GEOLOGY OF THE EL SEGUNDO SAND HILLS

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Master of Science

by
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ABSTRACT

A geologic study was made of an area along Santa Monica Bay composed of old cemented sands overlain by a strip of active sand dunes next to the coast. An eolian origin is assigned to the older sands on the basis of the undulating dune-like topography and the wind-blown characteristics of the sand grains.

The old dunes were formed along successive shorelines of a sea regressing over the marine Upper Pleistocene Palos Verdes sand. Buried soil layers in the dunes indicate changing climates during the upper Pleistocene and Recent epochs. Contours on the surface of the Palos Verdes sand show a long coastal upwarp with an adjoining inland trough.

Characteristic exposures of the dune sands exhibit beds of hard, dark reddish-brown, cemented sands interlayered with softer, light-colored sands. Differential weathering causes the more resistant beds to appear as ridges with an anastomosing character. As these ridges and inter-ridges are found truncating primary cross-bedding, they are believed to be secondary features.

INTRODUCTION

Area

The region investigated is an elongate area of cemented, brownish-red sands with active dunes overlying the older sands along the seaward margin. The dunes extend along Santa Monica Bay from Playa del Rey to Malaga Cove, a distance of 11.7 miles (fig. 1 and pl. 3). Displaying a variable lateral extent, they range from 2.0 miles in width in the northern part of the area to an extreme of 4.2 miles in the southern portion (pl. 1). The active dunes have an average width of 0.4 miles along their extent from Playa del Rey to Redondo Beach.

Following the nomenclature of Poland (1945) the area covered by both the ancient sands and by the active dunes is termed the "El Segundo sand hills" in this paper.

Climate

The coastal area of southern California has been said to have one of the most equable climates in the United States (Marvin, 1930). The temperature range is comparatively small with rainless and moderately warm summers and mild winters during which some sunshine is received almost every day.

The average annual temperature in Los Angeles over a period of 53 years was 63° with an average maximum of 73° and an average minimum of 52°. January was the coldest

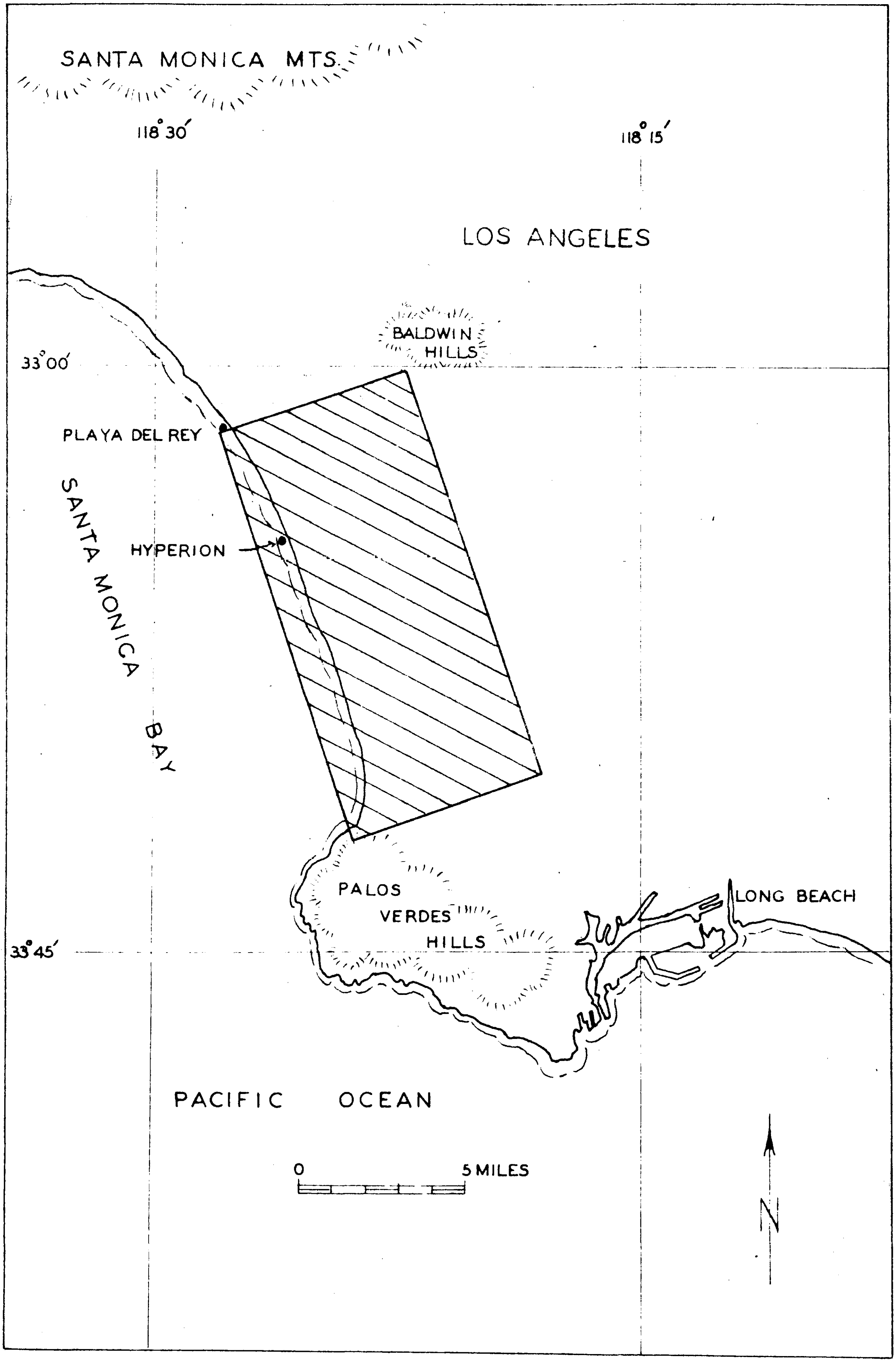


Fig. 1.- General location of the El Segundo sand hills.

Pl. 3.- View of the El Segundo sand hills looking south. The active dunes appear as a light colored belt along the coast with the undulating topography of the older dunes on the landward side.

month with an average of 55° and August the warmest with an average of 71°. The average precipitation over a 53 year period was 15 inches with January being the wettest month and July and August having no rain at all (Marvin, 1930).

The monthly wind velocities, directions, and extremes for the city of Los Angeles over a 70 year period are shown in table 1. (These figures were obtained through courtesy of the Weather Bureau Airport Station, Los Angeles Munincipal Airport.)

Table 1.-Monthly wind averages and extremes in the Los Angeles area, 1876-1946.

Month	Average hourly velocity	Prevailing direction	Highest velocity (mph)	Direction highest velocity
Jan.	6.3	NE	48	N
Feb.	6.5	NE	36	S
March	6.5	W	38	NW
April	6.4	W	34	W
May	6.2	SW	35	W
June	6.0	SW	28	SW
July	5.8	W	21	SW
Aug.	5.7	W	25	SE
Sept.	5.7	W	38	S
Oct.	5.7	W	34	N
Nov.	5.9	NE	40	N
Dec.	6.3	NE	42	SE

Soil and Vegetation

According to the soil survey of Los Angeles County in 1919 (Nelson, et al, 1919), the soil developed on the cemented sands is the Oakley series of wind-laid soils. A brown color predominates, ranging from a reddish-brown to a buff. The soil is low in organic matter and is quite retentive of moisture. Native vegetation consists only of grass and small scrubby brush.

The active dunes have little or no soil development due to their constant movement. Sand verbena, Mesembryanthemum and sand grass are the most common representatives of the sparse dune flora.

Positions of Wells and Samples

The locations of all well logs, test holes, and field locations are shown on plate 2. The small circles are water wells and test holes and the crosses are field locations where samples were taken and examinations made by the writer. The system of location is that used by the United States Geological Survey and is related to the land surveys. For location 3/15-12B2, for example, the first part of the number indicates the township and range (T. 3 S., R. 15 W., San Bernardino base line and meridian), the digit or two digits following the hyphen indicates the section (sec. 12) and the letter indicates the 40 acre subdivision of the section shown in the accompanying diagram.

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

Within each 40-acre tract the wells are numbered serially as indicated by the final digit or digits of the number. Thus location 12B2 is in the NW¼NE½ of sec. 12 and is the second location in that tract to be listed.

Purpose of Study

The study was originally undertaken to determine the causes of a peculiar ridging effect noted in an exposure of the older cemented sands along Sepulveda Boulevard. During the investigation, it was found that the origin, thickness, and sedimentary features of this ancient sand group had been generally neglected in the literature. The purpose of this study is to determine the origin of the sands, to eleucidate the geologic history of the region, and to account for the kind of differential weathering seen commonly in exposures.

Previous Literature

References to the El Segundo sand hills in the literature are sketchy. One of the first workers to note their presence was W. C. Mendenhall in his work on the ground waters in the western coastal plain region of southern California (1906). He believed the sands to be entirely of eolian origin and noted that the inland dunes are not now active.

The wind-blown sands were delimited in the soil survey of the Los Angeles area in 1919. Mention was made that the hilly topography was formed almost entirely of material drifted inland from the sandy ocean beaches.

Rollin Eckis (1934) believed that the hills in the area were formed, in part, as a series of offshore bars upon the ocean floor and were later modified by stream and wind action

W. P. Woodring, M. N. Bramlette, and W. S. W. Kew allot a brief section to the area in their paper on the Palos Verdes Hills (1946). They believed the sands to be wind-laid and to overlie the upper Pleistocene first terrace non-marine cover.

The most recent reference to the sand hills area was made by J. F. Poland, A. A. Garrett, and Allen Sinnott in their unpublished work on the ground waters in the Torrance-Santa Monica area (1947). The cemented sands are considered to be offshore bars modified by wind and stream action.

Method of Study

The area was studied by means of aerial photographs, topographic maps, well logs, and field observations and samplings. Aerial photographs, made as recently as 1946, were available and of great use in interpreting the physiographic problems involved. The logs of about 200 water wells in the area were obtained from the Ground Water Division of the United States Geological Survey to aid in subsurface interpretations. In addition to these, the logs of many test wells put down at Hyperion prior to the excavation there were studied.

The limits of the area are shown on plates 1 and 2. Solid lines indicate contacts determined in the field by soil observation and the dotted lines follow boundaries based on a study of the topography by aerial photographs.

In performing the field work, all the roads in the region were traveled and samples were taken from fresh exposures. Although these samples were limited to the uppermost part of the formation, the writer was fortunate in being able to observe and sample the lower portions in three locations.

Shortly before the beginning of the investigation, the city of Los Angeles began construction of a sewage treatment plant at Hyperion. During this work 14,200,000 cubic yards of sand were removed and used to widen the beach nearby. Much time was spent at the excavation examining and sampling the fresh outcrops. (For location, see pl. 2, sec. 10 and NW¼ sec. 11 in T. 3 S., R. 15 W.) Accurate elevations for many exposures were obtained on the several occasions that the writer accompanied the surveying party of the excavating company.

