140. Continental Margins as Slip Lines of Earth's Crust.

(First Communication.)

By Hantaro NAGAOKA and Toshiaki SHIRAI.
Institute of Physical and Chemical Research and Earthquake Research Institute.
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By reducing pendulum observations, Helmert found a slight increase of gravity on the continental margin, a decrease from the shore to a value below the normal, then a slow increase in the ocean, approaching to the normal value as given in the figure. This was attributed to the deviation of the plumb-line. Another simpler explanation is an increase of density of the crust near the margin and a decrease on the oceanic slope. According to the inverse square law, the effect of density variation is more felt nearer the place of variation of the crust, since step-like faults as a rule accompany the margin of a continent. Volcanoes are also situated not far from the shore, indicating the presence of rupture lines not far from the margin.

Geologists are accustomed to imagine the presence of stress acting on the crust in various directions, which best accord with the observed formation. Though there are some doubts as to the line of action, the appearance of stress cannot be denied, as the ellipticity and probably the axis of rotation have changed during geological ages, and moreover the secular cooling of the crust can at the same time call forth such stress. As the rigidity of the earth far exceeds that of steel, the resemblance in the behaviour of the crust and steel against the action of stress can be easily conceived, by taking into account the difference in the elastic limit, of which the former is much narrower than the latter. The plasticity of the crust is probably easier to call forth slip lines marking the position of the maximum shear than in steel. The existence of such lines is verified in steel by laboratory experiment, if the stress exceeds a certain limit. In the crust, the stress changes very slowly for millions of years and can attain an enormous value, so that the slip lines corresponding to it appear in

1) Helmert: Sitzber. Preuss. Akad. 18 (1909), 119; Enzykl. mathem. Wiss. 6, 1B s. 143.
the crust, and finally break down owing to the brittleness of the constituent material. If the continental margin be conceived as slip lines, a large part of the crust near it is distorted and crushed, while the border lines are compressed and the density of the crustal material slightly increased. The crushed part may sometimes extend a hundred km. from the shore. Thus the change of gravity found by Helmert is a direct consequence of the formation of crustal slip line. If the pressure be conceived to act between two planes inclined to each other, the slip lines are given roughly by a logarithmic spiral \( r = ae^{b\theta} \), where \( a \) and \( b \) are parameters and \( r, \theta \) polar co-ordinates. Luders' lines by circular application of pressure are also such curves. If the above assumption be valid, the continental margin should form a portion of the spiral, considering a small part of the earth as a plane.

For this purpose, a reference spiral \( r = 728 \text{ km.} e^{0.440\theta} \) was constructed and margins of the continents drawn from a globe (1 m. diam.) were tested, if they actually fit in with the spiral contour. Many portions of the continents were found to osculate to one and the same spiral (i.e. \( a \) and \( b \) remaining the same), if due care be taken to include shallow water as land; for example, NE of Australia. N. of S. America, a small part of W. Africa.

Test pieces of steel plates usually show several slip lines, which generally form a principal group; besides, there are other lines not so long and of smaller dimensions, running nearly at right angles to the principal. In the case of continental margin, similar lines seem to be formed, as it has capes or peninsulas projecting from the general contour, the surrounding being crumbled down on account of the brittleness of the material. Examples are Korea, Shangtung peninsula, Cochin-China, Florida, Spain and Portugal, and numerous others. In such cases, slip lines cross the projected land, so that the neck is liable to be torn off, leaving it as an island; examples are Ceylon, Tasmania, Hainan and others.

Fig. 2 shows reference spiral and continental margins osculating to the curve; W. Africa is typical, the curve extending 6400 km. and subtending 210° at the pole. Coast of California and W. Mexico conform to two arcs; the Bay of California seems to have been formed by the break down of minor fissures running parallel to the peninsula.

2) We cannot attach much importance to the asymptotic pole and the initial line; they are given simply for orientation of the spiral.
resembling San Andreas fault formed on a more grand scale. Northern part of S. America also consists of two arcs, with the isthmus protruding from it. The coast of China has shallow part off Shantung, so that the arc protrudes into the China Sea. The Rift Valley has Nyassa (?), Tanganyka, Kivu, Edward, Albert, Albai lakes on the
arc, and proceeds to the S. boundary of triangular volcanic extrusions in Abyssinia. With the spiral turned in the other direction, the main Japanese Islands fit in fairly well with two spirals as boundaries. The mean line appears somewhat disturbed by the presence of fossa magna in the middle. The Ryukyu archipelagos from Formosa to Kyushu fit into the spiral, running at right angles to the median Japanese arc. Similarly Kurile Islands lie on a long arc, extending from the E. coast of Kamtchatka to Hokkaido. Perhaps the slip line proceeds to Siberia, causing partial crush near Vladistock Bay. Otherwise the Maritime Province of Siberia forms a portion of the spiral. The Aleutian Islands fit in with the reference curve almost exactly. S. and E. coasts of the U.S.A. and E. coast of Australia are as shown in the figures, the deviation being small, if the shallow sea be included in the margins. Java and adjacent islands with the festoons of Sumatra to Andaman Islands lie on the spiral as shown in the figure.

These are some of the main features; numerous examples can be cited about other rather complicated coast lines as well as mountain chains as Himalaya and Andes ranges; the discussions are reserved for future communication as space is wanting. The stress distribution in the crust can be roughly estimated from the slip lines in the form of a logarithmic spiral, so that the geological and seismological questions, which remain still unsolved, can in the future be approached on a more physical basis.