THE GEOLOGY OF THE PINYON PEAK AREA, EAST TINTIC MTS., UTAH

Thesis by

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TABLE OF CONTENTS

TABLE OF CONTENTS (Contd)

Abstract

In G. F. Loughlin's report of 1919 on the Geology of the Tintic mining district,[1/] a new formation, the Pinyon Peak limestone, was described

1/ Lindgren, Waldemar, and Loughlin, G. F., Geology and Ore Deposits of the Tintic Mining District, Utah: U. S. Geological Survey Prof. Paper 107, 1919.

and tentatively assigned to Upper (?) Devonian age. This outcrop of limestone on Pinyon Peak is the only known occurrence of Devonian rocks in the Tintic mining district. The limited presence of the Pinyon Peak limestone was offered by Loughlin as evidence for the dating of a Lower Mississippian unconformity in the district....to be correlated with a suspected Lower Mississippian unconformity in other parts of Utah. Loughlin mapped the Pinyon Peak limestone as occurring below the Gardner formation (L. Miss.) and below the Victoria quartzite (L. Miss.). Loughlin found little more than five or ten feet of the Victoria quartzite exposed on Pinyon Peak. Recent field work in the Pinyon Peak locality has disclosed that a two-hundred-foot thickness of Victoria quartzite is present on Pinyon Peak and that the Pinyon Peak limestone occurs above this formation. Several days were spent in the field in search of fossil remains in the Pinyon Peak limestone. A few poorly preserved fragments were found but nothing of diagnostic value. Attempts to locate Loughlin's original fossils have been unsuccessful.

The author suggests, on the basis of evidence set forth in this paper, that the Pinyon Peak limestone is a limestone equivalent to a dolomitized member of the Gardner formation; that the Pinyon Peak limestone

should be relegated to the status of a member of the Gardner formation; and that its age is still much in doubt.

Introduction

Several reports on the geology and ore deposits of the Tintic mining district have been published. The Tower and Smith report of 1898[2/]

2/ Tower, G. W., Jr., and Smith, G. O., Geology and Mining Industry of the Tintic District, Utah: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3. pp. 601-767, 1898.

represented the first comprehensive study of the geology and ore deposits of this important mining district. Later developments in the district prompted a resurvey of the area, which resulted in the 1919 report of Lindgren and Loughlin.[3/] G. W. Crane has published at least two papers on

3/ Lindgren, Waldemar, and Loughlin, G. F. op. cit.

the district.[4/]

4/ Crane, G. W., Geology of the Ore Deposits of the Tintic Mining District: A.I.M.E. Tr., vol. 54, pp. 342-355, 1917.
and
Crane, G. W., XVI International Geol. Cong., Guidebook 17, Excursion C-1, The Salt Lake Region, pp. 105-107, 1933.

In addition to these reports, several master and doctorate theses, filed at Stanford University and the University of Utah, have dealt with various aspects of the ore deposits and geology of the region. As far as can be determined, however, no detailed report since Loughlin's has been published on the stratigraphy and geology of the Pinyon Peak locality. This lack of interest in the Pinyon Peak area undoubtedly can be attributed to the absence of commercial ore deposits in that vicinity.

The author became interested in the Pinyon Peak area through the efforts of W. P. Fuller, Jr. (M. S. California Institute of Technology 1942; geologist for the Anaconda Copper Company at the North Lily Mine, Eureka, Utah.) Fuller expressed some doubt concerning Loughlin's interpretation of the stratigraphic section exposed at Pinyon Peak...particularly the question of the Pinyon Peak limestone. Upon his suggestion and with the approval of the Division of the Geological Sciences at the California Institute of Technology, the author undertook field work in June and September of 1947 to study the Pinyon Peak locality.

Aerial photographs, approximate scale: 1" equals 800', were used as a base map in the field. An advance sheet of a new U. S. Geological Survey topographic map of a portion of the East Tintic Mountains, scale: 1" equals 800', was borrowed in September 1947 from Dr. T. S. Lovering of the U. S. Geological Survey and copies of the Pinyon Peak area were made. A modified traverse method of mapping was employed with point locations established by estimation and by resection with the Brunton compass. Emphasis was placed on stratigraphic section studies and fossil collecting. Field investigation was limited to one week in June and two weeks in September. A collection of fossiliferous-looking material was made at the time to be studied in detail later in the laboratory.

Assistance from the owners of the Chief Consolidated Mine in facilitating the research project is gratefully acknowledged. Special thanks are due to W. P. Fuller, Jr. for his interest, suggestions, and discussions in the field. Dr. Lovering and his assistant, H. T. Morris, are also to be thanked for valuable suggestions, field discussions, and for their kindness in permitting the author to use their drafting facilities.

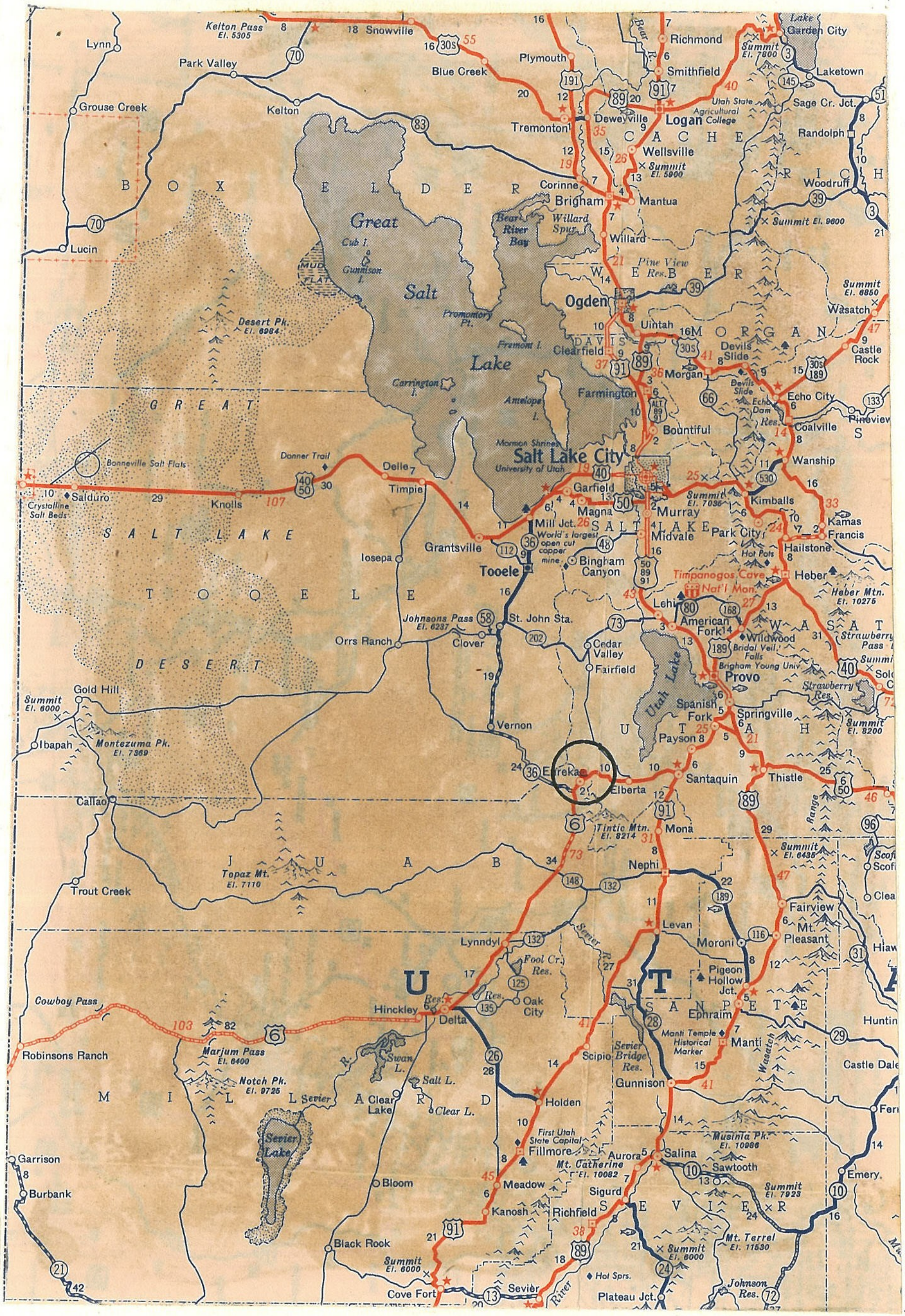


Figure 2 - Location of the Pinyon Peak area

Geography

Pinyon Peak (see Photo No. 1) is one of the higher peaks located in the East Tintic Mountains...the easternmost range of the block-faulted mountains in the Basin and Range Province. The East Tintic Mountains trend north-south and are approximately sixty miles south of Salt Lake City and twenty miles west of the southern part of the Wasatch Mountains. Pinyon Peak is approximately one mile east of the meridian of longitude 112 05' and one-half mile south of the 40th parallel of latitude.

The area studied is a tilted block of Paleozoic limestones, dolomites, and quartzites bounded on the southeast by a large normal fualt, on the west by the Tertiary Packard rhyolite and alluvium, and on the north and northeast by the Opohonga limestone (L. Ord.). Pinyon Peak covers approximately one and one-half square miles and rises to a height of 7702 feet above sea level. The maximum relief in the area mapped is approximately 1800 feet. Except for several fifty to one hundred-foot cliffs, the slope nowhere exceeds forty degrees. Three long spurs with a gentler gradient serve as suitable paths of ascent and one, the east spur (see photo No. 2.), provided ideal exposures for a detailed section study.