Near the end of the investigation, the Los Angeles Sanitation District began laying a sewer pipe from Manhattan Beach to points inland beyond the limits of the sand hills area. (For location, see pl. 2, central part of secs. 23 and 24, T. 3 S., R. 15 W. and sec. 19, T. 3 S., R. 14 W.) Shafts were put down at frequent intervals to facilitate construction of the underground tunnel and at one location an open cut was made for a distance of about 100 feet (3/14-19H1). Due to miners' superstitions, the writer was unable to go down the shafts, but her husband, Dr. Richard Merriam, went to the bottom of several. Unfortunately the shafts were shored as they were dug and the samples could be taken only at the bottom from rather poor exposures. The open cut, however, was readily accessible and provided excellent sampling opportunities.

A third area where extensive cuts can be seen is along the Ballona escarpment which forms the north border of the area. An altimeter was used to determine the elevations of the various exposed beds. Corrections of the readings were made by returning to a reference point as often as possible and by calling the local Weather Bureau each evening to obtain the barometric changes for the day.

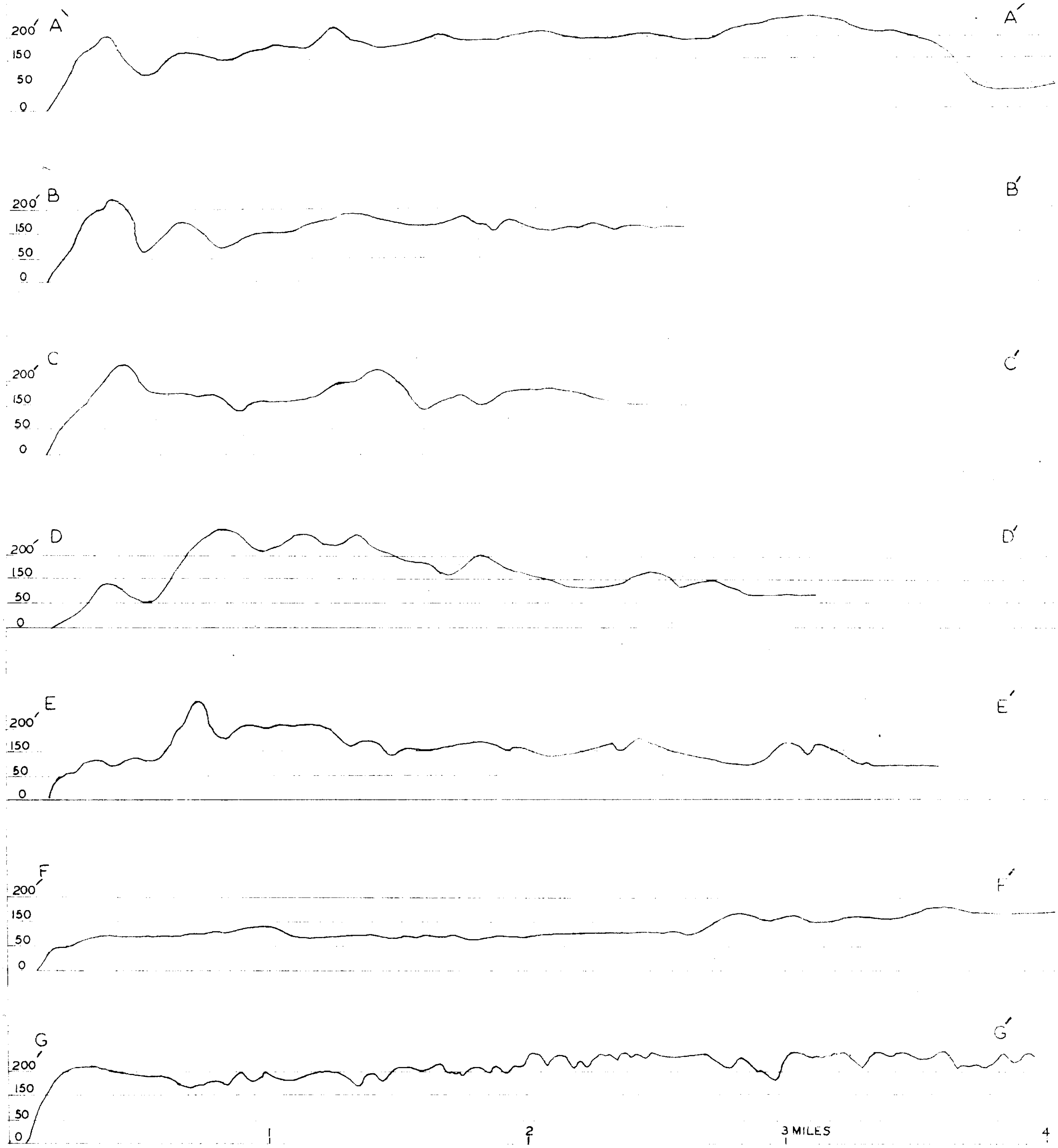
Acknowledgements

The writer's gratitude is especially due Mr. John Mann for suggesting the problem and providing invaluable aid, and to her husband, Dr. Richard Merriam, who did much of the drawing during the final days of preparation and was unfailing in his encouragement. Dr. K. O. Emery, head of the writer's graduate committee, made numerous suggestions throughout the course of the investigation which were of great value. The cooperation of the other members of the committee, Dr. Thomas Clements and Dr. W. H. Easton is heartily appreciated. For courtesies extended to her by Mr. J. F. Poland of the United States Geological Survey and Mr. R. A. Richtor of the California State Department of Water Resources the writer is grateful.

PHYSIOGRAPHY

One of the most interesting physiographic features of the area is the pronounced ridge which extends along the coast from Playa del Rey to Manhattan Beach. From Manhattan Beach to Redondo Beach there is a sharp topographic high about one-half mile inland which may be a continuation of this ridge. Profiles A to E on plate 4 (see pl. 1 for location of profiles) are normal to the shoreline and show the position of this ridge with respect to the coast. The slope on the windward side of this ridge is 6 to 7 degrees while the slope on the leeward is about 18 degrees. Plate 5 shows this leeward side at a point about half way between Manhattan Beach and Hermosa Beach. The rather low leeward slope is due to the holding of the sand by vegetation. On the small active dunes lying on top of the main coastal ridge, the angle of rest is much higher.

The active dunes overlie this ridge and the entire structure resembles a great transverse dune. Superimposed upon this are many small longitudinal dunes which extend in long irregular ridges over the top of the main structure. Bagnold (1943) discusses this phenomenon, whereby instabilities normally found in the crest line of a main transverse dune cause local increases in wind velocity which break the ridge up into a number of barchan or longitudinal dunes. Profile G, plate 4, extends along the crest of the



Pl. 4.- Land surface profiles. For location, see plate 1. A and E are transverse to the coast and F and G are parallel to it.

Pl. 5.- Leeward slope of coastal ridge between Manhattan Beach and Hermosa Beach.

Pl. 6.- Cut being made at Hyperion which shows active dune sands above consolidated ridge.

main ridge and shows the many surface irregularities.

An asymmetrical valley, with its steeper slope to the west lies on the inland side of this coastal ridge. Profiles A and B, plate 4, show its position quite well. Profile F follows the lowest parts of the valley in the northern part of the area where it is most pronounced.

Undrained depressions and rounded or elongated hills are typical of the inland portion of the area. Lines were drawn in the direction of elongation of each of the hills to see if there were some prevailing direction. An alignment parallel to the coast was noted in the ridges lying on the east side of the asymmetric valley (see pl. 1). Elsewhere in the region a heterogeneous arrangement existed.

Effects of erosion by streams can be seen in the inland area and they account for some of the irregularities. However, the undrained depressions and irregular hills appear very much to be the results of wind erosion.

STRATIGRAPHY

Palos Verdes Sand

A marine-cut terrace, correlative with the lowest and youngest marine terrace of the Palos Verdes Hills presumably underlies the Newport-Inglewood belt of hills and the surrounding plains and uplands (Poland, 1945). The Upper Pleistocene Palos Verdes sand was deposited on this terrace during a high level of the sea (Woodring, et al, 1946).

The Palos Verdes formation consists generally of coarse-grained sand and gravel but includes sand, silty sand, and silt. Limestone cobbles are the prevailing constituents of the gravel, but granite and schist pebbles are locally abundant. Molluscs are common in places with an association indicating protected shallow water.

Abundant outcrops of the Palos Verdes sand were observed along the Ballona escarpment. One fossiliferous location about two miles northeast of Playa del Rey has been described. From a study of the fauna, Willet (1937) considered these sands to be the stratigraphic equivalent of the Palos Verdes sand at a Baldwin Hills locality described by Tieje (1926).

Marine sand lying on the platform of the lowest terrace along the coast of the Santa Monica Mountains (Hoots, 1931) contains a fauna like that described by Willet from the locality near Playa del Rey. Woodring, et al (1946) believe this terrace to be continuous with the lowest terrace in the Palos Verdes Hills. The absence of exposures of the sand between the Santa Monica Mountains and Playa del Rey is evidently the result of a slight deformation warping the terrace below sea level (Woodring, et al, 1946).

Exposures were also examined at the Hyperion excavation which are now covered.

Nonmarine Terrace Cover

Upper Pleistocene nonmarine terrace sediments began to accumulate after emergence of a terrace. According to Woodring, et al (1946) the nonmarine deposits of the lowest terrace dip down to the level of the Los Angeles plain at the northwest border of the Palos Verdes Hills and extend northward along the coast to Playa del Rey under a cover of dune sand. No mention is made, however, of actual observations of the cover in the sand hills.

Poland (1947) noted the sediments capping portions of the Santa Monica-Torrance area and described them as non-fossiliferous red sands and silty sands ranging from a few feet to about 20 feet in thickness. Again there is no reference to a specific occurrence of the cover in the sand hills.

There is considerable difficulty in distinguishing the terrace cover from the reddish-brown cemented sands of the area due to the similarity of the two formations.

Poland (1947) also recognized that the upper few feet of the Palos Verdes sand, when modified by weathering, could appear similar to the nonmarine cover.

Cemented Sands

Statements regarding the age and stratigraphic relationships of the reddish-brown sands are scarce. Woodring, et al (1946) believed them to be dune sands which overlie the first terrace nonmarine cover. At their southernmost extent at the northern border of the Palos Verdes Hills the dune sands grade into the cover. They are considered to be of Recent age.

Poland (1947) considers the older sands to be in part marine offshore bars that overlie the Palos Verdes sand. After emergence of the bars they were modified by wind action. Pleistocene (?) and Recent is the age designation given the sands.

Active Sand Dunes

The active dunes overlie the cemented sands in a belt along the coast. They are wholly of Recent age and derive their sands almost entirely from the adjoining beach and to a minor extent from outcrops of the cemented sands.

