dissolved—usually 10 minutes. The solution is centrifuged for 30 minutes at high speed, and the clear supernatant fluid is added drop by drop to 95 per cent. alcohol in 50 cc centrifuge tubes using 1 cc of the supernatant fluid to each 20 cc of alcohol; a precipitate forms immediately. The tubes are centrifuged for 5 minutes at low speed, the alcohol is poured off and the tubes are filled with 95 per cent. alcohol which contains 0.2 per cent. HCl. The sediment usually adheres to the sides and bottom of tubes. This should be scraped by means of a pipette and thoroughly mixed with the acid alcohol; care should be taken to break up large clumps. This is centrifuged for 5 minutes, the acid alcohol poured off and the sediment washed twice in 95 per cent. alcohol, using the same procedure as above. After the final washing, the alcohol is drained off and the sediment dissolved in saline, using 10 times the amount of the original packed cocci. The sediment dissolves readily in the saline, and in order not to lose any of the sediment, the necessary amount of saline is added to the centrifuge tubes. The solution is then collected and placed in sterile centrifuge tubes and heated in boiling water for 20 minutes. It is then centrifuged for 30 minutes at high speed and the clear supernatant fluid collected aseptically into small sterile vials and stored in the ice box.

The antigen is standardized by testing with known homologous and heterologous serums, using various dilutions of the antigen and the optimum dilution of the antigen is determined by repeated tests. This dilution is then used as the standard dilution for the routine testing of the antimeningococcic serums.

The antigen can be kept almost indefinitely when stored at 8 to 10° C. Care should be taken not to contaminate it. We have been using antigens prepared according to this method for the past several years in testing our therapeutic serums, also to follow the response of the horses during the process of immunization, and found the antigens stable and highly specific.

Lucy Mishulow

SPECIAL ARTICLES

INVESTIGATION OF OVERTHRUST FAULTS BY SEISMIC METHODS[1]

In the great mountain belts the earth's crust has been severely buckled and fractured, apparently mainly by horizontal compressive forces. Of the various types of folds and faults that developed in the course of this deformation the enormous overthrust faults are among the most important and interesting. Along these horizontal or gently sloping fractures huge slabs of the crust ranging from thousands of feet to miles in thickness have been thrust forward for distances of miles and sometimes for many tens of miles. The length of these faults, traced along the surface, is from tens to hundreds of miles. Their extension backward and downward into the crust is presumably of comparable dimensions, but in view of the limited thickness of that part of the crust which has suffered mountain-making deformation, it is unlikely that the depth to which they reach exceeds a few tens of miles. On our own continent the Rocky Mountains of the northern United States and of Canada have been thrust many miles eastward over the margin of the Great Plains along such overthrust faults. In the southern Appalachians each of the several slabs shown in any cross section has ridden westward over its neighbor. In the Alps and in the Highlands of Scotland overthrusts on a tremendous scale have been recognized.

Until the shape of the fault surfaces is known it will be very difficult to gain an understanding of the mechanics of the overthrusting process. Suppositions regarding their form have ranged from convex upward to concave; Longwell has suggested that the presumable convexity of the portion near the trace may change to concavity farther back under the plate. It has been difficult, however, to ascertain the three-dimensional form of these remarkable structures, since observation of them is limited to the trace—the intersection of the fault surface with the land surface—and to occasional fensters or windows where a stream has cut through the overriding plate to expose the undermass. Clearly it is desirable to gain any information possible regarding the shape of the fault surface, or of any part of it back of the trace. So far as known, no previous attempt has been made to secure such data for great overthrusts by utilizing seismic reflections. The experiment was tried only after several years' experience with the method and after considerable success through its use had been attained in determining folded structures in stratified formations.

Elastic waves in the crust of the earth are reflected when they encounter a surface between two layers or bodies in which the waves are propagated at different

[1] Contribution 164 of the Balch Graduate School of the Geological Sciences, California Institute of Technology, Pasadena.

velocities. In most applications of seismic methods to stratified rocks the velocity in the layer above the reflecting surface is lower than that in the layer below it, but in the case of great overthrusts the velocity in the upper layer is usually the higher.