The vegetation in the area is characteristic of a high, arid region. The slopes, where covered at all, have a thin mantle of low sagebrush (particularly the lower slopes) with occasional spotty occurrence or small concentrations of stunted and gnarled trees...e.g. piñon (pine), mountain mahogany, and juniper. The higher slopes are fairly well tree-covered.

Rock exposures are particularly good on the east spur and the south-east slope of the mountain. The west slope has poor exposures due to an almost complete mantle of talus.

Limestone (because of its massiveness) is the most resistant to weathering and tends to form most of the cliffs. One or two prominent cliffs in the Bluebell dolomite (L. to Upper Ord.), however, are made up of a particularly massive dolomite. The fractured and thin-bedded dolomites, quartzites, and limestones are rapidly broken down by mechanical weathering to form talus slopes. The rock exposures are, on the whole, very good and permit fairly detailed mapping.

Generalized Columnar Section
of the
Rocks Cropping Out in the Pinyon Peak Area

Scale 1" = 200'

Section measured on
east ridge of Pinyon Peak

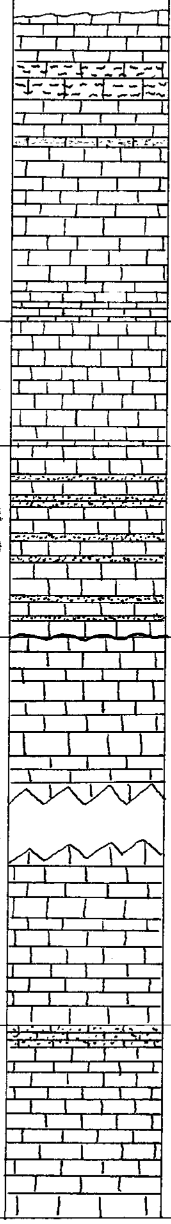
Age	Name	Columnar Section	Thickness in feet	Character
Lower Miss.	Gardner Form.		375' (exposed at top of Pinyon Peak)	Fine to medium grained limestones and dolomites. Color ranges from dark bluish-gray to pinkish-white. Fossil fragments are abundant. Notable is a fifty foot cherty dolomite member. Bedding is well-developed.
U. Dev.- L. Miss. (?)	Pinyon Peak Ls. Member		130'	Very fine grained, well-bedded, gray-blue limestone which weathers yellowish-gray. (Lowermost member of the Gardner Fm.)
Dev.- Miss. (?)	Victoria Quartzite		200'	Reddish-brown, medium grained quartzites (1'-2' thick) interbedded with ashy-gray, fine to medium grained dolomites (2'-5' thick). Lowest member of this formation is a speckled dolomite.
Lower to Upper Ordovician	Bluebell Dolomite		700'	Light gray-blue to dark blue, fine to medium grained dolomite. Bedding distinct, thick-bedded in part (6'-8') with two good cliff-forming members. An abundance of white, calcitic inclusions give this formation a distinctive appearance.
Lower Ordovician	Opahonga Ls.		section not measured	Medium blue, fine grained, flaky, argillaceous limestone weathering yellowish-brown to reddish brown. Bedding is well-developed. Intraformational conglomerates are notable.

Figure 3.

Stratigraphy

Since the primary aim of the field investigation at Pinyon Peak was to examine the Pinyon Peak limestone and determine its age and relationship to the other rocks in the section, much of the time in the field was devoted to stratigraphic study.

Figure 1 is designed to supplement and clarify the discussion of the stratigraphy of the area.

Figure 1 attempts a correlation of the nomenclature used in three important papers on the Tintic district and includes the results of the section study made at Pinyon Peak by the writer. Differences in thickness figures for the various formations are probably due to: a) the factor of personal error, b) non-recognition of repeated strata due to faulting, and c) different interpretation as to the location of formation boundaries.

The author has based his delineation of formation boundaries on the description of G. W. Crane. Crane's detailed description of the Eureka Peak stratigraphic section was made available to the author by W. P. Fuller, Jr.

Description of the Pinyon Peak Stratigraphic Section: Opohonga Limestone (L. Ord.)

The Opohonga limestone is the lowest horizon studied and mapped by the author. It is, on fresh surface, a medium-blue, fine-grained, flaky, argillaceous limestone. The weathered surface gives a striped to mosaic appearance with a yellowish-brown to pinkish color dominant. Lenticular nodules of limestone (several inches long) are characteristic of some beds. Also notable is the frequent occurrence of intraformational conglomerates. The upper fifty feet of this formation have a distinct sandy texture and are fairly non-resistant to weathering. Immediately below, however, is a distinct and persistent cliff-former some twenty-five to fifty feet thick. The thickness of the Opohonga limestone was not measured since it was arbitrarily chosen as the lower stratigraphic limit of mapping. Outcrops are good on the east spur, north slope and northwest spur. The upper limit of the Opohonga was mapped at the limestone (Opohonga)-dolomite (Bluebell) contact. Age determination is based on fossil descriptions in Loughlin's report. The intraformational conglomerate and argillaceous and sandy nature of the rock suggest that it was a near-shore deposit in a shallow sea in which the water level fluctuated slightly or in which epeirogenic movements raised and lowered the level of the shore line.

Bluebell Dolomite (L. to U. Ord.)

The Bluebell dolomite has good exposures on the east spur, north slope, and northwest spur. It is marked by two massive cliff-forming members which are particularly persistent. The less massive, thinly bedded, fractured members are much less resistant to erosion and form talus slopes. Seven hundred feet of the Bluebell dolomite was measured on the east spur. The formation is made up of alternating light gray-blue and dark gray-blue dolomite members. The beds are generally fine to medium grained and characteristically contain many vermicular calcite inclusions which give the bed a distinctive appearance. Bedding is well developed, the beds ranging in thickness from six inches or less to six to eight feet (in the case of the thick-bedded cliff-formers). Age determinations are based on Loughlin's investigations. The sediments going to make up the Bluebell dolomite were probably laid down under fairly quiet marine conditions.

<u>Victoria Quartzite</u> (Dev.-Miss.?)

The Victoria Quartzite is made up of approximately two hundred feet of ash-gray, fine to medium grained, fairly thick, well-bedded dolomites with a number of prominent quartzite beds ranging from one to two feet in thickness. The quartzites are often calcareous, and they are medium-grained, and weather brown to reddish-brown. At least ten well-defined quartzite beds within the Victoria were noted on Pinyon Peak with others possibly obscured by talus. The Victoria, as a whole, is not very resistant to weathering, the outcrops being poor everywhere except on the east spur. Here, though forming a saddle in the ridge, the formation is almost completely exposed. The base of this formation was mapped at a speckled dolomite horizon (the same horizon is used as the base of the Victoria in the Eureka Peak section). Loughlin, who found no fossils, dated the Victoria at the base of the Mississippian on the evidence of his Lower Mississippian unconformity. He considered the Victoria quartzite to be the basal member of the formations stratigraphically above the unconformity. No angular discordance was noted between the Victoria and the underlying Bluebell dolomite.

<u>Pinyon Peak Limestone</u> (Upper? Devonian) ?

Approximately one hundred and thirty feet of the Pinyon Peak limestone crops out on the east spur of Pinyon Peak. On the east spur, as a cliff-former (see photo No. 3), the rock is very fine grained, dense, gray-blue, with a tendency for conchoidal fracture. It weathers white with a yellowish tinge and is very well-bedded, beds ranging from four inches to two feet in thickness. A facies change in the Pinyon Peak limestone is noted in following the trend of the outcrop along the southeast slope of the mountain. The formation maintains its textural characteristics although a yellowish-brown weathering tendency becomes more and more evident. In addition to this, the formation, as a whole, loses its cliff-forming capacity and gradually merges into the talus slopes---only a few relatively thin members still cropping out. Also, cherty and calcitic inclusions become more prominent. The base of the Pinyon Peak limestone was mapped at the limestone (Pinyon Peak)-dolomite (Victoria) contact, and, as far as could be determined, the relationship between the two formations is a conformable one. The age, based on a small assemblage of fossils collected by Loughlin, has been tentatively set as Upper (?) Devonian. The author found the formation to be very poor in recognizable faunal remains and was unable to identify any of the fauna either in the field or in the laboratory. The fine-grained, well-bedded character of the Pinyon Peak limestone indicates that it was probably deposited under very quiet marine conditions.

Gardner Formation (L. Miss.)

The Gardner formation, three hundred and seventy-five feet of which is exposed on Pinyon Peak, has been divided into a number of mappable units for the sake of convenience. The formation, on the basis of abundant fossil evidence, has been designated Lower Mississippian in age in Loughlin's report. It lies conformably upon the Pinyon Peak limestone.

Shaly Limestone Member.....This is stratigraphically the lowest member of the Gardner formation and consists of fifteen to twenty feet of nonresistant, fine grained, flaky, light gray-blue limestone which has a definite pinkish coloration on the weathered surface. The limestone is very thin-bedded. Fossil fragments are very abundant, especially fragments of crinoid stems.