GENERAL DESCRIPTION OF SANDS

Hyperion Excavation

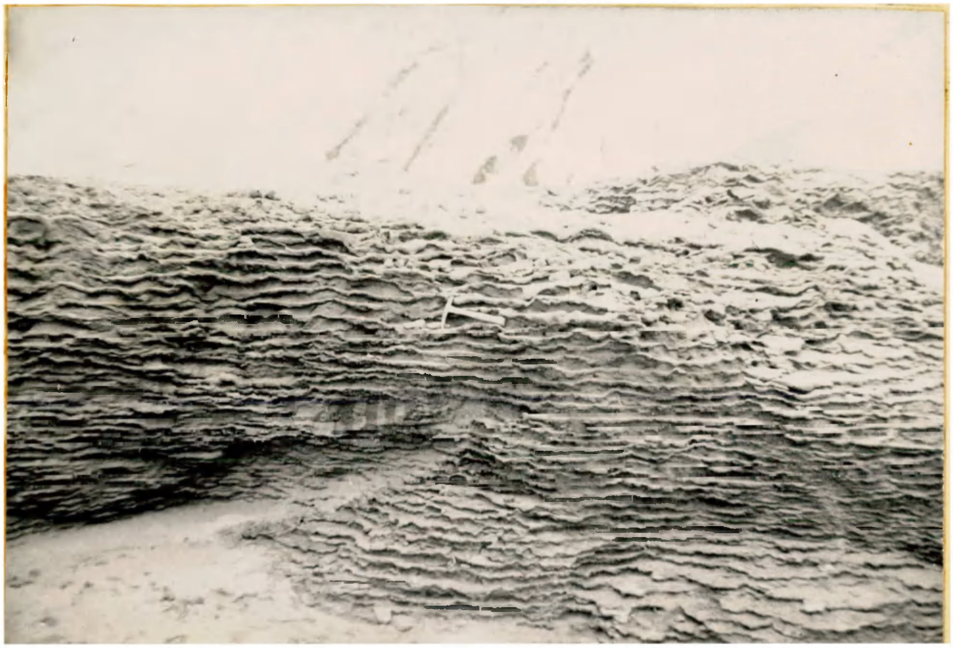
Several stages in the development of the cemented sands were observed at the Hyperion sewer plant excavation. To facilitate a discussion of these stages, numbers have been given to the parts with number one being the lowest discussed and number four the highest. Plate 7 shows the excavation at Hyperion as it appeared during September, 1948. The arrows point to the top of each of the stages discussed.

The active dune sands comprise stage 4, the highest. Their thickness is rather variable, ranging from a few feet near the ocean to as much as 30 feet near the highest parts of the coastal ridge.

Beneath these active sands lies a cemented group whose resistant surface projected through the mask of blown sand throughout the excavation. Plate 6 shows the active dunes lying on stage 3. The top two to five feet of this resistant sand showed no layering and was gray. It appeared to be an old soil surface. Below this hard, unbedded layer, anastomosing ridges formed by highly cemented bands of sand alternating with softer bands were seen. This differential weathering became less evident in the lower part of the section. Plate 8 shows stage 3 with the solid ledge on top and the ridges beginning several feet below the surface and

Pl. 7.- Excavation at Hyperion. Numbers refer to the stages of sand development described in the text.

Pl. 8.- Exposure in Hyperion showing ledge-forming sands on top grading into ridged material which becomes less evident lower in the section.



Pl. 9.- Well-cemented sands in Hyperion exposure.

then fading with depth.

The lower part of this stage was essentially unconsolidated. It was light tan with only a trace of ferruginous cement. Cross-bedding, somewhat ill-defined, was observed in several exposures of this lower part. The thickness of the stage ranged from 30 feet near the highest parts of the coastal ridge to a feather edge as it lensed out near the ocean.

The poor consolidation of the lower part of stage 3 made stage 2 stand out as the best defined cliff-making member of the group. For as long as one year after the last cuts were made, the surface of the bed could be seen projecting through the wind blown sand. Anastomosing ridges and inter-ridges were noted below the cemented grayish top layer. The sands below the ridges were not so highly cemented and the alternating ridges were parallel. This stage was about 25 feet thick near the highest parts of the ridge and lensed out near the ocean.

Stage 1 was the most highly consolidated group seen in the area (pl. 9). The ridges resulting from differential weathering were contorted. Streaks of black sand were noticeable several feet below the top and well-rounded gravel of the Palos Verdes sand could be seen 5 to 15 feet below the surface.

Ballona Escarpment

Good exposures of the well-consolidated sands with anastomosing ridges may be seen in the northeast portion of the Ballona escarpment. The ridged member is underlain by parallel beds of alternating light and dark laminae with streaks of black sand running through it. In many places the top of this laminated sand is highly consolidated and forms a distinctive ledge (pl. 10). The Palos Verdes sand lies below this group. Plate 11 shows the anastomosing sand, the laminated sand, and the gravel exposed along the Ballona escarpment.

Open Cut

A cut 40 feet deep was exposed for several days during an excavation to lay sewer pipe. (For location, see pl. 2, 3/14-19H1.) Cross-bedded sands were seen to intersect the anastomosing ridges as is shown in figure 2. A hard ledge with ridged sand below was found about 10 feet from the bottom and slightly consolidated cross-bedded sands could be seen in the lowest parts of the cliff.

Base of the Cemented Sands

Inasmuch as the nonmarine terrace cover may lie below the cemented sands, it is difficult to determine accurately the base of the consolidated group. The first main lithologic break would be the Palos Verdes sand. However, if the nonmarine terrace cover were present, it

Pl. 10.- Ledge cropping out along Ballona escarpment.

Pl. 11.- Exposure along Ballona escarpment showing anastomosing ridges, laminated sands, and gravel of Palos Verdes age below.

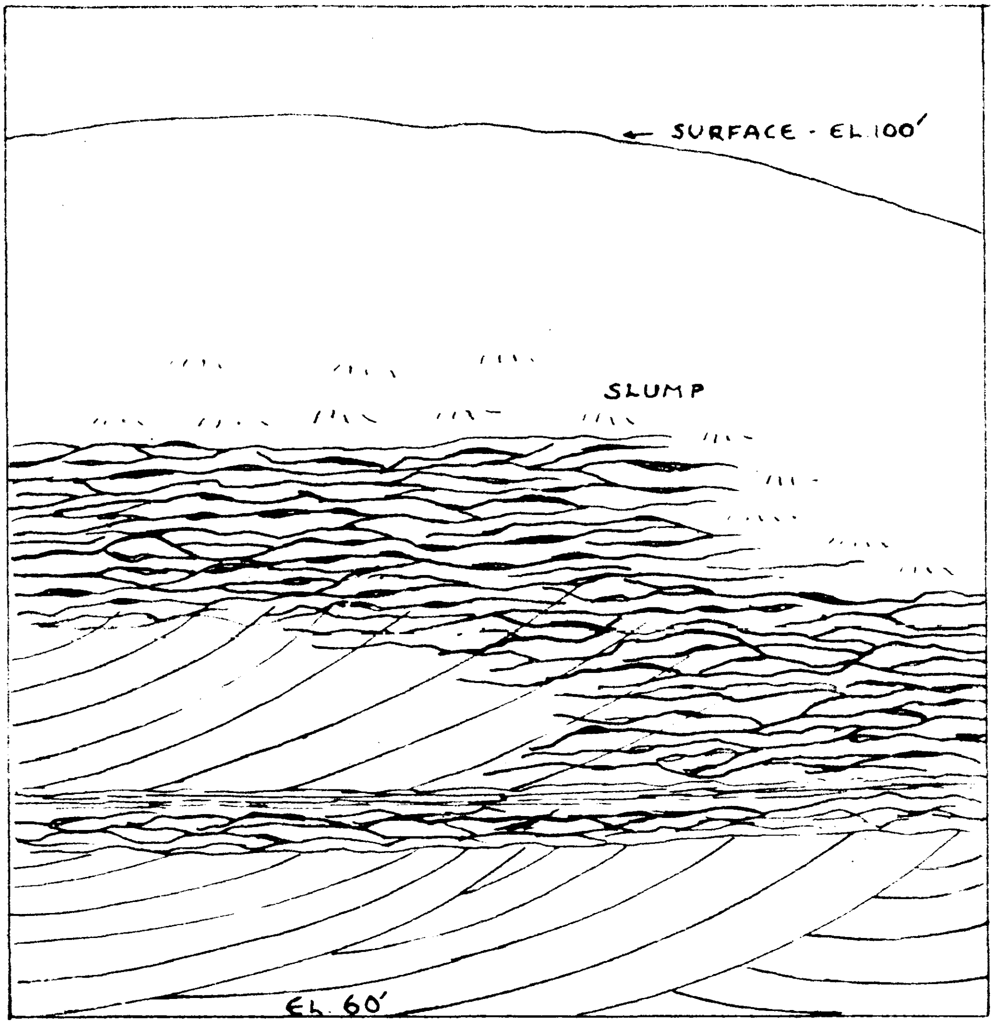


Fig. 2.- Exposure in open cut for sewer pipe showing anastomosing ridges intersecting the primary cross-bedding.

would be quite thin judging from exposures of it in other areas. Thus the slope of the base of the dunes would follow the same general slope as does the surface of the Palos Verdes sand.

With this thought in mind, the well logs were studied quite carefully and the elevation of the topmost silt or gravel bed noted. Due to the varied lithology of the Palos Verdes sand, either the silt or gravel could be its uppermost part. Some additional data was offered by the exposures at Hyperion, the open cut for the sewer pipe,and the Ballona escarpment.

When the elevations of the Palos Verdes surface were determined as closely as possible, contours were drawn on this surface. The results are shown on plate 2. The solid contours are based on many elevations and the dashed lines infer a scarcity of wells in that vicinity. A low ridge parallel to the coast with a trough east of it is shown on the geologic section near the margin of the plate.

The thickness of the lens of sand is greatest near the coast where it reaches 150 feet. The usual range of thickness is from 100 to 120 feet.

It was impossible to determine the elevations for the Palos Verdes sand surface at the north boundary of the Palos Verdes Hills. The strata are quite deformed here and no correlations could be made from the well logs.

Spirit leveling along Manchester Boulevard at intervals between 1925 and 1937 indicates a subsidence west of Lincoln Boulevard and a progressive rising east of Lincoln Boulevard. Grant and Sheppard (1939) determined the rates of annual vertical movement in hundreths of a foot. These annual changes in elevation are shown in red on plate 2. It is interesting to note that the positions of recent subsidence correspond fairly well with low points on the surface of the Palos Verdes sand and that recent rises occur in the direction of increasing elevation on the ancient surface.

Archeological Site

Mr. E. F. Walker of the Southwest Museum uncovered a site of former human occupation at Malaga Cove. Four well-defined cultural levels of occupation were found in the nonmarine terrace cover and what Woodring, et al (1946) called dune sand. The following ideas are drawn from an unpublished paper the writer was privileged to read.

The lowest level was in the upper 3 feet of the nonmarine terrace material. An age of several thousands of years is suggested by the presence of artifacts similar to those found on the terraces of Lake Bonneville and at a Folsom site in Colorado. The occurrence of the level in the Pleistocene terrace cover would also indicate a considerable age. This was evidently a seasonal village. The inhabitants came after the receding of a river no longer present and camped on the partly dried mud and gathered shellfish. Thousands of remains of these molluscs were uncovered in the excavation.

The next level was found in the lowest 2 feet of the sand dune. Metates and manos were the distinguishing artifacts. After about 2 feet of dune sands accumulated these people disappeared.

The next to top layer was about 8 feet thick. In this large stone mortars and pestles and shell fishhooks were found.

The top level was about 15 feet thick with its uppermost part covered by 8 feet of dune sand. It was brought up to the historic period by the presence at the very top of a few small glass trade beads such as the Spaniards brought in about 1800. It is not known when the village was abandoned but when the Franciscan Missions became securely established they removed the Indians from island and coastal villages and brought them to live in the grounds of the missions.

