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Reviews

Properties and Processes of Earth's Lower Crust

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This monograph is a collection of papers presented at the IUGG Symposium U7 held in Vancouver, Canada in August 1987. As pointed out in the preface, the principal objective of this symposium was to update our understanding of the properties of the lower crust and to review the physical and chemical processes which may have taken place or still going on in the deep crust. Although, seismologists have been using tables based on a two-layer crust, recent seismological and other geophysical studies have detected signals indicative of further details and layerings within them. These discontinuities give indications of changes in the physical properties or chemical composition at these depths. Simultaneous studies of signals from various geophysical observations help to constrain the hypotheses which would satisfy all data. The studies included in this report have been greatly facilitated by modern instrumental advances and techniques of data processing.

The papers have been grouped under five broad heads, each based on the method of observation. Thus there are Deep Seismic Sounding (near vertical reflection), DSS wide angle reflection/refraction, Seismicity studies, Geophysical and Geological studies.

The studies included in the first group cover observations in Australia, France and different regions of USA. In Eastern Australia Finlayson *et al.* outline large scale lenticles as features of the lower crust in areas of significant Devonian deposition and deformation which appear to be attenuated or absent under basement highs. The velocity in the lenticles (in the Thomson Fold Belt) is higher than in the overlying crustal rocks. The authors suggest that some form of dense high velocity fraction from the upper mantle has been added to the lower crust. In France the layered lower crust is almost flat and uniform in areas which underwent Variscan Orogeny whereas it is deformed and/or attenuated in areas which experienced late Jurassic—Cretaceous rifting. The authors propose that the observed layering was emplaced between late carboniferous and early middle Jurassic in the lower crust either by metamorphism and mafic magmatism and/or cracks filled by the fluids associated with moderate extensional shearing (C. Bois *et al.*). A variety of discontinuities interpreted as faults or shear zones has been shown in the studies in the Appalachian Caledonian System and the northern Appalachians. In the former (J. Hall *et al.*) the discontinuities and diversity observed are attributed to variation in depth of detachment and the position of the structure within the mobile belt. In the northern Appalachians Francois, M. *et al.* define three major blocks underlying the Appalachians. Moho offsets which displace the Moho in a normal sense, they suggest, are related to extension and thinning of the old continental margin. Reverse displacements on the other hand are attributed to reactivation of extensional faults as thrust faults. Studies in the Basin and Range in NE Nevada and the Minnesota Basin (Scott B. Smithson) and Great Lakes region (Alan G. Green *et al.*) and Lake Superior and Michigan (J.C. Behrendt *et al.*) are also included in this group. Contrasting types of the lower crust are reported by Smithson; that in Basin and Range horizontally layered with a Moho showing strong reflectivity whereas in Minnesota reflection is weak, less continuous and absent. These features are explained by horizontal layering, probably as a results of extensional plastic flow during the Cenozoic in the Basin and Range. In Minnesota the deep crust seems to have been thicknened by stacking nappes which are floating in small bodies of anatectic granite. The results obtained along a number of sectors in the Great Lakes have been interpreted to the possible nature of the various layers and their relation to the orogen. These over Lake Superior and Michigan are considered in relation to the tectonic evolution of the Mid-Continent Rift system using a conceptual approach.