Blue Flaky Member.......one hundred and forty feet of light gray-blue, fine to coarse grained, flaky limestone with a few dolomitic horizons. Notable is an eight-to twelve-inch quartzite bed near the center of this formation. The Blue Flaky is thick-bedded on the east spur and is definitely a cliff-former and persists as such down the southeast face of the mountain. Occasional fossils were noted....especially the cup corals.

White Limestone Member.....forty-five feet of massive, medium to coarse grained, pinkish-white, cliff-forming limestone which weathers white. This formation is especially resistant to weathering and persists as a cliff-former almost the entire length of its outcrop on all sides of the peak. Occasional fossils fragments were noted in this formation.

Blue Shaly Member......thirty-five feet of well-bedded, ashy gray, medium to coarse grained limestone which has a platy tendency in the bedding and is not very resistant to weathering...forming a saddle on the east spur.

Black Dolomite Member....forty-five to fifty feet of a very distinctive marker horizon. A black, dense, hard, fine-grained thick bedded dolomite notable for an abundance of bedding plane chert and calcite nodules and lenses. The calcite occurs at the top and bottom of the member with the chert in the center. This member can be easily traced the entire length of its outcrop.

Sugary Dolomite Member....seventy feet of fine to medium grained, light gray-blue, massive, limey dolomite. This formation is best exposed on the southeast slope, near the south spur, and along the south spur. Several black chert beds none of which is over 1 foot thick run through the formation. Also notable are numerous large calcite pockets with large and well-formed crystals.

Fine Grain Pink Limestone Member...six feet of a very fine-grained, pinkish limestone in a single marker bed.

Blue Concretionary Limestone Member...two feet of a fine-grained gray-blue, banded limestone which forms an excellent marker horizon.

Blue Fossiliferous Member...twenty feet of a well-bedded, medium to dark blue, medium-to coarse-grained, highly fossiliferous limestone. This bed is best exposed at the top of Pinyon Peak and is the highest formation, structurally as well as stratigraphically.

Problem of the Pinyon Peak Limestone

Detailed field mapping by the author has revealed that the Pinyon Peak limestone is above, not below, the Victoria quartzite. This order of formations is a reversal of the order established by Loughlin on his geologic map of the area.

Reference to the geologic map of the Pinyon Peak area and figure 1 included with this report will clearly show the relationship between the two formations in question. An amplification of the description of the upper and lower boundaries of the Victoria quartzite and Pinyon Peak limestone is herewith given to locate as exactly as possible these boundaries as mapped by the author.

A. The base of the Victoria quartzite was identified both on Eureka Peak and Pinyon Peak as a speckled dolomite bed (a gray-blue dolomite liberally specked with small nodular calcite). This delineation of formation boundary is based on the standard stratigraphic column for the district as determined by G. W. Crane.

B. The Victoria quartzite-Pinyon Peak limestone contact on Pinyon Peak was mapped as the dolomite-limestone contact. The Victoria is capped by a fine grained, medium blue, dolomite with some calcite inclusions. Immediately above this dolomite, with a conformable relationship, is the very fine grained, sub-lithographic, pinkish limestone which is identified as the basal member of the Pinyon Peak limestone.

C. On the east ridge, where the detailed section study was made, the top of the Pinyon Peak limestone is easily defined. This is by reason of its massive nature. Further down the slope along the trend of the outcrop, the formation becomes less massive and the location of the upper contact is far from easy. The top of the Pinyon Peak limestone is marked by a change in lithology and a marked change in the abundance of fossil remains. The massive, sub-lithographic Pinyon Peak limestone gives way to the basal member of the Gardner formation which is a non-resistant, shaly and slabby limestone which has abundant fossil fragments (most easily recognized are the crinoid stem fragments.) The underlying Pinyon Peak limestone is decidedly poor in fossil material.

The question that immediately comes to mind is, "How could Loughlin, an experienced investigator, have made such an error?" The author was constantly plagued by this question and has attempted to work out a logical explanation for the commission of such an error.

First of all, what was Loughlin's error? According to Loughlin's geologic map, the Pinyon Peak limestone occurs below a slight angular unconformity. The Victoria quartzite is mapped as the first formation above the unconformity. In his description of the sediments, Loughlin indicates that there are only one or two thin quartzite beds of the Victoria quartzite exposed on Pinyon Peak. Recent field work by the author reveals that there is approximately two hundred feet of the Victoria quartzite exposed on Pinyon Peak and that the Pinyon Peak limestone occurs above the Victoria and, therefore, above the unconformity.

In attempting to "reconstruct" a logical picture, certain assumptions must be made:

A. Loughlin had been working in the immediate area prior to investigating the geology of the Pinyon Peak locality.

B. Because of the absence of commercial ore deposits near Pinyon Peak plus a lack of time plus the rather apparent nature of the structure (and stratigraphy) of Pinyon Peak, it is thought reasonable to assume that Loughlin spent very little time in this particular area. His investigation of the geology of Pinyon Peak must have been limited to a very brief survey (perhaps a traverse up one side and down the other side of the mountain.)

C. Loughlin was probably hoping to find some evidence to help date an unconformity he suspected as occurring sometime between the Ordovician and Mississippian periods. The geology of Pinyon Peak seemed to fit the situation very nicely.

A logical reconstruction might involve the following:

A. Prior to visiting Pinyon Peak, Loughlin had observed, in the area north of the Homansville fault (and approximately one-half mile south of Pinyon Peak) the apparently conformable relationship of the Gardner formation resting upon the Bluebell dolomite. From this observation he might have been led to believe that, for some reason, the Victoria quartzite was absent in this section of the East Tintic Mountains. As a matter of fact, this apparent conformable relationship between the Gardner and the Bluebell is actually a well-healed fault which has cut out the Victoria in this particular area, approximately one mile south southwest of Pinyon Peak. The fault has been detected in later detailed work on the surface and underground.

B. From Loughlin's description of the Pinyon Peak limestone, it is reasonable to assume that he first encountered this formation when ascending the southeast slope of Pinyon Peak. On this slope, the Victoria quartzite is very poorly exposed (the quartzite beds are obscured almost entirely by talus) and it would be entirely possible to overlook it. Here, the Pinyon Peak limestone is not a cliff-former but appears to be thin-bedded yielding few good outcrops and giving the impression of being a shaly limestone. It is probable that Loughlin's description of the Pinyon Peak limestone is based on observations made in this vicinity.

C. In describing the possible occurrences of the Victoria quartzite on Pinyon Peak, Loughlin says, "East of the summit of Pinyon Peak there is only one limy quartzite bed, less than two feet thick; on the north slope of the peak there are two thin quartzite beds separated by one of limestone conglomerate...."[5/] According to his mapping, the Victoria would

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5/ Lindgren, Waldemar, and Loughlin, G. F., op. cit., p. 39

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have to occur above the Pinyon Peak limestone. The occurrence of quartzite on the east slope can be attributed to the existence of a single quartzite bed in the Blue Flaky member of the Gardner formation. This would normally occur above the Pinyon Peak limestone. The two thin beds of quartzite described as being on the north slope may or may not actually be a part of the Victoria quartzite.....in all probability they are. A glance at Loughlin's map[6/] will reveal that he has the Pinyon Peak lime-

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6/ Lindgren, Waldemar, and Loughlin, G. F., op. cit., Plate lV

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stone pinching out before it reaches the north spur. In this way he could explain the Victoria quartzite appearing here, to a limited extent, while being absent on the east slope.

D. In the opinion of this writer, it is highly improbable that Loughlin could have covered the east spur of Pinyon Peak in his field investigations. Detailed section studies on this spur indicate the presence of the Victoria quartzite (at least 200 feet of it) with the Pinyon Peak limestone definitely occurring above the Victoria quartzite. If Loughlin had traversed this ridge, it is highly improbable that he would have missed the very good exposures of the Victoria. Further investigation would have revealed to him that his newly-described formation (the Pinyon Peak limestone) actually occurred above the Victoria quartzite, not below it.

E. From the evidence and conjecture cited above it is reasonable in the opinion of the author, that even an experienced investigator such as Loughlin could have made this mistake.

Certain questions readily come to mind when the new facts concerning the stratigraphic relationships on Pinyon Peak are considered.

Is the Pinyon Peak Limestone Actually Upper Devonian In Age?

In Loughlin's report, the following appears concerning the fossils found in the Pinyon Peak limestone:

"Fine fossil fragments are also abundant but only a few recognizaable forms were found. These were determined by Mr. Kirk as Pleurotomaria sp., Cyathophyllum sp., Rhombopora sp., and Spirifer sp. They indicate Upper Devonian (Threeforks) age, but none of them are of sufficiently critical value to render this correlation final.7/

7/ Lindgren, Waldemar, and Loughlin, G. F., op. cit. p. 36

The author devoted three days in the field to searching for fossils in the Pinyon Peak limestone. Approximately one hundred pounds of the most promising-looking fragments of this formation were collected and brought back to the laboratory for detailed study.

Some two hundred cuts (semi-polished) were made of the field samples with the diamond saw in an attempt to detect fossil material. No identifiable fossils were located by this method. Several chunks of the material were later treated with hydrochloric acid, the residue screened, and the screenings studied under the binocular microscope. No identifiable fossil materials were found.

A letter was sent recently to Mr. John B. Reeside, U. S. Geological Survey, Washington, D. C. inquiring about Loughlin's original fossils. The author was in hopes that the original fossils might still be in existence; that a loan might be arranged; and that they might be studied in detail. Word was received from Mr. G. A. Cooper of the National Museum in Washington, D. C. that the Devonian collections could not be located.

