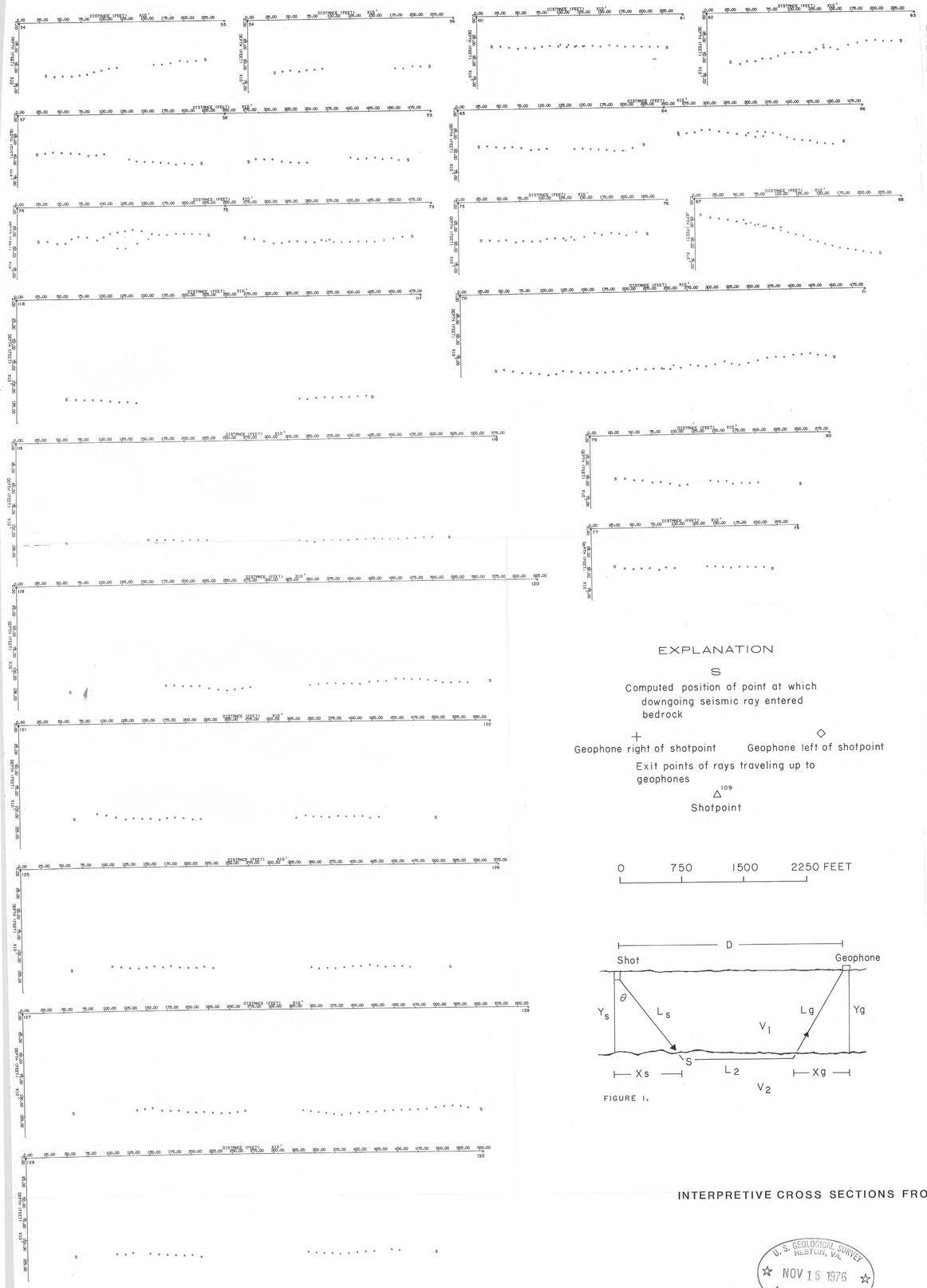
HAZLEWOOD–CONTOUR MAP AND SECTIONS, BEDROCK SURFACE, SOUTH SAN FRANCISCO BAY REGION, CALIFORNIA



