Two major difficulties, however, are still left, and it is to these that I wish to direct attention. In the first place, the general acceptance of an asthenosphere ranging from depths of 120–200 km. below the surface of continents and 70–200 km. below that of oceans does not fit with the presence of deep-focus earthquakes ranging down to 800 km. in depth, with a continuity of thrust planes, marked by their epicentres, with those of the shallow-focus earthquakes. This would seem to imply that it is not only the lower crust, the lithosphere, in Dietz's sense, that moves with the continents but also a rigid upper mantle down to about 900 km., below which the heavier material of reduced density 4 and some degree of plasticity seems to predominate.

To be consistent, the expansion of the oceans must occur down to this depth and from it, too, must proceed the material which by successive crack filling provides for the extension of the oceanic floor and for submarine vulcanicity and particularly for extensive basaltic flows and intrusions. This basaltic material may not derive directly from the lower mantle but may be, so to speak, pumped through the cracked crust from the asthenosphere by the buckling of the upper mantle due to the pressure of the convection currents beneath it. This process, as Gaskell has pointed out, is likely to occur catastrophically rather than continuously and its effects disappear in time by subsidence.

The difficulty of reconciling these two sets of facts turns on the rheological properties of the asthenosphere. It is clearly not a liquid or shear waves would not be transmitted at all but, also, evidently it admits easy creep for earthquakes never originate there, in contrast to the rigidity of the layers above and below it. One possibility is that it is crystallographically heterogeneous in which some minor constituent may be melted thus giving it physical properties similar seismically to poorly consolidated sediments. Such a paste sandwich held between rigid rock above and below might well admit both 45° thrust planes and vertical transcurrent faulting as one rigid body. It may also be that the reason why its upper limit lies higher under the oceans than under the continents is because it is actually hotter there owing to upward convection. The apparent equality of flow of heat through continents and ocean beds might well be an almost accidental compensation, the continental masses making up by their greater radioactive content for the heat flow due, under the oceans, to the closer approach of heated material. These speculations might be amenable to test by heat-flow studies on continental margins and oceanic rifts.

The second difficulty is older and more fundamental. It touches the mechanism of the geochemical differentiation between the sima of the ocean beds and the sial of the continents. Apart from an entirely hypothetical solution like the extraction of the Moon from the Pacific basin, it would seem that this is the result of a progressive tangential concentration of sialic material. Continents seem to grow on their active oceanic margins by the pushing in of an undifferentiated crustal material. But how does the mechanism which Dietz invokes, of the sloping under of the ocean floor, transfer its sial content to the base of the crust? Here, I think, more geochemical analysis is necessary. Something might be found by comparative analytical studies of the clearest example of this under-thrust which occurs in Central America where the Pacific type blocks appear to have been pushed right under the Cordillera of the isthmus and come up again in the Antillean arc, limited by the great transcurrent faults of Cuba and Trinidad.

On both these questions of the real depth of the continental blocks and of the concentration of aluminium in these and not in the oceanic block, experimental methods, both chemical and mechanical, as well as observation and analysis should have a part to play.

J. D. BERNAL

Birkbeck College,
University of London.

[1] *Nature*, **190**, 854 (1961).

REGARDING Prof. J. D. Bernal's communication, I am pleased to learn that he finds the concept of ocean floor spreading, marking the top of mantle convection cells, at least generally palatable.

Regarding the question of deep-focus earthquakes, I am inclined to favour the idea of the lithosphere extending to about 70 km. both under the continents and ocean basins. This is, of course, derived from isostatic evidence. Below this level, in the asthenosphere, permanent stresses seem not to accumulate. Deep-focus earthquakes down to 800 km. apparently indicate that stresses do accumulate for short periods of at least a few years, but this does not prove their accumulation for thousands or millions of years. Hence deep-focus earthquakes do not disprove the existence of an asthenosphere at moderate depths. As Bernal emphasizes, much depends on the rheological properties of the mantle substance, about which little is known. To describe it as a viscous solid, as a quasi-liquid, etc., must all fail as adequate descriptions.

I agree with Bernal that the apparent equality of flow of heat through the continents and ocean basins may well be a matter of accidental compensation. The surprisingly high flow of heat from the ocean floor with poorly radioactive rocks may be explainable by convection, whereas the heat flow from the highly radioactive granite rocks of the continents must depend on diffusion.

Regarding the sialization of the continents, I visualize that the sima, rising from the deep mantle, contains some juvenile sialic material. By spreading, this 'sial-sima' is eventually slid under the continents. On subsidence of the sima beneath the continent, the sialic fraction gets largely squeezed out (gravitationally differentiated) and is plastered to the underside of a continent. Hence the suggested origin of sial is much like the generally accepted origin of juvenile water. But the mantle substance would tend to be dewatered at the convection cell divergence while it would tend to be de-sialized at the convergences which are necessarily under the continents because of continental drift to the convergence zones. At present, the process seems especially operative around the Pacific, where the mantle seems to be slipping under the continental block and not coupled with it, in contrast to the Atlantic. This added new buoyancy would help account for the recent epeirogenic uplift of the Pacific margin. Thus, I support the concept of new sial being added mostly under the continental block rather than merged laterally and annularly as Tuzo Wilson believes.

ROBERT S. DIETZ

U.S. Navy Electronics Laboratory,
San Diego, 52,
California.