Reference to the literature 8/ would indicate that none of the genera

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8/ Shimer, H. W. and Shrock, R. R., Index Fossils of North America. John Wiley & Sons, inc., New York. 1944.

Von Zittel, Karl A., Text-Book of Paleontology, MacMillan and Co. LTD, London.

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described by Loughlin is sufficiently diagnostic to limit the Pinyon Peak limestone definitely to Upper Devonian age. Pending any more exact determination as to age range or the nature of the species found, either an earlier (e. g. Silurian) or later (e. g. Mississippian) age might fit the Pinyon Peak limestone just as well.

No Silurian rocks have been found at Pinyon Peak, although the upper part of the Bluebell dolomite is suspected of possibly being Silurian. It would, therefore, seem risky to assign the Pinyon Peak limestone to a Silurian age. On the other hand, abundant fossil evidence is present in the Gardner formation. The Gardner has been assigned, on the basis of this evidence, to Lower Mississippian age. Reference to the section study will reveal that the Gardner formation rests conformably on the Pinyon Peak limestone. It is the contention of this writer that the Pinyon Peak limestone may well be of Lower Mississippian age. Until definite positive evidence can be found, however, Loughlin's Upper (?) Devonian age determination will have to stand.

Is the Pinyon Peak limestone a distinct and separate formation?

The author considers the Pinyon Peak limestone to be another member of the Gardner formation and cites the following evidence and reasoning to support this belief:

A. As exposed on Pinyon Peak, the Pinyon Peak limestone lies in a conformable sequence; between the Gardner formation and the Victoria quartzite.

B. The Gardner formation, from a lithologic standpoint, is somewhat of a "catch-all" in that it includes dolomites, limestones, and shales. The Victoria quartzite, on the other hand, is a distinct lithologic unit being made up of alternating beds of limy quartzite and dolomite. From a lithologic standpoint, it would be reasonable to assign the Pinyon Peak limestone to the Gardner formation.

C. Reference to Figure 1 reveals that Crane's Eureka Peak section and the Pinyon Peak section, as measured by this investigator, check in detail as far down as the Blue Flaky member of the Gardner formation. At this point, the following divergence is noted:

Eureka Peak Section		Pinyon Peak Section
Blue Flaky member (ls)	120'...............	Blue Flaky member (ls) 140'

Eureka Peak Section		Pinyon Peak Section
Mottled dolomite member 72' (dol.)	....	Shaly member 15-20' (ls)
		Pinyon Peak Limestone 130' (ls)
Victoria quartzite 209' (dol. & qtzte.)	....	Victoria quartzite 200' (dol. & qtzte.)

Accordingly, there might be some relationship between the Mottled dolomite member (as seen on Eureka Peak) and the Pinyon Peak limestone (and possibly the Shaly member) as seen on Pinyon Peak. The writer suggests that the Mottled dolomite is actually a dolomitized equivalent of the Pinyon Peak limestone and that, if the exposures were good enough, the Pinyon Peak limestone could be traced laterally into the Mottled dolomite. Supporting evidence for this theory would include:

1) work by T. S. Lovering in the general area which indicates that hydrothermal alteration of limestone to dolomite is a common occurrence in this district. 9/ This type of alteration is particularly strong in the mineralized localities north of the Homansville fault (Eureka Peak is in this general area.)

2) No conclusion can be reached regarding the origin of the dolomites in the Tintic district on the basis of information now available. Some of the dolomites may have formed in response to diagenetic processes which took place during the lithification of the sediments. Hydrothermal alteration of limestone to dolomite appears to be definitely established for this area. Since hydrothermal activity was undoubtedly more intense in

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9/ Personal communication from Dr. T. S. Lovering the vicinity of Eureka Peak (the presence of commercial ore deposits suggest this) than in the Pinyon Peak area, it is not unreasonable to postulate that the Pinyon Peak limestone is equivalent to the Mottled dolomite member of the Gardner formation as seen on Eureka Peak.

The evidence cited above greatly enhances, in the opinion of this writer, the probability that the Pinyon Peak limestone is merely another member of the Gardner formation.

<u>With the new facts in mind, what is the status of Loughlin's Lower Mississippian unconformity?</u>

With regard to this unconformity, Loughlin says;

"At some time during late Devonian or early Mississippian time the newly formed sediments were elevated above sea level over a considerable part of Utah. This uplift was followed by a period of erosion, sufficient in the Tintic district to remove the Devonian, possibly the Silurian, and Upper Ordovician and in some other places to remove all the Ordovician and much of the Cambrian limestones.

In early Mississippian time this area was entirely submerged and covered by a great thickness of sediments. In the Tintic district the earliest Mississippian sediments consisted of a small quantity of siliceous material (the Victoria quartzite) derived from some exposed portion of the Cambrian quartzite or possibly from an Ordovician quartzite now completely removed by erosion.[10/]

10/ Lindgren, Waldemar and Loughlin, G. F., op. cit., pp. 102-103

If the Victoria quartzite is the basal formation above this unconformity, and if the Pinyon Peak limestone is actually Upper Devonian, then this unconformity would have to be pre-Upper Devonian. Since the exact age of the Pinyon Peak limestone is questionable, a discussion of the possible age of the unconformity would be pointless.

Geologic Structure

Pinyon Peak is essentially a fault block of Paleozoic limestone, dolomites, and quartzites....a structure typical of the Basin and Range province. The strata making up this peak are part of the west flank of a pre-faulting anticline which plunged to the northwest. The collapse of this anticline in a period of faulting left part of the west flank standing as Pinyon Peak.

Faulting

The trace of the major fault bounding the southeast face of the mountain is marked by a zone of chert and jasperoid alteration that ranges in width up to two hundred feet. The attitude of this fault could not be determined although, from the trace on the ground, it would appear that it dips steeply to the west under Pinyon Peak. The displacement on either side of this fault is demonstrated at one point where the Victoria quartzite on the northwest side is adjacent to the Gardner formation on the southeast side. The attitude of the formations on either side are approximately the same: southeast side...N10W, 10W; northwest side... N30W, 10W. The displacement on this fault is at least five hundred feet and probably considerably more.

A second fault of somewhat different character trends almost north-south along the base of the west side of the mountain and dips fifty to sixty degrees west. Here the west side is depressed, with the Blue Flaky member of the Gardner formation resting against the Victoria quartzite. No zone of mineralization or alteration was noted in connection with this fault. In one stream cut, however, the relationships are clearly seen and the presence of faulting is unmistakable (see photo No. 4.)

All other faults in the area are of minor extent and in no place involve offsets of more than seventy or eighty feet. The general trend of these faults is approximately N40W, with the fault planes almost vertical. These faults are best detected along the south spur or on the west slope of the mountain by displacements of key horizons (e. g. Black Dolomite, Sugary Dolomite, and the White Limestone members of the Gardner formation.) In almost every place, these faults are marked by some sort of chert or jasperoid alteration in the vicinity of the fault zone. A number of prospect pits have been dug along these zones, the alteration having been taken as an indicator of the possibility of the presence of ore. These faults are all normal and probably represent adjustments to tensions set up at the time of the major faulting in the area.

Folding and Minor Structures:

There is little or no evidence of folding in the Pinyon Peak area. Some warping of beds was noted, especially on the lower west slope. This warping may have been associated with the north trending fault in the immediate area. One zone of intense shearing occurs on the outcrop of the Pinyon Peak limestone on the southeast slope. Interestingly enough, however, the shear, which is normal to the bedding, is not accompanied by any visible offset of the beds involved.

Geologic History

According to Loughlin,[11/] the Opohonga limestone and Bluebell dolo-

11/ Lindgren, Waldemar, and Loughlin, G. F., op. cit., p. 102.

mite were probably laid down in one continuous series of sediments. Depositional conditions accounted for the argillaceous nature of the Opohonga and the non-argillaceous character of the Bluebell. Loughlin suggests that the upper part of the Bluebell, which is non-fossiliferous, may represent the Silurian and Lower Devonian sediments. The thickness of the Ordovician-Devonian strata in the Tintic region, however, is much less than in the other parts of the state. Loughlin suggests[12/] that the Sil-

12/ Lindgren, Waldemar, and Loughlin, G. F., op. cit., p. 102.

urian and Lower Devonian periods may be represented by a "concealed unconformity." Depositional conditions existed in the Upper Devonian, however, to permit the formation of the Pinyon Peak limestone. This theory of a concealed unconformity to explain the absence of Silurian and Lower Devonian strata does not agree with Nolan's[13/] belief in continual deposi-

13/ Nolan, T. B., The Basin and Range Province in Utah, Nevada, and California: U. S. Geol. Survey Prof. Paper 197-D, 1943.

tion through the Silurian in the Great Basin seaway with the rise of a geanticline in western Nevada at the end of Devonian time.

On the basis of the Pinyon Peak limestone occurring below the Victoria quartzite, Loughlin postulates a period of uplift and erosion in the Upper Devonian-Lower Mississippian interval. Since the current work has disclosed that the Pinyon Peak limestone is above the Victoria quartzite, doubt is cast on the exact age of the pre-Victoria unconformity. The author suggests pre-Lower Mississippian-post Ordovician as the limiting times.