If the top of the uppermost culture level indicates the end of Indian occupation in 1800, it may be surmised that the 8 feet of dune sand above the uppermost culture accumulated in 150 years, or at the rate of about 0.05 feet a year.

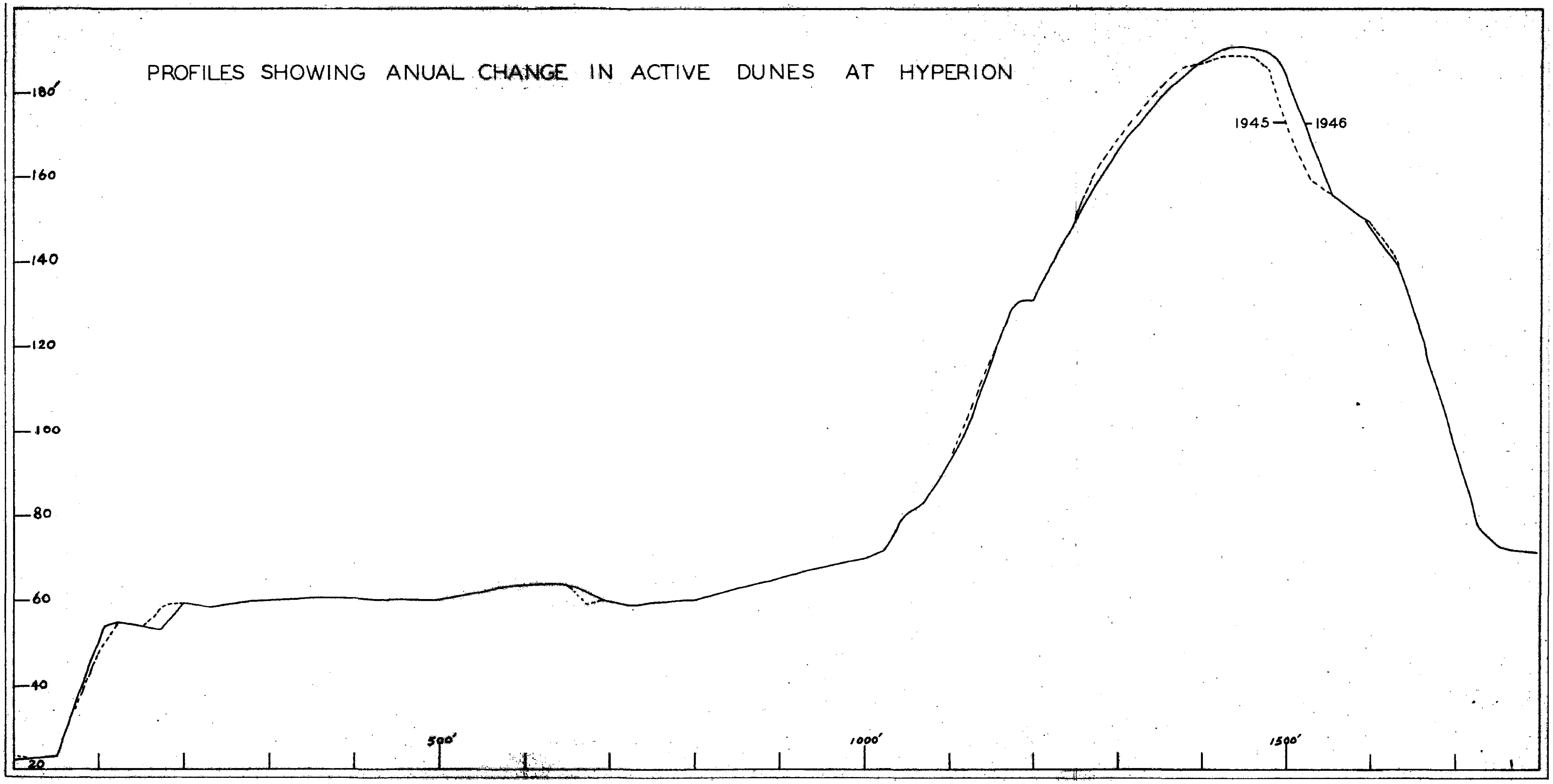
It is hoped that archeologists soon will be able to assign dates to the cultures so that quantitative data on the age and rate of accumulation of the dunes may be obtained.

Rate of Active Dune Movement

In surveying the Hyperion area prior to construction of the Sewage Disposal plant, it was discovered that the sand level around the base of several poles at the Power Plant had dropped about 4 feet in the 7 years since the previous survey was made. The poles are located about 600 feet inland from the beach (3/15-10H4).

Evidence of another shift in sand is illustrated in two profiles of the same line surveyed one year apart (pl. 12). The sand was evidently moved from the windward side of the coastal ridge and carried down the steep leeward slope where further movement inland was retarded by the greater amount of vegetation and the protection from the westerly winds offered by the high coastal ridge. This protection is no longer in existence in parts of El Segundo. In the removal of sand from the Hyperion area, the high coastal ridge was entirely cut through at one place. Oil wells and homes, formerly protected by this ridge, are now experiencing considerable difficulty with wind-blown sand.

The figures given and data from the profile may be summarized as follows:



PROFILES SHOWING ANUAL CHANGE IN ACTIVE DUNES AT HYPERION

Rate of vertical sand removal (at power pole)	0.57 ft. per year
Rate of horizontal movement west of crest	5.00 ft. per year
Rate of horizontal accumulation east of crest	20.00 ft. per year

Although these figures are interesting, they are hardly valid enough to warrent special attention. The general dune outlines have not changed since the early topographic surveys, so a state of equilibrium is evidently approached in many parts of the dunes.

COMPOSITION

Grain Size

Forty samples of the cemented sands were boiled in hydrochloric acid and stannous chloride to disaggregate them. After drying, they were placed in Tyler Standard Screen Scale Sieves and shaken in the Ro-Tap Automatic Shaking Machine of the Allan Hancock Foundation for 20 minutes. The computations of size distribution were according to the Wentworth Grade Scale.

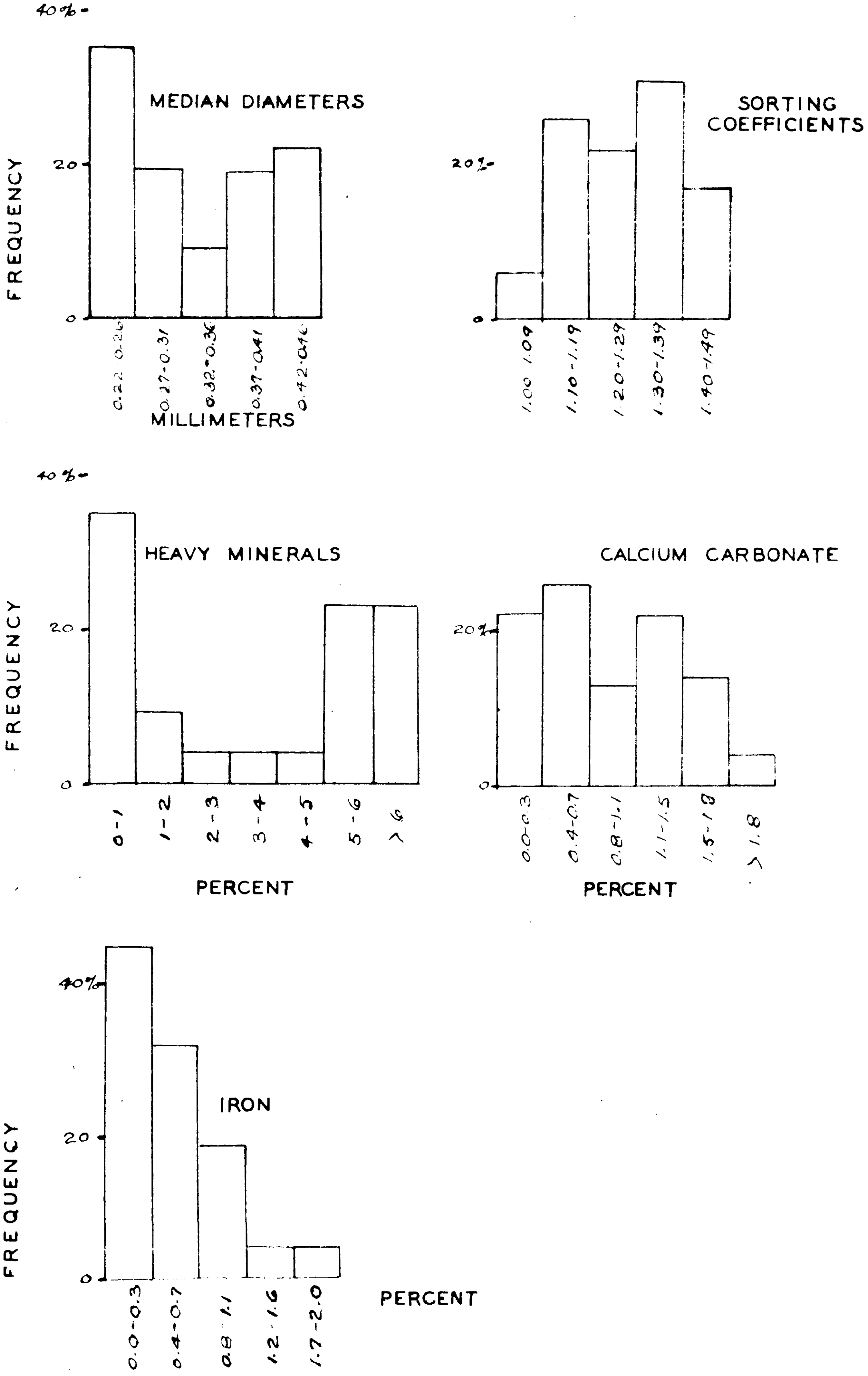
In 72 per cent of the samples, the modal class was $\frac{1}{4}$ to $\frac{1}{2}$ mm; in 18 per cent of the samples it was $\frac{1}{2}$ to 1 mm; and in 10 per cent it was 1/8 to $\frac{1}{4}$ mm. Works by Udden (1898), Cressey (1928), Calver (1940), Lutz (1941), and Bagnold (1943) indicate that most dune sands fall in a size range from 1/8 mm to $\frac{1}{2}$ mm. This range is not so well defined in marine sands due to the greater variability in current and wave capacity. Thus the grain size is not diagnostic in determining the origin of the cemented sands.

It was stated by Udden (1894), Lutz (1941), and Keller (1945) that in dune sands the second largest class percentage falls on the coarser side of the largest percentage and in marine sands it falls on the finer side. In 50 per cent of the samples the grade second in quantity fell on the coarse side of the maximum leaving no conclusions possible.

The median diameters ranged from 0.22 to 0.46 mm with an average of 0.33 mm. The per cent range is shown in figure 3. Velocities of winds necessary to transport sediments of certain average diameters were determined by Thoulet (1908). He found that winds of 2 meters per second (4.6 mph) transport grains of 0.16 mm; winds of 4 meters per second (9mph) will transport grains of 0.33 mm; and winds of 8 meters per second (18 mph) will transport grains of 0.65 mm. By referring to table 1 it may be seen that the average velocity of winds from the west or southwest (the only winds which could transport sand from the source beach to the dunes) is 6 mph. According to Thoulet's work, most of the grains in the area should have an average diameter of around 0.25 mm if of eolian origin. However the constant change of wind velocity, competence, and direction as well as the varying velocities at different heights add complications to Thoulet's theory. The size of the sand available and the distance the grains move would also be a factor.

