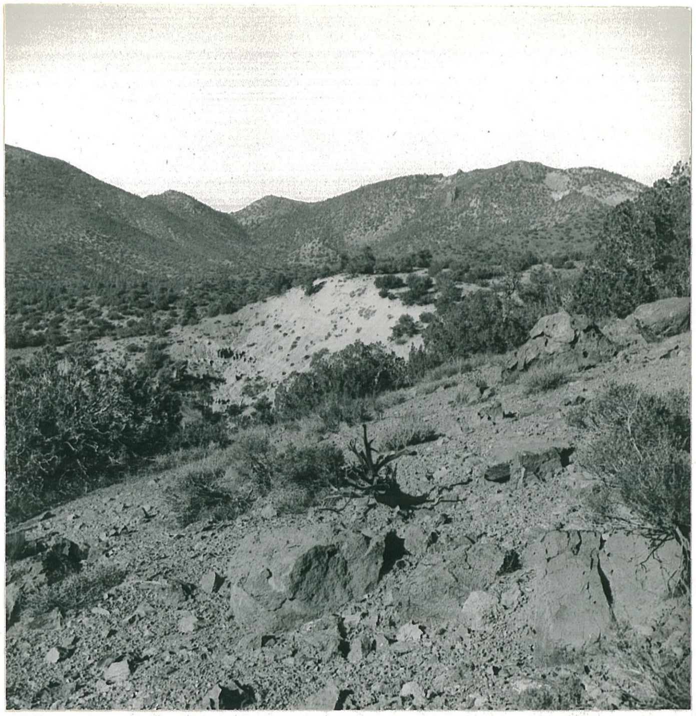

Fig. 10. View of the collecting location of the Phillips Ranch Fauna. Looking toward the north. White beds denote the location.

Fig. 11. View of the collecting region of the Cache Peak Fauna. Taken from the center of Horse Canyon looking east. Distant beds furnished the most of the collection.

STRUCTURE

Regional --

When attempting to evaluate structural features found in the Cache Creek Region, the adjoining geological structures (see fig. 12) must be studied fully, and the former related to the latter wherever plausible. Inasmuch as the Garlock Fault and the southernmost topographic extension of the Sierra Nevada meet near this vicinity, it would seem likely that the tertiary history of this junction could be more accurately determined in the Cache Creek Region than in any other.

Approximately 45 miles to the southwest is the San Andreas fault -- possibly the most outstanding tectonic feature of California. Although this is too far away to be safely related to any specific features of the map region, its relationship to the Garlock Fault and its role in the formation of the "wedge" of the Mojave desert (formed by the Garlock Fault on the northwest, and by the San Andreas Fault on the southwest) should be analyzed briefly.

The movement of the San Andreas Fault is essentially strike-slip and the northeast side moves toward the southeast. The magnitude of displacement is not agreed upon by those who have studied it, but the present concensus of opinion favors approximately 20 miles. The Garlock Fault, which trends toward the northeast, has essentially a strike-slip movement also with the northwest side moving toward the southwest, but simultaneously shows a great deal of vertical movement in the vicinity of this map project, with the northwest side moving upward. This is indicated by the Sierra Nevada and the El Paso Range, which are formed along the northwest side of the fault, the south side being alluvium. However, the major movement in terms of total feet-displacement is in the horizontal direction.

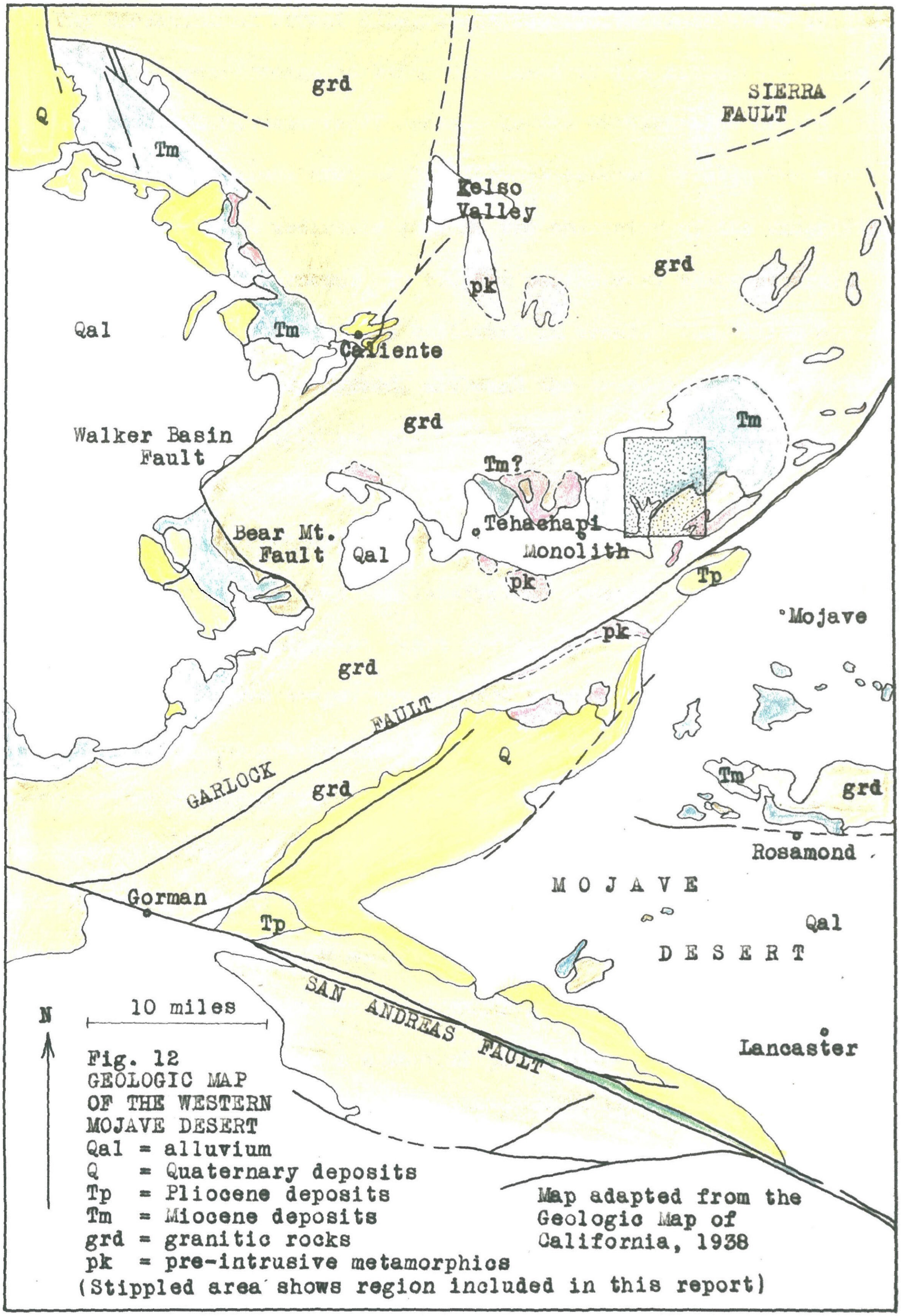

Fig. 12
GEOLOGIC MAP
OF THE WESTERN
MOJAVE DESERT

Qal = alluvium
Q = Quaternary deposits
Tp = Pliocene deposits
Tm = Miocene deposits
grd = granitic rocks
pk = pre-intrusive metamorphics
(Stippled area shows region included in this report)

Map adapted from the
Geologic Map of
California, 1938

The direction of offset along these two faults immediately suggests that the Mojave Desert wedge is being displaced to the eastward -- like soap being squeezed between two fingers. In the western side of the wedge, in Antelope Valley, most of the area is covered by alluvium and other recent undeformed sediments so that the character of the underlying rock is only imperfectly known. In the few territories where outcrops exist, the structure appears to be east-west in trend. The Willow Springs Fault is the major feature exposed, although the trend of the underlying granitoid rocks is generally in this direction too (Locke, Billingsly, and Mayo, 1940). Extrapolation from these meagre indications is a risky procedure, but no other evidence is known to this author. East of Barstow, this generalization falls down completely; the general trend becomes a well defined northwest-southeast fault system.

Within the Mojave wedge, the exposed bedrock can be divided into two series: first the pre-Nevadan Revolution (?) series (equivalent possibly to the subjacent series of the Sierra Nevada) consisting of Jurassic and undifferentiated intrusive rocks with scattered pendants of metamorphosed limestones and schists. The second series (equivalent to the superjacent series of the Sierra Nevada ?) is predominantly of Miocene and Pliocene volcanic rocks and continental sedimentary rocks. Overlying these is alluvium as well as a number of playa lake deposits.