The Gardner formation represents continued depositional conditions through Lower Mississippian time. Since no sediments any younger than the Gardner are found on Pinyon Peak, it must be assumed that they either were never laid down or that they were deposited and have subsequently been removed by erosion.

Study of the regional structure indicates that Pinyon Peak is part of the west flank of a northwestward plunging anticline which, sometime after the period of folding, was dissected by faulting leaving Pinyon Peak as a topographic high. The original anticline was probably a broad open fold formed in the period of Jurassic diastrophism in the Basin and Range Province which had the greatest intensity of deformation in the west (western Nevada).

The two major faults in the area, along the southeast flank and the lower west slope, probably came into being during the Oligocene-Recent period of normal faulting. The present relief of Pinyon Peak indicates that the faulting is fairly recent.....otherwise erosional forces would have reduced the mountain to a much more subdued form.

One theory of the cause of faulting postulates that the faults may be directly related to the Late Tertiary volcanism which may have been a contributing factor in the collapse of the anticline.

Loughlin suggests [14/] that, at one time during the Tertiary, the vol-

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14/ Lindgren, Waldemar, and Loughlin, G. F., op. cit., pp. 103-104.

canic flows may have buried all of the earlier sediments. Since that time, erosion (particularly during humid Quaternary time) has removed the volcanic rocks from the higher ridges....e. g. Pinyon Peak. No traces of any of these Tertiary volcanics were found on any of the higher slopes of Pinyon Peak so this theory will have to rest on conjecture and probability for support...at least in the case of Pinyon Peak.

The period of adjustment faulting probably accompanied and followed the block faulting and may be fairly recent in age.

In any case, at present the region appears to be in a relatively inactive phase of the orogenic cycle. Destructional forces are now dominant. The semi-arid to arid climatic conditions favor the mechanical type of weathering, the fractured and thin-bedded rocks yielding more easily than the more massive rocks.

Summary of the geologic history

1. Deposition of approximately twenty-two hundred feet of chemical, organic, and fine grained clastic sediments from Lower Ordovician to Lower Mississippian time with a marked unconformity tentatively dated pre-Lower Mississippian, post-Ordovician.

2. Pennsylvanian-Jurassic period is not represented in the present stratigraphic column. The land was probably above water most of this time since marine conditions of deposition ceased in the Cordilleran region in general at the end of the Permian.

3. The Jurassic-Eocene diastrophism accomplished the folding of the major anticline.

4. Collapse of the anticline by faulting (possibly associated with volcanism) occurred in Late Tertiary time. Volcanic rocks covered the region.

5. Erosion and adjustment faulting become dominant continuing up to Recent time and removing most of the volcanics to reveal Pinyon Peak as a topographic high.

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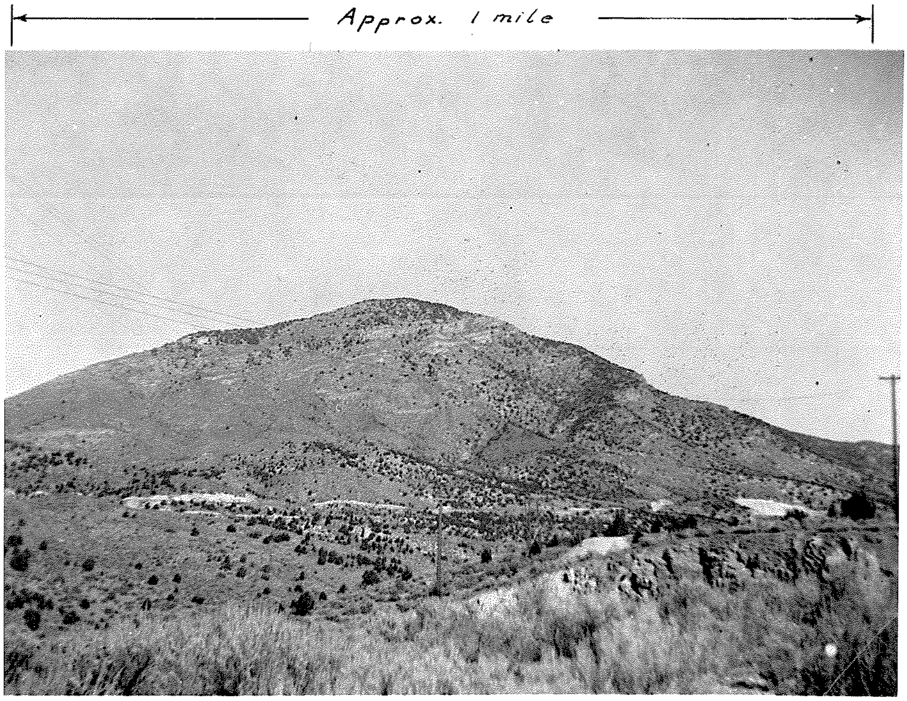

Photo No. 1 - View of the southeast slope of Pinyon Peak

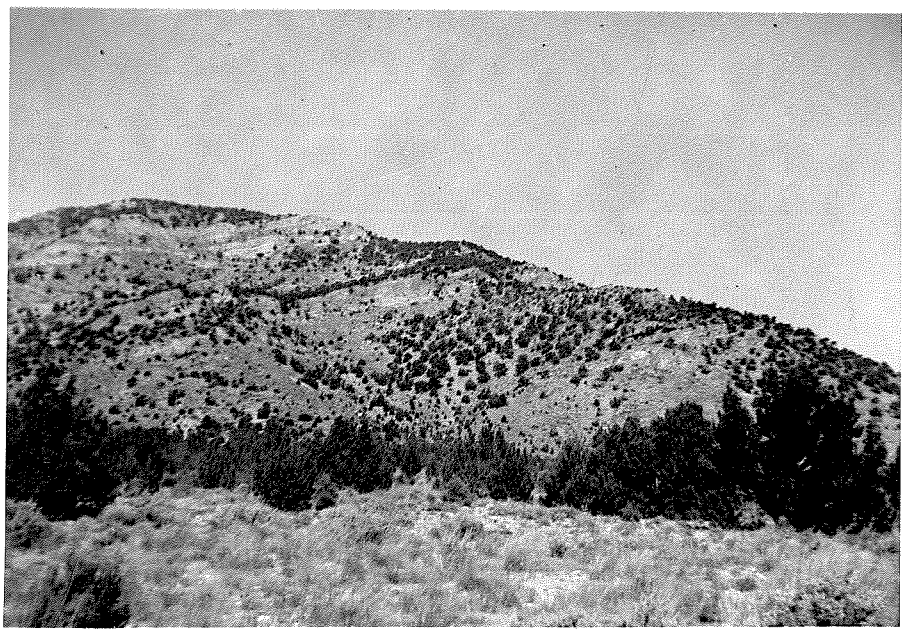

Photo No. 2 - View of the east spur of Pinyon Peak

Photo No. 3 - The Pinyon Peak limestone as seen on the east spur of Pinyon Peak.

Photo No. 4 - Faulting at the base of the west slope of Pinyon Peak. The Gardner formation, on the right, is faulted against the Pinyon Peak limestone, on the left.

THE GEOLOGY OF THE UPPER TICK CANYON AREA, LOS ANGELES COUNTY, CALIFORNIA

Thesis by

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In Partial Fulfillment of the Requirements
For the Degree of
Master of Science

California Institute of Technology
Pasadena, California
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TABLE OF CONTENTS

TABLE OF CONTENTS (Contd)

ABSTRACT

The upper Tick Canyon area is in the northwest quarter of Los Angeles County, California. Within this area at least 5000 feet of Oligocene (?) Vasquez sediments and interlayered basaltic lavas is faulted against an undetermined thickness of pre-Cretaceous gneisses and is overlain unconformably by Tick Canyon clastic sediments of probable late lower Miocene age.

The Vasquez sediments exposed in the upper Tick Canyon area are composed of cobble and boulder conglomerates, sandstones, siltstones, shales, tuffs, borate-bearing beds, and volcanic ash beds. The nature of the sediments strongly suggests fluviatile and lacustrine deposition in a continental basin under semi-arid to arid climatic conditions. The presence of four distinct flows of lava totaling at least 2300 feet indicates that Vasquez time was a period of active vulcanism in this part of Southern California.

Structurally the mapped area consists of a west-plunging syncline of Vasquez rocks faulted against the up thrown block of pre-Cretaceous gneisses to the north. Beds on the north limb of this fold dip vertically. Two minor anticlinal flexures occur in the synclinal trough which is further complicated by several major oblique slip faults of northeast trend. Measurable horizontal components of movement along these faults range from a few hundred to at least 1200 feet.

In interpreting the geologic history of the region, pre-

vious investigators have suggested that the Vasquez sediments and lavas probably accumulated during early or early middle Tertiary in an east trending, canoe-shaped basin that was defined by block faulting in Eocene or early Oligocene time.

The soft and relatively fine-grained Vasquez sediments in the upper Tick Canyon area responded to the compressional stresses exerted at the end of Vasquez time by folding to a much greater degreee than the predominately coarser beds elsewhere in the region. Yielding also occurred along faults with an oblique-slip movement. Uplift and erosion at the end of the post-Vasquez orogeny was followed by the deposition of Tick Canyon terrestrial sediments, chiefly; conglomerates, sandstones, and silts.

The presence of several levels of terrace gravels suggests a number of periods of uplift during Quarternary time in the Tick Canyon Area. At present, the region is being eroded by rejuvenated streams, which have developed a local topographic relief of approximately 1000 feet.

