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ENGINEERING GEOLOGY OF THE WARFORD MESA SUBDIVISION, ORINDA, CALIFORNIA

By

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This report is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

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INTRODUCTION

Purpose of investigation

On March 22, 1956, the San Francisco Office of the Federal Housing Authority requested the Menlo Park Office of the U. S. Geological Survey to conduct a preliminary engineering geology investigation of certain parts of the Warford Mesa Subdivision in Orinda, California. The site was visited for 4 hours on March 26, 1956 by Reuben Kachadoorian and George Plafker. A brief preliminary report was prepared by Kachadoorian and Plafker. The report was submitted to the Federal Housing Authority by the Chief Geologist of the Geological Survey on April 12, 1956. On May 21, W. R. Lomax, Director of Personnel, Federal Housing Authority, requested the Geological Survey to conduct a more detailed investigation that would include the entire area of the Warford Mesa Subdivision. Accordingly, Reuben Kachadoorian spent 19 days mapping the area, from June 18 to July 13. He was assisted by Dorothy H. Radbruch for a period of 5 days.

Methods of field work

Field mapping by the Geological Survey consisted of a series of foot traverses during which notes and samples were taken, and geologic information was gathered and plotted on a topographic map of 1:1,200 scale and on vertical aerial photographs of 1:8,000 scale. The information was later transferred to a topographic map of 1:2,400 scale.

Acknowledgments

The base map used in this report (pl. 1) is a reduction from 1:1,200 to 1:2,400 of a topographic map made by and obtained through the courtesy of the East Bay Municipal Utility District, Oakland, California. The San Francisco Office of the Federal Housing Authority furnished plot maps of the Warford Mesa Subdivision.

GEOGRAPHIC SETTING

Topography

The Warford Mesa Subdivision lies in the south-central part of the Briones Valley 7-1/2-minute quadrangle. The subdivision lies immediately northeast of the town of Orinda, and is bounded on the west and north by California State Highway 24, locally referred to as Mount Diablo Boulevard, on the south by the Mount Diablo Base Line, and on the east by the 122° 09' 48" meridian.

The topography of the area is typical foothills consisting of north-northeastward-trending ridges with moderate slopes and moderate V-shaped stream valley profiles. This type of topography is considered to be late youth stage of development. The altitude ranges from approximately 500 feet at the extreme southwest corner of the area to 1,000 feet in the vicinity of Baseline Reservoir in the southeast part of the area.

The subdivision is drained by several intermittent streams. The west and northwest part of the area is drained by streams that flow westward, cross under the State Highway and then flow south-southwestward into San Pablo Creek, immediately south of the mapped area. Most of the remaining portion of the area is drained by streams that flow southwestward into San Pablo Creek. San Pablo Creek flows northwestward into San Pablo Reservoir, approximately 2 to 3 miles northwest of the mapped area.

Vegetation

The vegetation of the area consists of (1) wild oats, grasses, and small patches of poison oak on the hilltops and on the gentler slopes, and (2) oak, buckeye, laurel, small colonies of manzanita, and a lush growth of poison oak on the steeper slopes and in the gullies and canyons.

GENERAL GEOLOGY

The general geology of the Warford Mesa Subdivision is shown on plate 1. The only formation exposed in the subdivision is the Orinda formation of Tertiary age, which is composed of interbedded conglomerates, sands, and clays. The surficial deposits are landslides and soilslides of Quaternary age. Soilslides are herein defined as landslides that are confined to the soil profile.

Orinda formation

The Orinda formation is chiefly continental, lacustrine, and fluviatile deposits and consists of interbedded (1) coarse to fine moderate brown to blue-gray conglomerates; (2) coarse- to fine-grained light greenish-gray to yellowish-gray sands; (3) dusky yellow, light olive-gray, and greenish-gray to blue-gray clays, and (4) a thin yellowish-gray rhyolite tuff bed. All colors in this report are taken from the Rock-Color Chart published in 1951, which was prepared by the Rock-Color Chart Committee, and distributed by the Geological Society of America.

