The Montrose-La Crescenta (California) Flood of January 1, 1934, and its Sedimentary Aspects.

by

W. D. Chawner

Submitted in partial fulfillment of the requirements for the degree of Master of Science, Balch Graduate School of the Geological Sciences, California Institute of Technology

Pasadena, California, 1934.

<u>Frontispiece</u> -- Picken's Wash, looking north-easterly towards the south flank of the San Gabriel Range from a point on the north flank of the Verdugo Mountains. Picken's Canyon is in the left distance of the picture, Hall's Canyon in the right distance. The course of the spread of the flooding waters is easily followed by the lighter colors of the fresh sediments left on the fan slope. The prominent white building in the central part of the picture is the American Legion Hall of Montrose where 25 persons were swept away, many of them losing their lives.

The Montrose-La Crescenta (California) Flood of Jan. 1, 1934.

New Year's morning, 1934, the residents of Southern California were aware that the rainstorm of the last two days had been severe, and especially so during the night before. But to most of them, if they thought about it at all, it was only a slight inconvenience. The majority of the residents of Los Angeles County did not realize or suspect that during the night a major disaster had occurred in their midst. The small foothill communities of Montrose and La Crescenta, twelve miles north of the center of Los Angeles, and a part of the larger community of Glendale, five miles south of Montrose, had been partially torn away or buried by an overwhelming flow of water, mud, and rock from the steep canyons of the San Gabriel Range to the north of them.

Much has been published in the daily papers concerning this flood, and investigations have been made by city, county, and state officials and agencies, chiefly the Los Angeles County Flood Control Board and the United States Forestry Service. The results of these investigations have not yet been made public in any comprehensive way. Motives were largely to determine the extent of the damage, and to discover, if possible, means of averting a repetition of such a catastrophe. At the suggestion of Dr. John H. Maxson and Dr. Ian Campbell of the California Institute of Technology, to whom thanks are due for helpful criticisms, the writer of the present paper spent a number of days in the Montrose-La Crescenta area shortly after the flood waters had subsided, and during the clean up of the debris by C. W. A. and other county workers, with the object of collecting all pertinent data from a geological point of view, considering the type and manner of deposition, thickness and character of sediments and related data. It is hoped that the description of the flood, and the data collected may be of interest and use to other geologists interested in sedimentary processes.

A glance at the topographic map (Plate I) will enable the reader to visualize the physiographic setting of Montrose, La Crescenta, and Glendale. Montrose and La Crescenta are small communities built on the south-sloping bajada in the inter montane depression between the south flank of the San Gabriel Mountains and the north flank of the Verdugo Mountains.

The alluvial fans on which these two communities are located were built by the unloading of debris carried down Hall's and Picken's Canyons from the south flank of the San Gabriel Range. In the continued building of these fans and their contemporaries on the west their frontal edges have been pushed against the north slope of the Verdugo Mountains. Along the foot of this north slope a broad, deep wash has been cut which leads into and down Verdugo Canyon, directly across the structure of the Verdugo Mountains — San Rafael element. At the southern end of Verdugo Canyon the stream has built up another alluvial fan, a large, broad feature upon whose slopes the city of Glendale is built. At the outskirts of the Glendale fan drainage falls into the Los Angeles River. The present main drainage channel from Verdugo Canyon, called Verdugo Wash, passes through the northern part of the City of Glendale. The building fan has pushed the course of the Los Angeles River westward against the east end of the Santa Monica Mountains.

None of these streams is flowing the year round. In fact most of them carry no visible water except during and for a short time after the irregular rains. R. J. Russell (1) has classified the climatic zone of

(1) Russell, R. J.: Climate of California; Univ. of Calif. Pub. Geol. Vol. 2, pp. 73-84, 1926

which the area is a part, as "hot summer mediterranean type", after the classification of Vladimir Köppen.(1) This is a division of Mesothermal-humid climate with at least three times as much rain in winter as in summer. This classification applies only to the mountain slopes, as the valleys of Southern California approach the arid type of climate. It may be said then, that the climate is characterized by moderate temperatures in winter, warmth in the summer, with an abundant winter rainfall in the mountains, and semi-aridity on the fan slopes and in the Los Angeles River Valley.

The La Crescenta Valley is essentially a down dropped block between two horsts. According to W. J. Miller(2) the Verdugo Mountains, San Rafael Hills element, and the San Gabriel Mountains block are essentially horsts made up largely of igneous and metamorphic rocks and themselves broken up into many minor blocks. The southern flank of the San Gabriel block is the dissected scarp of the Sierra Madre fault. Similarly the south flank of the

(1) "Die Klimate der Erde" - (Berlin, 1923).

(2) Miller, W. J.: "Geomophology of the Southwestern San Gabriel Mountains." Univ. of Calif. Publs. in Geol., Vol. XVII, No. 6, p. 197, and map, p. 208, (1928).

Verdugo Mountains is the dissected scarp of the Burbank fault. Miller (loc cit) maps what he calls the Verdugo Fault along the northeast flank of the Verdugo Mountains, curving southward to cut across the Verdugo-San Rafael element, this fault thus determining the location ~~the location~~ of Verdugo Canyon. On the same map Miller locates La Cañada fault running approximately northwest-southeast the length of the intermontane depression through Sunland, La Crescenta, and La Cañada.

The foregoing is a brief resumé of the physical setting of the flood area. There follows a description of the more immediate conditions which occasioned the disaster, namely, the forest fire which denuded the mountain slopes, and the period of heavy precipitation which followed a few weeks later.

In the latter part of November, 1933, a forest fire which raged out of control for three days and more, burned over some 7,000 acres of water sheds on the slopes of the San Gabriel Mountains immediately draining into the La Crescenta Valley. The water sheds of Picken's and Hall's Canyons were completely laid bare of all vegetation. Immediately after the fire was extinguished rock check dams were started in a number of the canyons. These had been efficient on other occasions in holding back some of the tons of soil sure to be carried down the canyons and onto the fans below in the event of occurrence of heavy rains before a new growth of vegetation could spring up. The forestry service also set about planting mustard seed and trees in an effort at reforestation. However, a little more than a month later the long delayed rains set in. The last day of 1933 broke all previous records for rainfall in the County of Los Angeles. (For details of precipitation refer to Table 1. The data for Sister Elsie Peak and Haine's Canyon Stations are most applicable since these stations are located in the burnt over watershed immediately north of La Crescenta Valley.)

It may not be generally known that California held (in 1914) and probably still holds the records among all the states for the greatest amount of monthly and "cloudburst" rainfall.(1) The monthly record was made at Helen Mine, California, with 71.54 inches in January 1909. The "cloudburst" records are two. One was made at Campo (San Diego County) on

(1) McAdie: The Rainfall of California; Univ. of Calif. Pub. Geol., Vol. I, #4, pp. 171-173, 1914.

Table 1. -- Rainfall intensities at selected stations in Los Angeles County during storm of December 30, 31, 1933, and January 1, 1934 (From office records of L. A. Co. Flood Control Board).

Name of Recording Station	MAXIMUM RECORDED PRECIPITATION		
	10 Minutes	30 Minutes	1 hour
Griffith Park Nursery	.26 inches Midnight 12/31 to 12:10 1/1	.60 inches Midnight 12/31 to 12:30 a.m. 1/1	1.15 in. Midnight to 1:a.m. 1/1
Flintridge Fire Station	.34 inches 12:12 to 12:22 a.m. 1/1	.84 inches 12:12 to 12:42 a.m. 1/1	1.33 12:10 to 1:10 a.m. 1/1
Haine's Canyon	.27 inches 11:42 to 11:52 p.m. 12/31	.50 inches 11:22 to 11:52 p.m. 12/31	.94 in. 10:52 to 11:52 p.m. 12/31
Sister Elsie Peak	.30 11:47 to 11:57 p.m. 12/31	.50 11:27 to 11:57 p.m. 12/31	.88 10:57 to 11:57 p.m. 12/31
Calif. Institute of Technology	.25 3:10 to 3:20 p.m. 12/31	.65 2:30 to 3 p.m. 12/31	1.04 2:00 to 3 p.m. 12/31
Topango Canyon Ranger's Station			1.52 3 to 4 p.m. 12/31
Opid's Camp (Near Mt. Wilson)			.84
Wilson Canyon	.52 5:55 to 6:05 p.m. 12/31/33		1.06 5:55 to 6:55 p.m. 12/31
Hoegee's Camp			

AND TIME OF ITS OCCURRENCE			Rainfall for Storm
2 hours	12 hours	24 hours	
1.58 inches 11:02 p.m. 12/31 to 1:02 a.m. 1/1	5.84 inches 1:02 p.m. 12/31 to 1:02 a.m. 1/1	8.36 inches 1 a.m. 12/31 to 1 a.m. 1/1	.....
2.14 inches 11:55 p.m. 12/31 to 1:55 a.m. 1/1	9.21 inches 1:55 a.m. to 1:55 p.m. 12/31	13.19 inches 7 a.m. 12/31 to 7 a.m. 1/1	14.03
1.64 inches 9:52 to 11:52 p.m. 12/31	6.69 inches 11:52 a.m. to 11:52 p.m. 12/31	8.17 inches 11:52 p.m. 12/30 to 11:52 p.m. 12/31	12.00
1.34 inches 9:57 to 11:57 p.m. 12/31	5.30 inches 1 p.m. 12/31 to 1 a.m. 1/1	8.07 inches 2:30 a.m. 12/31 to 2:30 a.m. 1/1	11.04
2.18 inches 1:30 to 3:30 p.m. 12/31	7.98 inches 7:50 a.m. to 7:50 p.m. 12/31	8.53 inches 7:50 p.m. 12/31 to 7:50 p.m. 1/1	12.97
			.....
	7.66 inches 2 p.m. 12/31 to 2 a.m. 1/1	13.94 inches 5: a.m. 12/31 to 5 a.m. 1/1	17.93
			......
		14.76 *inches* 6:20 a.m. 12/31 to 6:20 a.m. 1/1	17.41

August 12, 1891, when 11.50 inches fell in 80 minutes. The other was recorded at Opid's Camp near Mt. Wilson a few years ago (the exact date not at hand) when 1.02 inches fell in one minute, an all-time world record.(1)

The Los Angeles County storm of last December and January did not equal any of the foregoing records, but did set a new California record for 24 hour sustained downfall.(2) At Hoegee's Camp in the San Gabriel Mountains a total of 14.76 inches fell between 6:20 a.m. December 31, and 6:20 a.m. January 1.

While rainfall was general throughout the central and southern part of the state, the records are sufficient to show, without going into too much detail, that a storm of unusual intensity fell upon Los Angeles County, particularly in the mountainous watershed. The second fact of importance to note is that the rainfall was slightly less intense in the watershed back of La Crescenta Valley, as indicated by the records of Sister Elsie Peak and Haine's Canyon stations (Table 1) than in other parts of the San Gabriel watershed

(1) The Opid's Camp record is a newspaper report, as yet unverified. The other records cited are from McAdie (loc. cit.).