INTRODUCTION

Location and physical features:

The upper Tick Canyon area is in the northwestern quarter of Los Angeles County, California, at 34 degrees and 29 minutes north latitude and 118 degrees and 22 minutes west longitude. It is approximately rectangular in shape and covers about six square miles.

The area is most readily reached over the Davenport Road, a graded and partially surfaced road that connects the Los Angeles-Palmdale-Mojave highway (U.S. Highway 6), with the Aqua Dulce Canyon road to the east. Dirt roads provide access to points within half a mile of any spot within the area, but most of these routes are dangerously slippery in wet weather.

Maximum relief is about 900 feet, the vertical lava flows underlying the highest peaks and steepest slopes. Tick Canyon, Mint Canyon, and their tributaries drain the area, but flow of surface water is intermittent, and then only during the rainy season.

The few inhabitants in the area are weekend visitors, ranchers who glean a meager existence from raising goats and other livestock, and prospectors who are currently mining gold at several scattered localities in the old crystalline rocks north of the Vasquez formation. All the landowners were willing to cooperate in facilitating the field investigation. The brushy type of vegetation in the area was at no time a hindrance to travel.

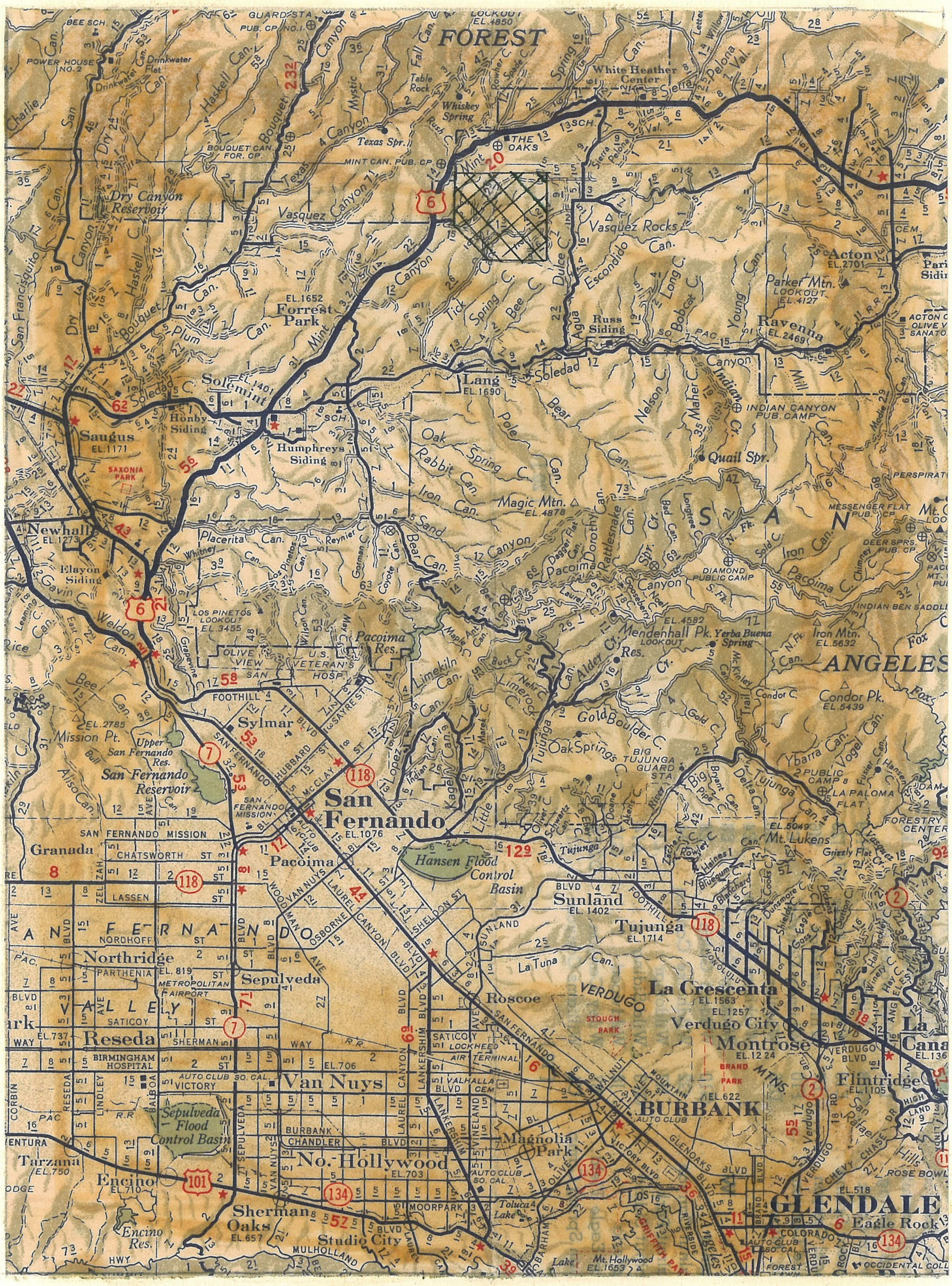

Figure 1 - Location of the upper Tick Canyon area.

Purpose and scope of the investigation:

The current survey was undertaken primarily as a structural study of the Vasquez rocks exposed in the upper Tick Canyon area, where the tight folding and extensive faulting are ideal for such a purpose.

Twenty days, during the period of September 1947-March 1948, were devoted to the field investigation. A modified traverse method employing the Brunton compass was utilized. Dr. R. H. Jahns supervised the investigations and was of considerable assistance in supplying information and suggestions in field conferences.

REVIEW OF THE LITERATURE

An excellent review of the literature pertaining to the general Tick Canyon region published prior to 1935 is contained in a report by R. P. Sharp. (1935, pp. 7-14). Sharp (1935) and H. W. Menard (1947) have described the area to the east with special attention to the lower Tertiary stratigraphy. Ygnacio Bonillas (1935) mapped the upper Tick Canyon area on a scale of 1:12000 in conjunction with his studies of Miocene vulcanism in Southern California, and has described in some detail the petrography of the Vasquez lavas. G. B. Oakeshott (1937) described the rocks of the San Gabriel Mountains to the south. Jahns (1940) mapped the Tick Canyon and younger rocks to the west, with emphasis on the Miocene stratigraphy and age determinations based on vertebrate fossil studies. W. T. Holser (1946) mapped in detail the area immediately to the west and southwest, with special attention to a survey of the

Tick Canyon formation.

STRATIGRAPHY

General statement:

The rocks exposed in the upper Tick Canyon area consist of old crystalline rocks ("basement complex"), Vasquez terrestrail sediments and extrusive lavas, and Tick Canyon terrestrial sediments. The pre-Cretaceous metamorphic rocks of the "basement complex" are in fault contact with the Oligocene (?) Vasquez formation, which in turn is overlain unconformably by the Miocene Tick Canyon formation. Quaternary terrace gravels and alluvium (not shown on the geologic map) are exposed along stream courses.

"Basement complex":

The "basement complex" was treated as the northernmost limit of mapping and consequently was not studied in any detail. The contact between these older rocks and the Vasquez sediments and volcanics was traced as accurately as possible, and was determined to be a steeply dipping normal fault. Holser (1946, pp. 10-12) described these rocks as a series of gneisses, the most common facies of which is a leucocratic biotite-hornblende gneiss. He also discussed the possible origin of these gneisses, and adopted E. C. Simpson's (1934) pre-Cretaceous age assignment for them.

Vasquez formation:

The Vasquez formation is a series of extrusive lavas and interbedded sandstones, shales, silts, tuffs, and conglomerates and has a total thickness of at least 5000 feet as measured in upper Tick Canyon. For purposes of description and correlation, this formation is herein deivided into eight lithologic units. Four of these are volcanic, three are sedimentary, and one is sedimentary with an interbedded amygdaloidal lava.

Basal sediments: (Tvl)

The basal sedimentary series, in fault contact with the "basement complex" gneisses, comprises 1200 feet of conglomerates composed of subrounded to subangular gravel, with cobbles and boulders ranging in diameter from a few inches to two feet. The matrix is coarse, poorly indurated quartz and feldspathic sand. The pebbles and larger fragments are quartz, granodiorite, gneiss, schist, diorite, and more basic rocks. The dominance of gneisses indicates a possible source in the "basement complex" to the north. Coarse sandstones and conglomerates or red, white, gray, and yellow-brown hue make up the greater portion of this member. These sediments generally are poorly indurated, although local well-cemented beds serve as excellent marker horizons. Bedding is well-developed, with individual units ranging from six inches to three feet in thickness. Near the eastern boundary of the area several beds of gypsiferous shales were noted, the gypsum occurring in beds from a few inches to a foot in thickness. Abandoned mine workings in this locality indicate that these relatively impure deposits have been mined from time to time. At the top of the basal sedimentary sequence is a ten-to-fifteen foot thickness of thin-bedded volcanic ash best exposed in two prospect pits in the northeastern part of the area just east of hill 2950.