The studies conducted through wide-angle reflection and refraction profiling reports in the second group complement those of the first group. They bring out the differences in the characteristics of the discontinuities observed from region to region. In the Lake Superior Mid-Continent Rift System (Duryodhan Epili and R.F. Mereu) P^* is not a simple arrival and *PmP* reflection from the Moho is strong and will observed only from shots fired near ends of the line : the signals from the middle arrive late and form very weak complex wave trains. The observations are interpreted to probably indicate disruption of the Moho. The authors support the rift theory for the structure of the lake. *PmP* data in the studies from the COCRUST experiments (R.F. Mereu *et al.*) show that the Moho is a poorly defined transition zone, except in a few exceptional profiles. Again indications are that tectonic forces disturb the Moho and once so disturbed the period for the Moho to re-establish itself may be very long. *S*-wave observations in association with *P*-waves studied in Southwest Germany (Holbrook) revealed no corresponding *S*-wave reflectivity. A model of the lower crustal lamination based on a compositional layering rather than the presence of fluid filled cracks is advocated. Two studies of DSS results from India (Kaila *et al.* and Krishna *et al.*) also bring out variations in the structure along the profiles. In the Narmada — Son lineament a low velocity layer probably of Mesozoic sediments is reported below the Daccan Traps south of the Narmada. The upper crust above the crystalline basement reveals a block structure and Narmada—Son lineament reflected as a fault feature. The deeper crust shows a large number of reflectors at various depths down to the Moho and indicates a uniform crustal reflectivety rather than transparent upper crust over a relatively more reflective lower crust. In the Koyna region travel time and relative amplitude modelling with the aid of synthetic seismograms results in consistent models of crustal velocity structure with minor lateral variation. They (Krishna *et al.*) observe two low velocity layers in the upper and lower crust and suggest rheological stratification of this part of the lithosphere with levels of increased ductility at those depths. W. Henry and others present a study in South Kenya rift which has enabled the production of a model of crustal structure of 200 km profile. They find considerable relief in the crystalline basement and no evidence for the massive axial intrusion at shallow depth. Among others, a reflector at 12-13 km depth coincides with the brittle-ductile transition inferred from hypocentres. One paper using data from Ocean Bottom Seismographs (Yuri P. Neprochnov) reviews results obtained by the Shirshov Institute of Oceanology. The studies reported are scattered widely in the Pacific, Indian and Atlantic Oceans besides observing broad differences among basings, the author defines an essential age dependence revealing a cyclical pattern in the Eastern Pacific basin. The variations in the crystal structure are found to be in good agreement with the global tectonic cycles.

The third group of papers reports studies on the seismicity of the lower crust. These have come from the Kenya Rift Valley, the Mediterranean, Switzerland and Germany. In the Kenya valley Philippa Cocke and others report activity associates with the larger and older faults and no evidence for any seismic trend cross-cutting the rift. The earthquake depth distribution shows most activity about 12 km. The brittle —ductile transition is thus defined about this depth (refer refraction study by W. Henry *et al.*). Anelastic properties studies in the Mediterranean (A Craglietto *et al.*) reveal broad categories in Eastern Po Valley, North Central Adriatic Sea, the Apennines, the Rhinegraben etc and Tyrrhenian Sea. But the authors suggest considering a greater number of events for better resolution. In Switzerland (N. Deichmann & L. Rybach) earthquakes extend down to 30 km. The focal depth distribution is compared to results of two dimensional temperature field calculations and the authors arrive at a value of above 450° C for the lower crustal seismogenic zone which is higher than what is generally considered compatible with brittle fracture. Heat flow and seismicity, magneto-telluric, magneto variational and electromagnetic investigations have been reported by H. Wilhelm in the Black Forest, SW Germany. A decline of heat flow from north to the central part of Black Forest and anomalously high electrical conductivity at mid-crustal level are observed. Seismicity shows a regional variation in frequency and hypocentral depth distribution. The authors are led to the impression that the physical properties of the Black Forest crust are modified by presently acting fluid processes.