The formation of the Mojave Desert surface is somewhat enigmatic. Tremendous quantities of rock must have been removed by erosion in order to expose the old series of rocks. Also, the overall relief of the bedrock in the desert region is relatively low (when compared to the mountain systems to the north and the south) so it would seem probable that the region had in the past been reduced to a surface approaching that of a peneplain. The problem is now to explain the escape of the sediments. At present, the territory has internal drainage. If this arrangement existed at the time of beveling, and if we assume an original relief similar to that surrounding it now, the present situation of a slightly filled basin would not have resulted. The alternative is that the entire territory drained to the sea at one time, and in this way transported the debris from the area. One possible route for this would be for the river now known as the Santa Clara, to have extended back to the desert, tapping it about where Palmdale is now located. Later, in Quaternary time, there might have been extensive up-movement on the southwest side of the San Andreas fault and/or any of the extensive faults known between the San Andreas and the Santa Clara watershed. This would have dammed up the sole outlet for the detritus in the entire Mojave Desert, and would thus bring about the conditions of filling that now exist. Other alternatives are possible, but they are beyond the scope of this paper.

The second major feature that must be considered in the discussion of the structures in the Cache Creek Region, is the nature of the Sierra Nevada uplift -- in the north as well as in the southern extension.

North of the Walker Pass Road, about 30 miles north of the map region, the Sierra Nevada are formed mainly as a rigid fault block tilted to the westward. Along the east side are a large number of major faults and even fault scarps in the alluvium indicating the extensive recent faulting along this zone. However, approximately ten miles southwest of Inyokern, the "Sierra Fault" (zone) changes its direction from south to the southwest, and disappears in the crystalline rock to the westward.

Very little work has been published on the nature of this fault termination, so the author does not feel justified in correlating any of the features in the mapped area to this fault zone, although there are almost certainly many relationships that would be clarified if the detailed structure to the north were known.

Immediately south of the Walker Pass Road, the structural cause of the mountains is not so well known as the Sierra Nevada to the north. In this southern region, the trace of the alluvium no longer has the straightness so characteristic of the fault-scarp boundary to the north. Stream erosion has caused a number of anomalous re-entrants along the front face, and the topography of the highlands is less rugged. Only two tectonic features are known to the author in this area. The first is a fault trending north-northwest from the Garlock Fault about four miles west of Cantil. This fault is in part, the contact between the Pliocene sedimentary rock in the vicinity of Cantil (Ricardo Formation), and extends northward for an unknown distance -- probably about ten miles (Buwalda, oral communication). The second tectonic feature mapped in this territory is in the Kelso Valley, about 15 miles north of the Cache Creek region. Here, a fault has been tentatively placed by Mayo (Mayo, 1947) trending almost east-west. Again, the data are too scanty to make a safe correlation between these two structures.

About 25 miles west of the Cache Creek Region is a series of faults trending northeast and north. The Bear Mountain Fault trends northeast along the edge of Bear Mountain, terminates a few miles north of Caliente (Geol. Map of Calif., 1938) and is probably in part responsible for the formation of this mountain. The fault dips to the northwest according to Mayo (Mayo, 1947), thus making it a normal fault. The second fault known in this region is the Walker Basin Fault (Mayo, 1947) that trends almost due north. Evidence for this feature appears to be the contact between pre-Cretaceous metamorphic rock against the igneous rock of Jurassic (?) age just north of the Walker Basin. Also, the linear west side of this basin appears to be formed as a fault- or fault-line scarp. Mayo reports this fault to be dipping to the east, but no indication is made of the relative movement.

From the above brief description of the geologic structures to the north and west of the Cache Creek Region, only one major generalization can be drawn with any degree of safety; namely, that the trend of the major faults turns from the north-south trend observed in the main Sierra Nevada, to a northeast-southwest trend in the latitudes of the mapped region. This transition is observed in the eastern series of faults (the Sierra Nevada fault zone, and the Cantil and Kelso Valley faults), as well as in the western part (the Bear Mountain Fault and the Walker Basin Fault, as well as the Canyon Fault well to the north of the Walker Basin region [Mayo, 1947]).

Now let us see if the structures within the Tehachapi Valley Region conform to this idealized pattern.

The Tehachapi Valley Region consists of four individual valleys: Tehachapi Valley, Brite Valley, Cummings Valley, and Bear Valley. Of these, the Tehachapi Valley is the largest, Cummings Valley is almost as large, and Brite and Bear Valleys are much smaller. The formation of these valleys will be treated in the section on geomorphology; this section will deal only with the structure of the underlying rocks.

When Lawson visited the valley in 1906 to study the geomorphology of the region, he proposed a series of faults along the straight sides of these valleys, and thus accounted for their anomalous location (some 3500 feet above the neighboring San Joaquin Valley only 9 miles away from the western extremity). The fault system that he proposed (Lawson, 1906) trended northwest-southeast on the western side of the Tehachapi Valley Region, and east-west along the south side of the sector. The presence or absence of these faults will be discussed more thoroughly in the section on geomorphology.

If we accept the existence of this fault system, it is seen to deviate from the idealized pattern mentioned above. The northeast trend is not carried out in this system; in fact, it is almost the exact opposite -- i.e., trending northwest and swinging toward the east in its southern extensions. However, this does not mean that the originally proposed generalization should be discarded; instead, other fault systems should be examined to see if the Tehachapi Valley Region trends are similar to any of them. The California Coast Range structures are thus seen to be suggestive of these directional tendencies -- approximately northwest (Buwalda, 1920). The east-west fault proposed along the southern side of Tehachapi Valley can, by the same method of reasoning, possibly be attributed to the forces that produced the structural trends in the Transverse Ranges of southern California. Although extrapolation of forces over such distances may seem without basis, it should be noted that the forces or resolution of forces that caused the shift in direction of the Coast Ranges from the northwesterly to the east-west trend must have been of a major proportion, and are therefore unlikely to have been attenuated over a short distance.

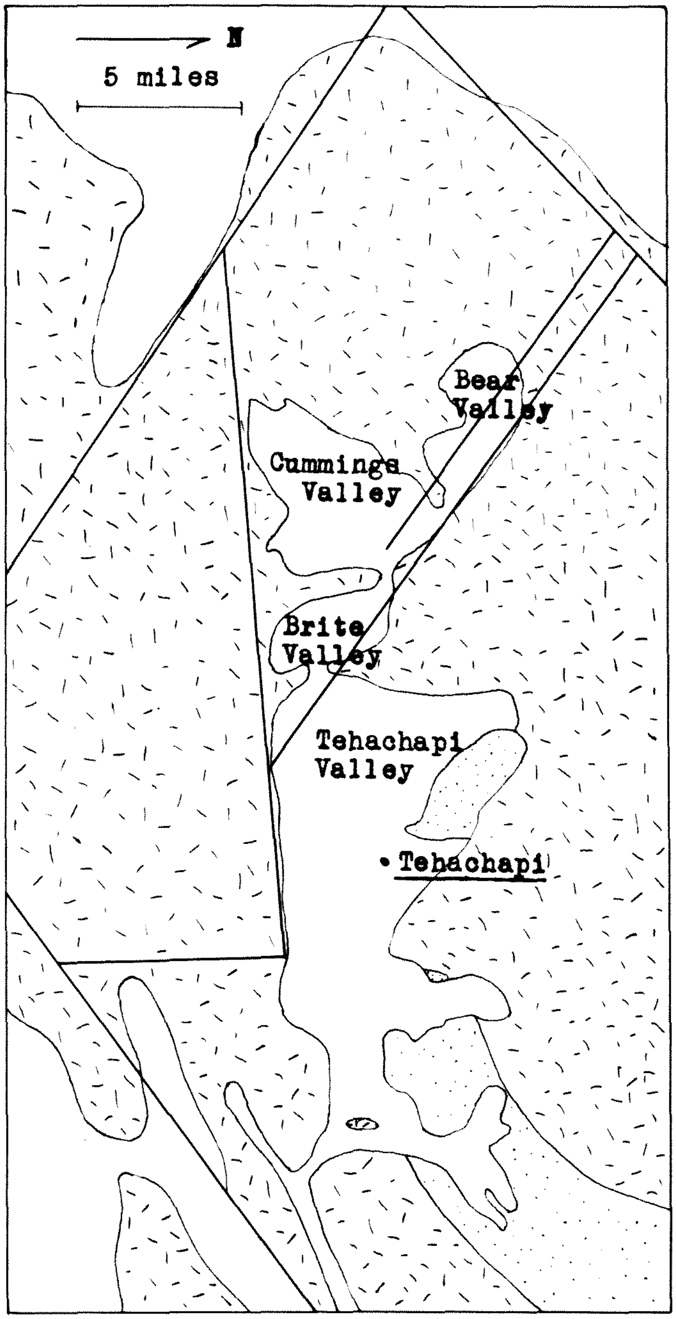

Fig. 13
A Reproduction of Lawson's map of the Tehachapi Valley region made in 1906.
Hachured pattern = crystalline rocks
Stippled pattern = sedimentary rocks

