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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 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.

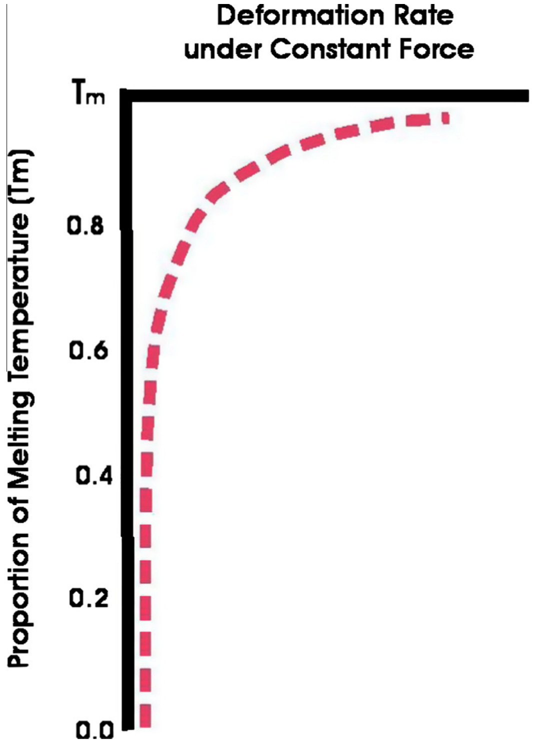

Figure 1 The generalized deformation rate as a function of melting temperature.

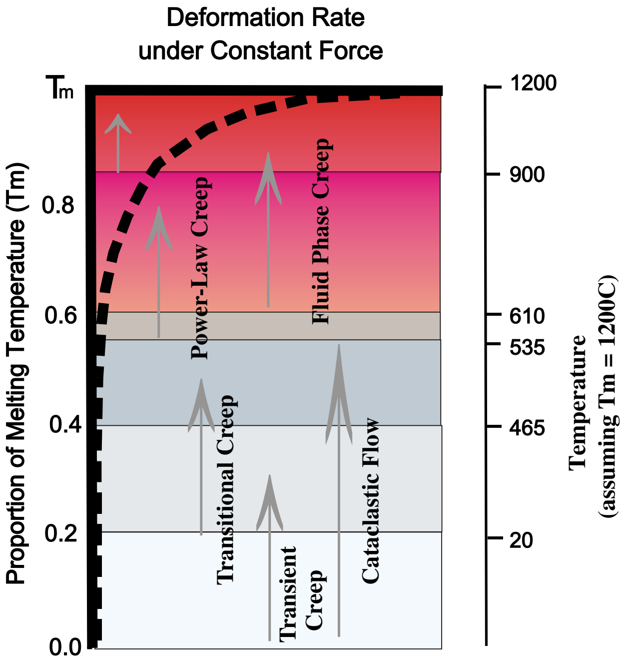

Figure 2 The deformation rate as a function of the melting temperature of olivine (~1200 °C). The predominant creep processes at different temperatures are indicated by arrows. All such processes continue to higher temperatures but, as the temperature rises, become subordinate to new, faster creep processes. 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).

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.

3. The composition and evolution of the Sun and planets

The most widely accepted model for the formation and evolution of the solar system is the "Cold Nebula Collapse" model initially formulated by Kant (1755) and Laplace (1796). However, as pointed out widely in the 19th century, such a collapse was completely inconsistent with the observed distribution of the moment of inertia between the Sun and planets. (Over 99% of the mass of the solar system is in the Sun, yet 97% of the moment of inertia lies in the planetary system; this is opposite to that predicted for a gravitationally collapsing mechanism.) The gravitational collapse model means that the Sun should be very rich in the heavier elements in a similar way that the inner planets are enriched. This was apparently supported by the early spectroscopic evidence of solar compositions that led Lockyer (1890) to propound his meteoritic origin of the Sun. This interpretation appeared to be further supported in the late 20th century when studies of meteorites and solar spectra show both to have almost all their heavy elements in the same ratios (e.g., Trimble, 1975). As elements heavier than iron are almost entirely formed in supernova explosions, the Kant–Laplace model was modified in the 20th C by proposing that the cold collapsing nebular cloud had been "seeded" by a nearby supernova prior to its gravitational collapse. However, such seeding by hot supernova debris should have raised the temperature of the nebula (Tarling, 2006). This would have destroyed the primordial oxygen isotope reservoirs (Clayton, 1993; Yurimoto and Kuramoto, 2004) whose existence was taken as proof of the coldness of the nebula.

