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Some outstanding assumptions in geophysical studies of the Earth

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Abstract Three examples of incorrect or incomplete assumptions are considered. (1) The oceanic geothermal gradient was originally established using an assumed temperature at the boundary between the rigid lithospheric tectonic plate and the underlying plastically deforming asthenospheric mantle. Revising this invalid temperature assumption has major implications for the concentration of radio-active elements within the mantle, convective patterns and the rate of cooling of the Earth, etc. (2) The earliest 19th century spectral observations of the surface of the Sun identified meteoritic components. This was plausible as Sunspots were thought to be meteoritic impacts, but are now known to be of internal origin. The Sun has no meteoritic materials and its age and origin require major revision. (3) Astronomical changes in the position of objects in the solar system provide causative mechanisms for periodicities in many Earth processes – climate, sea-level, sea-floor spreading, volcanism, etc. Unexplained spectral features probably originate from effects due to the same bodies influencing the solar processes that then affect the magnitude and nature of solar radiation, solar wind, electromagnetic storms, etc., reaching the Earth's upper atmosphere.

1. Introduction

The remarkable advance of science since the 17th C is largely attributable to its philosophical basis, as outlined by Popper (2005). A conjecture is put forward to explain certain observations. This is tested against predictions and new observations, leading to either its rejection or advancement towards a theory. However, all such conjectures, hypotheses and theories remain open to further testing. Commonly, when a theory finds (temporary) acceptance, the assumptions and reputed facts on which it was based are themselves considered to have been validated. This can make it difficult to assess which "facts" were actually assumptions and only appeared to be factual in the context of the available knowledge at that time. Here, examples are given of three assumptions in widely accepted theories, that appear implausible, or inadequate.

2. The oceanic geotherm in plate tectonics

When Bullard (1953) pioneered the measurement of the geothermal gradient in the world's oceans, he initiated

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measurements that were to lead to the acceptance of the Plate Tectonic theory. He made probes for measuring the temperature at different depths (initially a few metres, but later tens of metres) in the oceanic sediments. This near-surface thermal conductivity gradient was then extended to vastly greater depths on the assumption that the oceanic lithosphere–asthenosphere boundary was at ~1200 °C, the melting temperature of olivine at such depths. This was based this being the level below which seismic waves were slowed by the presence of a small amount (0.1%) of fluid. It was assumed that this fluid marked the onset of partial melting of olivine. However, partial melting is not the only possible source of such dispersed fluids. Initially Ringwood (1975), and a few others, had suggested that the fluid was a result of the dehydration of minerals, such as pyroxene, at such pressures and temperatures. However virtually all these proponents withdrew their support of this de-hydration concept in view of the near-universal acceptance of the plate tectonic theory based on this model (e.g., McKenzie, 1969). However, Tozer (1973) not only espoused the dehydration model, suggesting the fluid was derived from amphiboles, but also went on to demonstrate that the partial melt model was completely inconsistent with the principles of fluid dynamics. Significant flow (power-law creep) occurs at least 200 °C below the melting point of the mantle constituents (Figs. 1 and 2) making a simple conductive gradient inappropriate as a geotherm. If the lithosphere–asthenosphere boundary was at 1200 °C, this zone would be characterized by super-fluidity – a state not observed in seismic data until the surface of the upper (fluid) core. The presence of 0.1% water, as a consequence of dehydration, would have little effect on mantle rigidity but can account for the observed decrease in velocity of seismic waves at such depths. Thus