The fourth and fifth groups include reports on work using various geophysical parameters and geological studies respectively. The geophysical parameters studied included *P*-wave variation with depth and heat production, resistivity, magnetisation and gravity. Converting the Vp (Z) profiles into radioactivity, Vladimir Cermak and Louise Bodri report, in various tectonic units in Central and Eastern Europe, decrease of the *D*-parameters $[A\ (Z) = Ao\ \exp\ (-Z/D)]$ with depth contrary to expected increase. They attribute this to difference in the radioactive structure of the upper and lower crust and possibly to re-distribution of *U* in the upper part up to a depth of 10-15 km due to deep ground water circulation. Resistivity studies in Finland, Western United States and Pannonian Basin show the presence of a conduction zone in the lower crust and lead Vanyan and Shilovski to attribute it to super-critical fluids in pores and microcracks. Magnetisation in samples of old shields is seen to be great enough to explain all magnetisation values required by distinct model bodies for the interpretation of fields anomalies. On the other hand elevated crustal blocks generally passes too small a magnetisation (Hahn & Roeser). On studies of magnetisation off east coast of Canada by applying a generalised inversion technique, Arkani-Hamed and Verhoef consider three different models for the magnetic crustal layer. They report better correlation of crustal magnetic susceptibility models with geological features than do the observed magnetic anomalies. The ocean-continent boundary was not found to show a pronounced magnetic signature, the gradient in the anomalies rather corresponding to the deepening of the basement. They conclude that the magnetic anomalies are largely due to lateral variations in the magnetisation of the crust. Inversion of the MAGSAT *Z*-anomaly in the Indian Region (Singh *et al.*) demarcates five fold belts that form the Indian platform, their differences in character extending into the lower crust. The study supports the flexuring of the crust under the Ganga basin due to root formation of the Himalayas. Areas of negative magnetisation over south India are seen to be associated with a thin crust, high heat flow or seismotectonic activity. Verma and Prasad studied the gravity field and DSS data in northwest Himalayas. To explain the gravity anomalies they report that the roots of the Himalayas need be made up of highly basic to ultrabasic rocks. The results do not support continental underthrusting as a possible mechanism of the crustal thickening.

The last group includes reports based on studies geological processes. David M. Fountain has shown that the lower crust in extensional regimes will grow and modify to varying degrees during extension. Studying the granulite terranes of the Superior Province (Canada) Percival finds that collisional (ancient) and accretionary (metasedimentary) setting lead to rapid exposure of high grade metamorphic rocks through tectonic thickening, heating and consequent erosion; however, thickening through magnetism rarely results in extremation of deep crustal rocks. Phase transformations are dicussed by Sobolev and Babeyko who show that quartz tholeite chemical composition of the lower crust is consistent with seismic data if kinetics of solid state phase transformation is considered. The emplacement of thin mafic intrusions into the mafic lower crust produces seismic layering even if the intrusions have the same chemical composition as a bulk of the lower crust. Turcotte purposes as a working hypothesis that the mechanisms for the addition of mantle material to the continental crust at the present time, *viz.*, island are volcanics, continental rift and hot spot volcanics have also been responsible for the same in the past. He proposes that delamination of substantial portions of the continental lithosphere including the lower crust removes the mafic lower crust in order to achieve a bulk silicic composition for the continental crust. Yu Xueyuan discusses the geochemistry of Rb, Sr and REE of Niutoushan Basalts in the coastal areas of Fujian Province, China.

The studies reported represent a multi-disciplinary approach to the problem relating to the lower crust. Naturally increase in data acquisition and their interpretation have stressed a number of hypotheses as to the nature of fermation and age of the layerings there. In so far as these have to be consistent with known and well tested ideas, they help to narrow down the region of divergence. To resolve the few that appear equally sound, further studies need naturally be made. As in the case of Plate Tectonics which helped to explain most of the observations from different disciplines one hopes that our understanding of the lower crust will, in course of time, improve to a well accepted model. The volume has succeeded in bringing out such a perspective, and so in providing thoughts, and may give directions for further efforts.

The publication by the AGU has kept up the very high standards of its previous numbers, with each report highlighting the main points, with clear and self explanatory diagrams well printed. It should prove a very good addition to any geophysical library. Individual scientists, in any field of specialisation in geophysics, will also find in it much to add to and enlarge their knowedge of the latest trends.

— H. M. CHAUDHURY