The conglomerate, sand, and clay beds strike from N. 85° W. to N. 40° W., and dip both northeastward and southwestward. More commonly the strike of the beds is N. 70° W.

Approximately 30 percent of the Orinda formation exposed in the Warford Mesa Subdivision is conglomerate. The conglomerate beds, interbedded with sand and clay beds, range from 1 to 45 feet in thickness and average about 6 to 8 feet in thickness. Several of the conglomerate beds were mapped and are shown on plate 1. Only those beds that can be correlated from exposure to exposure are indicated on plate 1. The conglomerate beds are massive and moderately cemented. Locally, however, some of the beds are poorly cemented, friable, and porous. The pebbles consist chiefly of chert, quartz, fine-grained volcanic rocks, and minor amounts of sandstone which were probably derived from the Franciscan and Cretaceous rocks west of the area. The pebbles are subrounded to rounded and average only three-eighths of an inch in diameter. Although uncommon, pebbles up to 3 inches in diameter occur in the conglomerate.

The matrix of the conglomerate is fine-grained sand consisting of quartz and feldspar grains, and clays of the montmorillonite group.

Locally, illite and kaolinite clays are associated with the montmorillonite.

Sandstone makes up approximately 15 percent of the exposed sediments of the Orinda formation. Most of the sandstone beds are massive, moderately cemented, and range from 2 to 15 feet in thickness, and average 7 to 8 feet in thickness. Locally, the beds are friable and crumble easily. The sands are coarse- to fine-grained, subangular to subrounded, and consist principally of quartz and feldspar grains. Clay was not observed in the sandstone.

With the exception of a 6-foot rhyolite tuff bed, the remaining 55 percent of the Orinda formation exposed in the mapped area consists of beds of clay. The clay beds are as much as 110 feet thick and average from 30 to 35 feet in thickness. In approximately 50 percent of the clay beds, swelling of the clays was noted in the field. The remaining 50 percent of the clay beds are relatively massive and show very little evidence of swelling and shrinking.

Six samples of clay were collected from the clay beds to determine the kind of clay minerals present. X-ray diffraction techniques were used. The clay beds consist chiefly of clays of the montmorillonite, kaolinite, and illite groups, and fine grains of quartz and feldspar. Several of the clay beds also contain fragments of white, chalky bituminous shale. This white, chalky shale was derived from the erosion of the Claremont shale to the north and west of the mapped area.

Microscopic analyses of clay stained by malachite green and safranine-Y were used to determine the various percentages of the clay groups in the collected samples. These analyses indicated that the percentage of montmorillonite ranges from 35 to 95 percent and averages from 45 to 50 percent. Kaolinite and illite are minor constituents.

From an engineering standpoint the chief difference among the montmorillonite, illite, and kaolinite clay groups, is that montmorillonite swells appreciably when saturated by water. Tests were conducted on the six samples collected in the Warford Mesa Subdivision to determine the free-swelling characteristics of the material. The following procedure was followed in conducting the free-swelling tests: 3 milliliters of material passing the 30-mesh screen and retained on 50-mesh screen (U. S. Standard Sieve Series) were collected and placed in a graduate containing 10 milliliters of water. The mixture was left standing for approximately 30 minutes and the top of the clay material recorded. The percentage of expansion of the material was then calculated. All of the samples contained montmorillonite. The expansion of the clays averaged 30 percent and ranged from 20 to 100 percent.

The yellowish-gray rhyolite tuff bed in the Orinda formation was derived locally from volcanic rocks in the Berkeley Hills. The matrix of the tuff consists principally of montmorillonite clay.

The Orinda formation is mantled by soil as much as 10 feet thick. The soil was formed in place and has not been transported into the area.

Structure

The general structure of the Orinda formation is a large west-northwestward-trending synclinal trough with subordinate folds. The mapped area lies on the southern flank of this synclinorium. Two of the subordinate folds are represented by a west-northwestward-trending anticline in the southern part of the mapped area and a similarly trending syncline in the northern part of the area.