Lava (Tv2)

This 1350-foot thickness of extrusive lava represents by far the thickest of the volcanic flows in the region mapped. Bonillas (1935, pp. 7) has described this lava as a basic hypersthene andesite on the basis of a study of almost a dozen thin sections of the rock. Simpson (1934, pp.394, 395, 401), on the other hand, has called this lava a normal basalt with a Johannsen classification of 2312E. Megascopic examination of outcrops of this lava reveal that it has a trachytic texture displayed by the subparallel alignment of well-developed feldspar laths. The rock weathers distinctively a reddish-brown color. The upper portion of the flow has a greenish color and an appearance that suggests extensive weathering during Vasquez time. Certain of the green sands and conglomerates in the Vasquez and Tick Canyon formations undoubtedly derived the green coloration from the weathered Vasquez lavas.

Sediments with an interbedded amygdaloidal lava (Tv3)

The sediments with an interbedded amygdaloidal lava member, some 270 feet thick, are composed of approximately 100 feet of well-bedded, fairly well-indurated, brick-red sandstones that are overlain by a 50 foot flow of a distinctly purplish amygdaloidal lava. Most of the amygdules are chalcedony, but zeolites occur locally. The amygdaloidal flow is, in turn, overlain by a series of white, buff, and green sandstones with an easily recognized white tuff horizon.

The lava-sediment sequence provides an excellent marker horizon for mapping, and has aided considerably in the solution of structural problems.

Flow breccia (Tv4)

Approximately 290 feet of flow breccia was measured in upper Tick Canyon. The lava matrix is red in color, aphanitic in texture, and basaltic in composition. It encloses numerous angular fragments of shale, sandstone, and other rocks.

Sediments (including the borate-bearing beds) (Tv5)

Overlying the flow breccia noted above is a sequence of shales, borate-bearing beds, sandstones, and tuffs more than 950 feet thick. The borate-bearing beds are underlain by sandy shales of purple, green and yellow-brown color. According to Foshag (1921, pp. 204) the chief mineral of the borate series is colemanite, although botryoidal howlite and irregular masses of ulexite are also present. A series of brownish shales and sandy shales grading upward into red and white to buff sandstones caps the borate-bearing beds and makes up the greater part of this sedimentary series.

Lava (Tv6)

Above the borate-bearing sedimentary member is a 425-foot thickness of lava. Baking at the lower contact and a 20-foot weathered zone at the upper contact indicate that this lava was extruded. Megascopically this lava appears to be basaltic, with a definite trachytic texture. It is highly vesicular and contains many chalcedonic amygdules. Cooling phenomena are characteristic of this lava.

Sediments (Tv7)

A series of red, buff, yellow, purple and green shales and sandstones about 175 feet thick make this sedimentary member a very colorful unit. The shales have been prospected for borates and do contain some borate-bearing strata, but apparently not in commercial concentrations. The sandstones are particularly distinctive for their bright color and well-defined beds ranging in thickness from inches to three feet.

Conditions of deposition:

The Vasquez sediments and lavas were laid down in a canoe-shaped basin that trended nearly west and sloped seaward in the same direction. The sediments in this basin are of local derivation, and have not yet been satisfactorily correlated with any other sedimentary sequence in Southern California. Sharp (1935, pp.28) described the Vasquez lithology in areas to the east, and measured a 13,000-foot thickness of interbedded lavas and coarse fanglomerates. He found no finer-grained sediments of the Tick Canyon variety there. The sediments to the east, in the Ravenna Quadrangle, dip gently to the west, and probably were deposited at or near the eastern end of the basin.

Studies of the Tick Canyon borate deposit by Eakle (1911) and Foshag (1918) indicate that the borates were formed in shallow-water lakes or marshes in a closed basin under generally arid to semi-arid climatic conditions. Eakle states: (1911, pp. 180-182)

"It seems probable that the original site of the deposit was a marsh containing marl and calc tufa with mud and considerable organic growth, and that later waters charged with boric acid flowed into the basin and converted the carbonate of lime into the borate. Some and perhaps the greater part of the argillaceous material which forms the shales was precipitated by the decomposition of the impure limestone, together with organic matter.....The absence of soda compounds and the presence of abundamt plant life indicate that the lake or marsh was fresh into which springs containing boric acid discharged....The origin of the boric acid is presumably volcanic and the springs probably issued from vents in the immediate vicinity of the basin."

Age of the Vasquez formation:

Sharp (1935, pp. 35-38) reviewed in detail the problem of the age of the Vasquez formation and tentatively assigned a middle Miocene age to the formation. Later work by Jahns (1940) indicates that the overlying Tick Canyon formation is lower Miocene in age and that the Vasquez therefore is early lower Miocene or Oligocene in age.

An unsuccessful search for fossil remains in some of the more promising looking Vasquez sediments was made during the present investigations. As no additional data can be contributed to the dating of this formation, Jahn's Oligocene (?) assignment is herein accepted.

Tick Canyon formation:

The Tick Canyon sediments dip gently to the south and overly the Vasquez formation with a distinct nonconformity. The discordance of bedding ranges from thirty to ninety degrees. The basal member of the Tick Canyon formation is a well-cemented cobble to boulder conglomerate that forms a dip slope in the area east of Tick Canyon. Reddish- to buff-colored clays, siltstones, and sandstones are well exposed along the Davenport Road on the west side of Tick Canyon. The presence of vertebrate remains in the Tick Canyon sediments strongly suggests terrestrial conditions of deposition for this formation. Jahns (1940, pp. 169) has determined the beds to be late lower Miocene in age.

STRUCTURE

General features:

The outcrop pattern of the Vasquez rocks in upper Tick Canyon reveals that they have been severely deformed. These rocks have been folded and cut by normal and oblique-slip faults. Faulting of comparable magnitude and frequency has occurred in all of the surrounding areas. The relatively incompetent Vasquez sediments and lavas, however, have responded to compressional forces to produce a tightness of folding not found in any of the nearby regions. Sharp (1935, pp. 61) found no evidence of folding of the Vasquez rocks in the Ravenna quadrangle to the east, but mild flexures have been noted in the Mint Canyon formation by Jahns (1940) and Holser (1946) in areas to the west and northwest.

The major fold in the area is a tight syncline with a steeply dipping north limb. The Vasquez rocks in this fold are faulted against the "basement complex" to the north and plunge to the west beneath the Tick Canyon beds. Two minor anticlinal flexures are present in the synclinal trough, which has been cut into slices by two major oblique-slip faults with northeast trend, as well as by several minor faults of more random orientation.

The detailed structure of the upper Tick Canyon area is shown in plan on the geologic map. Six north-south sections, spaced 1500 feet apart, show the nature of the folding and faulting.

Faulting:

An early Tertiary period of faulting must have occurred before and during Vasquez time, when the basin of deposition of these coarse clastics and lavas was outlined, but there is no direct evidence of this in the upper Tick Canyon area. It is probable, as suggested by Jahns (1940, pp. 169), that the faults of this period were dip-slip in type and the forces producing them tensional.

The Basement Complex fault represents the earliest faulting in the mapped area. Poor exposure makes it impossible to observe the fault plane itself, so that the attitude and direction of movement along this fault must be derived by inference. In places the basal sediments of the Vasquez dip very steeply to the north. The apparent overturning of these beds may be explained by 1) reverse movement on the steeply dipping Basement Complex fault, or 2) normal movement along the Basement Complex fault with post-fault tilting of the entire area. If this fault came into existence during the post-Vasquez - pre-Tick Canyon period of folding, then a reverse movement would be in harmony with the type of stresses being applied at the time. If, on the other hand, the fault originated during a period of tensional stresses, and tilting of the upper Tick Canyon region has occurred, normal movement might well have taken place. Although conclusive evidence cannot be cited, the writer believes this fracture to be a steep normal fault developed along old lines of weakness, and that the area has been tilted to the south during one of the Pleistocene periods of uplift.

A third period of faulting of an oblique-slip nature must have taken place soon after (and perhaps during) the period of activity of the Basement Complex fault. The oblique-slip Tick Canyon fault and the Skyline Ranch fault, the two major breaks in the area, are en echelon and trend northeast. The east side of each fault has moved north with respect to the west side. Displacement of key horizons reveals that there has been at least 800 feet of horizontal movement on the Tick Canyon fault and approximately 1200 feet of horizontal movement on the Skyline Ranch fault. Both cut the Basement Complex fault to the north, and can be traced southward to the Tick Canyon formation, where they appear to die out. The faults were active, therefore, during post-Vasquez-pre-Mint Canyon time.

Many exposures of slickensided surfaces in the strata cut by these faults reveal that the striations dip fifteen to twenty degrees to the south, indicating that the last movement along these faults was of an oblique-slip nature.

The Skyline Ranch fault has a particularly sinuous trace. In the southern part of the area it appears to be heading for a junction at an acute angle with the Tick Canyon fault. Along its trend to the north it forms the boundary between the Tick Canyon and Vasquez formations for a short distance, its strike being subparallel to the strike of the Vasquez sediments. Thence it curves northward so that, at the northern edge of the area, its strike is practically normal to the strike of the Vasquez strata. Slickensides, fault scarps, and offsets of key strata permit definite location of the trace of this fault in the northern and southern parts of the area. Its central portion, on the other hand, is for the most part inferred.

The principal reason for the current location of the Skyline Ranch fault hinges on the solution of the structural and stratigraphic situation (best seen in section B-B', C-C', and D-D') involving the anticlinal flexures in the trough of the major syncline. W. S. W. Kew (1924) and Bonillas (1935) mapped the sedimentary outcrop (designated Tv5 and Tv7 on the current geologic map) across the southern part of the area without a break. A close examination of the sediments involved (see the description of the stratigraphy) indicates that these two sedimentary series are not contiguous, the lithologic differences being so pronounced as to preclude the possibility of even a very rapid facies change. Terrace gravels and alluvium obscure the northern flank of the syncline in the Tv7 sediments. Scattered and meager exposures, however, point to the existence of the synclinal configuration of these strata and act as supporting evidence for mapping the Skyline Ranch fault immediately to the east.