The second explanation for the anomalous direction of these faults in the Tehachapi Valley region, could be that they are associated fractures to be correlated with the major features in the more immediate area -- the Sierra Fault, and the Garlock Fault. By this analysis, the northwest trending series could be related to the Garlock Fault as shear fractures resulting from the strike-slip movement of the Garlock Fault and, if this were true, these too would probably be strike slip. An explanation for the east-west fault, along the south side of the Tehachapi Valley will be discussed after the mapped region has been included.

A third explanation that can be offered for the pattern of faulting in the Tehachapi Valley Region, is that they are the result of local forces that are entirely absent, or more likely, unknown in the adjoining region. This is an academic argument, though, and if used on all geologic features (and it easily could be applied in most cases), would prohibit any and all progression in the science of geology.

Structure of the Cache Creek Region

When analysing the structures in the Cache Creek Region, the most important features to be kept in mind are: 1) the proximity of the Garlock Fault which has been essentially strike slip during its past history, and 2) that in recent time, the motion along this zone in the immediate vicinity has been to move upward the northwest side. This is indicated by fault scarps in the alluvium in a number of places as well as topographic evidence (Buwalda, oral communication).

The oldest of the structures within the region is the thrust fault along the southeast side of Oil Canyon which extends toward the southwest across the open Cache Creek Valley and apparently under Proctor Dry Lake.

Contemporaneously with this faulting, the lower Tertiary Witnet Formation (the only Tertiary formation deposited at that time) was intensely folded with the axes trending almost exactly parallel to the trace of the thrust (i.e., about N 55° E). In all exposures which are limited with one exception to the lower parts of Oil and Cache Creek Canyons, the Witnet Formation is seen to dip in only one direction, viz. to the northwest. One small outcrop along the southeast side of Horse Canyon showed a dip in the opposite direction, which served to help localize the fold axis of Oil Canyon. The Witnet Formation is seen to be overturned in a number of places along the southeast side; in fact this was the best evidence to indicate the presence of the thrust. All degrees of overturning can be seen:more than 50° near the fork in the Oil Canyon streams. The fact that the attitude of these beds changes from vertical or overturned to horizontal, within a distance of about half a mile, suggests that they were unable to transmit the forces over long distances, and instead absorbed them by localized deformation. The extent and degree of deformation beyond the narrow strip of exposures is completely unknown, however, so any statements based on this meager evidence must be taken with reservations.

After the movement along this thrust, erosion took place. During this period, the Witnet formation was entirely removed from the upper plate of the thrust, so that south and east of the thrust trace, no Witnet ormation is known. The fact that Kinnick formation was deposited directly on igneous rock in <u>all</u> areas in the thrust plate, and <u>only</u> in these areas, is the most convincing proof of the age of the thrusting.*

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* At the northeast limit of the main-thrust fault, a small patch of Kinnick was deposited over the small-scale thrusts found in the lower plate of Witnet. Unfortunately, this feature was too small to portray on the map.

Fig. 14. View of the south side of Oil Canyon showing the major overthrust. Looking south.

Fig. 15. View of the north side of Oil Canyon showing the minor thrust of Kinnick over Witnet. Looking north.

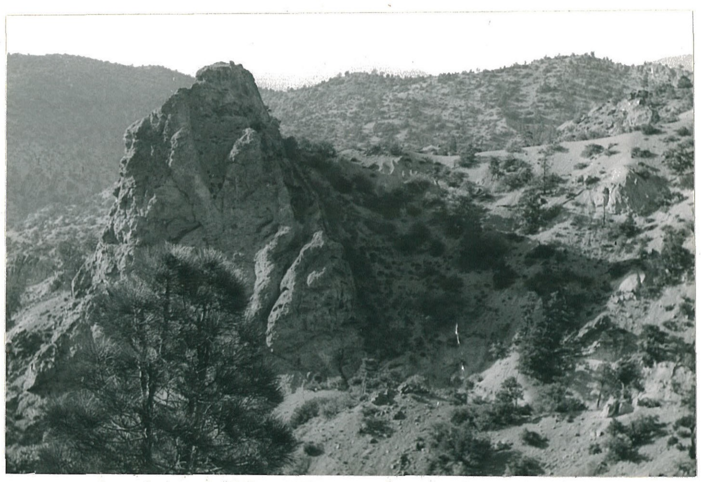

Fig. 16. View of a post-Bopesta normal fault in upper Oil Canyon. Looking west-northwest. Crystalline Complex on left, Kinnick on the right.

This same feature, however, also deprives us of any clue as to the total magnitude of movement along the thrust, and also removes any evidence, except for the drag effect on the underlying Witnet Formation, as to the exact direction of horizontal movement (although the side that moved up is indicated by this feature as mentioned above). For this same reason, we have no evidence about the areal extent of the Witnet formation in the period immediately preceding its deformation.

As the thrust is traced toward the northeast, it is seen to be terminated by an east-west fault. This fault is probably of post-Bopesta age and, although the slickensides on the surface indicate a strike-slip movement (and for that reason has been so indicated on the map), there has been enough vertical motion, with the south side moving up, to conceal the thrust-fault from view. Indications of the location of the thrust fault are missing beyond this point, except for the isolated instances of the Kinnick resting directly on the igneous rock about 2,000 feet to the east of this point.

The southwest limit of the thrust fault is unknown. It is concealed by alluvium in the southwest corner of the mapped region, but can be approximately located by the two hills projecting above the fill; one hill is of Witnet and Kinnick, and the twin knobs to the south of it are of igneous composition. Any extrapolation southwest of this point must be regarded as a guess, but three possibilities should be suggested: 1) that the thrust terminates in the region covered by the alluvium of Tehachapi Valley; 2) that the thrust is truncated by the east-west fault proposed by Lawson along the south side of the Valley (see the section on regional structure), and thus removed from view; and, 3) that the east west fault proposed by Lawson is the extension of this thrust. This last hypothesis would mean that most of the region that now makes up Tehachapi Valley, was at one time covered by an igneous and metamorphic thrust plate that has since been removed, along with a substantial part of the under plate, by erosion. Although an entertaining idea, there is no conclusive evidence known to the author that would substantiate this theory -- or either of the other two, for that matter -- as the correct solution. This is a problem that must be left to future investigations.

Two other phases of the evidence exposed along the thrust should be discussed. The first is the width of the shattered zone along the contact. Although poorly exposed throughout much of its extent, the width of excessive shattering can be determined in several places:

1) In the southwesternmost limit of the trace, the zone of shattering is traceable to the crest of the hill (approximately 25 feet vertically), and consists mainly of brecciated igneous rock that has been recemented to a resistant mass. Although the Witnet is poorly exposed at this point, it does not appear to be crushed as severely as the granitic rock.

2) On the south side of Oil Canyon (just southeast of the word "canyon" on the map) the zone of shattering is apparently confined to the Witnet formation. Here for a vertical distance of about 15 feet, the Witnet is seen to be badly broken and anomalous dips are found throughout it. Although the igneous rock is not well exposed here, it does not appear to have been as thoroughly crushed as in the first locality mentioned.

3) About 1,000 feet southwest of the fork in Oil Canyon, the fault is again well exposed, and here the brecciation again appears to have been concentrated in the over-riding crystalline rocks.

4) In the northeastern limit of the fault, the contact is never well exposed, but in most of the igneous rock exposed, there are numerous small faults in random directions, while in the Witnet the only deformation is the occurrence of small thrust surfaces that are assumed to reflect the attitude and strike of the major thrust above. The best examples of this type of deformation are at the northeast terminus of the thrust, in Oil Canyon.