The median diameter of the cemented sands compared quite favorably to that of the sands of the nearby beach. Kerr (1938) and Foster (1947) found that the median diameters of sands along Santa Monica Bay vary from 0.25 to 0.50 mm. If the cemented sands are marine in origin, they would be expected to compare favorably with the sands on the

FIG.3 COMPOSITION OF SANDS



adjacent beach. If they are eolian, the short transportation from the beach would leave them relatively unchanged and a similarity would be expected in this case also.

The sorting coefficient ranged from 1.08 to 1.49 with an average of 1.26. Figure 3 shows the frequency percentages of the coefficients. The sorting in the cemented sands may be considered quite good as Trask (1932) found that a value less than 2.5 indicates a well-sorted sediment.

Surface Characteristics

Roundness of the grains was determined through a binocular examination of the grains using the Krumbein chart (Krumbein, 1941). Very few round grains were observed. When present, the rounded grains were more than 1 mm in diameter. About 30 per cent of the grains in the ½ to 1 mm group were subround, and the remainder were subangular. Below ½ mm, the grains were subangular to angular, with the angularity increasing with decreasing grain size. In general, 5 per cent of the grains were round, 30 per cent were subround, 40 per cent were subangular, and 20 per cent were angular.

Rounded grains have often been said to be indicative of eolian transportation. Galloway (1922) said that if 50 per cent of the grains are well rounded, no agent of abrasion is indicated. He also mentioned that the lower effective limit of rounding by wind is 0.03 mm whereas that of water is 0.05. Calver (1940) concluded that roundness increases with increasing distance from the beach. However, this increase is negligible and roundness is not a good criterion to use in differentiating dune from beach sand.

As far less than 50 per cent of the cemented sands are well-rounded, they would not fit Galloway's definition of an eolian sand. However, if the sand was derived from the adjacent beach the transportation would have been too short for much rounding to be done. Thus no agent of transportation is established from this criterion.

Only the largest grains (over 1 mm in diameter) showed any appreciable frosting or pitting. There was no frosting on grains less than ½ mm and no pitting on grains less than ¼ mm. In general, 5 to 15 per cent of the grains in each sample were frosted and pitted. Twenhofel (1945) states that only an eolian agency will frost grains less than 1 mm in diameter. If grains greater than 1 mm are frosted either wind or water may be the agent.

Mineral Content

Heavy mineral separations were made using bromoform (Sp. G. 2.87). The percentage of heavy minerals present in the samples varied from 0.21 to 12.8 and averaged 2.55 per cent (fig. 3). The minerals in the light and heavy fractions were determined with a petrographic microscope.

(See table 2.)

Among the heavy minerals, hornblende was the most common, ranging from 10 to 60 per cent. Dark colored, opaque, non-magnetic rock fragments were second and magnetite third. Other heavy minerals present were epidote, zircon, titanite, garnet, actinolite, clinozoisite, chlorite, muscovite, tremolite, and tourmaline.

In the light fraction, quartz was most common, varying from 60 to 80 per cent. Rock fragments and feldspar were next in abundance, with the rock fragments as high as 25 per cent and the feldspars as high as 20 per cent. Chalcedony was also present in small amounts in many samples.

To determine the calcium carbonate content, the samples were leached with dilute hydrochloric acid and the weight loss calculated. The amount present ranged from 0 to one extreme case of 6 per cent. The average for the samples was 1.06 per cent (fig. 3).

The reddish-brown color of the sands was found to be the result of the presence of iron oxide. Therefore quantitative tests were run on 29 of the samples to determine the iron content. In the process, the sample was heated to the boiling point in hydrochloric acid and the ferric iron reduced by adding stannous chloride drop by drop until the yellow color disappeared. The sediment was filtered off and the filtrate titrated with potassium permanganate. The

Table 2

	Relative abundance in heavy mineral fraction													Relative abundance in light mineral fraction		
	HORNBLENDE	ROCK FRAGMENTS	MAGNETITE	EPIDOTE	ZIRCON	TITANITE	GARNET	ACTINOLITE	CLINOZOISITE	CHLORITE	MUSCOVITE	TREMOLITE	TOURMALINE	QUARTZ	ROCK FRAGMENTS	FELDSPAR
2/15-25C4	A*	C*	R*	R	R	-	-	R	-	-	-	-	-	A	C	R
2/15-25C4	C	C	C	-	-	C	C	-	-	-	-	-	-	A	R	R
2/15-25C4	A	-	C	R	R	-	R	-	-	R	R	-	-	A	R	C
2/15-25C4	R	-	A	-	R	R	R	R	-	-	-	R	-	A	C	R
3/14-19H1	C	C	C	R	R	R	-	R	-	-	-	-	-	A	R	R
3/14-19H1	C	R	C	R	R	R	R	-	-	-	-	-	-	A	R	C
3/14-19H1	A	R	-	R	R	R	-	-	-	-	-	-	-	A	C	R
3/14-19H1	A	C	C	R	R	R	-	R	-	-	-	-	-	A	R	R
3/14-19H1	A	C	C	R	-	R	-	-	-	-	-	-	-	A	R	R
3/14-19H1	A	C	C	R	-	C	-	-	-	-	-	-	-	A	R	R
3/15-10H3	C	C	A	R	-	R	R	-	-	-	-	-	-	A	C	C
3/15-10H3	C	C	A	C	-	R	R	-	-	-	-	-	-	A	C	R
3/15-11E6	C	C	A	C	R	R	R	-	-	-	-	-	-	A	R	R
3/15-11E6	C	A	A	R	R	-	R	R	-	-	-	-	-	A	C	R
3/15-11E6	R	A	A	R	R	R	-	-	-	-	-	-	-	A	C	C
3/15-11E6	C	A	A	R	R	-	R	-	-	-	-	-	-	A	R	R
3/15-24H1	R	C	C	R	R	R	R	R	-	-	-	-	R	A	C	R
3/15-24H1	C	A	C	C	C	C	-	-	R	-	-	-	-	A	R	R
3/15-24H1	C	A	R	R	R	R	-	-	-	-	-	-	-	A	C	R
4/14-5C1	R	A	R	R	R	R	-	-	-	-	-	-	-	A	C	C
4/14-5C1	C	C	R	R	R	R	R	-	-	-	-	-	-	A	C	C
4/14-18R1	A	C	R	R	R	R	-	-	-	-	-	-	-	A	C	R
4/14-18R1	C	A	R	R	R	R	R	-	-	-	-	-	-	A	C	R

*A - abundant
*C - common
*R - rare

iron was found to vary from 0 to as high as 2.3 per cent with the average amount being 0.63 percent (fig. 3).

Fragments of small highly comminuted mollusc shells were seen in many samples. One sponge spicule and a piece of a bryozoan were also found. More accurate identification was impossible due to the fragmentary nature of the specimens.

SEDIMENTARY FEATURES

Cross-bedding

Cross-bedding was noted at several locations. It appeared to be of an eolian type in that the truncating planes were not parallel but had varying dips. Twenhofel (1939) believes this to be the essential difference between eolian and aqueous cross-bedding. Figure 2 shows the cross-bedding in the open cut where dips as high as 40° were observed.

Ridging

One of the most interesting features and the one that first brought the writer's attention to the area is the ridged appearance of the exposures. Exposed faces consist of dark reddish-brown layers of variable thickness and undulating character, separated by softer lighter colored sand. The darker layers are sufficiently resistant to erosion so as to appear as ridges, giving the exposed face a step-like appearance. Figure 4, C is a line drawing of a typical exposure, and plate 13 shows a recent cut. Plate 14 shows a very old exposure which still exhibits the ledged surface.

Measurements of the thickness of the beds were made in 10 exposures. The average thickness of the ridge sand was 22.3 mm and that of the inter-ridge, 41.6 mm. The range of thicknesses for the ridge was 20 to 40 mm and for the inter-ridge, 12 to 150 mm.

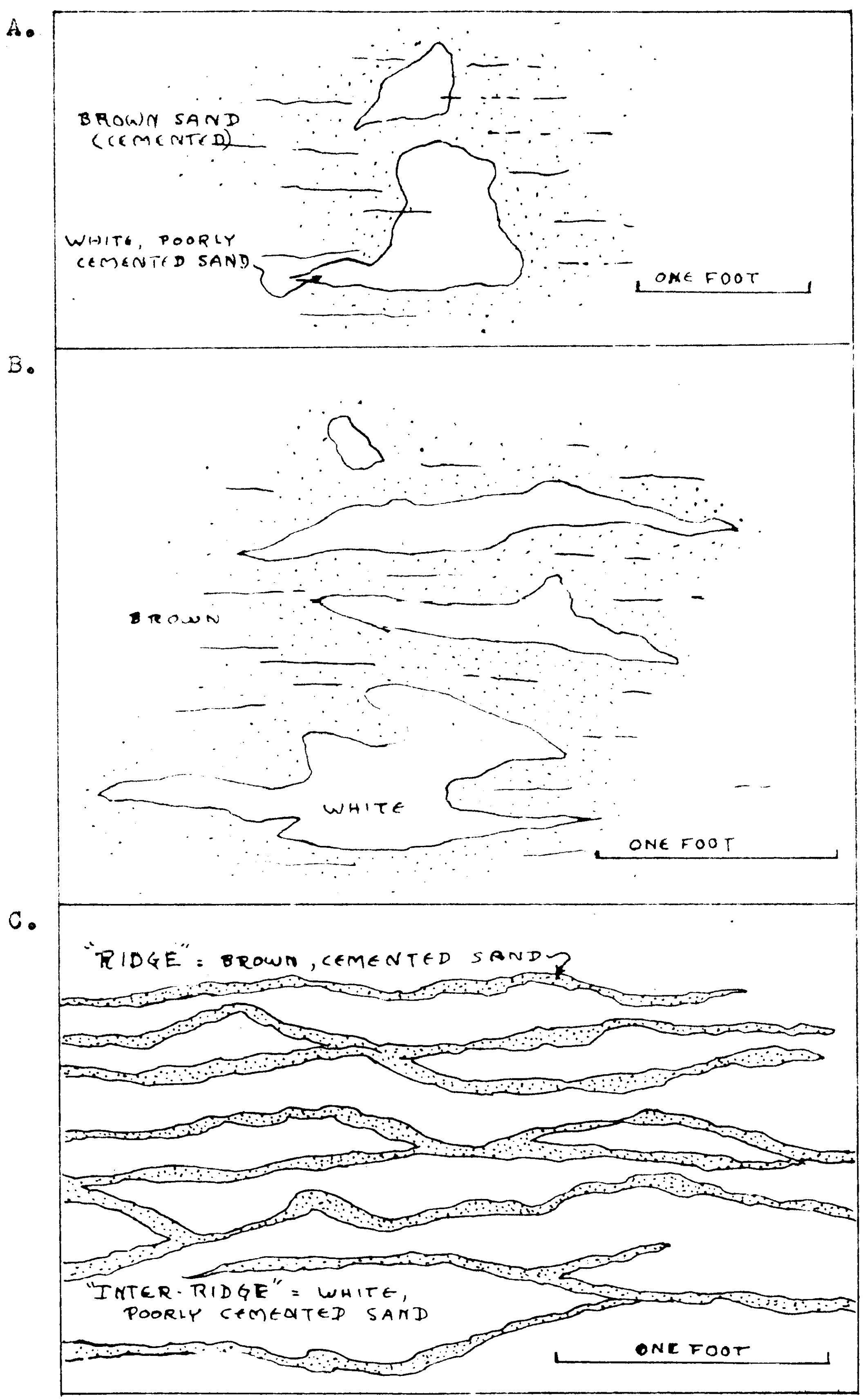


Fig. 4.- Ridge and inter-ridge structures and similar features.