INTERPRETIVE CROSS SECTIONS FROM REVERSED REFRACTION PROFILES, SHOTPOINTS 54 THROUGH 134

EXPLANATION

S
Computed position of point at which downgoing seismic ray entered bedrock

+ Geophone right of shotpoint

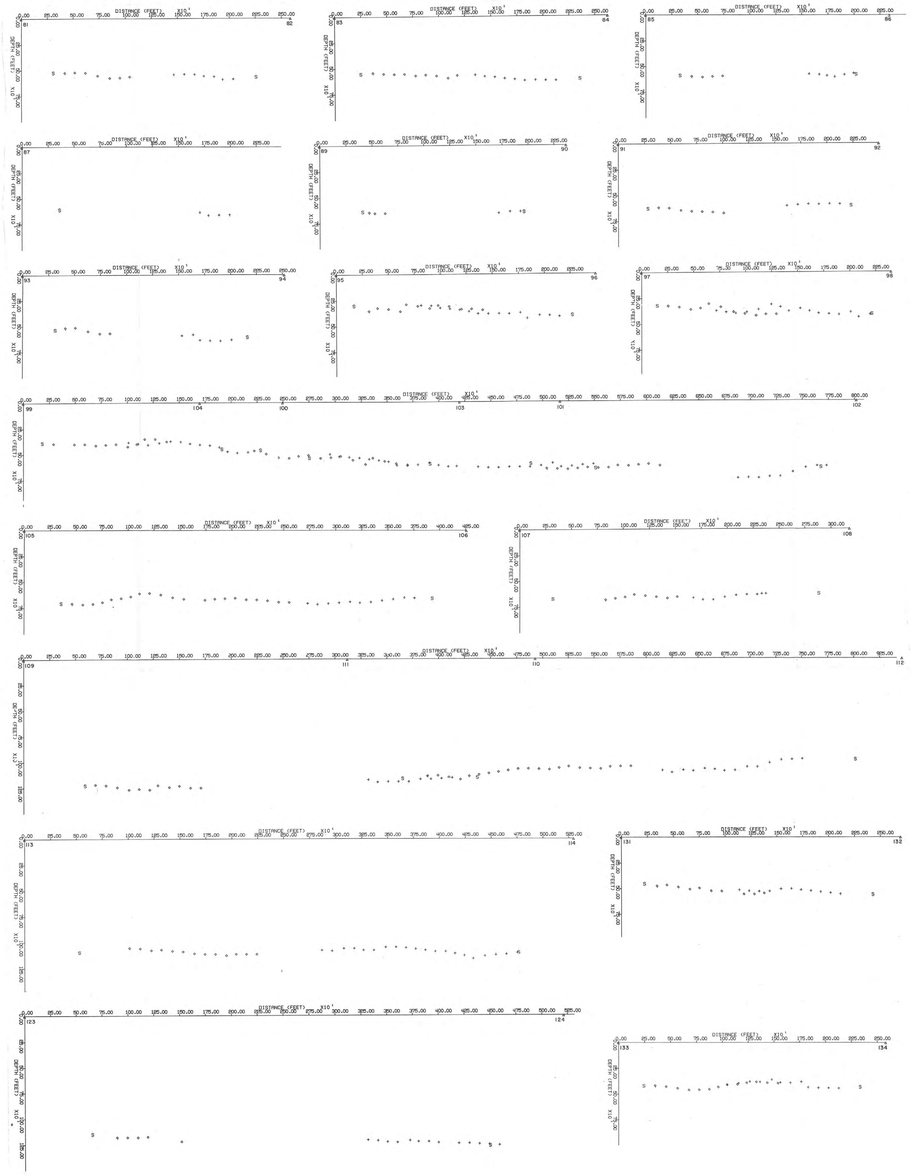
◇ Geophone left of shotpoint

Exit points of rays traveling up to geophones

Δ^{109}
Shotpoint

0 750 1500 2250 FEET

FIGURE 1.



SEISMIC REFRACTION SURVEY OF THE SOUTH SAN FRANCISCO BAY REGION

The U.S. Geological Survey conducted a seismic refraction survey of the southern San Francisco Bay region in Alameda, San Mateo, and Santa Clara Counties, California, to determine the seismic velocity in the bedrock and the material overlying it and the depth and configuration of the bedrock surface.

A 24-trace refraction seismograph, mounted in a four-wheel-drive vehicle, was used to obtain the seismic records. The standard reversed-profile method of shooting was employed. In this method, the geophones are arranged in a straight line, and an explosive charge is detonated alternately in the shotholes at the ends of the line. The shotholes were drilled to a depth of 20 to 25 ft with a gas-powered auger mounted on a trailer. The geophones were spaced at 100-ft intervals, and the profiles ranged in length from 2500 to 7200 ft. Small charges of explosives, averaging a few pounds per shot, were sufficient to provide adequate seismic energy. Seismic profiles were run only on the levees or areas where it was possible to obtain a straight-line distance of the length necessary for the raypaths to reach the bedrock surface and where conditions made it possible to drill shotholes and detonate explosives.