(2) Talk by F. H. Hay, chief hydrographer of the County Flood Control District, reported in Pasadena Star-News, January 24, 1934.

where the resultant damage was slight.

The flooding water, gravel and mud, as a result of the heavy rains in the mountains, filled every available channel to overflowing. Washout of bridges and other property damages were reported from various parts of Southern California and the collecting water in the lowlands along the coast, particularly in the vicinity of Venice, partially inundated several small communities. But the greatest damage and loss of life occurred in the communities of Montrose, La Crescenta and Glendale. In Montrose 150 houses were completely destroyed, in La Crescenta, 125, and in Glendale, 96. In addition, many hundreds of homes and other buildings were damaged. The large loss of life constituted the major disaster. Forty-two bodies were found amongst the wreckage or half buried in the silt and mud. A number of missing may well have been washed on out to the sea which was strewn with wreckage and brown with silt and mud for a reported distance of twelve miles beyond the mouths of the Los Angeles and Santa Ana Rivers.

The Character of the Montrose-La Crescenta Flood

A glance at the map (Plate XIV) will indicate the paths of the flood currents as they came from Picken's and Hall's Canyons and as they passed through the residence district of Montrose and La Crescenta. These current directions were mapped after personal inspection on the ground, and with the aid of aerial photograph taken after the flood, by Fairchild Aerial Surveys (A number of these photographs were joined to form the aerial map displayed as plate XV).

All day Sunday, December 31, the runoff from the burnt area roared down the available channels and overflowed many of them. Home-owners were busy putting up sand bag barricades. C.C.C., C.W.A., county and city employees and home-owners worked hastily throughout the day attempting to keep the flow of sediment-laden water within its channels through Montrose and the Verdugo Wash in Glendale. Many bridges were washed out. There was no auto traffic along Foothill Boulevard and many an automobile was abandoned by its occupants as it stuck in the mud-covered streets. Until near midnight this rush of water continued, but damage was largely confined to lost automobiles, debris-filled streets and washed-out bridges and gardens. The rainfall up to this time had been heavy and persistent, but with gradually increasing intensity until it reached a peak (as evidenced by Haine's Canyon and Sister Elsie rain gauges) at about 11:45 p.m.

In all the accounts of those who personally experienced the flood, at about this time (11:40 - 12:00 p.m.) the overburdened streams leaped out of their old channels entirely and tore madly across the shortest distances to the bases of their fans, carrying death and destruction with them. An eye witness who lived in Picken's Canyon reported: "About 11:40 we heard a dull roar reverberate through the canyon. Before we could get to the porch, a flood of water swept through the house - - - all of us were carried far down the canyon. Then from the higher ground we watched - - - a wall of water nearly 15 feet high roared through the canyon carrying with it houses, trees, boulders and people." It was reported that a 50-foot check dam failed in the canyon and precipitated the major flood. It is true that the check dams were nearly all swept out but most of them might have been already washed away, and how much responsibility can be laid to the failure of these is questionable, especially since the crest of the flood occurred in two separate adjacent canyons at approximately the same moment, roughly coinciding with the time of greatest downpour of rain. Other witnesses, and later investigations of high water level fail to indicate such a high "wall" of water, at least not on the fan slopes. But the sudden and nearly simultaneous burst of the two streams into new channels was undeniably caused by a comparatively sudden increase in the amount of flow from the mountain canyons. Additional factors entered in, as will be pointed out later.

Some witnesses gave descriptions of the nature of the fluid mass constituting the flood. It was not a slumgullion type of mud flow, although some phases of it had a consistency about comparable to thick pea-soup.

One person, living on a slightly domed elevation, on Montrose Avenue, did not have the misfortune of others but was in an excellent position to observe. He reported that about midnight, or shortly after, he was startled by calls for help from outside and rushed out to find the north-south street a torrent of muddy water. One person was helping to extricate another from a flow which was about the consistency of "pea-soup", and moving rapidly. In mid-current, which held the middle of the street, a partially demolished four-room house floated and crashed against a telephone pole. A few hundred feet to the east, a~~nother~~ small house floated down and crashed against another where it foundered.

Many houses were completely washed from their foundations (see plate V, fig. 1). The walls of others, perhaps more firmly attached to their foundations, gave way against the increasing pressure of the debris laden fluid on their northern sides and the accumulated mud and rock swept through and out the opposite wall, or if the opposite (southern) wall held, was retained inside in depths of one to three feet of mud and rock (see plate VII).

No samples of the actual fluid were available, but it is likely that it varied considerably. Phases of it may have been similar to that collected in Roger's Creek (east of Pasadena) after the 1924 fire in that area, in which the sand, silt, clay and ash content of the fluid was from 30% to 40% by weight.(1)

The writer has been somewhat undecided concerning the proper designation for a flood of the character here described. Should it be termed a mudflow or a violent stream-flood? Blackwelder(2) in his excellent article on mudflows says: "The descriptions indicate that the mudflow of the semi-arid mountain canyon is intermediate between the better known landslide and the ordinary stream-flood. There are, in fact, all gradations between them." In the same paper Blackwelder reviews a number of described occurrences of mudflows and none of them exactly fit the Montrose case. In reviewing the general characteristics of mudflows he says (pp. 472-473 op. cit.): "The mudflow contains just enough water to swell the clay colloids, reduce internal cohesion, and make the mass slippery........ In most respects the mass behaves much like a lava flow......the various phenomena indicate that it glides or slides over the surface without that internal churning that characterize a rapid stream of water. Irregularities

(1) Hoyt, W.G. and Troxell, H.C.: "Forests and Stream flow"; Am. Soc. Civ. Eng. Proceedings, Aug. 1932, pp. 1037-1066.

(2) Blackwelder, Eliot: "Mudflow as a Geologic Agent in Semi-arid Mountains." Bull. of G.S.A., V. 39, pp. 465-484, 1928.

in the base doubtless cause some commotion, but many of them, such as trees, are sheared off and carried forward." Mudflows also terminate with sharp, abrupt edges, and are deposited in definite sheets which, in some localities where they have recurred with regularity, form distinct terraces.

It is evident from the observations made by the author, that the Montrose-La Crescenta flood was largely a violent, torrential, mountain-stream flood whose waters were overcharged with rubble. Its course was split into definite, radial, stream channels. Its movement was swift. Trees and houses were beaten down by a bombardment of water and boulders and not "sheared off" as would be expected in a thick mud flow. Insecurely attached houses or sheds were carried bodily on the surface. Locally due to rapid settling of debris where obstructions reduced the velocity of the current, and perhaps intermittantly due to the momentary localization of rainfall in the mountains and back of it on the fan the flood assumed a mudflow character. Many of these localized mudflows may have been entirely obliterated by the more limpid phases of the flood. The author believes that even where the flood assumed mudflow proportions there was a large excess of water in the upper portion of the flow, which, being less viscous, rushed onward as a stream-torrent.

The Contributing Causes of the Flood

1. The fire-stripped watershed: Hoyt and Troxell (op. cit.) show that the maximum daily discharge in Fish Canyon after the fire of 1924 increased 1700% and that the maximum peak discharge rate increased to 16 times normal after deforestation. This was not alone due to increased runoff of water, but to actual increase in volume of debris as well. The same principles are applicable to the recemt flood where the peak discharge from the burnt-over watersheds of Picken's and Hall's Canyons may well have been 16 times the normal runoff rate before deforestation. These figures alone serve to show the absolute necessity of conserving our forest cover.

2. The heavy rainfall: As has been pointed out, the rainfall for this 24-hour period broke existing California records, and the peak rainfall coming at the time of the major damage and loss of life was perhaps the "last straw which broke the camel's back" and swelled the already swollen streams sufficiently to cause them to seek new channels.

3. The large amount of debris carried by the streams: This was undoubtedly due to the lack of forest cover whose leafy canopy and matted roots had heretofore

protected the loose soil from erosion. This greatly enlarged amount of available debris after it is washed into the stream channels from the sloping hillsides acts in two ways to increase the tendency towards overflow.

First, debris increases the volume of the stream flow. As has been stated before, the material in suspension may make up as much as 40% of the content. Not only this, but a large amount of debris, too heavy to remain in suspension, comes down as rolling load or traction load. No estimate of the amount of this material is feasible, but adding a reasonable amount to the 40% we might expect the moving material as a whole to be about 60% debris and 40% water. An even more liberal estimate than this for the Montrose flood was made by a County Flood Control engineer who estimated that the flow was 75% debris and 25% water. (1)

Secondly, at any point along the course of a capacity-loaded stream where current velocity is slightly checked, the stream will deposit some of its load thus raising the bed of the channel to a point

(1) F. H. Hay: Loc. cit. in "Pasadena Star-News."

where it may overflow. If the fan has reached an adult stage, a stage at which the stream has already built up the fan to an even gradient with its canyon, that is, at a time when there is no abrupt lessening of gradient from the canyon mouth outward on the fan, this slowing down of stream velocity occurs gradually. But if at any point there is a curve in the channel or an insufficient conduit, a rapid reduction in current velocity and a deposition of some of the load results, thus further choking the channel and leading to overflow. At Picken's Canyon and Montrose Boulevard the conduit under the boulevard was completely choked at the upper end with sediment, absolutely unstratified as if it had all settled at once. In this instance the flow was through a square concrete culvert, 50 square feet in cross section, into a round corrugated culvert, 19 square feet in cross section. Of course, as soon as the flow reached the capacity of the corrugated tube the flow behind it was retarded and the sediment immediately settled. So rapidly did it settle that it completely choked the conduit without any indication of stratification. In fact the rapidly settling debris probably collected on the upstream side of the conduit and flowed into the tube as a thick mud.

It is significant that the town of Tujunga, situated a few miles West on the alluvial fan at the mouth of Haine's Canyon, suffered only minor damage from storm water. Haine's Canyon with a water-shed of 1.3 square miles, about the same as Hall's Canyon, was about half burned over in November and received the same rainfall as Picken's and Hall's Canyons. But at the head of the Tujunga fan a "debris basin"(1) with a capacity of 100,000 yards had been built. After the storm this basin was half filled with about 50,000 cubic yards of sand and gravel, while the partially clarified water had passed off without causing damage.

4. <u>Tampering with natural drainage channels</u>: It was observed that many of the aqueducts under streets in the Montrose area were completely clogged with debris so that the flood water was dammed up behind them and compelled to spread through residence districts. The conduit at Picken's Canyon and Foothill Boulevard was one of the foci for the general spread of the destructive waters. The conduit under the

(1) A "debris basin" is a settling basin which takes the coarser sediments from the water before it passes on through the fan channels.

boulevard was of insufficient size. Eddies produced by the obstructions, and "backing up" of the water retarded the flow of the stream at these points and part of the load was dropped to clog the already insufficient channel. At Montrose Boulevard and Picken's Wash the same effect was noticed, and again at Hall Canyon Wash and Ocean View Boulevard. At the latter place an additional retarding effect was produced by a curve in the channel near the point where the conduit went under the boulevard. With the insufficient conduits clogged, the waters left the aqueduct and took a direct radial course down the alluvial fan, such a course leading through the residence section of Montrose. Picken's Wash also straightened its course and in so doing, took the American Legion Hall and 25 occupants with it.