Thus, in three of the four localities studied in detail, the major shattering appears to have been in the thrust plate, and the lower plate has been relatively unbrecciated. This is the situation that might at first be predicted when one considers that the lower plate is being tightly confined by the weight of the upper plate, and any shattering will only tend to increase the volume, and this volume increase can only find relief by lifting the upper plate or by squeezing laterally to some other region less confined. The upper plate, on the other hand, needs only to lift itself vertically or laterally to obtain space for an increase in volume, and thus can theoretically find relief from stress by shattering. In the zone immediately overlying the fault contact, however, the difference in weight of rock resting on the upper and lower sides of the fault surface, would seem to the author to be extremely small -- altogether too small to account for the different degree of shattering. Thus another factor may be involved, namely; that the crystalline rock was more brittle than the Witnet. In other words, the deforming forces were applied more rapidly than the crystalline rock could accommodate by plastic flow and molecular re-arrangement. The Witnet formation, on the other hand, was made up of granular fragments that were rather poorly cemented and thus could absorb forces by rotation, and probably by further compaction (almost certainly, the rocks were at the time of deformation less well cemented than now). As a result, the formation was able to deform at a rate that nearly equalled the rate of force application, and formed folds as a mode of relief from the thrusting stresses, in preference to brecciation as found in the crystalline rocks.

The final evidence to be discussed in connection with this thrust fault, is the change of dip as one progresses from southwest to northeast. In the first exposure of the fault plane, the contact is almost level -- measured as 3°. Progressing up into Oil Canyon, the dip was found to increase to about 25° just southwest of the fork in the stream. Still farther along, the dip was found to be still approximately 25° (this reading was very indefinite), and at the final terminus of the fault, the dip was nearly 40°. At first analysis, this would suggest that the fault was changing into a reverse fault, possibly the first step in the termination of the feature. Another hypothesis might be that since the southwest end of the plate is nearly level, this would indicate that the center of the entire thrust plate was nearby. However, when one takes into account the fact that since the time of thrusting, there has been major folding and faulting in the region, the present attitude of the thrust contact cannot be relied upon for an indication of the original dip of the thrust surface. The components of dip that would have to be subtracted, are altogether too complex to be attempted.

After the movement along this thrust, a period of erosion occurred. The character of the topography that resulted can best be studied by noting the lower contact of the Kinnick formation. In the south fork of

Oil Canyon, half a mile east of the stream junction, there is exposed a spire of granitic rock projecting 50 feet or more through the Kinnick formation. A thousand feet south of this point, at the 5,400 foot contour, the contact between the two formations can be closely studied, and is seen to consist of a rather rugged relief, although the zone of weathering beneath the contact is up to twenty feet thick -- a condition that would normally be expected to produce more gentle slopes. The topography of the granitic regions is more gentle to the southwestward of this point, and the exhumed surface (?) (see geomorphology) is more gentle and nearer a flat condition. It does not appear to be unreasonable to assume that this change in topographic character is a function of the rock type, and thus was found on the pre-Kinnick surface as well; the granitic rocks that are exposed today seem to have weathered in the same manner, i.e., forming steep cliffs and spires in the northeast, and smooth rounded slopes in the southwestern part, the line of demarcation being just south of the fork in the Oil Canyon streams.

By lower Miocene time, erosion had reduced the region to the above-described topography, and the Kinnick formation was deposited. Deposition appears to have occurred at a rapid rate -- the resulting beds are poorly stratified and in places no bedding is visible (see stratigraphy).

Following this period, folding occurred coincidentally with a gentle uplift on the southeast corner of the region. The folding produced dips in the Kinnick Formation up to 38°, with the axes trending northeast in the region immediately east of Sand Canyon, and trending north-northeast in the area to the south. The similarity of these directions to those of the thrust trace should be noted. This coincidence suggests strongly that the forces were from the same direction as those that produced the thrust (if we may assume for the moment that horizontal forces can cause both), although they were separated by a period of deposition. The main feature produced during this folding was a gentle syncline about a mile northwest of the junction of the three main canyons. The axis forms a sigmoid pattern trending northeast, and plunging in this direction at about 10°. A number of smaller fluctuations in the dip were caused during this period also. The basis for dating these folds at this time, instead of post-Bopesta, is the fact that the degree of deformation is markedly greater than any of that found in the Bopesta formation.

A second type of deformation that took place at this time, was a thrust fault of unknown displacement which was formed on the ridge that separates Oil and Horse Canyons. Evidence for this thrust of younger rocks over older rocks, consists mainly in the three features: 1) the angle of contact between the overlying Kinnick formation bedding and the formation contact, ranges from 0° to 16° -- almost certainly too high to be a normal angle of initial dip, even for torrentially-deposited materials, 2) the contact between the two formations was exposed in several places to show slickensides, and grooves up to two inches deep, both indicating movement toward, or from, N. 55° E.,* and 3) in the region immediately beneath the proposed fault surface, there was a very intense shattering of the rounded quartzitic boulders and cobbles in the Witnet formation,

* A large number of slickensides with similar directions were noticed in the eastern part of Oil Canyon, especially on the ridge that contains the east-west dashed fault that dips 75° toward the north, but isolated evidence of this kind was construed to be indicative only of the most recent movements, along the fault surfaces.

and this intense crushing was limited mainly to the zone (up to ten feet thick) immediately below the faulted contact. In view of the above evidence, the writer concluded that the contact was of a thrust nature of a very limited extent, and of unknown amount and direction of displacement.

A third type of deformation that took place in the period between the deposition of the Kinnick formation, and the Bopesta formation, was the formation of a number of small folds with axes trending north to northwest. These can be seen in the western half of the north boundary of the map, on the northeast side of Sand Canyon, and on the hill that separates the lower half of Oil and Horse Canyons. The change in dip of the minor thrust surface that is included in this trend of flexures would suggest that the folding was post-thrust, as any such marked curvature of the surface of thrust movement is difficult to visualize. This third deformation, however, could be of post-Bopesta age as well as in this period; no evidence was found that would eliminate either possibility. Generally these folds are of a gentle nature (usually dips of less than 15°), and plunge to the southward at 10° or less.

Thus, the sequence of events in this period would be: 1) folding of a fairly strong nature producing axes trending northeast, 2) minor thrusting from the northeast or southwest, and 3) further folding by forces from this direction, thus axes running northwest-southeast.

During this interim, a general degradation of the Kinnick formation on the eastern edge of the region was occurring. In one part of the easternmost sector of Oil Canyon, this process removed all of the Kinnick formation, thus exposing the granitic part of the section. In the rest of the immediate area, the Kinnick formation was reduced to tens or hundreds of feet in thickness. Although not included in the mapping project, the writer suspects that to the east of this point, the overlying Bopesta formation is resting directly on the granitic complex throughout most of its extent. To the west and north of the above mentioned sector, the thickness of remaining Kinnick probably became progressively greater, with the maximum thickness being found to the west of the basin in which the Bopesta was later deposited.

The location of the Bopesta basin of deposition is a matter of conjecture; it certainly included the region now retaining the formation, but its extent to the west of the present contact is indeterminable. In other words, the elevation of the Sand Canyon region may have been pre-Bopesta, thus forming a western topographic limit on the basin of sedimentation approximately where it is now seen, or the western edge may have been uplifted in post-Bopesta time, thus destroying all trace of the formation west of the present contact. The eastern limits certainly stretched far beyond the map project, as the greatest thicknesses of the formation are today found in that direction, Cache Peak being made up entirely of the Bopesta formation (Buwalda, oral communication).

After the deposition of the Bopesta formation in upper Miocene time, another period of deformation took place. This period was characterized by a large number of small strike-slip and dip-slip faults, generally in a northwest-southeast direction. Swarms of these are present along the northwest side of Cache Creek Canyon, and along the northwest side of Horse Canyon. Two or more may be seen offsetting the thrust fault trace along the south side of the Oil Canyon-Cache Creek Canyon junction. Most of the northwest-southeast faults found on the large scale Oil Canyon map are assumed to be part of this system, and a number of these can be seen to cut the Kinnick-Bopesta contact in this region, thus dating them as post-Bopesta. Possibly, one result of this large-scale horizontal movement, was the dislocation of the axis of the Sand Canyon syncline, shifting it to the northwest on its northeastern portion. The direction of the shift on the faults in Horse Canyon would tend to uphold this idea, but the magnitude of these alone is not nearly sufficient to produce the resulting deformation. Possibly additional faulting could have brought about the deflection of the axis, but the evidence exposed in the field is insufficient. The reason for placing all the faults displaying this trend in the same period of orogeny, is simply the consistent similarity of the direction, a feature that could be produced in a number of different ways, but more definite evidence is missing so the simplest solution is proposed.