A third oblique-slip fault, following the en-echelon pattern of the Tick Canyon and Skyline Ranch faults, is in the western part of the area, where it cuts out units Tv5 and Tv6. This fault, in dropping the Tick Canyon sediments on the west, appears to have had a larger vertical component of movement than the two previously mentioned oblique-slip faults.

Several minor oblique-slip faults also are present in the area. Two of the more important ones lie near the Borax mine and immediately west of hill 3030. The general trend of these faults is northwest, and the horizontal displacement does not exceed 200 feet. These faults are apparently of the same age as the larger oblique-slip faults. No evidence was found to indicate activity on any of the faults in the area since the post-Vasquez-Pre-Mint Canyon period of compressional stresses.

Displacement of marker horizons is the most useful criterion for the tracing of faults in the Tick Canyon area. Slickensided surfaces, especially in the lavas, are helpful in locating the fault traces more accurately. Gouge and brecciated zones a foot or two wide and minor scarps were noted in several localities; regolith material, however, obscured the exact trace of the faults in most places.

Menard (1947, pp. 23,24) has noted the sinuous strike of the oblique-slip faults in the region immediately east of the upper Tick Canyon area. He further notes that R. T. Chamberlain (1919) and R. E. Sherrill (1929) have mapped sets of en- echelon faults that display the same sort of sinuous strike. These authors contend that torsion is the cause of en-echelon faulting. M. P. Billings (1947, pp. 194-195) cites a number of examples of sets of en-echelon gravity faults (which locally have a strike-slip component of movement) and diagrams a strain ellipsoid to explain the forces involved. Jahns (1940, pp. 169) suggests that these oblique-slip faults have a gash-fracture relationship to the San Andreas fault zone which lies several miles to the north. The field evidence in the upper Tick Canyon area seems to point to oblique-slip movement with a minor component of vertical movement. The gash-fracture explanation would, in this case, seem to best explain a possible causitive force for these faults.

Folding:

The poorly indurated, fine-grained Vasquez sediments in the upper Tick Canyon area responded to regional compression by folding as well as by faulting. As mentioned above, tight folding is not developed in the surrounding areas of Vasquez rocks because of their greater competency.

The major fold of the area is a syncline with a east to east-northeast trend and a gentle plunge to the west. Dips on the north limb are vertical and dips on the south limb are as much as 70 degrees. This structure is readily detected from a study of the configuration of the outcrop of the Vasquez rocks. The synclinal nose lies just east of the area mapped. Even the most cursory inspection of aerial photographs of the area reveals the folding of the Vasquez lavas and sediments in synclinal form.

An anticlinal flexure trending east-northeast has been developed in the trough of the larger syncline. This fold is best seen in the Tv5 Vasquez sediments as exposed just north of the Davenport Road in the eastern part of the area. The nose of another such anticlinal flexure in the same sediments is found in the extreme eastern edge of the area.

Unconformity:

The unconformity between the Vasquez formation and the overlying Tick Canyon formation is best seen just east of Tick Canyon. At this contact the Vasquez sediments of Tv5 are dipping approximately sixty-five degrees to the north whereas the superjacent Tick Canyon conglomerates dip twenty-five degrees to the south.

Structural features in the lavas:

Cooling structures are developed on a spectacular scale in some of the lava flows. Concentric layering in a basalt spheroid approximately 40 feet in diameter occurs in Tv6 about 1000 feet east of Tick Canyon. The concentric layering is apparently a cooling phenomenon. Contortion of these lavas is also well displayed in Tv6. Some of the fractures may have been generated in response to nearby faulting. Most of the fracture patterns, however, appear to be cooling phenomena.

GEOLOGIC HISTORY

The geologic history of the eastern Ventura Basin (including the upper Tick Canyon area) has been summarized by Jahns (1940, pp. 172-173). The history, as interpreted from the geology of the upper Tick Canyon area, is herewith outlined.

1) A narrow basin, draining to the west, was possibly formed by block faulting in late Eocene or Oligocene time. This continental depression was ringed by crystalline highlands which, through repeated movement along bordering faults, maintained considerable relief.

2) This basin was partly filled with at least 5000 feet of interbedded sediments and extrusive lavas probably during Oligocene or early Miocene time. Borate deposits in the sediments probably indicate semi-arid to arid climatic conditions. The great thickness of fanglomerates to the east would suggest relatively rapid desert-type erosion. The finer sediments in the Tick Canyon area suggest lacustrine conditions of deposition, the lakes being shallow and probably very similar to the playa lakes now found in nearby desert regions (e.g. Searles Lake in San Bernardino County).

3) The close of sedimentation was marked by a period of intense deformation. A steep normal fault, the Basement Complexfault, was developed in the northern part of the area, where the Vasquez sediments were dropped down at least several hundred feet. Folding and oblique-slip faulting occured

soon afterward. The beds were folded into a syncline plunging to the west. Minor anticlinal flexures developed at this time in the trough of the major syncline. Oblique-slip faults trending northeast sliced the area into roughly parallel strips. These faults appear to have a gash fracture relationship with the San Andreas rift to the north. The sediments attained enough elevation at this time to permit active erosion.

4) A later series of clastic sediments was deposited unconformably on top of the partially eroded earlier series during late lower Miocene time.

5) Work done by earlier investigators in nearby areas indicates that Tick Canyon sedimentation was probably followed by uplift and minor folding. Deposition of Mint Canyon fluviatile and lacustrine sediments followed. Post-Mint Canyon uplift then occurred followed by marine invasion from the west and deposition of uppermost Miocene "Modelo" sediments.

6) Several levels of terrace gravels indicate uplift of the region in Quaternary time. The area is, at present, in a youthful stage of erosion -- the intermittently flowing streams cutting sharp V-shaped valleys, which are in many places rigidly controlled by the underlying sediments.

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Photo 1 - Looking east at the upper Tick Canyon area. The ridge on the skyline is Vasquez flow breccia. The borax mine dump is in the mid-foreground with a Quaternary Tick Canyon terrace in the foreground.

Photo 2 - Abandoned remnants of the mill at the Tick Canyon borax mine.

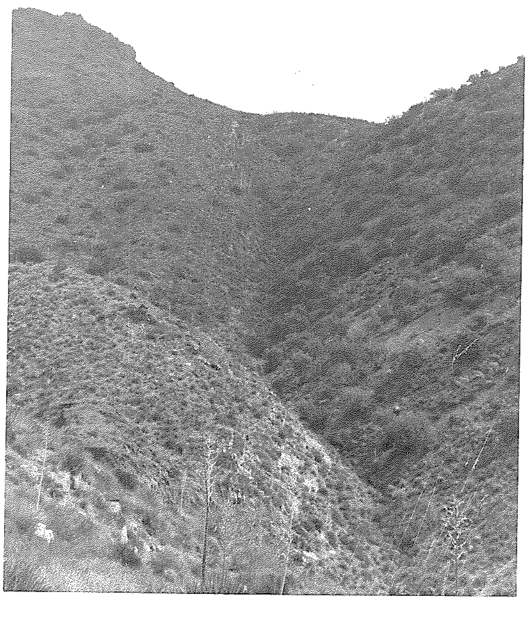

Photo 3 - A view of the Vasquez (Tv3) sediments (in center) showing lithologic and structural control of drainage.

Photo 4 - Concentric layering in a basalt spheroid seen in one of the Vasquez lavas (Tv6). This structure is probably a cooling phenomenon. Bush in the center is two feet high.

Photo 5 - Slickensided lava on the fault cutting through the borax mine.

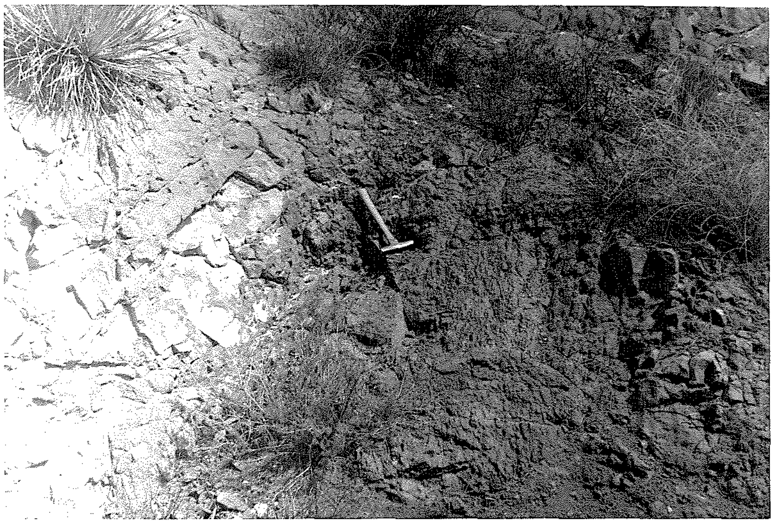

Photo 6 - A close-up of the contact between amygdaloidal lava and sandstone in Tv3.

Photo 7 - The Vasquez (Tv4) flow breccia.