In view of these facts it seems obvious that some steps should be made to prohibit the building of conduits with a smaller cross section than the natural water channels they occupy. Another suggested improvement to prevent the recurrence of a catastrophe would be a widened direct storm-drain from the mouth of each canyon across its fan to the Verdugo mountain slope. Catchment basins for debris at the mouths of each of the canyons would also be advisable.

Within a few years the natural process of growing vegetation will refurnish the mountain slopes with their protective coverings and thus eliminate the chief cause of the recent flood and the threat of its recurrence in any such violent nature. Even should precipitation of equal intensity recur today, its effects would not be so disastrous as that of last January 1. because much of the loose soil of the water-shed has already been removed, and the amount of rock debris carried in proportion to volume of stream flow will decrease in importance.

Comparison of the Wasatch Flood of 1923 with the Montrose Flood.

Professor Frederick J. Pack of the University of Utah has written a description of a torrential flood at Farmington and Willard, towns situated on alluvial fans at the base of the western slope of the Wasatch Mountains in Northern Utah.[(1)] The physical settings for the Wasatch flood and the Montrose flood were similar. In each case the damage was done by sediment-laden water currents overflowing or leaving entirely their old channels on alluvial fans located at the edges of dissected fault scarps. Pack remarks that "the principal cause of flooding in such places (close to the edge of a stream in an arid region) is, of course, the unequal time-distribution of precipitation."

The Wasatch flood was occasioned by an extremely heavy precipitation of short duration, the most intense of local records, and considerably more intense

(1) Pack, F. J.: Torrential Potential of Desert Waters, Pan American Geologist, V. XL, pp. 349-356, 1923.

although of shorter duration, than that experienced by the Southern California Area. On the other hand the Wasatch Mountains had not been deforested by fire.

According to Pack, periods of flooding on the fans could be divided into three distinct phases: Firstly, a short period of gradually increasing stream volume; secondly, a longer period of "cataclysmic intensity" which consisted of tremendous flowing quantities of rock, waste and water "somewhat resembling that of great mud flows" during which period "the impulses of water seemingly followed somewhat closely the old channels, but the mud flow could not conform ....therefore at sharp turns it left the old channel and made for itself a new course, ...straight ......and broadly V-shaped"; and thirdly, a long period of decreasing intensity during which the flow consisted largely of water corroding the channels, deepening and widening them, and sometimes cutting into the mudflow phase. "The three phases were occasioned respectively by the water that preceded, accompanied, and followed the breaking of the temporary (vegetal debris) dams in the canyon streams."

In the montrose flood there was no general and obvious mudflow period, although locally, where obstructions caused a lessening of the velocity of the stream, and hence an unloading, the bottom portion of the fluid flow must have kept on moving as a mudflow. Such a conception explains the heterogeneous character of the filling material in conduits and houses and particularly in the case of the house pictured in Plate VII which was filled with mud flow material to a depth of two or three feet, whereas the front of the house was practically untouched by water or mud.

Sedimentation by the Flood

The extent and thickness of the sediments:

A rough survey of the thicknesses of the sediments deposited in the overflow of Picken's and Hall's Washes is shown in Plate XIV. The irregular nature of the deposits made it impossible to obtain very accurate data on thicknesses. Also the irregularities of the surface, such as road cuts, retaining walls, fences, gutters, etc., affected the location and thickness of deposits considerably and contributed to the general lack of regularity. Most of the north-south streets were filled with boulders and coarse gravel to a moderate depth of six inches or a foot, but the east-west streets which retarded the flow of fluid were filled to greater depths and with finer sediment. In this respect the character and distribution of the sediments may be considerably different than would be on an alluvial fan unmarred by artificial features. On the other hand, street levels, lawns, etc., as they were uncovered by pick and shovel were convenient to use in estimating depth of deposit. There would be few markers of equal value on any natural unmarred fan surface.

The demarcations of thickness areas were made in the field on the basis of numerous actual measurements and a much larger number of estimates, nevertheless they must be regarded as only rough approximations. Allowing the red area an average of three feet of sediment, the blue area an average of one foot, and the yellow area an average of four inches, surely conservative figures, the total volume of sediment is over 700,000 cubic yards deposited over an area of about 800 acres.

All of this sediment came from two small watersheds, Picken's Canyon with approximately 1500 acres, and Hall's Canyon with approximately 1000 acres. Not considering an inestimable amount of finer sediment which washed through and out Verdugo Wash, to be deposited later on the mud flats of the Los Angeles River or on the Pacific Ocean bottom, this would equal a film of rock and soil averaging 2½ inches in thickness taken from the combined area of the two watersheds. Of course it is not intimated that any such evenness of erosion took place. Gullying, soil slides, etc. characterized the erosion of the watershed.

<u>Stratification and lenticularity:</u>

Visible stratification is discernible in only a few places. In the majority of cases it is evident that even slight check in the velocity of the current precipitated a general unloading, so rapid that there was no size sorting of grains, and hence no stratification.(1) This is particularly true of the thickest deposits (red area of Plate II), where rude lenticularity was the nearest approach to bedding.

In some of the east-west streets and usually toward the outer part of the fan where the deposit becomes less coarse, there are places where rude stratification is discernible, probably caused by the pulsations of back water off the main currents. (See Plate VI, figure 1)

Boulder size and mechanical analyses:

The deposits of an alluvial fan are characterized chiefly by their coarseness, the angularity and slight decomposition of their fragments, and their low degree of sorting. A. C. Lawson(2) proposed the name "fanglomerate" for the coarser deposits of an alluvial fan, and its use has been accepted by many geologists. The lower size limit of "fanglomerate" is analogous to "conglomerate".

(1) See Plate V, figure 2, and Plate VII.

(2) The Petrographic Designation of Alluvial Fan Formations. Univ. of Calif. Pub. in Geol., V. 7, pp. 325-334, 1913.

W. H. Norton[(1)] makes no use of the term "fanglomerate" but classifies such sediments as "bajada breccia" characterizing them as "fringing rock wastes of rugged mountains in desert regions". The writer prefers fanglomerate as a term because it is expressive and specific and, apparently, has priority over "bajada breccia".

In the coarser fanglomerates boulders of tremendous size (Plate VII, figure 1) are found associated with a mixture of sizes of material ranging down to fine sand. In general, coarseness decreases from the apex downwards, and the distribution of the finer materials will be found in greatest abundance at the outer part of the fan. The following table of maximum boulder sizes, arranged in order of increasing distance from the mountain front, illustrates this principle of decreasing coarseness away from the fan apex. According to Rollin Eckis[(2)] this decrease in coarseness is more rapid on small fans than on large

(1) "A Classification of Breccias." Journ. of Geol,, V. XXV, pp. 160-194, 1917.

(2) "Alluvial Fans of the Cucamonga District." Jour. of Geol., V. XXVI, pp. 224-247, 1928, Table I.

ones. In each case in the following table (table 2), measurement of distance is made radially from the crossing of the stream on Foothill Boulevard, this being approximately the apex of spread of the January flood.

Boulders of much greater size than those given in table 2 were found along with them, partially buried in fanglomerate, unmoved by the December 31-January 1 flood. Their presence indicates that floods of greater intensity than the present one had occurred in the earlier history of the building of the fan. One such boulder is 38 feet in circumference and was estimated to weigh close to fifty tons.

TABLE 2

MAXIMUM SIZES OF BOULDERS DEPOSITED IN JANUARY FLOOD

Location	Distance from Foothill Blvd.	Circumference Measurement	Approximate WEIGHT (tons)
1. Picken's Wash & Foothill Blvd.	0 ft.	31 ft. & 25 ft.	32
2. Picken's Wash & Ensenal Street	900 ft.	30 ft. & 20 ft.	23
3. Picken's Wash & Altura Street	1,400 ft.	19 ft. & 20 ft.	11
4. Picken's Wash & One block north of Montrose Blvd.	2,400 ft.	19½ ft. & 13 ft.	5½
5. Picken's Wash & Montrose Blvd.	2,800 ft.	18 ft. & 13 ft.	5
6. Honolulu Ave. & Orangedale	4,600 ft.	12 ft. & 9 ft.	1.6
7. Verdugo Road & Ocean View (from Hall's Wash)	6,800 ft.	9½ ft.	1.2
8. Verdugo Road & La Crescenta (from Hall's Wash)	8,300 ft.	6½ ft.	700 lbs.

Note: Circumference measurements of boulders were made in two planes, approximately at right angles. The average of these two measurements was used to calculate the volume, using the formula for the volume of a sphere ($1/6 \pi d^3$) and assuming a weight of 165 pounds per cubic foot (average specific weight of granite). Hence the formula is:

$$\text{approximate weight in tons} = \frac{1/6 \pi d^3 \times 165}{2,000}$$

It was impractical to make complete mechanical analyses of the sediments to include the boulders of one to three feet in diameter, but a number of samples of the finer gravel and sand were brought into the laboratory and analysed to determine grain size distribution. The results are given in the form of histograms on Plate X. On Plates XI to XIII are given a number of histograms of analyses of various types of sediments which may be compared with those of Plate X.

All of the mechanical analyses exhibited in Plates X to XIII were made by the author with the exception of the one illustrated as figure 1 of Plate XII, taken from a list of analyses by J. A. Udden.(1) The method used in making these analyses is given later in this report.

The first character to be noted about the Montrose samples in all of the analyses is the low percentage of fine material. In the grades below coarse silt there is never over 5% of the total sample, except in number five. Number five is an analysis of the dried

(1) Udden J. A.: "Mechanical Composition of the Clastic Sediments." Bull. G.S.A., V. XXV, pp. 655-744.

mud splashings taken from outside walls under the eaves of a house, and represents an attempt to analyse the character of material held in suspension by the flood waters. Samples one to four represent that material not retained in suspension by the flood waters. Of course it is to be expected that number five would carry a much larger percentage of fines than do the other four samples. Even so, it is probable that number five does not give an adequate representation of the silt, clay, and colloid which washed completely out of the Montrose area and was deposited along the coastal flats and in the Pacific Ocean. In this feature (i.e. very small percentage of finely divided material) alluvial fan deposits are related to all the other deposits for which analyses are here given. Only in such places as lakes, broad mud flats, playas, deltas and quiet ocean basins does one expect an accumulation of fine silt, clay and colloid. "Slumgullion" mud flows and glacial tills might be expected to contain a much larger percentage of silt, clay and colloid even though the sorting closely approaches that of fanglomerates.

The second characteristic of the Montrose samples is that their maxima fall in the coarse or very coarse sand grades. This is also true of the fan gravel from the Mohave Desert (Plate XI, figure 2) and, of course, might occur in almost any type of sediment. The position of the maxima in grade size is largely dependent upon the distance from the apex of the fan, falling in the coarse grades near the apex, and in the fine grades near the outskirts of the fan. Of course there are other factors which would influence the average coarseness of the deposit, among them being the size of the contributing stream, the grade of the fan, and the average grain size of the rocks of the watershed.