A pronounced joint system occurs in the Orinda formation. The joints strike from north to N. 20° E. and dip from 65° west-northwest to 75° east-southeast. More commonly, however, the dips are from 80° west-northwest to 75° east-southeast. In those clay beds which have expanded and shrunk with wetting and drying the joints are not readily noted, but in the more massive clay beds and in the sandstone and conglomerate, the joints are quite pronounced. The joints are closely spaced, ranging from 1 to 3 feet apart.

Age

The Orindan formation as originally defined by A. C. Lawson and Charles Palache (1902) applied to all of the nonmarine Pliocene deposits of northern Alameda and Contra Costa counties. Later, Lawson (1914) changed the name of these nonmarine Pliocene deposits to the Orinda formation.

Landslides

Several landslides are present in the Warford Mesa Subdivision. Most of the landslides are confined to the long, north-northeastward-trending canyon immediately west of the Baseline Reservoir (pl. 1). The largest slide is in the west-central part of the mapped area; California State Highway 24 crosses over the toe of this slide. Many of the slides are relatively old and their escarpments are not well defined.

The landslides are not particularly restricted to any lithologic unit of the Orinda formation. The conglomerate, sand, and clay beds are so evenly distributed that all observed slides transcend two or all of those units. With minor exceptions, the direction of sliding is parallel or nearly parallel to the strike of the beds of the Orinda formation. Sliding may be influenced by the north-northeastward-trending joints. Very little sliding was noted along bedding planes.

The percentage of landslides whose movement is parallel or nearly parallel to the strike of the beds is unusually high in the Warford Mesa Subdivision. A higher percentage of sliding should be expected along the dip slopes of the bedding planes than occurs in the mapped area. Time did not permit a complete study and evaluation of this problem. A tentative explanation, however, is herein offered. A combination of the following factors may be considered: (1) migration of ground water, (2) a north-northeastward-trending joint system, (3) expansive characteristics of the clay, (4) sparseness of vegetation on the east and west slopes, and (5) topography of the area. These factors are discussed in the following paragraphs.

1. Undoubtedly the main factor of general landsliding is the saturation of the beds at the surface and near the surface by ground water and to some extent by the surface water. In the mapped area ground water migrates downward through the pervious conglomerate and sand beds until it strikes an impervious clay bed. The water flows both down the dip slope of the beds and laterally along the bedding planes, eventually emerging as springs along the slopes. The development of such a spring can be observed on the State Highway cut immediately west of the Warford Mesa Subdivision.

The downward and lateral migration of the water may take months to saturate the slopes to produce slide conditions. For example, engineers of the Hersey Inspection Bureau (1956) reported that water was encountered at approximately 18.5 feet in a test hole on one of the slides in the north-northeastward-trending canyon immediately west of the Baseline Reservoir. Their investigation was conducted during and immediately following the heavy rains of December 1955. The hole was reoccupied on June 20, 1956, and the water table was found to be 4.1 feet below the surface. In the 5 or 6 months following the investigation by the Hersey Inspection Bureau, the water table had risen approximately 14.4 feet.

2. The joint planes appear to be planes of greater weakness than the bedding planes. Migrating water lubricates the closely spaced joint planes by increasing the plasticity of the clays within and along the walls of the joints, thereby making the material more susceptible to sliding.

3. The water wets the clay beds and as a result, materially weakens the cohesive and shearing strength of the clays.

4. Vegetation is sparser on the west and east slopes in the area. This sparseness of vegetation provides very little if any stabilization of the slopes.

5. The topography of the area is also a factor in the development of the slides. Most of the canyons and gullies trend normal or nearly normal to the strike of the beds. Thus, most of the landslides in moving downslope will move parallel or nearly parallel to the strike of the beds. This does not explain, however, the lack of major landslides in the northwestward-trending canyon in the north-central part of the area.

Thus, the high percentage of landslides with movement parallel or nearly parallel to the strike of the beds are caused by combinations of the above factors.