Individual strata a few feet or even a few tens of feet in thickness do not reflect the waves; a layer must be about a wave-length in thickness, *i.e.*, of the order of 100 feet, to cause strong reflection. Only if the instruments are located a long distance from the shotpoint does less reflected energy reach them when the high-velocity rock is on the upper side of the reflecting surface.

As a consequence of the usually reversed velocity relation in overthrust plate and undermass, waves passing the boundary surface into the undermass of lower velocity are *refracted* back toward the surface only at distances too great for observation. Consequently, it is usually not possible to utilize the so-called *refraction* method for the investigation of the thickness of overthrust plates. The *reflection* method is effective in this case, however, for the intensity of a *reflected* wave, if its path meets the boundary surface approximately at right angles, differs but little whether it encounters that surface from the high velocity or the low velocity side.

NATURE OF METHOD USED

The underlying principle involved in the reflection method is, of course, the precise measurement, to the nearest one thousandth of a second, of the time required for the passage and return of an elastic wave or miniature earthquake, produced by detonating a charge of dynamite, from a reflecting surface in the crust. Knowing the velocity of the wave in different media, the distance or depth to that surface can be calculated. In soft formations the charges are usually fired in holes about 40 feet deep, since at less depth a large part of the energy is dissipated into the uppermost layer and into the air, causing surface waves and atmospheric sound waves which unduly disturb the instruments. Overthrust plates are commonly so hard, however, that surface-waves are not produced. Moreover, 40-foot holes can not easily be drilled into them, and in the experiments herein described the dynamite was fired in holes not exceeding a few feet in depth. The distance between the shotpoint and the instruments and the amount of dynamite must be such that neither the direct waves through the uppermost layer nor the sound wave interfere with the recording of the reflected waves. Usually the distance was so chosen that the reflected waves arrived either in the interval between the arrival of the direct waves and the sound wave, or shortly after the sound wave.

BEARTOOTH OVERTHRUST

The first attempt to measure the thickness of an overthrust plate was made in July, 1934, on the Beartooth Plateau in northwestern Wyoming and south-central Montana, roughly 12 to 20 miles southwest of Red Lodge, Montana, along the new Red Lodge-Yellowstone Park highway. The experiment was carried out as part of the Yellowstone-Beartooth-Bighorn project initiated by Dr. W. T. Thom, of Princeton University. The funds which made the test possible were made available by the Geological Society of America. Only one day was available for the experiment.

The Beartooth overthrust plate consists of old crystalline rocks, granitoid in character at the localities occupied and locally somewhat gneissic. Flattish-topped, the Beartooth Plateau descends rather suddenly on its eastern side to the trace of the bounding overthrust fault which separates the overthrust plate from the over-ridden block. The surface parts of the latter are composed of Paleozoic and younger sedimentary formations.

Charges were fired and records made at three localities, at each of which different shotpoints, charges and distances between shotpoint and instruments were utilized.

The very first seismogram recorded not only a very definite reflection from the overthrust fault surface but also reflections from underlying strata. Using a velocity of 5.5 km/sec, calculated from the direct waves between shotpoint and instruments (maximum distance 337 meters) the thickness of the overthrust plate was found to be about 3,300 meters (10,800 feet). Similarly, at the second point the thickness was determined to be about 2,500 meters (8,200 feet), and at the third point the depth below the surface was about 2,100 meters (6,900 feet). The data appear to agree very well with such geologic facts regarding the fault as can be observed at the trace.

FRAZIER MOUNTAIN OVERTHRUST

A second test of the seismic reflection method for determining the thickness of overthrust plates was made on Frazier Mountain during three days of field work in November, 1934. The mountain rises immediately west of Tejon Pass, where the Sierra Nevada joins the Coast Ranges of California, about 90 miles northwest of Los Angeles. Its east-west length is about 8 miles, its north-south width about 4 miles, and the elevation of its broad flat top is between 7,000 and 8,000 feet. The upper parts of the side slopes are precipitous.