As has been pointed out by Udden,(1) analyses of coarse sediments frequently show two maxima which he terms the primary and the secondary maxima. The secondary maximum, always the coarser of the two, may represent that portion which is rolled along the bottom, whereas the primary maximum represents that portion which is deposited from suspension. Whether the interpretation be true or not, poorly sorted sediments commonly show maxima of two grade sizes.

(1) Udden, J. A.: "Mechanical Composition of Clastic Sediments." Bull. G.S.A., V. XXV, pp. 658, 736, 737, (1914) "The Law of the Secondary Maximum", p. 737.

Montrose sample number one has two such maxima, one in very coarse sand grade (1mm-2mm)[1] and the other in small cobble (64mm-128mm) grade. If samples three and four had been extended to include the cobbles and boulders with which they were associated, it is probable that their analyses would also show secondary maxima in the coarser grades.

Assorting[2] is the process of placing each fragment of certain size with those others of its size or grade. Obviously the best assorted sediments are those in which all grains in a single bed are in the same size grade.

According to Udden (loc. cit, p. 655), wind sediments "are less heterogeneous in their mechanical makeup than water sediments are"; but it is evident from his published analyses and from those on Plates XII and XIII of this paper that sediments of large rivers may approach or even surpass in degree of sorting, those from beach or wind-blown deposits.

(1) Wentworth's scale is used throughout this report. See C. K. Wentworth: "A Scale of Grade and Class Terms for Clastic Rocks," Journal of Geol., Vol. XXX, pp. 377-392, (1922)

(2) Some writers prefer "assorting" and others prefer "sorting" but there does not seem to be any reasonable difference in their meaning.

It is obvious from a comparison of the histograms in Plates X, XI, and XII, that fanglomerates are poorly assorted and that sediments of large rivers are well sorted, but there are many uncertainties which enter into an interpretation of such analyses. For instance, the sample of dune sand on Plate XIII (figure 3) could represent a sand 90% of which would go in a grade size between .33 mm and .66 mm, in which case it would show a perfection of sorting much greater than either of the other two beach sands (Plate XIII, figures 2 and 3). Sediments may become well sorted by water or wind and in many different environments. Also poorly sorted sediments may accumulate under several different sets of conditions. It is obvious, then, that grain size distribution is only one characteristic of a sediment, and one which may be identical in sediments produced under entirely different conditions.

I can only partially agree with E. W. Shaw,[1] who says: "Apparently most mechanical analyses barely furnish bases for guesses as to genesis, and often one guess is as good as another." No petrographer would attempt to determine an igneous rock on the basis of its texture alone. He must know its field

[1] Shaw, E. W. : Sorting in Sedimentary Rocks, G.S.A. Bul., vol. XXVIII, p. 925-932, (1917).

relations and its mineralogical content. Even more truly in sedimentary petrology, texture should be considered as only one of many characters; and yet one which should be of great importance, as are field relations and fossil and mineral content, in the deduction of the environmental conditions under which the sediment came into being.

Method of mechanical analysis:

There are several methods of obtaining the grain size distribution of sediments. Thoulet,(1) Marcus Goldman,(2) and Udden(3) are usually cited as the pioneers in the methods of making mechanical analyses. In all cases the coarser sediments, usually those above .06 mm, are run through sieves, while the finer sediments are separated on the basis of their maximum settling velocity in water. Several methods of this finer separation have been devised. The most

(1) Thoulet, J.: "Precis d'analyse des fonds sous-marin actuels et anciens." Paris (1907) and also "Instructiones pratiques pour l'etablissment d'une carte bathymetrique-lithologique sous-marins." Bull. de l'Inst. Oceonograph, No. 169, Monaco, 1910.

(2) Goldman, M.I.: Maryland Geological Survey. Upper Cretaceous Volume, 1916, pp. 113-123.

(3) Udden, J.A.: Mechanical Composition of Wind Deposits, Augustana Library Publ., No. 1, 1898.

prominent of these are: the current elutriation method, the sedimentation method in which the weight of sediment settling on a pan is read at stated intervals of time, and the decantation method.*

The decantation method, because of its simplicity, was used in this study. The details of the method were worked out in 1926 by George E. Ekblaw, then at Stanford University, now with the Illinois State Geological Survey. Essentially the method consists of the following steps:

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* These various methods are discussed in the following publications:

F. G. Tickell: "The Examination of the Fragmental Rocks." Stanford Univ. Press, pp. 10-18, 1931

Arthur Holmes: "Petrographic Methods and Calculations." 1921.

W.W. Rubey: "Lithologic Studies of Fine-grained Upper Cretaceous Sedimentary Rocks of the Black Hills Region." U.S.G.S. Prof. Paper 165-A, 1930.

H. Ries: "Clays, Their Occurrence, Properties, and Uses." 3d edition, pp. 195-207, 1927

(1) Weigh out a sample of convenient size, the size to be determined by the coarseness of its grains, the coarser the sample, the larger it should be to get accurate results. (The sample should be reduced by quartering until the convenient size is obtained).

(2) Thoroughly soak the sample in a beaker of water until all particles are separated. ~~The sample should be reduced by quartering until the convenient size is obtained~~. If the sample is an incoherent sand thorough stirring will be sufficient. If it is a coherent clay or indurated it may be necessary to carefully grind with a rubber-tipped pestle or to treat with ammonium hydroxide or sodium hydroxide in case of siliceously cemented sediments. Sediments with ~~lime~~ carbonate cement ~~and~~ may be treated with weak hydrochloric acid. ~~in case of sediments cemented with carbonate~~. In the present study the sediments were incoherent and broke up readily.

(3) Separate out all gravel and some of the coarse sand either by rapid decantation and washings with a wash bottle or by removing the gravel with the fingers. Then pour the sand and finer material into a large graduate glass or other suitable container holding a 15" column of water. Turn the graduate over with the

palm of the hand on the top so as to thoroughly mix all of the sediment, then turn it back on its base and let it settle for two minutes ($\pm$ five seconds). This will separate nearly all sand from the silt. If the solution is very muddy it will be necessary to take off a five-minute separation first, followed by the two-minute separation. Decant with the use of a 14" glass tube and rubber siphon, being careful to keep the bottom of the tube above the point where it will suck up the already settled sand. To reduce this danger, it is best to have a 16" or 17" column of water, and to draw off the top 15".

(4) Let the silt and clay settle 1½ hours in a one-liter beaker with a five-inch column of water. Nearly all particles above .005 mm. (silt) will settle in this time; the clay will stay in suspension. Decant the clay and let settle overnight in a five-inch column.

(5) Run the silt through the 15" graduate, siphoning off at the end of five minutes. During this time most of the coarse silt (above .03 mm) has settled.

(6) Allow the decanted liquid to settle in the 5" column of water in a liter breaker for 5 minutes. During this time nearly all medium silt (above .015 mm) will settle.

(7) Dry all residues, properly labeled, in small beakers either in a drying oven or over a slow hot plate until they are perfectly dry, then weigh them.

(8) The liquid which is left after the clay has settled over night contains fine clay and colloid and should be evaporated if it appears by the color or cloudiness to contain more than a trace of this very finely divided material.

Theoretical Considerations:

L. Sudry (1) in his monumental work on the transporting power of water and air, shows that seven factors enter in to the determination of the size of grain held in suspension by an upward current of water. They are:

a. velocity of the water current

b. inclination of the current from vertical

c. density of the grains

d. shape of the grains

e. temperature of the water

f. amount of material in solution and

g. amount of material in suspension in the water.

(1) Sudry, L.: "Experiences sur la puissance de transporte des courants d'eau et des courants d'air et remarques sur le mode de formation de roches sédimentaires, détritique et des dépôts éoliens." Annales de l'Institute Oceanographique. Tome IV, fascicule 4, 68pps (1912); pps. 22-27, a discussion of results of experiments on the influence of various factors in determining the grain size of a particle held in suspension by an upward current of water.

In selecting the factors which enter into the falling velocity of a particle in stagnant water, factors (1 and 2) involving current may be eliminated and grain size substituted. Hence the important factors which enter into the falling velocity of a particle in water, in their relative order of importance in the performance of grain size analyses by the decantation method, are as follows:

1). Size of grain:

Sudry's experiments show that the diameter of a particle in suspension in a vertical current of water is proportional to the square root of the velocity of the current (Sundry, loc. cit. p. 22). Since it is recognized that the falling velocity of a particle in a fluid is equal to the velocity of the vertical ascending current which would maintain the same grain in suspension, it follows that the falling velocity of a particle is proportional to the diameter squared.

2). Shape of grains:

Spherical grains settle more rapidly than irregular grains and plate-like grains such as micas settle least rapidly, for the reason that "les grains tombent, soit en tournant sur eux-mêmes autour de leur axe d'allongement, soit en oscillant, soit en demeurant immobiles, mais toujours de manière à présenter la plus grande surface horizontale possible." (Sudry: op. cit., p. 6).

3). Density of the grain:

In a current of given velocity "the diameters are inversely proportional to the square root of the relative densities (absolute densities less density of water)" (Sudry, page 22).

$$\text{If } d \propto \frac{1}{\sqrt{a}} \qquad \text{then } d^2 \propto \frac{1}{a}$$

where d = diameter and a = the relative density.
From 1) above it was found that $V \propto d^2$
Hence falling velocity (V) is inversely proportional to the relative density.

