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### **Pioneering Ideas on the Relationship Between Rock Deformation and Tectonic Earthquakes Presented in 1878 by Albert HEIM (1849-1937)**

This study commemorates the 130th anniversary of the publication of the two-volume book (including an atlas): "Investigations into the Mechanism of Mountain Building, Appended to the Geological Monograph on the Tödi-Windgällen-Group" (translated from the German title), by Albert HEIM (professor of geology at the ETH Zürich - then called Polytechnikum - and the University of Zürich). This classic work has been characterized as "a survey and synthesis of structural geologic principles of remarkably modern tone" (MILNES, Geology 1979). The present review emphasizes Heim's fundamental efforts to understand the causes of tectonic earthquakes in terms of rock deformation.

In his detailed field work and microscopic study of deformed Mesozoic and Paleogene/Neogene sediments in the Helvetic zone of the Alps (including the famous Glarus overthrust which he initially misinterpreted as a "double fold"; see TRÜMPY & OBERHAUSER, Abh. Geol. B.-A. 56, 1999), HEIM noticed that rocks at shallow levels were often broken and displaced whereas the same rock types at deeper levels were stretched and folded without fracturing. He deduced from his observations that rocks can undergo diverse deformation mechanisms such as brittle fracture, frictional sliding, and plastic flow, and that the mode of rock failure varies systematically with depth. He concluded that the Earth's crust can generally be subdivided into an upper zone of brittle fracture and a lower zone of plastic flow, separated by a gradual transition where both mechanisms overlap (brittle-plastic transition).

HEIM recognized the implications of his model for the source mechanism of earthquakes. As a cofounder of the Swiss Seismological Commission (1878), he was well aware of new ideas on tectonic causes of earthquakes (Eduard SUESS 1873/4). HEIM argued that tectonic earthquakes are caused by fractures and displacements on preexisting faults, and that rapid stress release can only occur in the upper layer whereas the lower layer deforms slowly and continuously. Since instrumental focal depth determinations that would have enabled HEIM to test his idea were not yet available, he could only tentatively conclude that earthquakes are a shallow phenomenon. However, he pointed out that earthquakes with foci much deeper than the brittle-plastic transition must be caused by other processes. This farsighted inference preceded the discovery of intermediate and deep focus earthquakes by more than 40 years.

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HEIM's insights inspired efforts by rock mechanicians to determine the depth of the brittle-plastic transition, e.g. the first experiments under high confining pressure and temperature in the 1910s. By the early 1930s, improved location accuracies of local earthquakes achieved in California showed that focal depths are limited to the upper 15-20 km, thus supporting HEIM's concept of a rheological stratification of the crust. Recent results such as locations of earthquakes in the lower crust of several regions (including the Alpine foreland), may eventually prove to be compatible with Albert HEIM's long-standing paradigm.