The geological mapping of the Tejon Pass region by field parties from the California Institute of Technology had previously revealed that the structure of the mountain is most unique. The entire upper part consists of old crystalline intrusive and metamorphic rocks. These extend down the north slope to the San Andreas fault at the foot of the mountain. But for more than three quarters of its periphery Tertiary beds form the lower slopes, and the contact line between the Tertiaries and the crystalline complex roughly parallels the contour lines. In one excellent exposure the contact is horizontal. These and other evidences led to the interpretation that Frazier Mountain is an overthrust slab of old crystallines on Tertiaries—a mountain without roots. It seemed desirable to ascertain if possible the thickness of the slab at a few points by seismic methods. Here, again, are rocks of high wave velocity lying on others of low velocity.

Four instruments stations were occupied, of which the first was used primarily to determine optimum distances between shotpoint and instruments and the proper dynamite charges. The other three stations were on a north-south line, one near the south edge of the mountain top, another near the north edge and the third in an approximately median position.

After some experimenting at each point the travel times of the reflected waves were found to be 0.265 second at the southern point, 0.24 second at the middle point and 0.34 second at the northern point. The velocities in the uppermost layer and its thickness differed considerably at the three localities, but the value of 4.1 km/sec, derived from the longest refraction profile (1,087 meters) shot at the northern point to secure velocity data, was used at all three points for all but the uppermost layer, to which the lower local velocities were applied. On the basis of the above data the thickness of the overthrust plate was calculated to be about 370 meters (1,200 feet) at the southern point, about 430 meters (1,400 feet) at the middle locality and about 580 meters (1,900 feet) at the northern point, with a possible error of a very few hundred feet caused by inadequate velocity data. Subtracting these thicknesses from the surface elevations, about 7,700 feet at all three points, the corresponding fault surface elevations are 6,500, 6,300 and 5,800 feet. The distance between the north and south points is about 8,800 feet and the average north-south component of the dip of the fault surface is therefore about 5° toward the north. The data also indicate that the average dip steepens toward the north. The seismic results agree as well as could be expected with our geological knowledge derived from study of the periphery of the mountain.

CONCLUSIONS

The investigations clearly demonstrate that it is possible to measure the thickness of overthrust plates by use of the seismic reflection method, and from a number of such measurements to determine the form of the fault surface.

Since the method depends upon difference in the elastic constants of the rocks above and below the fault surface, it is applicable not only to those cases in which soft young low-velocity strata overlie or underlie bodies of old crystalline high-velocity rocks but also to those cases in which old crystalline rocks occur both above and beneath the fault surface, provided the velocities above and below differ materially. Since velocities in different intrusives and metamorphics do vary considerably, and since quite different crystalline rocks are brought together along overthrust surfaces due to the great displacements, there is good probability that in favorable cases the surfaces can be followed back from the fault trace to much greater distances than the rear margin of the overridden soft sediments.

The method can not be used successfully on those parts of overthrust surfaces which separate rock bodies in which elastic wave velocities are nearly equal, because the fault itself does not reflect the waves. Also, since the thickness of fault gouge and breccia is usually considerably less than a wavelength, these materials can not be expected to serve as effective reflectors.

However, the maximum distance back from the fault trace to which reflections can be secured gives a minimum extent for the fault surface. It is quite possible that if reflections can be recorded again at localities more distant from the trace than intervening futile points the fault surface can once more be identified and perhaps corroborated by backward projection of the dip determined from the points nearer the fault trace and forward projection of the dip derived from the more distant points.

The experiments indicate that the amount of dynamite needed per charge in the old crystalline rocks is generally very small. The best results were secured with charges ranging from a fraction of a pound to a very few pounds. These quantities contrast with the 20 to 40 pounds per charge required in our recording of reflections from depths approaching 45,000 feet in the soft Tertiary and presumably older sediments of the Los Angeles basin. In shooting on old crystalline rocks deep holes are not needed. For most effective operation a crew of about seven men is desirable.

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