4). The amount of material in suspension:

This is an important factor in increasing the carrying power of muddy streams, but in a laboratory analysis where small quantities of material are suspended in large volumes of water its effect is not important. But it is important to know that the use of much sediment in a small volume of water will materially lower the falling velocity of all the grains in suspension. Sudry's comment is that "the diminution of the falling velocity in a muddy water is therefore very considerable and impossible to explain by the slight increase in density caused by the suspension of the clay in the water." According to Sundry's experiments (page 26 opus. cit.) the relationship is given by the formula $d_n = d_o (1 + 50n^2)$ where d_o = diameter of particle suspended in a vertical current of pure water of density 1.

d_n = diameter of particle suspended in an equal current of muddy water of density $1 + n$

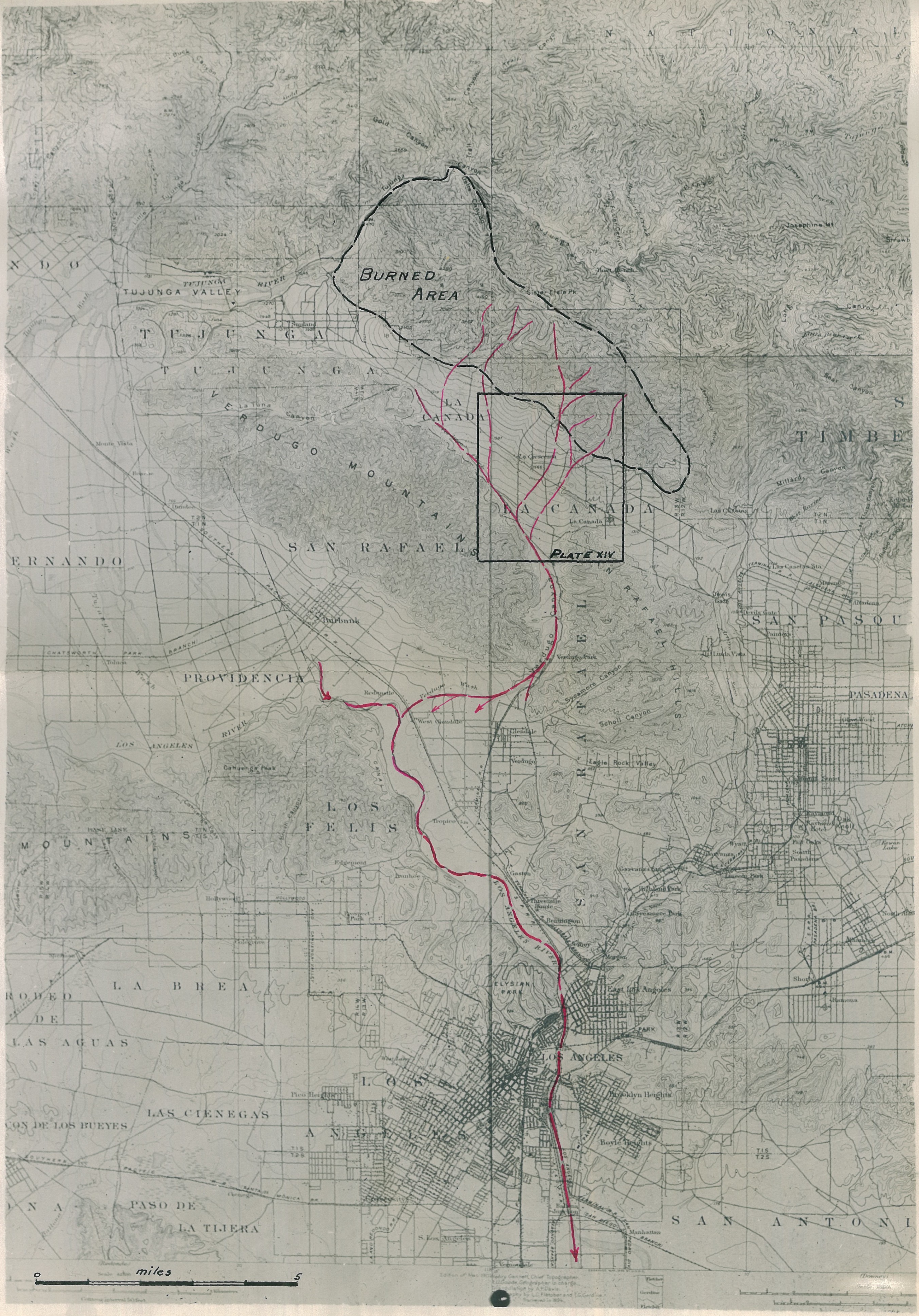
n = excess of density of muddy water over pure water.

The methods of separating fine sediment grades in water, including the method used in this study, but excepting current elutriation, have to contend with the fact that some of the finer grades near the bottom of the column of water will settle in the time it takes the coarser grade to settle from the top; and all methods will have inaccuracies in grain size separation due to the fact that the nearly spherical and the denser (specific gravity) fragments will settle more rapidly than fragments of equal volume, dimension, or weight but of irregular shape or less specific gravity. Considering the fact that these factors affect all sizes in about equal ratio, and that settling velocity in water is perhaps more important in a geologic classification than is size, shape or specific gravity, inasmuch as settling velocity is the principle which largely governed the original sorting of the sediment as it was laid down in nature, the irregularities in grain size separation are perhaps unimportant.

PLATE I

T O P O G R A P H I C

M A P



Topographic Map of a Portion of Los Angeles County - California

Plate I.

EXPLANATION -- Plate II

Fig. 1. A view up Hall's Wash, looking northeastward towards the south flank of the San Gabriel Mountains. The main flood current flowed down the center of the picture although the old wash channel is 1000 feet to the east (through the culvert seen near the right hand edge of the picture). A close up photograph of the white house in the center middle group is shown in Plate IV, fig. 1.

Fig. 2. Honolulu Avenue and Orangedale, Montrose, in the direct course of the flood from Hall's Canyon. Here the water had spread out, the current had less velocity, and large boulders were not so abundant in the deposits. The force, however, was still considerable as the caved in store fronts testify.

PLATE II

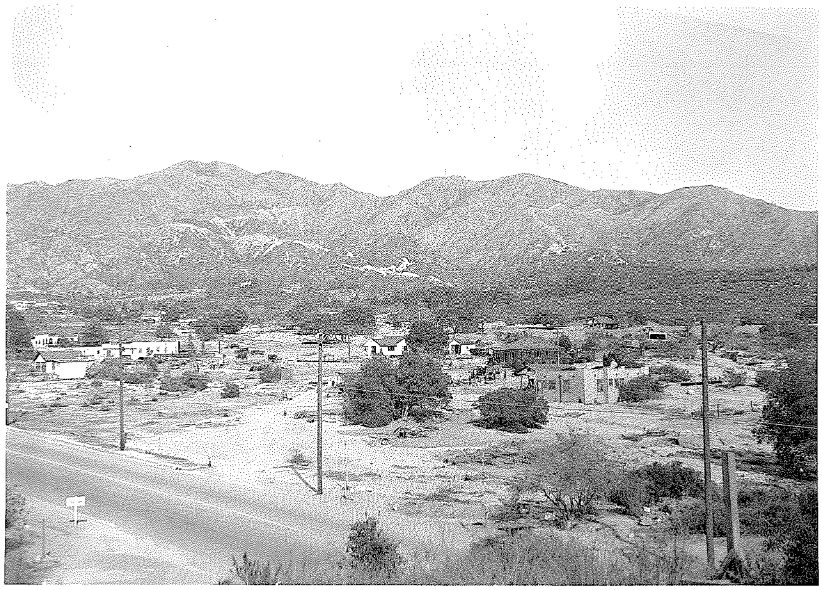


Figure 1.

Figure 2.

EXPLANATION -- Plate III

Fig. 1. Picken's Wash looking downstream from a point about 1000 meters south of Foothill Boulevard. The hummocky surface at the left suggests a mudflow surface. Such surfaces are extremely rare. The large boulder weighs about 10 tons.

Fig. 2. This house is located a little off the path of the main current down Hall's Wash. The house was not filled directly with thick mud as one might assume from the appearance. According to the occupants, they were able to slush around in water up to their knees with comparative ease, which would not be possible had the mud been very thick.

Figure 1.

Figure 2.

EXPLANATION - Plate IV

Fig. 1. One of the houses which received the brunt of the overflow from Hall's Wash, one block South of Foothill Boulevard and one block East of Ocean View.

Fig. 2. Mud splashing on the wall of the American Legion Club House. The splashings, from a new channel of Picken's Wash, serve to indicate the consistency of the fluid. A grain size analysis of this material will be found in fig. 5, Plate X.

PLATE IV.

Figure 1.

Figure 2.

EXPLANATION - Plate V

Fig. 1. The complete destruction and removal of this frame house by flood currents, whereas houses on either side were only partially or not at all damaged by water and mud, ~~This~~ serves to illustrate the confining of currents to definite channels. The location is two blocks south of Foothill Boulevard and ½ block southeast of Rosemont.

Fig. 2. A characteristic non-stratified deposit on Foothill Boulevard 2 blocks east of Ocean View Boulevard. Boulders up to 40 inches in diameter are erratically scattered throughout the 36 inches in thickness.

Figure 1

Figure 2.

EXPLANATION - Plate VI

Fig. 1. Deposits of sand and gravel in an east-west street (Florencita Drive) 1,000 feet west of Ocean View Ave. Total thickness in thickest part is nearly four feet. There is much better stratification in this deposit than in most.

Fig. 2. This deposit in Picken's Wash at Montrose Boulevard, filled the old channel to a depth of 12 feet at its thickest point. The thickness of the deposit is due to the retardation of the stream caused by an insufficient conduit under Montrose Boulevard.

Figure 1.

Figure 2.

EXPLANATION - Plate VII

Figure I. The north side of this house, here pictured, received the brunt of the force of the heavy laden fluid. Note the remains of coarse gravel from splashing on the roof. Only a fluid of considerable density could splash coarse gravel to such a height. Location is at the edge of Picken's Wash, two blocks South of Foothill Boulevard.

Figure 2. Same house as above, inside view. Deposits of unstratified, unsorted material three feet thick testify to the rapidity of deposit from a very heavily laden fluid, probably of mudflow consistency. However, the battered walls and doors indicate that the flood did not "ease" itself in but at same period rushed through with tremendous force and mobility. It is the author's opinion that mudflow phase was a separate and localized event, not a general or continuous phase.

Figure 1.

Figure 2.

EXPLANATION - Plate VIII

Fig. 1. Foothill Boulevard (Michigan Ave.) at Picken's Wash. This 30-ton boulder was left on the road at least 10 feet above the bottom of the Wash. Although it would normally be a part of the rolling or traction load, the boulder was in this instance lifted a number of feet by the flood waters, perhaps a result of the extreme turbidity of the fluid as well as of its velocity.

Fig. 2. This boulder weighs in the neighborhood of 10 tons, a size rather common in Picken's Wash deposits.

Figure 1.

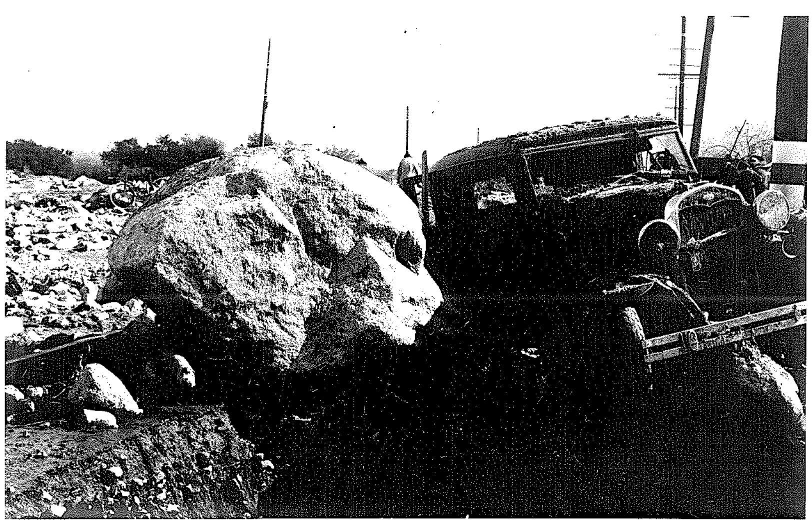


Figure 2.