Pl. 13.- Anastomosing, well-cemented ridges with softer layers between.

Pl. 14.- An old exposure of the ridged sands.

A feature a bit different from the ridging was seen at the base of one of the shafts for the sewer pipe 25 feet below the surface (3/15-24H1). Instead of the alternating ridges, there was a solid brown portion with irregular lenses of a light colored, less consolidated sand. Nearby, a solid light colored portion enclosing lenses of brown sand was seen. Line drawings illustrating these features are shown in figure 4, A, B and figure 5, A, B, C.

Another cement variation was seen along some of the cliffs of the Ballona escarpment. An irregular stain similar to that of the ferruginous cement appears to have been washed down the cliff from a higher cemented formation. (See pl. 15.)

Whenever well-defined cement variations were seen, separate samples were taken of the highly cemented and softer samds to determine what variation was responsible for the difference. After all of the samples were analyzed, separate studies were made of the two types of sand. The samples well be referred to as ridge and inter-ridge sands for convenience though one pair was taken from the cement variations at 3/15-24H1 described above. Five typical pairs were chosen for detailed study in this report.

Figure 6 is a chart of the mineral content, percentage of heavy minerals, percentage iron, sorting coefficients and median diameters of the five pairs. The samples are arranged with the softer sand shown first and the well-cemented member

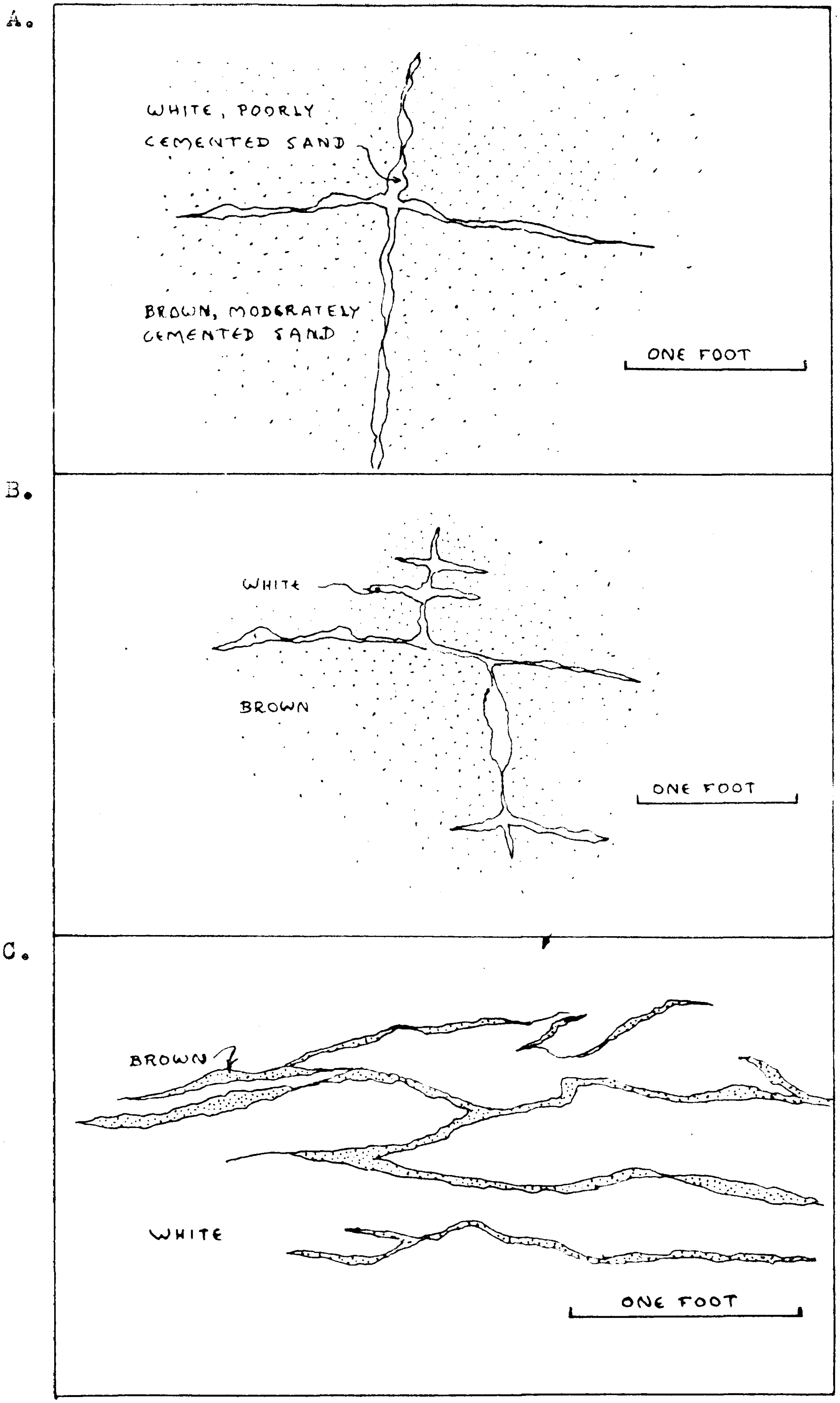
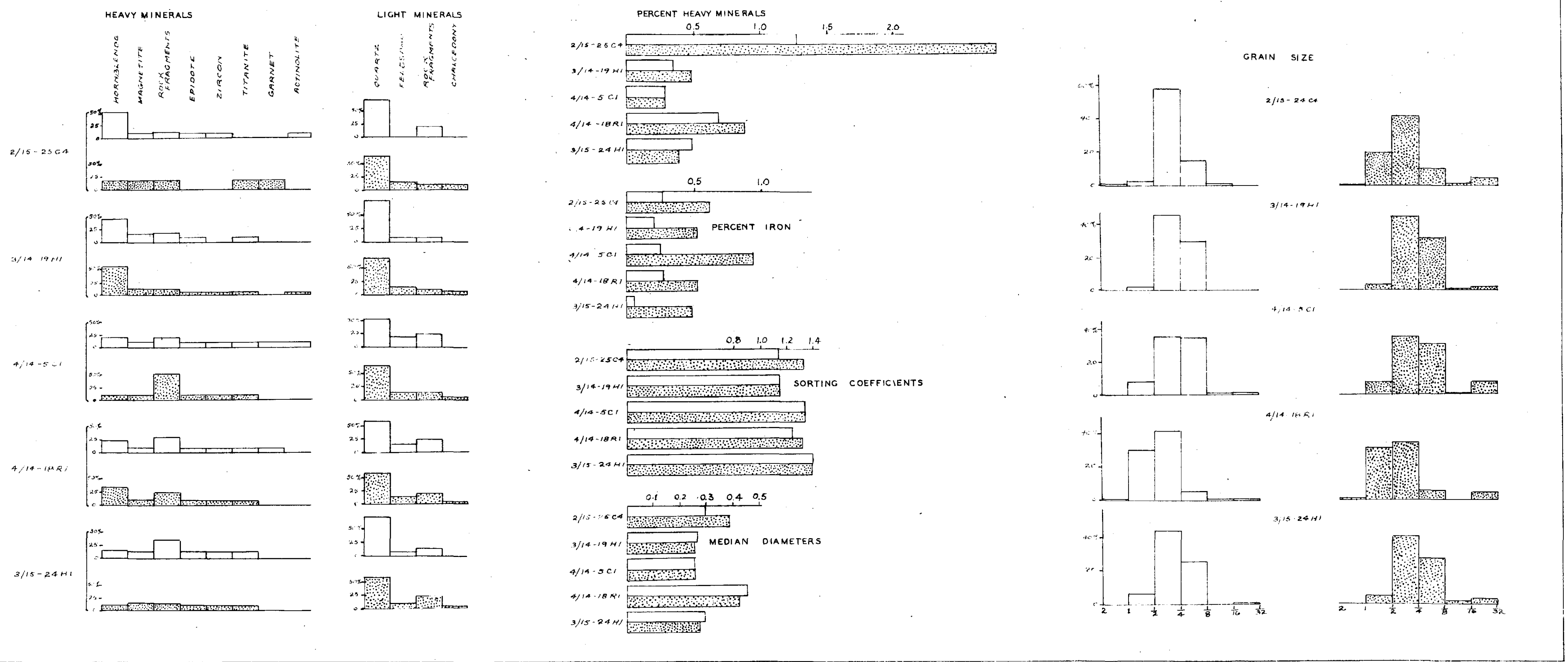


Fig. 5.- Features resulting from cement variations.

Pl. 15. - Staining of cliff with reddish-brown cement shown at left center. Ballona escarpment.

FIG.6 COMPOSITION OF RIDGE ▨ AND INTER-RIDGE ☐ SANDS



second. To facilitate further comparison, the graphs of the ridge sands are stippled and those of the inter-ridges left blank. The field locations of each pair are also indicated.

Regarding the heavy minerals, no good correlation seems possible. The ridge and inter-ridge sands show no minerals or percentages of minerals peculiar to themselves. Taking each pair as a unit, the percentages of various minerals are sometimes quite similar, but a general statement is not possible.

In the light mineral content, it is noticeable that chalcedony occurs only in the ridge sand. In no case was it found in the inter-ridge sands in the samples shown nor in any of the others analyzed.

In three of the pairs, the percentage of heavy minerals is higher in the ridge than in the inter-ridge. In the other two samples the percent is equal or less in the ridge. This distribution was also found in samples not shown on the chart. Over half of the samples showed the greater percentage of heavy minerals in the ridge but their occurrence in the inter-ridge sands also makes a general statement impossible. It may only be said that usually the greater percentage of heavy minerals lies in the ridge member.

The higher percentage of iron in the ridge sands is to be expected. These sands were always a darker reddish-brown than the inter-ridge and much better consolidated.

The sorting coefficients showed the inter-ridge sands to be better sorted than the ridge members though the difference is not marked.

The median diameters likewise showed no constancy for the ridge or inter-ridge members. There was some similarity within each pair but here again no correlations were possible.

The histograms bring out an interesting fact. There is a greater amount of silt and clay (grain size less than 0.65 mm) in the ridge sands.

Thus the tests made on the two types of sand show no distinguishing features other than a higher iron, silt and clay content for the ridge sands. This would indicate a greater amount of weathering and cementation in the ridge layer (Shaler, 1894).

It is certain that the ridging is secondary and not the result of primary characteristics of bedding. This was shown conclusively in the open cut where cross-bedding was found at an angle to the anastomosing ridges (fig. 2). The irregularities shown in figures 4, A, B and figure 5, A, B, C, also bear out this conclusion.