Probably the broad synclinal flexure in the Bopesta of upper Horse Canyon was produced at this time, as well as the more sharply defined folds to the south of this structure. The similarity in trend between the Sand Canyon syncline, and the small scale syncline seen directly east of its terminus in Horse Canyon, would strongly suggest that a part of the broad folding of the Sand Canyon flexure took place post-Bopesta, rather than in the interlude between Kinnick and Bopesta time, as is here suggested. The major reason for assigning the larger feature to the earlier date, is the strong similarity in the strike of the steeply dipping Kinnick formation (up to 35°) to the axis of this fold. In general the deformation in the Bopesta is not so marked, and it can be seen in upper part of Oil Canyon that an angular unconformity does exist (see stratigraphy) proving deformation between Kinnick and Bopesta time. For these reasons, the "ancestor" of the present Sand Canyon syncline was probably produced in the interlude between the deposition of the Kinnick and the later deposition of the Bopesta formation. Proof beyond these reasons is lacking, and it should be emphasized that some of the component of dip found in the Kinnick formation structures must be delegated to the deformation in post-Bopesta time. The important thing to point out at this time, though, is the similarity in trend of structural features produced in both periods -- middle Miocene, and post-upper-Miocene.

After the period of strike-slip faulting and associated folds, a number of periods of faulting occurred. One of these produced the major vertical fault that is traced north 30° west across Oil Canyon, at the point of junction of the north and south forks of the stream; this fault eliminates the Bopesta formation from all regions to the west, and also separates the minor thrust fault on the ridge between Horse and Oil Canyons from any known contact to the east. The second major fault of this period is the strike-slip fault that depressed the main thrust fault from view to the northeast. This feature trends almost exactly east-west, and is itself truncated on the west by another fault of unknown age and extent. In all probability, this east-west fault is a result of the upthrowing of the mountain mass to the south along the Garlock Fault, and thus the main component of movement is in a vertical direction, although the slickensides on the slip-surface indicate horizontal movement as the most recent. A number of the other fractures shown on the large scale map of upper Oil Canyon probably belong in this period of the deformational chronology; however, the evidence is lacking for a definite assignment in time, so they must be regarded as unknown quantities. As far as can be determined by structural evidence, these faults are the most recent in the mapped region. No date can be assigned closer than post-Miocene, but in view of the known recent motion along the Garlock Fault in Quaternary time, some of the structures probably occurred in this period.

Deformational forces --

In the first period of orogeny when the major thrust was formed, the direction of motion appears to have been normal to the Garlock Fault. Usually, a thrust is thought to have been caused by forces that are chiefly horizontal, or in terms of the strain elipsoid: the minor and intermediate axes in the horizontal plane, and the major axis in the vertical plane (thus the major and intermediate forces in the horizontal plane, and the minor forces vertical). In this example, the major force would have been normal to the Garlock Fault.

Plutonic forces that caused movement in this direction could be any one of numerous types and directions. The feature that one knows as a thrust fault is only the surface manifestation of the plutonic forces, and do not necessarily reflect the direction of the original stress. What occurs on the surface, it would seem to the author, is also a function of the ease of relief from the confining forces; in other words, when a force is applied, in order for a fracture to occur, confining forces must be overcome, and these forces may consist of adjoining crust, or gravity. In all probability, the relative resistance to forces in one direction would not be identical with that in any other given direction, and the fault pattern that would ensue would be such as to take advantage of the <u>easier</u> of these directions of relief.

Folds in the crust of the earth can be produced without any increase in volume such as is associated with faults. Any change in volume will only come about, it would seem to the author, by a compaction or recrystallization of the minerals involved, and these processes will only result in smaller volumes. Thus, folds are produced in a region that cannot absorb the tectonic forces by compaction and recrystallization alone, nor can entirely transmit these stresses to sections of crust that are more easily deformed than itself. Conversely, if a region is folded, it implies that the rocks involved were subjected to irresistible geologic forces transmitted from more resistant sections of crust, or that these other sections of crust could not deform sufficiently to absorb the entire stress placed upon them.

The factors that determine whether folding or faulting will result from the application of a force are: 1) The competence of the rocks involved. By this we mean the relative "susceptibility of different rocks to deformation by flowage" (Lahee 1941, p. 72); 2) the direction and intensity of force application; 3) the rate at which the forces are applied; 4) the areal extent of the deformable rocks; and 5) the ease of relief in the various directions.

For folding to take place in preference to faulting, the competence of the beds must be low (incompetent), the areal extent of the beds must be extensive enough for the stresses to be distributed over sufficiently large amounts of deformable material, confining pressures normal to the direction of stress must be less than the pressure actively produced by increasing the volume in that direction, and, most important, the rate of application of forces must be slow enough to allow the time consuming processes of plastic deformation to occur.

If these conditions are not met, and the rocks are not capable of transmitting the stress to another region, then, in all likelihood, faulting will take place. Let us now analyze the conditions that will determine the type of fracture that results, keeping in mind that the direction of force-application and the direction of easiest relief are major factors in these considerations.

By this reasoning, a normal fault would be the result of stresses that could be diminished most easily by transmitting the pressure horizontally toward the least resistant adjacent block, and vertically, by overcoming the force of gravity of the block being moved. The strike of the fault surface would be normal to the direction of easiest horizontal relief; the angle of dip would be a function of the ratio between the ease of the two directions of relief. Thus, if gravity were easier to overcome than horizontal confining pressures, the fault surfaces would be high angle, and if the horizontal direction afforded an easier path or relief, low angle faults would result. The fact that the latter seldom occurs would thus indicate that such a situation rarely was found.

By this analysis, a very high angle or vertical fault would indicate that the vertical component -- gravity -- was the easier of the several directions of relief by a large factor.

A reverse fault would suggest that the confining pressures on a given block that was undergoing pressure from horizontal or diagonal forces, and that the easiest path of relief was vertical -- the difference in ease being enough to compensate for the added resistance from friction.

A strike-slip fault could be explained by assuming horizontal forces that encountered the least resistance diagonal to the direction of force application, this resistance being less than the confining force of gravity or the directly opposing force.

A thrust fault, by this analysis, would be the result of horizontal forces that obtained relief most easily by horizontal motion, in preference to overcoming the confining forces of gravity on the block that eventually becomes the thrust plate. For this situation to occur, the horizontal resistance to pressure must be very low, and the horizontal tectonic forces must be very large. If horizontal resistance is too great, then the result will be a reverse fault, in spite of the added resistance of friction due to the slippage plane not being parallel to the maximum stress vector.

Thus, when analyzing the forces that have brought about a fault or series of faults, we should not forget that a given direction of force can produce more than one type of fault, and a given fault type can be related to more than one source of forces -- the direction of easiest relief being a second important factor that must be taken into account.

The above analysis does not in any way mean to suggest that the concepts of sources of pressure in regard to faults should be disregarded; it means, solely, that the factor of "the directions of least resistance" should be included in any analysis of the problem as one of the many causes that brings about the observed end result.

If we analyze the "direction of forces" <u>and</u> "directions of least resistance" as applied to the faulting of the Cache Creek Region, we arrive at the following results:

In the earliest period of deformation, that of the major thrust fault, it would appear that the direction of forces was toward the northwest, and the direction of least resistance was also in that direction.

The forces could have been derived from the Garlock Fault by some sort of a squeezing action that is not well understood, but similar thrusts are reported at a number of places along the San Andreas Fault -- also a strike-slip fracture. The opposing resistance probably consisted of the basin containing the Witnet formation, -- a topographic basin, as well as a structural basin that may have originated as a product of these forces in their earlier stages. These sediments would have offered little resistance to the thrust as compared to that offered by the crystalline rocks on the periphery of the basin. Also if the region was a topographic basin, escape to the surface could have been attained by this horizontal route more easily than by any vertical movement. Thus this period appears to have been characterized by intense horizontal pressures acting toward a basin containing the Witnet formation.

The second period of orogeny (after the deposition of the Kinnick formation and before the Bopesta), can be divided into three divisions: 1) fairly strong folding, 2) minor thrusting from the northeast, and 3) gentle folding.