EXPLANATION - Plate IX

Fig. 1. Private yard at Montrose and Rosemont Avenues, covered with one to three feet of gravel. Piles of gravel at the windows are of material being shoveled from the house.

Fig. 2. Montrose and Ocean View. The buried car is a measure of the depth of sediment.

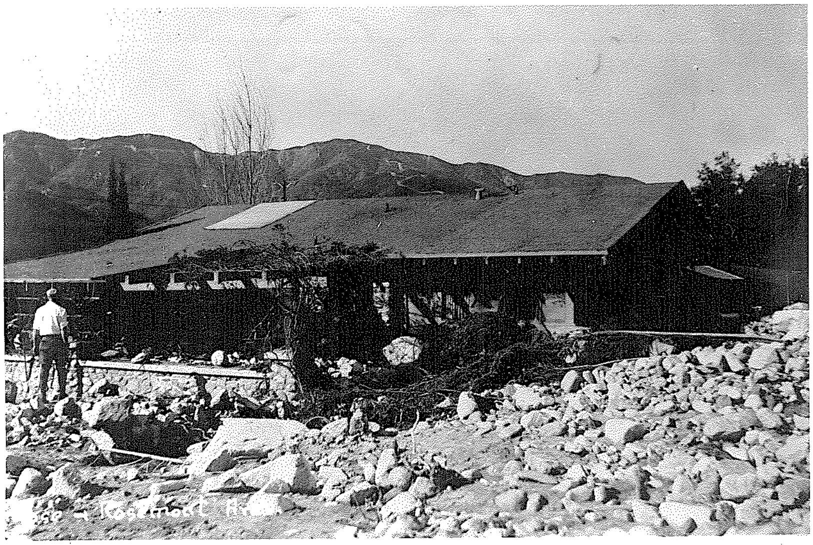


Figure 1

Figure 2.

EXPLANATION - Plate X

Histograms of Mechanical Analyses of Select Samples from the Montrose Flood Area.

<u>Locations of Samples</u>

Sample 1. Sample of a deposit 3 feet deep in a house on Picken's Wash near Altura St. (Same deposit as pictured in Plate VII) Boulders up to 18" are common in this deposit but, because of their size, do not appear recorded in the analysis. This sample, deposited in a place where sudden checking of current occurred, shows the poorest degree of assortment of any of the samples analysed. It was likely deposited in part from a mudflow.

Sample 2. Sample from a fine grained lense in a rudely lenticular gravel deposit at Picken's Wash and Montrose Boulevard.

Sample 3. From rudely stratified deposits four feet deep in thickest part and with scattered boulders up to 3 feet in diameter, collected on Florencita Drive 1,000 feet West of Ocean View. (See fig. 1, Plate VI).

Sample 4. From fine grained lense in Picken's Wash at Montrose Boulevard (near locality of Sample 2).

Sample 5. Mud splashings from the North-west side of a house on the edge of Picken's Wash near Altura St. For a picture of a similar mud deposit see Plate IV, fig. 2.

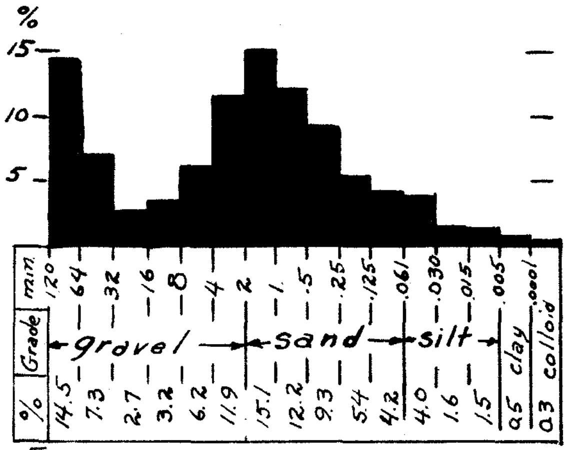


Fig. 1.

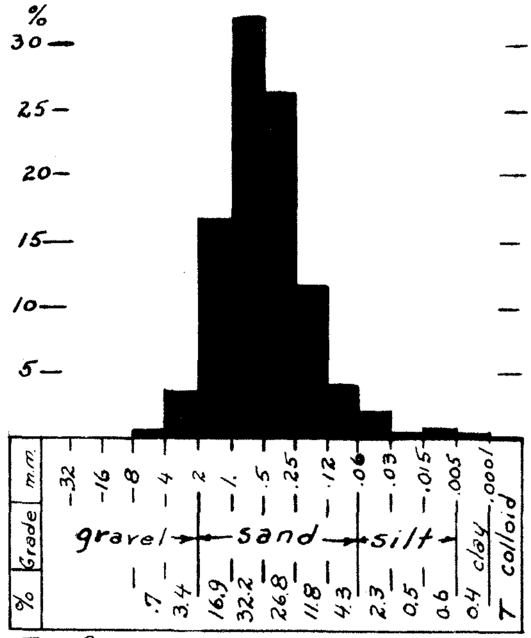


Fig. 2

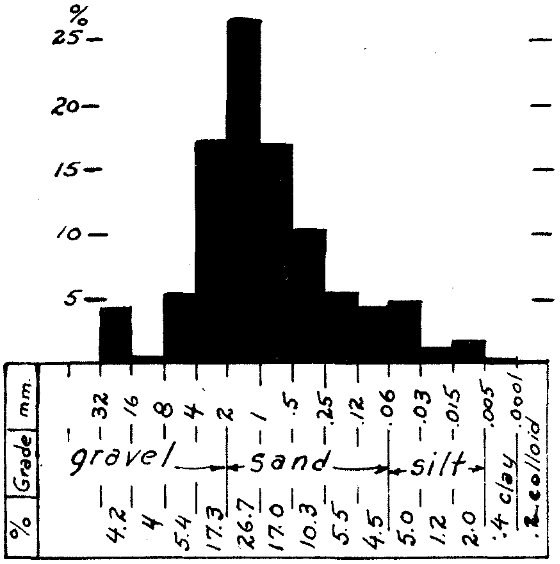


Fig 3.

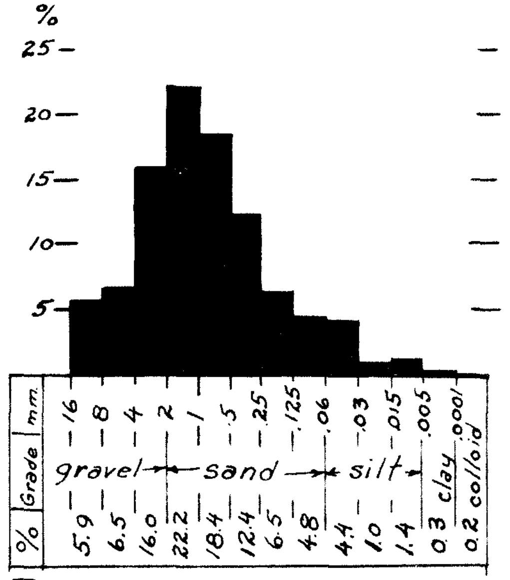


Fig. 4.

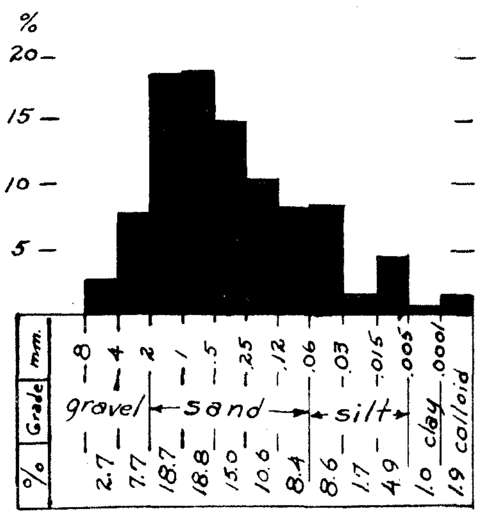


Fig. 5.

EXPLANATION - Plate XI

Histograms of Typical Sediments Exhibiting Poor to Good Sorting.

Fig. 1. A residual, decomposed medium grained granite collected on Montara Mountain in the Coast Ranges about 15 miles South of San Francisco (Number 524 in Stanford University Collection of Sediments).

Fig. 2. Alluvial fan gravel from the Mohave Desert near Barstow (sample number 1196 in Stanford University Collection of Sediments).

Fig. 3. Gravel from Livermore, California, deposited by a moderate sized intermittent stream (Sample number 512 in L. S. J. U. Collection of sediments).

Fig. 4. Sand from the Gila River at Dome, Arizona, At this point the Gila River is a continuous flowing stream of fair size in a desert environment (collected by George Ekblaw).

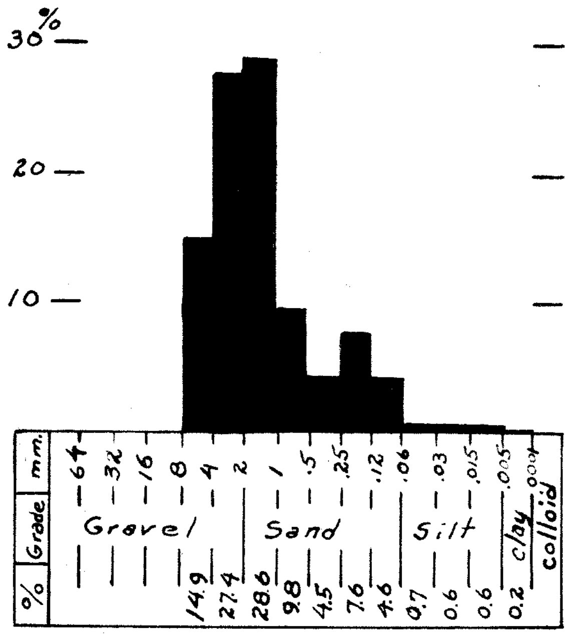


Figure 1.

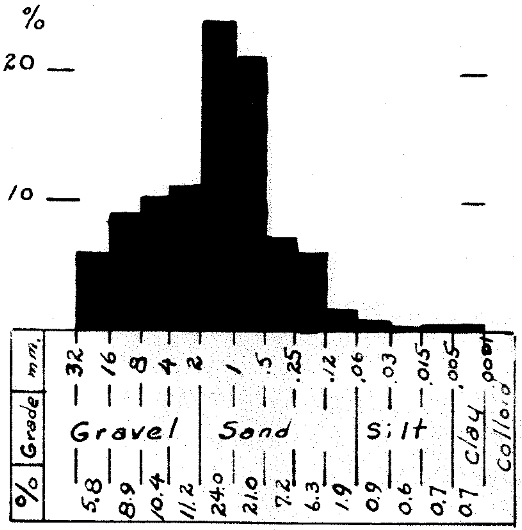


Figure 2.

