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Some Problems of the Lithosphere (Augustus Love Medal Lecture)

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In 1911 Augustus Love published a monograph: Some Problems of Geodynamics which in part dealt with the problem of isostasy and the support of mountain belts. In doing so he was one of the first authors to use the concept of the lithosphere. Although his analysis used the framework of linear elasticity, he clearly recognised that the evident structural heterogeneity of the Earth's crust could not simply be interpreted in terms of elastic displacement, and he had no simple explanation for what processes had produced the major topographic features of the Earth: continents, oceans and mountain belts. Today we have a far more complete understanding of those processes, but there are still unresolved problems. In this presentation I will focus on two of those problems that are of particular interest in understanding the geological evolution of the continents: the relationship of near-surface faults and ductile deformation in the lithosphere, and the stability of continental lithosphere in actively deforming zones. While the lithosphere certainly manifests elastic strain, most notably in the context of earthquakes and seismic waves, the large strains that have shaped the continents result from diffuse ductile strain at the deeper levels, coupled with movement on fault planes in the upper crust. Although plates in many regions move coherently with little internal deformation, the stresses that act on different parts of a plate may cause broad deformation zones to develop within a plate interior. Plate boundaries that cross continental regions also typically involve broadly distributed deformation. In recent years the distribution of deformation in such regions is measured accurately using GPS, and in general is explained well by a model in which the lithosphere behaves as a thin viscous sheet, albeit with a non-linear temperature-dependent viscosity law. Such models are broadly consistent with laboratory deformation experiments on small rock samples. However, the relationship between faulting and earthquake activity and the continuous deformation field below the seismogenic layer continues to be poorly understood. Prominent surface faults may be a natural consequence of the localization of strain caused by processes within the ductile layer such as shear heating, grain-size reduction, or simply the interaction of non-Newtonian constitutive law and irregular geometry. Where intra-plate convergence occurs the lithosphere must thicken, and the question naturally arises as to whether the thickened lithosphere will remain stable or somehow be removed by convective overturn with underlying asthenophere. Such overturn is expected of a viscous lithospheric layer that is denser than the asthenosphere; it will be denser because it is colder, unless there is some compositional contrast which makes it intrinsically buoyant. A relatively low viscosity is required, however, in order that the instability can grow at a sufficiently fast rate to overcome diffusive stabilisation of the temperature field. The high stresses created by plate convergence may provide the mechanism that activates the viscosity (and explains why the lithosphere elsewhere is generally stable). High-resolution tomographic investigations find convincing evidence of small-scale mantle drips occurring beneath recently active orogenic zones such as the western USA and the SE Carpathians. However, seismic observations of thickened lithosphere remaining beneath Tibet apparently contradict the interpretation of mantle overturn suggested by recent volcanism and uplift. Although the Tibetan mantle lithosphere may be relatively buoyant, the possibility that this layer has overturned internally may allow these conflicting interpretations to be reconciled.