Lockyer's (1890) meteoritic model was made at a time when sunspots were thought to be caused by meteorites impacting into the solar surface, but sunspots are actually generated by internal electromagnetic projections into its photosphere. Furthermore, most, if not all, objects approaching close to the Sun are vaporised and the resultant ions are carried away from the Sun in its solar wind, but they have never been part of the solar interior. They exist as part of the Sun's external atmosphere and hence are seen in studies of the photosphere. The absence of heavy (> beryllium) in the Sun is also demonstrated in studies of the propagation of sound waves through the Sun (helio- or astro-seismology e.g., Thompson, 2004; Chaplin and Ballai, 2005). Such studies are particularly sensitive to the presence of heavy elements and have confirmed that the Sun does not contain detectable amounts of elements heavier than lithium and beryllium. The absence of such elements has long been indicated by the Sun's density structure as determined using Moment of Inertia. Furthermore, many such "seeds" purported to be in the cold nebula include very short lived isotopes that had to be incorporated into the (so-called) "presolar grains" and chondrules (Sears, 2004). This occurred within, at the most, a few Myr of their supernova creation. For example, ^{26}Al decaying to ^{26}Mg requires such isotopes to become isolated with a solid only a few 1000 yr after their creation (possibly as short as a few 100 yr). Such timescales are incompatible with the Myr–Gyr timescales required for a gravitational collapse. Similar timescale arguments also negate other solar system Origin models, such as the dualistic "capture" models, e.g. the early models of Jeans (1919), Jeffreys (1929) and the more recent Woolfson (1964, 2000) model.

The absence of meteoritic material inside the Sun has major implications for its age. This is currently based on the oldest radiometric ages of meteorites. If the Sun contains no meteoritic material, then its formation is not necessarily synchronous with the oldest meteoritic material. However, a broadly similar age is indicated whether it is assumed that the helium and lithium present have been entirely generated by nuclear fusion within the Sun, but such estimates are poorly defined as they also depend on the uncertain duration of different generation rates during the Sun's evolution. A younger age for the Sun seems improbable on the basis of the common characteristics of the solar system – the similarity of the ecliptic plane and the solar equator, the similar sense of rotation of most of the objects in the solar system, etc. An older age for the Sun appears to rule out because of the lack of supernova debris in its composition, but if the Sun was then in a τ-tauri phase of extremely strong magnetic and solar flare activity, then high temperature plasmas from the supernova could become zoned within the ecliptic under the influence of the combined solar electromagnetic and gravitational fields (Tarling, 2006, this volume). Such a scenario would enable such condensates to aggregate into the planetary materials very shortly after the explosion of the supernova. While further models need to be considered, it is clear that the conventional cold-nebula model for the origin of the solar system is inconsistent with the present evidence.

4. Astronomical influences of geophysical processes

The gravitational effects of the Sun and Moon on the Earth's tides (atmospheric and oceanic) are self-evident as their timescales of days to decades are obviously causative. The gravitational influence of other planetary motions on Earth processes is much weaker and occurs over far longer timescales. These effects were calculated for the Earth by Milankovitch (1920, 1941) and still provide the current basis for most interpretations of any relationship between astronomical motions and long term geophysical processes (Tarling, 2010). These include natural-occurring climate change (e.g. House and Gale, 1995), reversals of the geomagnetic field (e.g., Iorio et al., 1998), changing of sea-levels and eustasy (Iorio et al., 1996), and volcanism. Although the matching of periodicities between different phenomena does not prove a causative relationship, it helps to constrain the search for such causative effects. However, virtually all current assessments are constrained to the *direct* effect on the Earth of solar and planetary motions, i.e., only the geocentric Milankovitch cycles are used. Milankovitch (1920) originally considered the gravitational effects on the Sun and recognised the gravitational effects of the changing positions of the planets. The orbital motions of the two major gas giants, Jupiter (317.8 Earth mass and 11.8618 yr orbital cycle) and Saturn (95.1 Earth mass and 29.4571 yr orbital cycle), are in 5:2 resonance and cause continuous changes in the locus of the solar system's centre of gravity within the Sun. Such motions, when synchronous with the timescale of solar processes, are particularly likely to influence convective rates and patterns within its Convection Zone, and probably also in its core and near surface activity. This conjecture suggests that the solar "constant" may have long term periodicities that are driven by these changing planetary locations. These, in turn, would directly affect the amount and nature of insolation, the intensity of solar flares and the solar wind, etc., as received at the Earth's upper atmosphere.

Such solar periodicities would particularly influence climatic changes, as insolation changes can be expected to have far greater effects than the relatively weak gravity fields of more remote planets. This may well explain some unexplained features in the climate spectra, such as the 100 kyr spectral peak, the combination of the 95 and 125 kyr eccentricity terms and provide a causative explanation for other spectral features.

5. Conclusions

There appears to be clear evidence that the present assumption of the temperature at the asthenosphere–lithosphere boundary is incorrect. Instead of being at the liquidus of olivine, ∼1200 °C, it must be significantly lower – probably in the region of 800–900 °C – and that the 0.1% fluid content of the asthenosphere cannot be due to partial melting, but results from an exsolution of water, or other fluid phases, within crystal lattices. This has major ramifications for the actual oceanic geothermal gradient and consequently the concentration of the radio-active heat generating elements within the oceanic mantle is some 30% lower than present estimates and similar to that in the mantle below the continental lithosphere. Similarly, the lack of meteoritic content in the Sun's interior is now evident from helioseismic studies. This requires re-evaluation of all of current models for the origin, timing and subsequent evolution of the solar planetary system on which many geophysical models for the Earth's development are currently based. Finally, the present attempts to understand the causative relationships between time series of climatic and geophysical processes, in and on the Earth, using only geocentric Milankovitch determinations need to be extended to include secondary effects, particularly the secondary effects of planetary motions on solar processes. It is probable that such secondary effects are far more effective agents for change than the changing positions of distant planets.

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