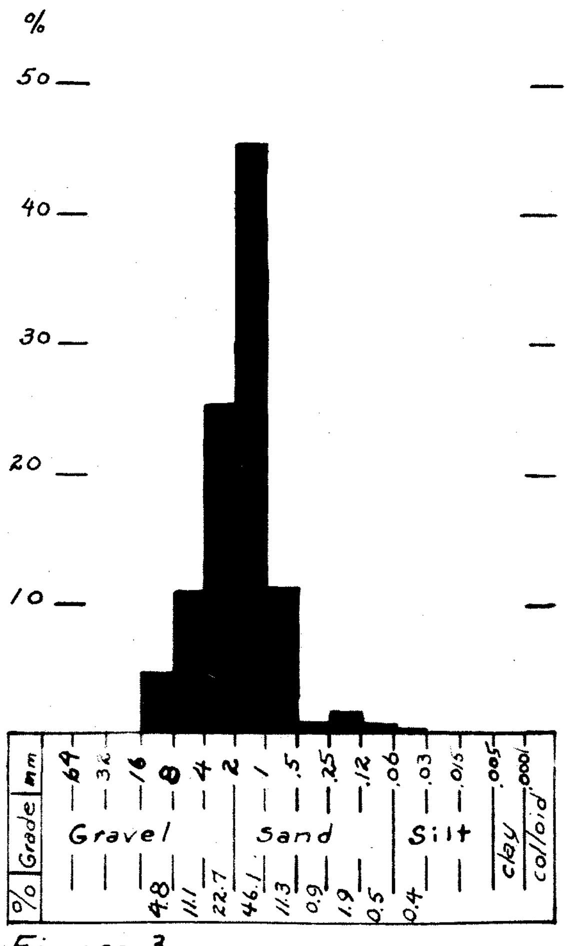


Figure 3.

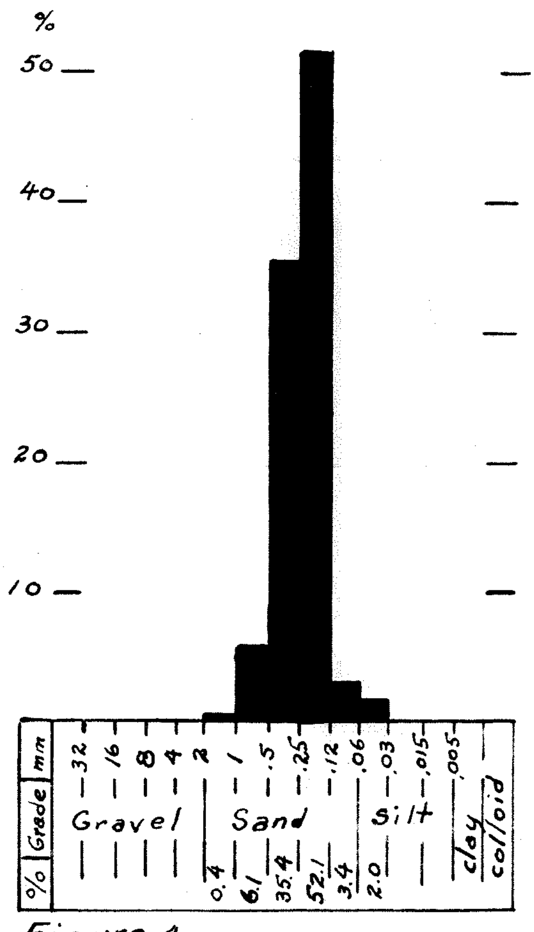


Figure 4.

EXPLANATION - Plate XII

Sediments

Figure 1. River gravel from the Yukon River at Holy Cross Mission, 200 miles above the mouth of the Yukon River, Alaska (Analysis by Udden from: J. A. Udden, "Composition of Clastic Sediments", Bull. G.S.A., V. 25, p. 700, sample #75, table #9).

Figure 2. River silt, Colorado River near Yuma, Arizona, from the river bank at low water (collected by George Ekblaw).

Figure 3. River sand from a fresh sand bar in the Merced River, California (sample number 521 in L. S. J. U. collection of sediments).

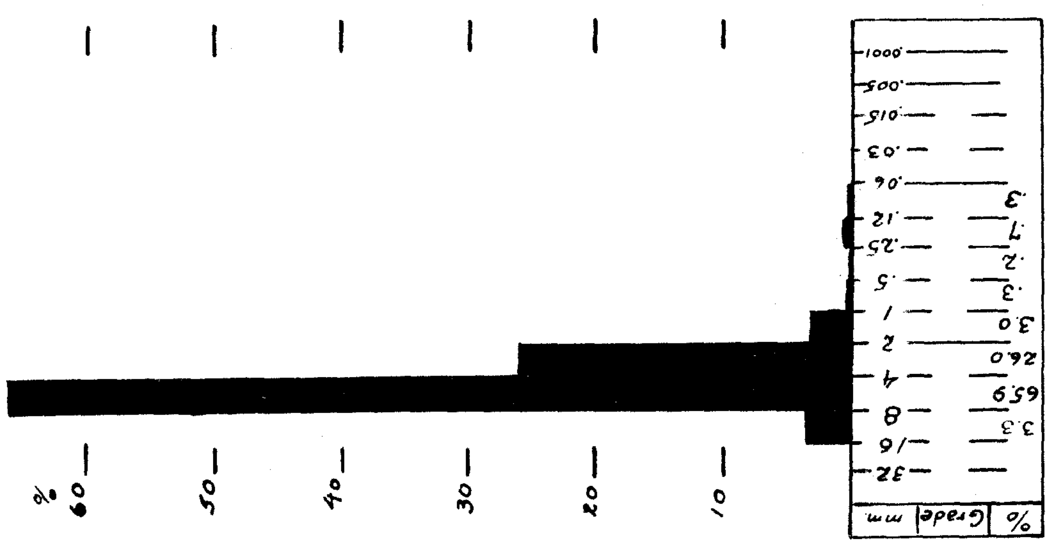


Fig 1.

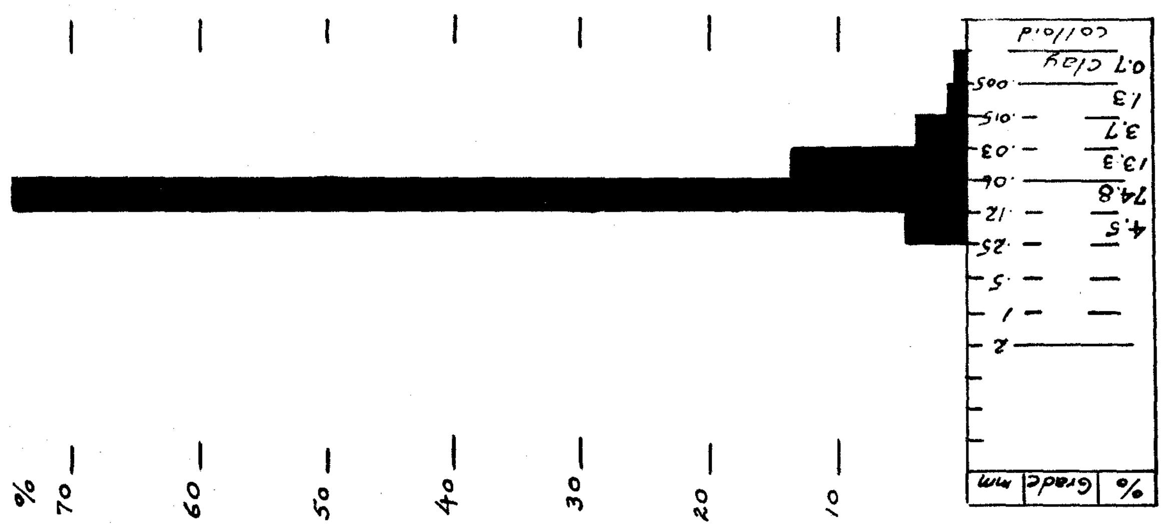


Fig. 2.

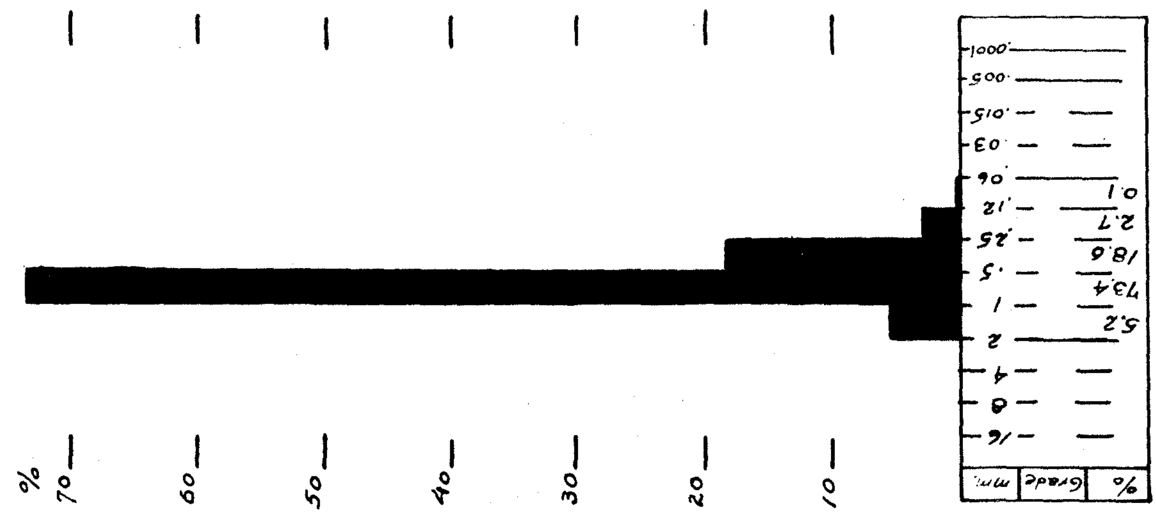


Fig. 3

EXPLANATION - Plate XIII

Beach Sands of the United States

Figure 1. Sand at Montara Beach, California, 15 miles South of San Francisco. This is reworked granite debris weathered from Montara Mountain (an analysis of the residual material is given on Plate XI, fig. 1).

Figure 2. Beach sand from Duxbury, Mass. (This sample is number 555 from the Stanford University collection of sediments).

Figure 3. Dune sand from Dune Park, Indiana. This is in reality a beach sand developed on the southern shore of Lake Michigan and blown up into dunes there by the incessant North wind. (sample number 66 in L. S. J. U. collection of sediments).