The description of the stages of sand development at Hyperion shows that the degree of consolidation lessens when going down a section from an old soil surface. Iron and silica rich solutions may have moved downward from the surface until all of the limonite and chalcedony was deposited. The cause for the chalcedony and a greater amount of iron being deposited in certain areas and not in others is difficult to understand since the difference is not dependent on primary bedding.

GEOLOGIC HISTORY

Following the deposition of the Palos Verdes sand upon the marine-cut terrace, a large region west of the Newport-Inglewood fault line was lifted above sea level (Eckis, 1936). The upper Pleistocene nonmarine terrace cover was deposited on this uplifted surface in the Palos Verdes Hills and various places inland (Woodring, et al, 1946; Poland, 1947). In order to decide whether the El Segundo sand hills are wholly of eolian origin or are partly offshore bars it should first be determined whether or not the nonmarine terrace cover underlies them.

If the lower part of the sands are offshore bars as Eckis (1934) believed, the bars must have been formed as the sea regressed over the Palos Verdes surface. There would have been no possibility of a continental deposit lying beneath the bars.

If the ancient sands are all of wind blown origin (Woodring, et al, 1946), there are two possibilities. First, the sea may have regressed with the sand dunes forming along each succeeding shoreline so that the innermost one would represent the oldest shoreline at which dune formation was possible. Second, the sea may have regressed so quickly or there may have been so little sand available, that the dunes did not start to form until the sea reached a point close to its present level. In this case, fluviatile nonmarine terrace deposits may have been formed in the inland parts of the area and have been covered as the dunes migrated from the coast.

Lithologically, it does not appear that the cemented sands are underlain by either offshore bar sediments or nonmarine terrace sands. If offshore bars were present, lagoonal deposits with considerable organic matter should have been deposited in the area. If the nonmarine terrace sands lay below the cemented sands, there should be some difference in the sedimentary characteristics or the mineral content of the two sands. Although the sands in the lower part of the section could have been derived from terrace deposits and have many similar properties, some differences should be noted in samples taken from the higher parts of the dunes. In samples along deep vertical exposures, there was no marked change between the lowermost, lying directly over the Palos Verdes sand, and that taken near the surface.

Thus it may be concluded on stratigraphic evidence that the El Segundo sand hills are composed entirely of eolian sands which lie directly on the Palos Verdes sand in most of the area.

Criteria for eolian origin such as frosting, pitting, rounding, and sorting are not considered conclusive. Reed (1930) recognizes the difficulty in distinguishing sands of different origins in the following statement:

> "Whether or not the average dune sand differs from the average beach or river sand, it is certain that any given beach or river sand may more closely resemble the typical aeolian sand than any one of several actual aeolian sands."

The dunes may have formed continuously as the sea regressed over the Palos Verdes surface. The thickness of the dunes is great (pl. 2) but high wind velocities, abundant sand supply, and the continual movement of the newer dunes over the older ones could account for the thickness. After reaching a point near the present shoreline, a section along the coast may have been uplifted, an adjacent inland strip lowered and the innermost portions raised to form the general topographic outlines seen today. Studies by Grant and Sheppard (1939) may indicate that these movements are still in progress.

Gerhardt (1900), Cobb (1910), and Lutz (1941) describe buried land surfaces in dunes which have similar characteristics to the cliff-making beds seen so prominently along the high coastal ridge at Hyperion. Evidently the wind velocity or the supply of sand was not constant over extensive periods of time, for vegetation was able to take hold and a soil horizon to form at these various levels.

The Ballona escarpment was cut by the antecedent Los Angeles River which formerly flowed to the ocean along the course of the present Ballona Creek. The entrenching occurred during the post-Palos Verdes uplift of the region.

The dunes appear to be of upper Pleistocene-Recent age. The lower portions of the dunes might be contemporaneous with the deposition of the nonmarine terrace cover on the lowest terrace in the Palos Verdes Hills which would place the dunes partly in the uppermost Pleistocene. However, deposition has been fairly continuous in the area from that time until the present, so the bulk of the sand would be of Recent age.

CONCLUSIONS

The topography of the El Segundo sand hills is dune-like, with irregular hills and undrained depressions indicating the uppermost sands in the area to be of eolian origin. No lithologic difference between the high portions of the sands and the sands directly overlying the Palos Verdes sands was seen in deep exposures. Thus, it may be concluded on the basis of lithologic and stratigraphic evidence and the presence of eolian cross-bedding at various elevations that the sands of the area are wholly of eolian origin.

The dunes were formed during an upper Pleistocene-Recent regression of the sea over a marine cut terrace on which the marine Palos Verdes sand had been deposited. A long uplift along the coast with an adjacent downwarp and a gentle rise inland of this began during the regression and may still be in progress. Buried soil layers along the coastal ridge indicate changing climates with resulting variations in sand supply and transportation during the dune accumulation.

The peculiar differential weathering resulting from variations in the amount of cementing material was caused by iron and silica rich solutions moving through the dunes after deposition. The paths taken by the aqueous solutions may have been determined by a difference in permeability in the sediments which would enable a greater proportion of the solution to travel through what are now the ridge layers and deposit its mineral content. The decomposition which must have occurred in the ridge layers, as indicated by the higher clay and silt content, may have masked the original nature of the sediments in such a way that the factor responsible for the greater permeability was lost.

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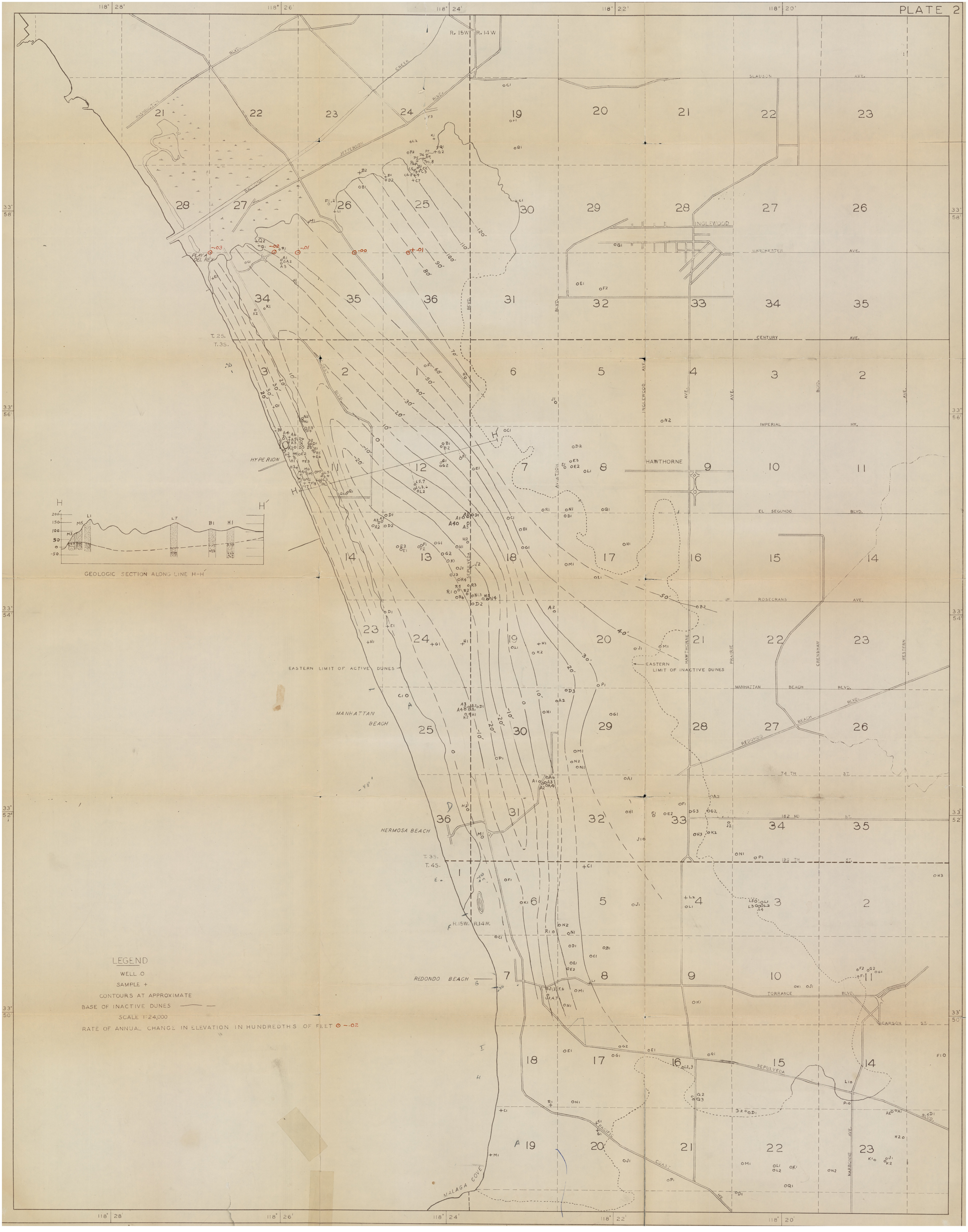
PLATE 2


118° 28'
118° 26'
118° 24'
118° 22'
118° 20'
33° 58'
33° 56'
33° 54'
33° 52'
33° 50'
R. 15W. R. 14W.
T. 2S.
T. 3S.
T. 4S.
PLAYA DEL REY
INGLEWOOD
HAWTHORNE
HYPERION
MANHATTAN BEACH
HERMOSA BEACH
REDONDO BEACH
MALAGA COVE
SLAUSON AVE.
MANCHESTER AVE.
CENTURY AVE.
IMPERIAL HY.
EL SEGUNDO BLVD.
ROSECRANS AVE.
MANHATTAN BEACH BLVD.
REDONDO BEACH BLVD.
TORRANCE BLVD.
CARSON ST.
SEPULVEDA BLVD.
PACIFIC COAST HY.
JEFFERSON
CREEK
BALLONA
INGLEWOOD AVE.
HAWTHORNE AVE.
PRAIRIE AVE.
CRENSHAW BLVD.
WESTERN AVE.
NORMANDIE AVE.
AVIATION BLVD.
EASTERN LIMIT OF ACTIVE DUNES
EASTERN LIMIT OF INACTIVE DUNES
120'
110'
100'
90'
80'
70'
60'
50'
40'
30'
20'
10'
0
-10'
-20'
-.03
-.02
-.01
-.00
-.01
H
H'
GEOLOGIC SECTION ALONG LINE H-H'
200
150
100
50
0
-50
L1
M5
M3
L7
B1
H1
LEGEND
WELL O
SAMPLE +
CONTOURS AT APPROXIMATE
BASE OF INACTIVE DUNES
SCALE 1:24,000
RATE OF ANNUAL CHANGE IN ELEVATION IN HUNDREDTHS OF FEET ⊙ -.02

PL. 1


BALLONA
Del Rey
Playa del Rey
Jefferson Blvd
SAUSAL REDONDO
AGUAJE DE LA CENTINELA
Westchester Sch
LOS ANGELES AIRPORT
NORTH AMERICAN AVIATION
DOUGLAS AIRCRAFT
LENNOX
El Segundo Sta
STANDARD OIL CO PIER
SEWER OUTLET PIER
SEGUNDO
EL SEGUNDO
Manhattan Beach Sta
MANHATTAN BEACH
HAWTHORNE
Wiseburn
Eucalyptus Ave Sch
Lawndale
LAWNDALE
SAUSAL REDONDO
SANTA MONICA BAY
HERMOSA BEACH
EDISON INTAKE PIER
REDONDO BEACH
Clifton
SAN PEDRO
TORRANCE
PACIFIC ELECTRIC CAR SHOPS
Dominguez Reservoir
El Nido
Perry School
Malaga Cove
PALOS VERDES HILLS
LOS PALOS VERDES
RADIO STA
HAWTHORNE
BOULEVARD
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
G
G'
N
Scale 1/24000
1
1/2
0
1 Mile
5000
4000
3000
2000
1000
0
5000 Feet
Contour interval 5 feet
Datum is mean sea level