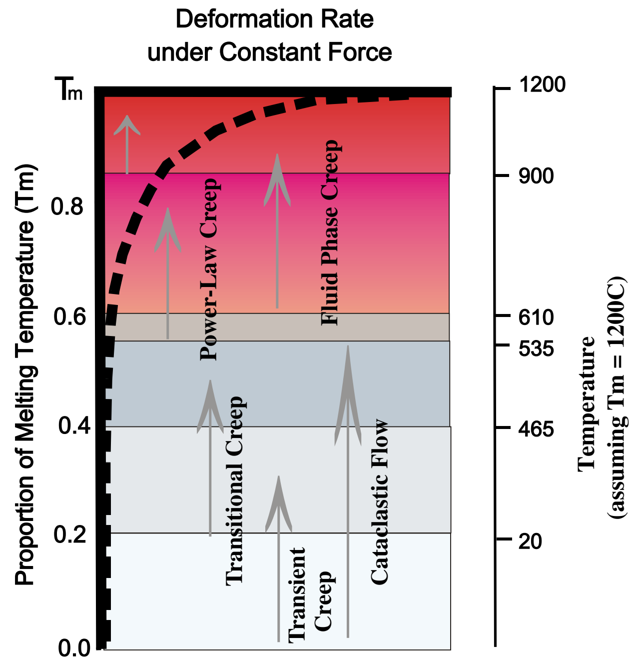

Figure 2 The deformation rate as a function of the melting temperature of olivine (~1200 °C). The predominant creep processes at different temperatures are indicated by arrows. All such processes continue to higher temperatures but, as the temperature rises, become subordinate to new, faster creep processes. Note that the base of the arrow above 980 °C indicates where Herring-Nabarro creep becomes significant, leading to the onset of super-fluidity on approaching the melting temperature (Tm).

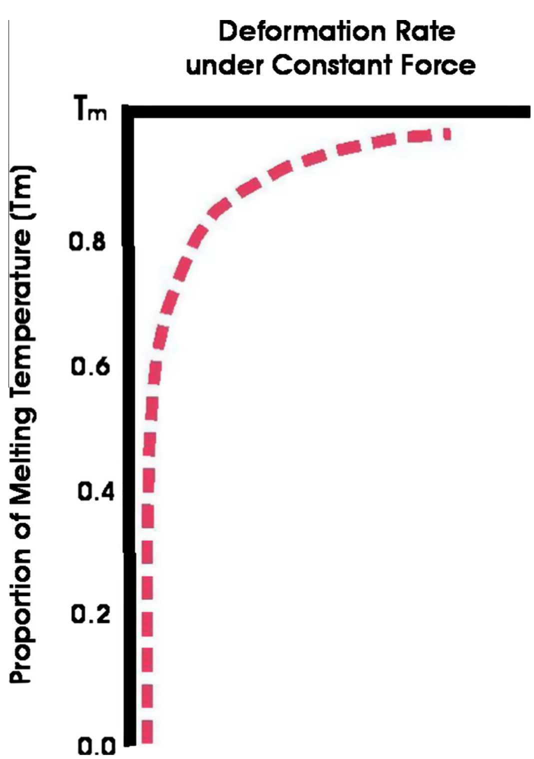

Figure 1 The generalized deformation rate as a function of melting temperature.

the temperature at this boundary is at least 300 °C, possibly 400 °C, below that of the olivine liquidus, i.e., it is at some 800–900 °C. Thus the actual oceanic geothermal gradient is not entirely conductive, as originally conceived, but is largely conductive at shallow depths, but increasingly modified by convective motions at greater depths.

While such a temperature revision is completely consistent with the current rigidity model of plate tectonic mechanisms (and does not detract from the great contribution made by Bullard), the far lower temperature at the lithosphere–asthenosphere boundary has major implications for the actual oceanic geothermal gradient and hence for the evaluation of many other mantle properties (Tarling, 1978, 2001, 2008). In particular it means that the loss of heat from the mantle is far less than currently calculated, implying that any internal heat being generated in the mantle is much lower than currently assessed, i.e., the radiogenic components of the oceanic mantle are some 30% less than existing calculations. Such a low radioactive content is consistent with the so-called "helium anomaly" (Anderson, 2007) as the quantity of helium escaping from the oceanic mantle is far less than predicted by the current model. This also makes the estimated radiogenic content of the suboceanic mantle identical to that of the subcontinental mantle. One consequence is that mantle flow would be far more laminar than currently estimated as little internal heat is being generated (Tarling, 2008). The low radioactive content also has major implications for establishing the region in the solar system within which the Earth acquired its mantle.