PLATE XIII

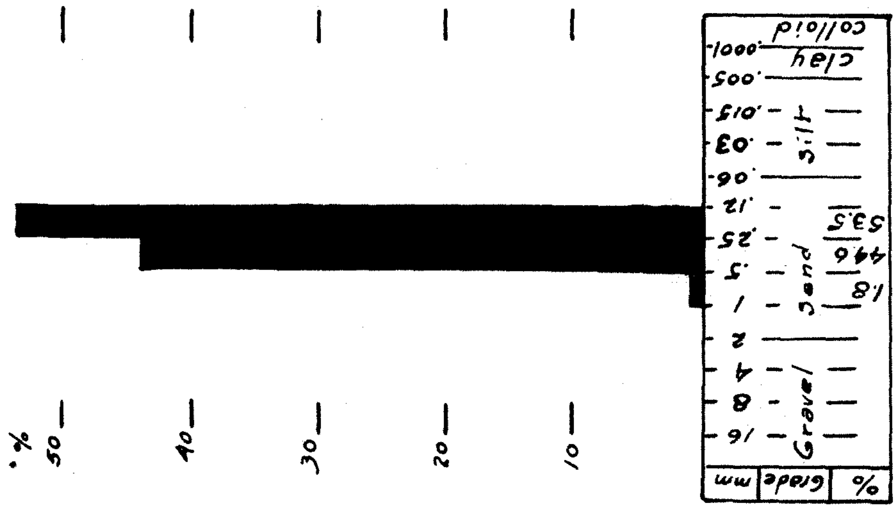


Fig. 3.

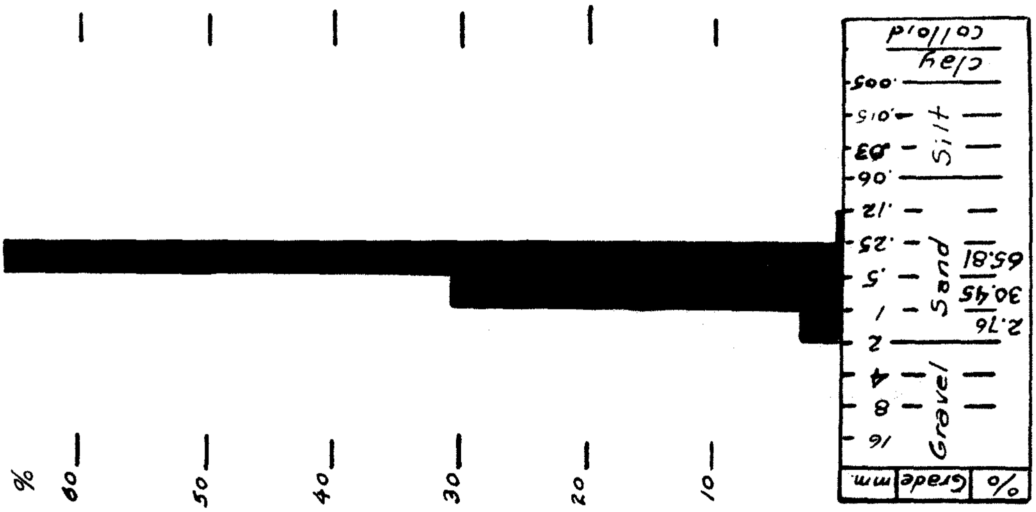


Fig. 2.

Fig. 1.

PLATE XV

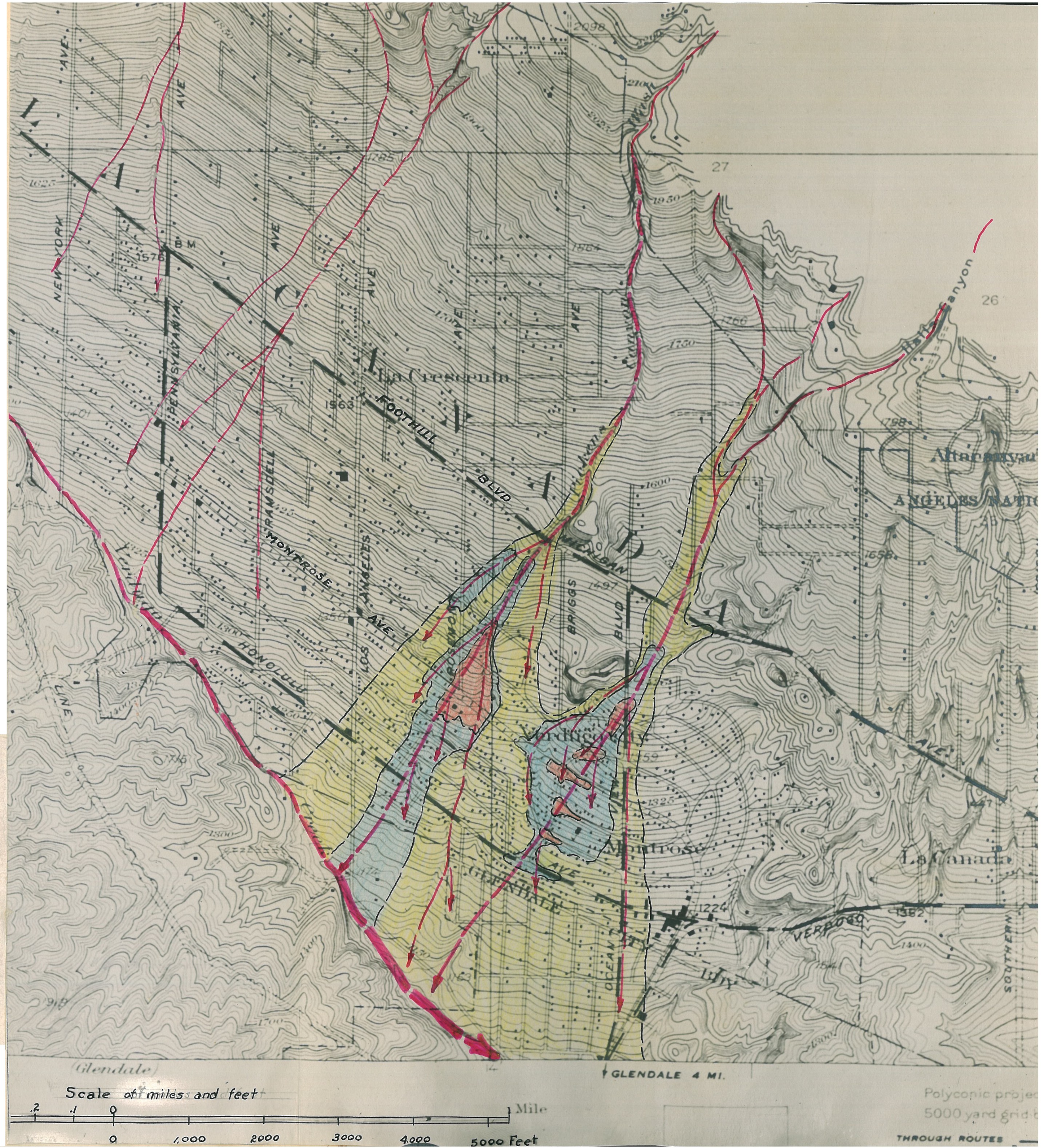
A E R I A L   M A P

MONTROSE and LA CRESCENTA
FLOOD AREA of DECEMBER 31st
and JANUARY 1st 1933-34.

Current directions are shown in red, the thickness of the line roughly indicating the volume of flow.

The approximate, average thicknesses are shown in color as follows:

Yellow = one inch to one foot.
Blue = one foot to three feet.
Red = greater than three feet.



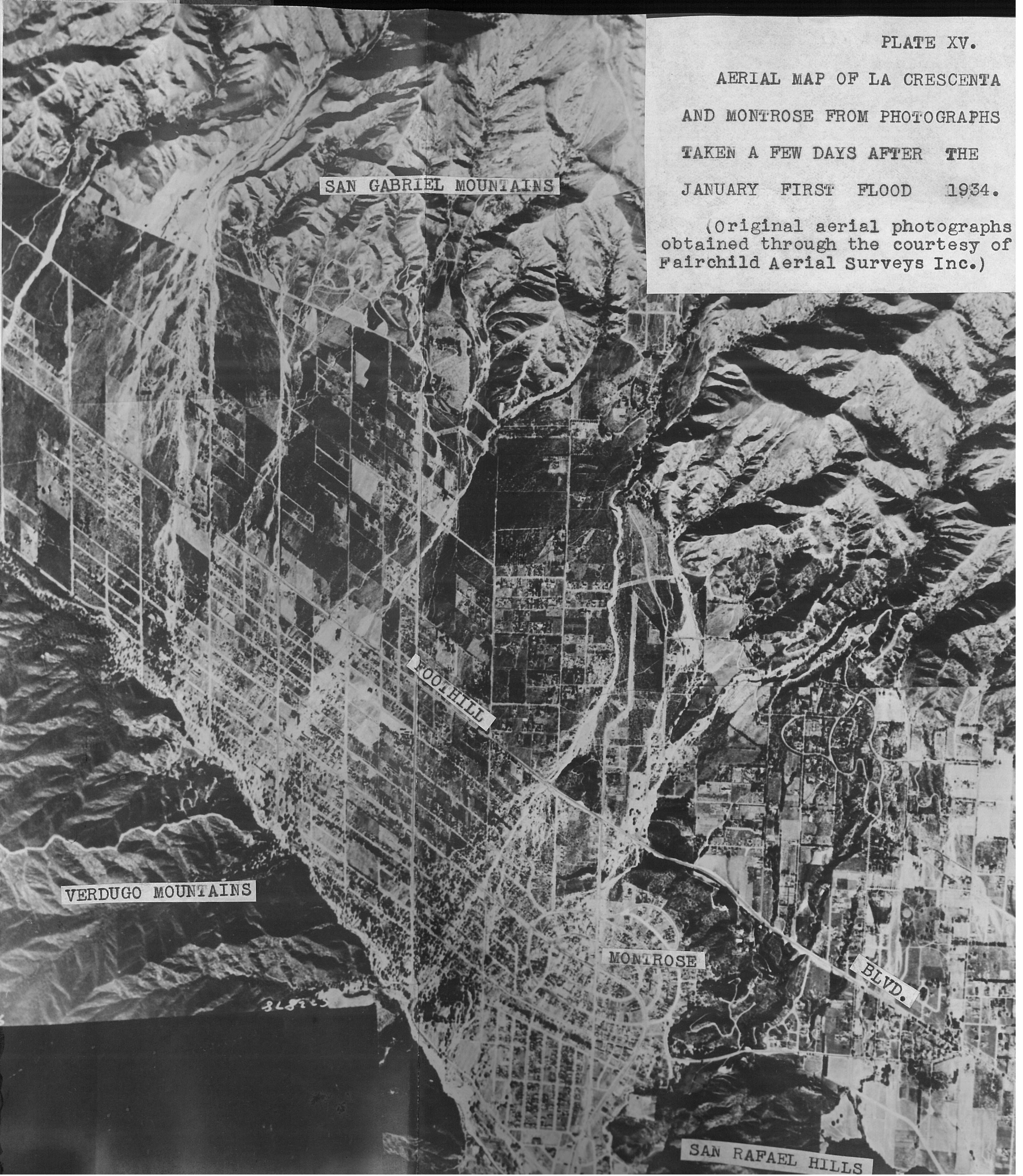


PLATE XV.

AERIAL MAP OF LA CRESCENTA AND MONTROSE FROM PHOTOGRAPHS TAKEN A FEW DAYS AFTER THE JANUARY FIRST FLOOD 1934.

(Original aerial photographs obtained through the courtesy of Fairchild Aerial Surveys Inc.)