The general geology of the San Francisco Bay, including the area of the seismic survey, is described by Nichols and Wright (1971) and Lajoie and Helley (1975). A summary description of the "young bay mud" by Schlocker (1968, p. 24–25) states:

> "The youngest deposits are mostly soft clay and silt (mud) and minor amounts of sand and gravel. The soft muds, the most common modern sediment, vary considerably in thickness. They are generally less than 10 feet thick near the shore, but are more than 100 feet thick offshore--for example, between San Francisco and Yerba Buena Island and in Richardson Bay. In the Redwood Shores-Bair Island area, soft muds are about 10 feet thick near Bayshore Freeway, but about 60 feet thick near the eastern shore of Bair Island, 3 miles to the northeast. At many places, mud is more than 60 feet thick only 1/2 to 1 mile from the landward edge of the marshlands. Near the mouths of such streams as San Mateo, San Francisquito, and Alameda Creeks, mud interfingers with sand, gravel, and silt brought into the Bay by the streams."
>
> "In addition to sand layers and lenses, significant peat and shell beds occur within the young bay mud in many areas. In the subsurface, young bay mud locally may extend well inland of the marsh line where the mud interfingers with alluvial deposits of the principal drainages such as the Alameda Creek fan in Fremont."

Sediments beneath the young bay mud is a thick sequence of beds defined as an old bay mud consisting of sandy clay and clayey sand, alluvial layers of sand or gravel, and complexly interlayered beds of varying composition that are substantially denser and stronger than the young bay mud.

The bedrock underlying these units is presumed to be the Franciscan Formation, which consists of marine sandstone, shale, chert with some conglomerate and limestone lentils, greenstone, diabase, and serpentine.

The velocity of the geologic units overlying the bedrock is 5500 fps (feet per second), and the average bedrock velocity is 12,000 fps. The interpretive cross sections showing the depth and configuration of the bedrock surface for shotpoints 54 through 134 are shown on sheet 2. Cross sections for shotpoints 1 through 53 were given by Hazlewood (1974) and cross sections for shotpoints 1R through 5R were given by Hazlewood and Joyner (1973). The bedrock contour map based on seismic data and drill holes is shown on sheet 1.

The interpretive cross sections (sheet 2) were made by an iterative method described in detail in the following section. Shotpoint numbers are shown on the cross section, and the position of the shotpoints at the ground surface is represented by triangle symbols. The letter S on the sections indicates the computed position of the point at which a down-going seismic ray from the shot enters the bedrock. The plus signs and diamonds indicate the exit points of the rays traveling up to the geophones; plus signs are used for geophones to the right of the shot and diamonds for geophones to the left. The plus signs and diamonds represent the migrated control points on the bedrock surface. A consistent interpretation requires that S symbols lie along the interface defined by the other symbols; the degree to which this condition is met is a measure of the consistency of the interpretation.

Approximate corrections for the effect of very near surface, low-velocity material were obtained by averaging the intercepts of the 5500-fps branches of the traveltime curves from opposite ends of the profile. These corrections were subtracted from the traveltime data before the cross sections were prepared.

METHOD OF PLOTTING REFRACTION CROSS SECTION

The method used for plotting a cross section for the refraction profile (as described by Hazlewood and Joyner, 1973) is based on the assumption of a layer with varying thickness and a seismic velocity, V_1, overlying a layer of higher velocity, V_2. Under that assumption, the path of a seismic ray from shot to geophone is diagrammed in figure 1. The completed cross section consists of symbols plotted at the points at which the seismic ray enters and leaves the subsurface refractor. The point of entry is marked by the letter S, and the point of exit is marked by a plus sign for lines shot toward the right-hand end of the profile and by a diamond for lines shot in the opposite direction. Every point on the V_2 branch of the traveltime curve is thereby used to construct a depth point on the refractor, and the depth points are migrated to their true subsurface positions. The depth and offset distances for plotting the symbols are determined from the traveltime data in the following way.

For a given shot-geophone pair, the traveltime, T_t, corrected as necessary for near-surface low-velocity effects, can be expressed as (fig. 1):

$$T_t = L_s/V_1 + L_2/V_2 + L_g/V_1$$

Since the distance L_2 is not known, it is convenient to rewrite the equation using the distance D between shot and geophone. If the dip of the interface is small,

$$T_t = (L_s/V_1 - X_s/V_2) + D/V_2 + (L_g/V_1 - X_g/V_2)$$

Introducing the definitions,

$$T_s = L_s/V_1 - X_s/V_2$$

$$T_g = L_g/V_1 - X_g/V_2$$

we can write

$$T_t = T_s + D/V_2 + T_g \qquad (1)$$

In the nomenclature of the time-term method (Scheidegger and Willmore, 1957), T_s and T_g represent the shot- and geophone-time terms, respectively.