In the initial period, the resultant folds trended northeast and changed to a more north-northeasterly direction in the southwest. Since the fold produced was a broad feature, the dip of the axial surface cannot be accurately ascertained, but apparently it is essentially vertical. Forces causing this feature, thus, by the method of analysis described above, would have been from the southeast and from the east-southeast in the southwest corner of the mapped area. These forces also would appear to have been essentially horizontal and the direction of relief vertical (producing the vertical axial surface), and were applied at a rate slow enough to be absorbed, at least in part, by plastic deformation. Therefore, in this period, the deformational forces apparently came from the same direction as the thrust fault forces, but were applied with less intensity and rapidity.

In the second type of deformation found in this period, the minor thrust surface found between Horse and Oil Canyons, the same method of analysis can be applied as to the main thrust surface. By this technique the direction of force application would be from the northeast or southwest -- about N 55° E or S 55° W.* This direction is almost exactly parallel to the Garlock Fault in this region, so, the forces would probably be the same as those that cause movement of this major feature, but on a very much smaller scale. Since the overall direction of motion of the Garlock Fault is for the northwest block (which includes this map area) to move southwest, this suggests a component of force from the northeast and this stress could have caused the minor thrust feature described in this territory. The direction of easiest relief cannot be analyzed because of the paucity of information about the depth of the thrust plate at time of movement, and the topography in the local region.

The later period of folding that produced axes normal to the direction of this minor thrusting, was very localized and correlation between the features is debatable. In the thrust plate, folding has produced dips up to 35°, although in the northern part of the region, the

* The evidence for the direction of motion is based solely on the consistent direction of the slickensides associated with the feature as well as in the vicinity. This is not a conclusive type of evidence, but when coupled with the axes of the later fold produced soon afterward in the thrust plate, it seems to be strongly indicative.

dips are somewhat less. All of the folds produced appear to plunge toward the southeast, but again, the evidence is incomplete. It would appear that these features were produced by a later version of the small-thrust-producing forces, perhaps reduced in intensity and rate of application, so that the stresses could be absorbed by plastic deformation in preference to fracturing. The localized nature of these features may be attributable to some kind of basement-control, or differential competence of the rocks.

In the period of folding that followed the deposition of the Bopesta formation, the axes trend in the same direction as those produced in the strongest flexures found in the Kinnick formation -- northeast-- and plunging in this direction at about 5° to 10°. Dips produced range as high as 53° (a half mile east of the cabin in Horse Canyon) but generally average approximately 10°. These folds can be analyzed the same as those produced earlier in this same direction, viz. caused by forces normal to the Garlock Fault, essentially horizontal, and applied at a rate slow enough to be absorbed by the processes of plastic flowage.

Deformation following this period of flexure is too complex to be allocated to any simple direction of force application or direction of easiest relief. The general nature suggests a general upward movement of the entire southeast corner of the mapped area as indicated by folding and a great deal of small scale brecciation. Owing to this characteristic, the deformation of this region is difficult to map and successfully to separate the major features from the minor. The large scale map of upper Oil Canyon portrays much of this type of structure; consequently no definite sequence can be assigned to most of the faulting, and it is assumed to be a result of this most recent orogenic trend. In view of the elevation of the mountains to the southeast, and the suggestion of high-angle fault scarps found on the opposite side of the range, it is probable that the forces causing this most recent deformation are generally vertical, and the easiest direction of relief from these stresses is against gravity or also vertical; any diminution of stress in a horizontal direction probably would involve opposition from a bulwark of crystalline rocks of the granitic Sierra (?) series.

Summary --

In conclusion, the sequence of force applications that can be deduced from the present fault pattern is as follows:

1) In pre-lower-Miocene time (and post-Nevadan?) there was a strong thrust-producing force normal to the feature we now know as the Garlock Fault.

2) In middle-Miocene time, forces emanated from the same direction as the earlier ones, but with less intensity, and thus produced folding parallel to the Garlock; also in this time forces were applied parallel to the Garlock Fault -- producing thrusting on a minor scale -- and this was followed by minor folding -- a sequence that suggests the most intense application at the beginning of the period, and later diminution.

3) In post Miocene time, forces of much less intensity normal to the causative fault caused broad folds and a number of minor faults normal to the flexures; later (probably in Quaternary time), vertical forces on the north side of the Garlock Fault forced a general uplift of the range to the southeast of the map area, which was expressed as intense fracturing within the map region.

If the major thrust fault can be attributed directly to activity along the Garlock Fault (and this hypothesis seems valid to the author) this means that the movement on this zone dates back at least to lower Miocene time, and possibly earlier, and activity, though apparently less intense, has continued to the present time. This is the most important point, in the opinion of the present writer, to be revealed in the structure of the Cache Creek Region.

GEOMORPHOLOGY

Regional --

One of the most perplexing problems in the Tehachapi Valley Region is how to explain the origin, at this elevation, of the four connected valleys. Tehachapi Valley lies at approximately 4,000 feet above sea level, and Brite Valley, the east side of which drains into Tehachapi Valley, lies at 4,300 feet. The west side of Brite Valley drains into Cummings Valley at an elevation of about 3,800 feet and the latter drains directly into the San Joaquin Valley. To the northwest of Cummings Valley lies Bear Valley at 4,100 feet, and this too drains directly into the San Joaquin Valley, at an elevation of about 500 feet above sea level.

In 1906, Lawson (Lawson, 1906) published a paper on the geomorphogeny of the region. The interpretations presented in the present paper are based upon the fault pattern described in Lawson's section about structure.* If we can accept, for the moment, these faults, the next problem would be the dating of the movements along these zones. Lawson does not delve into the problem extensively from the point of view of structural evidence. Instead, he regards them in part, if not all, as Quaternary, and presents geomorphic data as the substantiating evidence.

Since only one day was spent by the present author in this broader area, he is not in a position to comment authoritatively on the problem. However, it would appear that this pattern is correct in regard to the location of some of the main faults; the question in the mind of the author concerns the time of dislocation along these fractures. The two

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* See fig. 13 for the location of these faults.

hypotheses are: 1) that the faults are recent and were instrumental in the actual formation of the valleys in Qu ternary time, and 2) that the escarpments are of lower or middle Tertiary age, and that they caused basins of deposition to form. These basins were then filled with soft sediments which preserved the fault evidence, and in recent time, these softer sediments were excavated and removed by erosion, exposing the Tertiary surface and the features that are now interpreted as fault scarps of "recent age."

If the first suggestion were the correct one, the problem immediately arises: by what paths did the detritus escape from the basins? The present drainage of the western half of Brite Valley, all of Cummings Valley, and Bear Valley, is through a series of narrow gorges, the lips of which are well above the level of the lowermost alluvium. This rules out the excavation of the bedrock by present drainage. A second possibility would be that they drained into Tehachapi Valley and subsequently into Tehachapi Creek. The major objection to this reasoning is that the crystalline-rock ridge that connects Bear Valley and Cummings Valley, is some hundreds of feet higher than the alluvium in either, and this too would prevent the removal of bedrock down to the level of the basal alluvium. The path of escape for the debris from Cummings Valley into Brite Valley would have the same drawback. The material from Brite Valley could have escaped by either route.

Thus, the formation of the valleys without any movement on some faults, or folds, would seem almost impossible. However, the fact that these valleys exist at all -- that is, that they are anything more than normal mountain topography -- is a problem. Why broad open valleys should be present at this elevation, situated less than twenty miles from the San Joaquin Valley at 500 feet, is still not answered by proving the presence of faults alone. There must be some other important factor that controlled their formation.

For this reason, let us examine the second hypothesis regarding the age of the faults (i.e., in lower or middle Tertiary): At that time, the relative elevation of the rocks now exposed was probably much different (in view of the major movement that has occurred along the east face of the Sierra Nevada, as well as the deformation in Miocene and Pliocene rocks that are now exposed in this sector of California). At that time, there could have been formed valleys by the normal processes that occur when the region is close to local base level. These valleys then could have been filled by sediments -- probably coarse to medium grain continental deposits similar to those now being deposited in the San Joaquin Valley or the Mojave Desert. In upper Tertiary or Quaternary time, these were uplifted, along with the entire region, to the present elevation. Once at the current elevation, the softer sedimentary rocks would be more easily removed by erosion than the crystalline rocks beneath, and the same shaped valleys that were present in Tertiary time would be re-formed.