PLATE 1

e spurs are truncat
hill at the left term
scarp, from which it
lined tableland that is
On the map each of
beneath its position i

vertical distance in feet be
stated at the bottom of each
ing to the topography of the
it may be as small as 1 foot
y be as great as 250 feet. In
read more easily certain contour
made heavier than the others an
showing altitude. The heights of
intersections, summits, surfaces of
re also given on the map in figures,
he nearest foot only. More precise
benchmarks are given in the Geologica
n spirit leveling. The geodetic coordina
d transit-traverse stations are also publish

d the works of man are shown in black. B
s those of a State, county, city, land grant,
ervation, are shown by continuous or broken li
kinds and weights. Public roads suitable for
e greater part of the year are shown by solid d
oor public roads and private roads by dashed d
trails by dashed single lines. Additional public
cation if available is shown by red overprint.
ch quadrangle is designated by the name of a city,
prominent natural feature within it, and on the marg
map are printed the names of adjoining quadrang
hich maps have been published. More than 4,100
angles in the United States have been surveyed, and m
them similar to the one on the other side of this sheet
been published.

Geologic maps of some of the areas shown on the topogr
maps have been published in the form of folios. Each
includes maps showing the topography, geology, undergr
structure, and mineral deposits of the area mapped, and s
pages of descriptive text. The text explains the map
describes the topographic and geologic features of the co
and its mineral products. Two hundred twenty-five folios
been published.

Index maps of each State and of Alaska and Hawaii sh
the areas covered by topographic maps and geologic folios
lished by the United States Geological Survey may be obt
free. Copies of the standard topographic maps may be obt
for 10 cents each; some special maps are sold at different
A discount of 40 percent is allowed on an order amount
$5 or more at the retail price. The discount is allowed
order for maps alone, either of one kind or in any assort
or for maps together with geologic folios. The geologic
are sold for 25 cents or more each, the price depending o
size of the folio. A circular describing the folios will b
on request.

Applications for maps or folios should be accompani
cash, draft, or money order (not postage stamps) and shou
addressed to

THE DIRECTOR,
United States Geological Survey
Washington,

November 1937.

NOTE:—Effective on and after October 1, 1946, the price of standard topographi quadrangle maps will be 20 cents each, with a discount of 20 percent on order amounting to $10 or more at the retail rate.

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The maps 20 inches. Under divided into quadrangles meridians of longitude. These different scales, the scale selected for each is best adapted to general use in the development and consequently, though the standard maps are of different sizes. form size, the areas that they represent are of different sizes. On the lower margin of each map are printed graphic scales showing distances in feet, meters, miles, and kilometers. In addition, the scale of the map is shown by a fraction expressing a fixed ratio between linear measurements on the map and corresponding distances on the ground. For example, the scale $\frac{1}{62,500}$ means that 1 unit on the map (such as 1 inch, 1 foot, or 1 meter) represents 62,500 of the same units on the earth's surface.

Although some areas are surveyed and some maps are compiled and published on special scales for special purposes, the standard topographic surveys and the resulting maps have for many years been of three types, differentiated as follows:

1. Surveys of areas in which there are problems of great public importance—relating, for example, to mineral development, irrigation, or reclamation of swamp areas—are made with sufficient detail to be used in the publication of maps on a scale of $\frac{1}{31,680}$ (1 inch=one-half mile) or $\frac{1}{24,000}$ (1 inch=2,000 feet), with a contour interval of 1 to 100 feet, according to the relief of the particular area mapped.

2. Surveys of areas in which there are problems of average public importance, such as most of the basin of the Mississippi and its tributaries, are made with sufficient detail to be used in the publication of maps on a scale of $\frac{1}{62,500}$ (1 inch=nearly 1 mile), with a contour interval of 10 to 100 feet.

3. Surveys of areas in which the problems are of minor public importance, such as much of the mountain or desert region of Arizona or New Mexico, and the high mountain area of the northwest, are made with sufficient detail to be used in the publication of maps on a scale of $\frac{1}{125,000}$ (1 inch=nearly 2 miles) or $\frac{1}{250,000}$ (1 inch=nearly 4 miles), with a contour interval of 20 to 250 feet.

The aerial camera is now being used in mapping. From the information recorded on the photographs, planimetric maps, which show only drainage and culture, have been made for some areas in the United States. By the use of stereoscopic plotting apparatus, aerial photographs are utilized also in the making of the regular topographic maps, which show relief as well as drainage and culture.

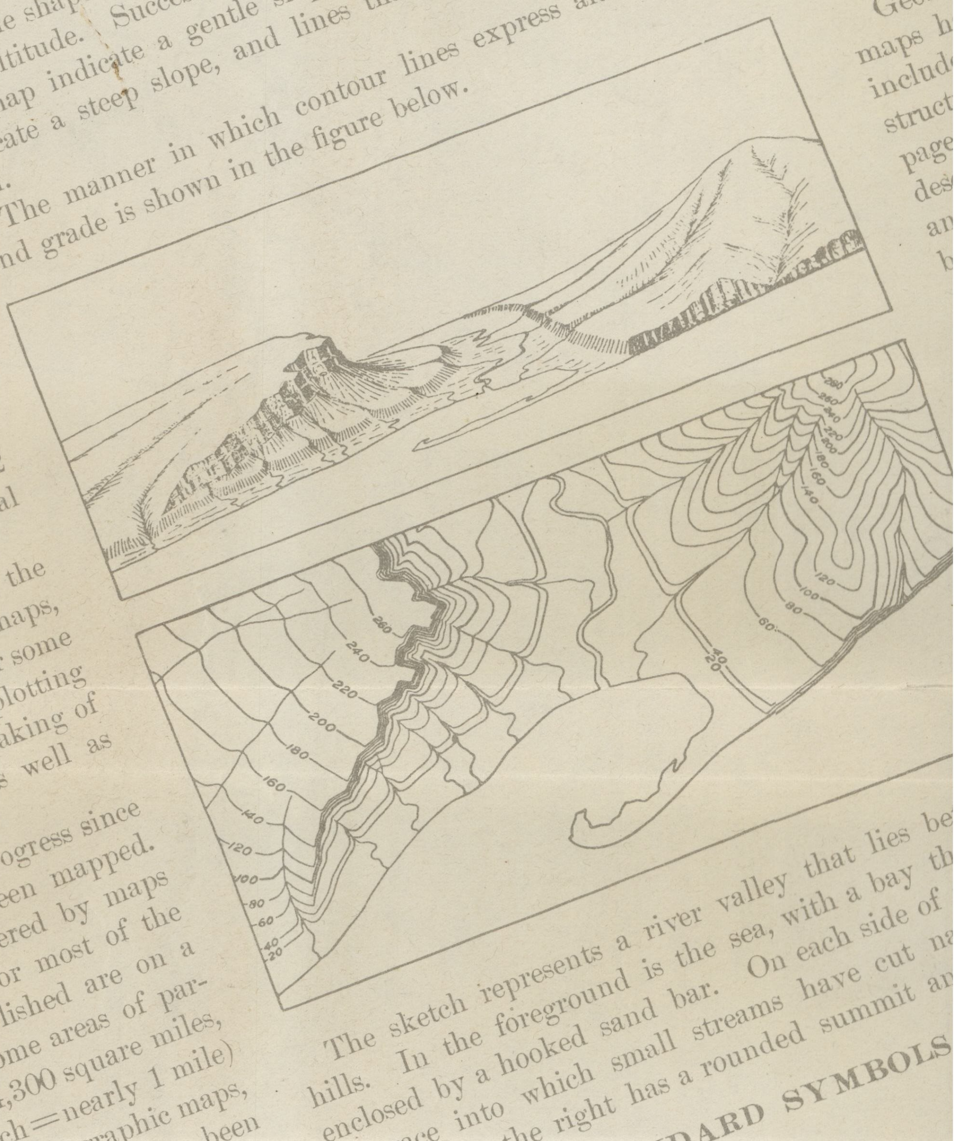
A topographic survey of Alaska has been in progress since 1898, and nearly 44 percent of its area has now been mapped. About 15 percent of the Territory has been covered by maps on a scale of $\frac{1}{500,000}$ (1 inch=nearly 8 miles). For most of the remainder of the area surveyed the maps published are on a scale of $\frac{1}{250,000}$ (1 inch=nearly 4 miles). For some areas of particular economic importance, covering about 4,300 square miles, the maps published are on a scale of $\frac{1}{62,500}$ (1 inch=nearly 1 mile) or larger. In addition to the area covered by topographic maps, about 11,300 square miles of southeastern Alaska has been covered by planimetric maps on scales of $\frac{1}{125,000}$ and $\frac{1}{250,000}$.

The Hawaiian Islands have been surveyed, and the resulting maps are published on a scale of $\frac{1}{62,500}$.

by accentuated streams—those whi are shown by lines of blue

Relief is shown by contour li maps are supplemented by shading show thrown from the northwest across the area repre purpose of giving the appearance of relief and thus aid the interpretation of the contour lines. A contour line represents an imaginary line on the ground (a contour) every part of which is at the same altitude above sea level. Such a line could be drawn at any altitude, but in practice only the contours at certain regular intervals of altitude are shown. The datum or zero of altitude of the Geological Survey maps is mean sea level. The 20-foot contour would be the shore line if the sea should rise 20 feet above mean sea level. Contour lines show the shape of the hills, mountains, and valleys, as well as their altitude. Successive contour lines that are far apart on the map indicate a gentle slope, lines that are close together indicate a steep slope, and lines that run together indicate a cliff.

The manner in which contour lines express altitude, form, and grade is shown in the figure below.



The sketch represents a river valley that lies be hills. In the foreground is the sea, with a bay th enclosed by a hooked sand bar. On each side of a terrace into which small streams have cut na The hill on the right has a rounded summit an

...hat lies between two ...th a bay that is partly ...ach side of the valley is ...have cut narrow gullies. ...summit and gently slop-

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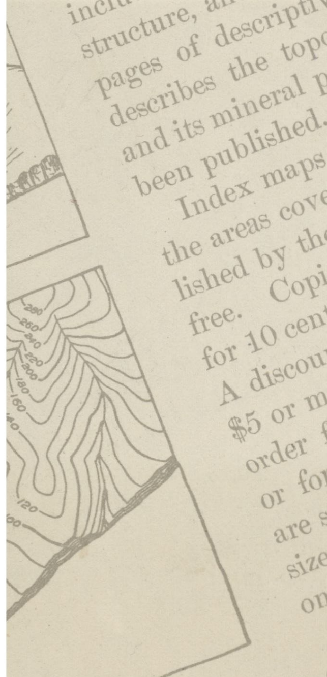

STANDARD SYMBOLS