The point at which the downgoing ray enters the refractor is determined by the coordinates X_s and Y_s (fig. 1). X_s and Y_s can be expressed in terms of T_s and the velocity values V_1 and V_2. Likewise, X_g and Y_g can be expressed in terms of T_g, V_1, and V_2. Thus, if the dip of the interface is small,

$$\sin\theta = V_1/V_2$$

and referring to figure 1,

$$X_s = L_s \sin\theta \qquad (2)$$

$$Y_s = L_s \cos\theta\,. \qquad (3)$$

Combining equation (2) with the defining equation for T_s, we obtain

$$T_s = L_s(1/V_1 - \sin\theta/V_2).$$

Solving for L_s and substituting in equations (2) and (3) give

$$X_s = T_s \sin\theta/(1/V_1 - \sin\theta/V_2) \qquad (4)$$

$$Y_s = T_s \cos\theta/(1/V_1 - \sin\theta/V_2). \qquad (5)$$

An analogous argument gives

$$X_g = T_g \sin\theta/(1/V_1 - \sin\theta/V_2) \qquad (6)$$

$$Y_g = T_g \cos\theta/(1/V_1 - \sin\theta/V_2) \qquad (7)$$

The first step in the interpretation is the determination of V_1 and V_2 from the traveltime plots in the conventional manner. Then, trial values are assumed for T_s for each shot. The velocity values and the trial values for T_s, along with the corrected traveltime data, are the input to a computer program that generates a plotted cross section. For each shot, equations (4) and (5) are used to determine the coordinates for plotting a symbol to mark the point at which the seismic ray enters the refractor. Then, for every geophone, equation (1) is solved for T_g; equations (6) and (7) are used to determine the coordinates of the point where the seismic ray leaves the refractor.

An error in the trial value for T_s shows up on the plotted cross section as an inconsistency between the plotted entry point for the ray from a given shot and the exit points for rays from other shots, especially the reverse shot. These inconsistencies are removed by modifying the original T_s values, and a new cross section is plotted. The procedure is repeated, if necessary, until a consistent solution is obtained. This process yields an unambiguous solution, provided that the shot and geophone coverage is adequate. The adequacy of the coverage can be readily evaluated by inspection of the plotted cross section.

One simple way of obtaining a starting value for T_s is to assume in equation (1) that T_s and T_g are approximately equal. On that assumption, T_s is approximated by one-half the zero-distance intercept of the V_2 branch of the corrected traveltime curve.

If an incorrect value of V_2 is used in preparing a cross section, the sequence of depth points generated by lines shot in one direction will cross at an angle to the sequence of points generated by lines shot in the opposite direction. Under some circumstances, an improved estimate of V_2 can be obtained by adjusting the initial value to enhance the consistency of depth points from reversed shots.

In deriving the equations for computing the coordinates of the migrated depth points, the assumption was made that the dip of the interface could be neglected. That assumption has been tested by applying the procedure to synthetic traveltime data graphically determined for dipping interface models where V_1 = 5500 fps, V_2 = 10,000 fps, and the interface dipped at 5° and 10° from a depth of 400 ft beneath the up-dip shotpoint. The maximum error of the plotted points in depth was 30 ft for the 5° dip and 80 ft for the 10° dip. The error in the 5° test is negligible compared with other sources of error in shallow-refraction surveying. Even in the 10° test, the error is tolerable, particularly since the errors for up-dip and down-dip lines are of opposite sign; if good reverse coverage is available, the plotted points will bracket the true position of the interface.

REFERENCES

Hazlewood, R. M., and Joyner, W. B., 1973, Preliminary report of seismic refraction survey, Redwood Shores, San Mateo County, California: U.S. Geol. Survey open-file rept., 9 p.

Hazlewood, R. M., 1974, Preliminary report of seismic refraction survey along the east side of the San Francisco Bay, Alameda County, California: U.S. Geol. Survey open-file rept., 10 p.

Lajoie, K. R., and Helley, E. J., 1975, Differentiation of sedimentary deposits for purposes of seismic zonation, in Studies for seismic zonation of the San Francisco Bay region: U.S. Geol. Survey Prof. Paper 941-A, p. A39-A51.

Nichols, D. R. and Wright, N. A., 1971, Preliminary map of historic margins of marshland, San Francisco Bay, California: U.S. Geol. Survey open-file rept., scale 1:125,000.

Scheidegger, A. E. and Willmore, P. L., 1957, The use of a least-squares method for the interpretation of data from seismic surveys: Geophysics, v. 22, p. 9-22.

Schlocker, Julius, 1968, Regional geology: Assoc. Bay Area Governments, Bay Area Regional Planning Program, Suppl. Rept. IS-3, 47 p.

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by
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