Once again, though, the objections that were raised in the first hypothesis must be answered (i.e., the escape route of the eroded detritus). To do this, a fault still seems to the author the best solution, and the location of the fault would appear to be the same as that which originally controlled the northeast margin of the valley systems. The reason for this suggestion is the similar relationship of the three valleys -- Bear, Cummings, and Brite -- to the feature that is now being interpreted as a fault scarp; the open valleys all lie to the southwest of this feature, and if the theory of the entombing Tertiary sediments were true, then the juxtaposition of all three features is strong circumstantial evidence for a correlation between these sediments and a fault scarp along the border.

In order to explain the removal of the debris in recent time, the material would have to escape before a recurrent movement along the zone of weakness moved the northeast block upward, thus sealing off the escape of the Tertiary sediments, and causing alluviation as is occurring at present. The present paths of drainage would be caused simply by the headward erosion of the steep streams, possibly aided by an overflow from the enclosed basins.

Affirmative evidence for this hypothesis is apparently not known. To the writer's knowledge, there are no patches of Tertiary sediments on the surrounding crystalline rim (Buwalda, oral communication), but this is only a lack of positive evidence, as opposed to negative evidence that would disprove it. Much more work must be done in the region to prove the mode of formation of these valleys. As was stated above, the ideas stated in the present paper are the result of only one day of field work in the region, and should be treated as such.

Local --

Within the Cache Creek area, there is little opportunity for geomorphic analysis. A few features should be mentioned, however.

In the southeast quarter of the small scale map, the top of the mountains formed by the overthrust granitic plate, appears to be made up of a number of sub-level surfaces. Although these are not perfectly flat, they do stand in marked contrast to the sides of the range which dip almost universally at 32° (the angle of repose of the fine weathered granitic rock fragments). In several places, small patches of Kinnick formation were found on the level surface in depositional contact. Also a few miles to the east beyond the mapped region, the Kinnick formation makes a cap-rock of the range and the lower contact has the same degree of topographic relief as the granitic summits to the west. This evidence, although inconclusive, suggests that these surfaces are probably exhumed remnants of the lower Miocene surface upon which the Kinnick formation was deposited.

In the northeast corner of the region -- in the uppermost parts of Cache Creek -- there is a topographic "amphitheater." This feature is the result of the soft nature of the Bopesta formation, and it has been excavated via the channel that now contains Cache Creek (Horse Canyon). Since the Kinnick formation is relatively resistant, the part of the channel cut within this series is more confined. It should be pointed out that the amphitheater is a structural as well as topographic feature, and thus is a fairly reliable indicator of the extent of the Bopesta Formation, as it overlies the Kinnick formation, as well as the broad plunging syncline that is formed within it.

Along the south side of Oil Canyon, near the fork in the stream, there are two small terrace deposits. Neither of these is more than twenty feet above the present stream level, but they are of interest because they indicate a lateral shifting of the stream from the south to the north. At present, the Witnet remnants are seen as knobs that project above the terrace, or at the same level, and stand between the terrace deposits and the present stream channel. This shift was not a simple meandering process, but involved the cutting of a new channel to the north through solid Witnet formation. This suggests a tilting toward the north as well as a recent uplift.

Although no accurate survey was conducted of the stream gradients, the following estimates of the alluvium gradients are of the correct order of magnitude and can be used for comparison: in Sand Canyon, the alluvium has attained a gradient of about 60 feet per mile, (or about $.65^\circ$). The fill in the narrow part of Horse Canyon is at approximately 100 feet per mile (or about 1.1°). The stream in Oil Canyon, just west of the fork, is running on a slope of about 215 feet per mile (or about 2.3°). Below the point of juncture of the three streams, the grade is virtually the same as the Sand Canyon alluvium -- 60 feet per mile. The significance of the progressively greater grade toward the southeast is beyond the scope of this paper; it probably is, in part, a result of the more resistant nature of the rocks in this direction (the lower Kinnick and Witnet formations, as opposed to those in the northwestern quadrant, the upper Kinnick and the Bopesta formations), as well as a function of the relative areal extent of the respective drainage areas (see fig. 17). Of even more importance, possibly, is the fact that the range of mountains in the southeast is currently being uplifted along the Garlock fault -- the uplift being sufficiently local to cause the difference within the map area (see Structure).

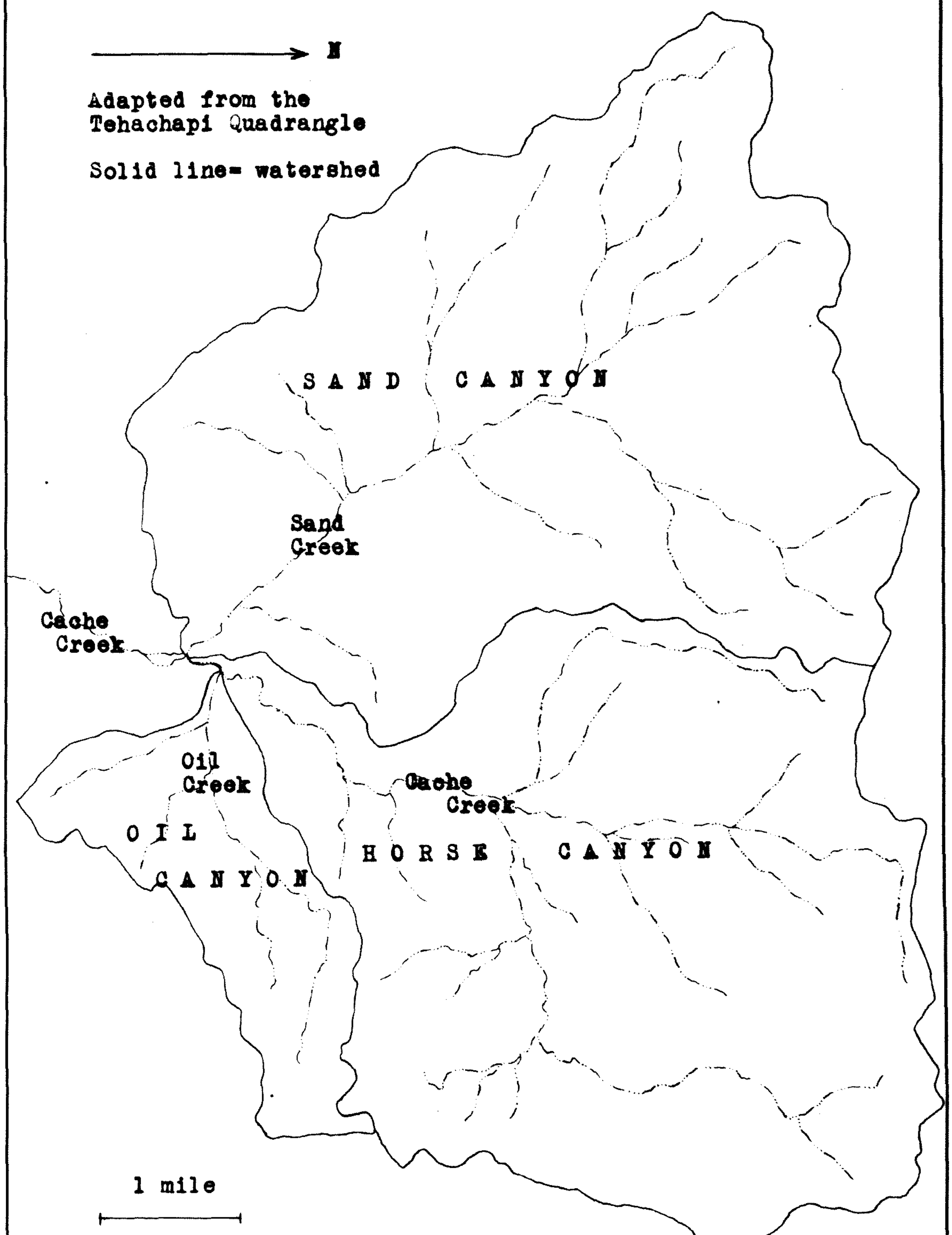

Fig.17
DRAINAGE MAP OF THE UPPER CACHE CREEK REGION

ECONOMIC CONSIDERATIONS

At present, the two main features of economic consequence in the upper Cache Creek region are: 1) the quarry rock, and 2) the water resources.

Quarry rock

The first of these is being carried on in two locations. A minor amount of rock is being quarried in the northern part of the region for use as building stones. The material is a green to blue-green tuffaceous sandstone that is found in local lenses. Due to this occurrence, the main difficulty in finding stone suitable for quarrying is the lack of easily-cleaved stone in lenses that are sufficiently large to allow the operation to be economically feasible. Also a road must be developed to the site, and the stone must be available without undue engineering problems or excessive dynamite. All of the green rock is in the Kinnick and the conditions of deposition of this formation, (i.e., generally rapid and unsorted) were not conducive to the formation of well-bedded lacustrine sandstones that would give good cleavage characteristics. For this reason, building stone removal has to be done on a local scale, and any search for new sources must be almost entirely "hit or miss."