Soilslides

Numerous small soilslides were noted in the area and are shown on plate 1. These slides, which are landslides that are restricted to the soil profile, generally occur on the steeper, vegetation-free slopes. Most of them are smaller than 50 feet across and do not generally slide to the bottom of the slopes upon which they lie. Many of these slides took place during or immediately after the unusually heavy rains of December 1955.

ENGINEERING GEOLOGY

The possible rejuvenation of the old landslides and the development of new landslides present the major engineering problem in the Warford Mesa Subdivision.

Although some of the landslides appear to be stabilized, they are actually in a delicate state of equilibrium and are subject to further movement if this equilibrium is materially disrupted. Two examples of further sliding of stabilized slides after they were disturbed are discussed below.

In the canyon west of the Baseline Reservoir, the following sequence of sliding events occurred: A large slide originating near the base of the reservoir moved downslope, westward, to the bottom of the north-northeastward-trending canyon, partially or completely blocking the stream that drains the canyon. The blocked stream gradually removed the toe of the landslide by erosion, thereby disrupting the equilibrium of the slide. Eventually a smaller secondary slide occurred. This smaller slide is confined to the older and much larger landslide.

The second example of equilibrium disruption, although not in the mapped area, is applicable because it occurs in similar beds in the Orinda formation and in a similar topographic and structural environment. In a housing development several miles east of the mapped area, five houses were placed upon the toe of a relatively old landslide. A portion of the toe was removed prior to the construction of the homes. During or shortly after the winter rains of 1955, the landslide moved and the homes became unsuitable for occupancy. Although the rains contributed to the rejuvenation of the slide, an important factor was the disruption of equilibrium by the removal of a portion of the toe of the slide.

Thus, it is not safe to assume that once a landslide has occurred, it will not slide again.

The development of new landslides on slopes as low as 30° (2:1, 2 feet of horizontal distance for every 1 foot of vertical distance) has been observed in the Orinda formation. Northeast of the mapped area a large landslide developed about the later part of June on a new highway cut. The slope of the cut is approximately 28°, slightly less than 2:1, and the slope distance (distance along the face of the cut) is about 100 to 150 feet. On several cuts of State Highway 24, which forms the west and north boundaries of the Warford Mesa Subdivision site, small landslides are developing or have developed in the recent past. The average slope of the cuts is approximately 35 degrees, slightly steeper than 2:1. Many of these slides have developed or are developing in cuts as low as 30 to 40 feet deep.

Conclusions

The following conclusions may be drawn about landslides in the Warford Mesa Subidvision area: (1) cuts in the Orinda formation with slopes steeper than 2:1 will probably develop landslides; (2) cuts sloping at 2:1 or slightly less than 2:1 may or may not develop slides;

(3) landslides are more likely to occur on the westward- and eastward-facing slopes rather than on the northward- and southward-facing slopes; (4) slides do not necessarily occur during the rainy season but may develop 6 to 8 months later; (5) the tendency for landsliding in the area will be reduced materially if proper subsurface and surface drainage techniques are employed and (6) the loading and unloading of the existing landslides and slopes that may be susceptible to sliding, by cut and fill construction techniques, may be sufficient to disrupt the equilibrium of the slopes and start new slides or rejuvenate the old landslides.

REFERENCES

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EXPLANATION

Recent

QUATERNARY

Qss

Landslides confined to the soil profile

Qls

Landslides

Pliocene

TERTIARY

Tor

Orinda formation
Includes clays, rhyolite tuff, coarse- to fine-grained sands, and coarse to fine conglomerate (conglomerate indicated by circles).

Contact
Dashed where approximately located, dotted where concealed

Syncline
(Showing approximate position of trough)

Anticline
(Showing approximate position of crest line)

45
Strike and dip of beds

Strike and dip of beds interpreted from vertical aerial photograph

75
Strike and dip of joints

$\frac{4' \text{ Qs}}{\text{Tor}}$

4 feet of soil overlying Orinda formation

Springs
(Open circle where intermittent)

Wooded area