The second use of this rock obviates this shortcoming. At the mouth of Horse Canyon, the quarry is in a bed of the light green volcanic tuff (Kinnick) devoid of any bedding characteristics, and the quarried rock is being ground to a uniform size and is being sold for a roof and shingle surfacing material. Owing to the low standards necessary, quarryable rock is virtually unlimited and the project can be, and is, close to an existing road. For these reasons, the major limiting factors of this operation are the local-preparation expenses and the transportation-to-market costs.

Water

In Sand Canyon and Cache Creek Canyon, a total of 28 wells have been drilled, and of these, logs were kept for 15. These logs show a great deal of variation in sediment types present in the alluvium, -- a large proportion of these being clays. Probably this last factor is the cause of the rapid decrease in water level when pumping is started. In this respect, the wells in Sand Canyon (i.e., S-7, S-8, S19a, S11, S12, and S13) are much superior to those to the south; draw-down between April and October was too small to be measured. In the Cache Creek Canyon region, the wells are deeper as a rule, and the depth-of-pumping increases rapidly as the irrigation season progresses.

At the present time, the wells appear to replenish their entire supply from year to year, according to the short term data that have been kept by the local office of the U. S. Soil Conservation Service. This means that no immediate problem will be encountered in this respect; however, the amount of water needed is increasing annually and in the future, the rate of increment may not be sufficient to maintain the present water-table level.

Below are the available data about the water-table levels, the depth to bedrock, and the available well logs. Also a map has been included to show the location of the wells mentioned.

Water levels --

Well number	April 18, 1950	July 21, 1950	October 11, 1950
S7	19.5 feet down	20.0 feet down	19.5 feet down
S9	38.8	39.0	39.3
S11	24.0	--	28.7
S15a	59.0	82.0	--
S15b	56.5	81.5	--
S16	22.9	--	--
S17	9.2	33.5	--
S18	--	--	72.0
S20	--	--	74.0

Depth to bedrock --

Well number	Feet down to rock
S10a	66
S11	72
S12	94
S13	more than 60
S14	102
S15c	98
S15a	92
S15	more than 185
S16	approximately 250
S17a	115
S20	more than 140

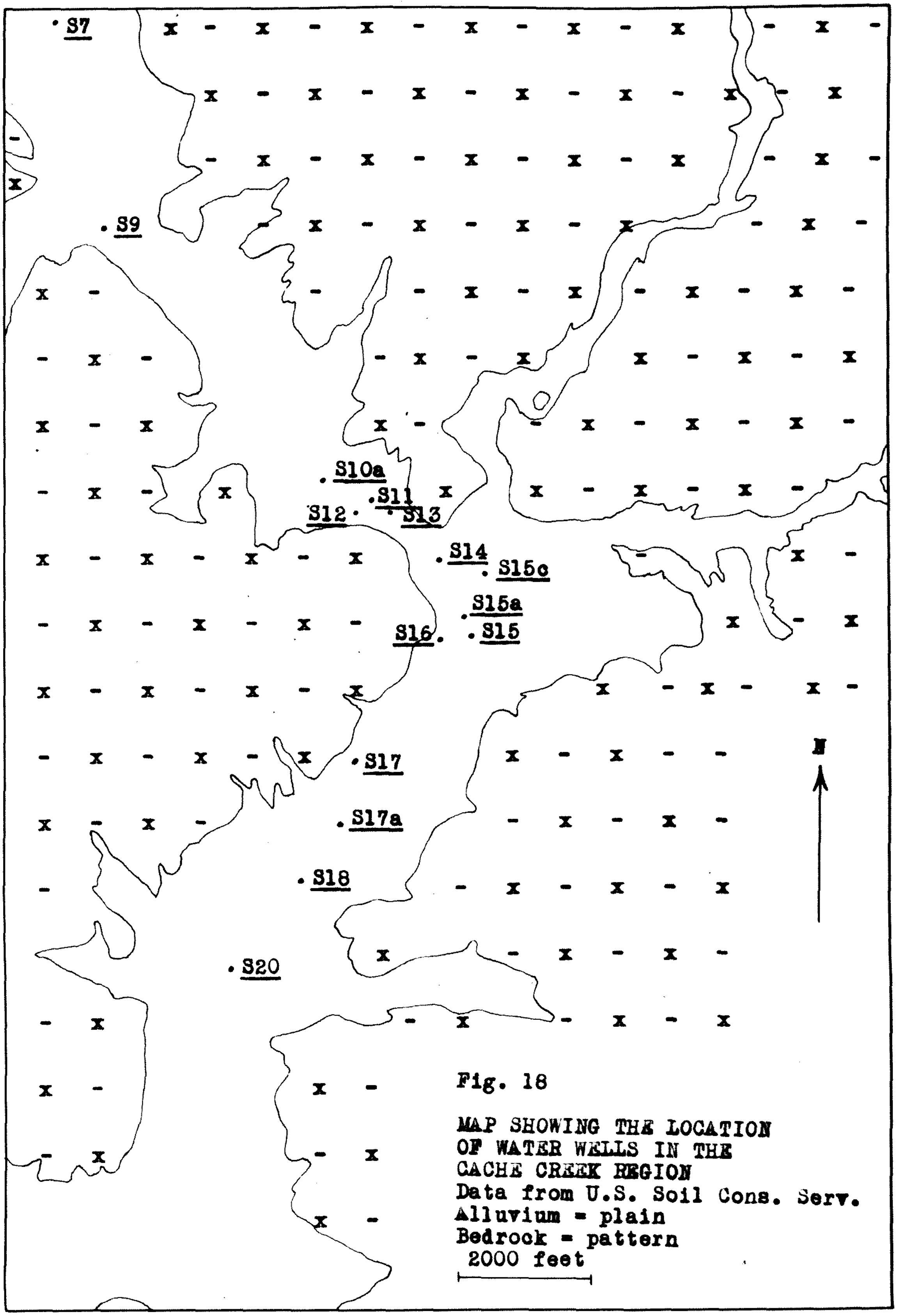

Fig. 18

MAP SHOWING THE LOCATION
OF WATER WELLS IN THE
CACHE CREEK REGION
Data from U.S. Soil Cons. Serv.
Alluvium = plain
Bedrock = pattern
2000 feet

Prospects for oil

Within the territory mapped, all of the rock exposed is intrusive or of continental derivation. The pre-Tertiary series of rocks are of two types: the pre-intrusive series of limestones and shales which have been metamorphosed to marbles and schists, and the intrusive granitic rocks, tentatively assigned to the Sierra Batholith period. The lowermost ertiary formation (Witnet formation) is a coarse arkosic conglomeratic sandstone, and the character of the bedding suggests rapid disposition by fluviatile or lacustrine mediums. Overlying this is the Kinnick formation. This too is almost certainly of continental origin as is indicated by the massive bedding, lenticularity of a given rock type, and most important, the presence of vertebrate fossils and land-plant remains. The uppermost formation, the Bopesta Formation, also contains abundant vertebrate fossils that indicate a continental plains type of deposition.

In the light of the rock types exposed within the region, it would appear to this author that the possibilities for oil production are virtually non-existent within the mapped territory as well as the entire Tehachapi Valley Region.

Other economic possibilities

Interspersed in the Kinnick formation are a great many lenses of volcanic lava. Much of this is vesicular in nature and in these regions agate and opal can be found in a great number of colors and of varying quality. None of the specimens seen by the author was of "commercial" grade, although the quality is sufficiently good to make the locality of interest to a great number of amateur mineralogists and collectors. The main collecting grounds are in the upper part of Horse Canyon, but the writer found some of the best quality opal about a half mile east of the Phillips Ranch Fauna locality. Besides this, several individual beds in the Kinnick formation have been silicified to the point of being almost pure chalcedony with a number of colored impurities irregularly mixed in, thus giving it a mottled appearance. These could be of commercial quality for use in polished-rock ashtrays and similar items, but the locations known are too far from any roads to make the project feasible.

Also in the northern part of the territory mapped, there are reputed to be some deposits of perlite and bentonite. No attempt was made to investigate these localities as to their true worth and extent.

No metallic ores of any kind are known to exist within the district.

FOOTNOTES

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