g2 Hess's sea-floor spreading hypothesis < heat flow >

It is *inconceivable* that basalt flows poured out on the ocean floor could be so uniform a thickness. —Hess, 1962 (before he had learned that Layer 3 is not serpentinite).[1]

A Herschel has pronounced [magnanimously] that 'Geology, in the magnitude and sublimity of the objects of which it treats, undoubtedly ranks in the scale of sciences next to astronomy; ...'—Buckland, 1836.[2]

A revolution in geologic thought in the 1950s was that ocean basins are young geologically.[3] This followed from sedimentation rates measured in the deep oceans that gave Bruce Charles Heezen (pronounced *Hay-zin*) (1924-1977), for one, sleepless nights. At the discovered rates (1 cm per1000 years when averaged globally), the ocean basins will have filled ten times over since Earth originated.

In 1960, Harry Hammond Hess (1906-1969), between puffs on his eternally lit cigarette, pieced together [4] Heezen's aired thoughts that: Earth, "coming apart at the seams," opens seafloor anew at mid-ocean ridges,[5] and, heat flow there is notably high.[6] Hess modeled (***Figure g2.1***)[7] thermal convection in plastically yielding mantle rock, as a driving force that elevates and rifts mid-ocean ridges along lines of surface divergences of mantle up-flows. The seafoor is the upper surface of advecting mantle. Continents floating in the mantle are as rafts in the flow. Continents on either side of an oceanic ridge, separate as the seafloor spreads between them.

In 1961, Robert Sinclair Dietz (1914-1995) named this "Hess's sea-floor spreading hypothesis" when he elaborated upon it.[8] In his model, mantle convection *below* the crust (for which he used the word "lithosphere") results in brittle fracture at mid-ocean ridges. Fissures there are intruded by basaltic magma that originates by decompression adiabatic partial melting of the mantle rock that rises beneath the ridges. The extrusive basalt that accumulatesmand the thicket of feeder intrusions below cool to form each year ~ 3.2 km^2 new basaltic seafloor crust.[9] The underlying flow of mantle rock outward from the ridge-line splits the new seafloor crust there and carries it aside. So are the deep oceans opened.[10]

An observation that both models address is that beneath the relatively thin superficial cover of seafloor sediments (of an unconsolidated "Layer 1" and a consolidated, underlying "Layer 2" that thickens away from the ridge) is "Layer 3, a strikingly uniform 4.7±0.7 km thick crust that transmits seismic p-waves at ~6.7 km/sec." Hess interpreted Layer 3 to be the outer part of the mantle of peridotite composition that has been 70% serpentinized in reaction with seawater that enters fractures as these open at ridge divergences. When Hess spoke of his "sea-floor spreading hypothesis" in his Presidential address to the Geological Society of America in 1963, mutterings afterwards were, as recalled by Konrad Bates Krauskopf (1910-2003): "I don't really like that kind of geopoetry." For that, Hess himself had primed the pump. His *History of Ocean Basins*, 1962, paper begins:

The birth of the oceans is a matter of conjecture, the subsequent history is obscure, and the present structure is just beginning to be understood. Fascinating speculation on these subjects has been plentiful, but not much of it predating the last decade holds water. Little of Umbgrove's (1947) brilliant summary [[11]] remains pertinent when confronted by the relatively small but crucial amount of factual information collected in the intervening years. Like Umbgrove, I shall consider this paper an essay in geopoetry.[1]

The theme had its precedent. Sedgwick had encouraged Charles Darwin in 1931 to a similar imaginative approach.

A bluff Yorkshireman, he [Sedgwick] had met the poet William Wordsworth when he was geologising in the Lake District in the early 1820s. They went on many long walks together, talking freely about their shared love for nature and poetry. When Sedgwick became President of the Geological Society of London in 1830, he told the society that their science could never be exact like astronomy because of the infinite complexity of the material facts. 'There is an intense and poetic interest in the very uncertainty and boundlessness of our speculations.' Some years later Wordsworth asked Sedgwick to write an account of the geology of the Lake District to add to his well-known *Guide to the Lakes.* The man of science was glad to make his contribution to the poet's book, writing that 'No one has put forward nobler views of the universality of Nature's kingdom than yourself.' The nobility lay in Wordsworth's metaphysical themes. Sedgwick believed that geological understanding complemented the insights about the natural world, the human mind and ultimate truths that Wordsworth had drawn from the landscape he loved. —Randal Keynes *Annie's Box*, 2001.[12]

The ocean crust, as a consequence of its advection to either side of the ridge, is of increasing age away from the ridge.

Hess's sea-floor spreading hypothesis was also to explain the discovery in the 1950s (when an explosion of data—that would lead to the plate tectonics theory by the end of the 1960s—began to emerge from the U.S. Navy's probings of the environment in which its nuclear submarines would operate) that the mean heat flow from the deep oceanic crust is approximately equal to that from continental crust. This was a surprise. Samples of the mantle had been identified where they had been caught up in fold mountains and exposed by deep erosion. These alpine-type peridotites have a radioactive content that is very much less than that of continental rock and a correspondingly weak heat-producing capability. So the heat-flow data is hard to explain if oceanic upper mantle is a static layer of peridotite. But if the upper mantle is convecting ...

Earlier (in 1952) Edward Crisp Bullard (1907-1980) had explained that the oceanic heat flow is either due to convection or that Earth's mean chemical composition is the same, to a first approximation, in continental and oceanic areas when averaged down to depths of several hundred kilometers.[13] Historically, the first possibility was not favored until Hess's sea-floor spreading hypothesis gained credence through field testing. However, Hess was merely of the moment. Convection as a mechanism for mountain building had been in the air since Arthur Holmes journal-publication in 1928, and by its inclusion in his *Principles of Physical Geology* (1944).[14] In this model, floating continental crust (sial) is carried by flow in the mantle (sima). The continental crust is divided and moves away from where rising mantle convection diverges and is folded into mountains where mantle convections converge. Oceans open behind the trailing edge of the rafted continents. The model had its appeal, and as early as 1939 David Tressel Griggs (1911-1974) had published on a series of his bench experiments, with materials' properties appropriately scaled, to show how it could work.[15] But at that time when oceanography was in its infancy, no one could devise a good field test for its reality. ❑

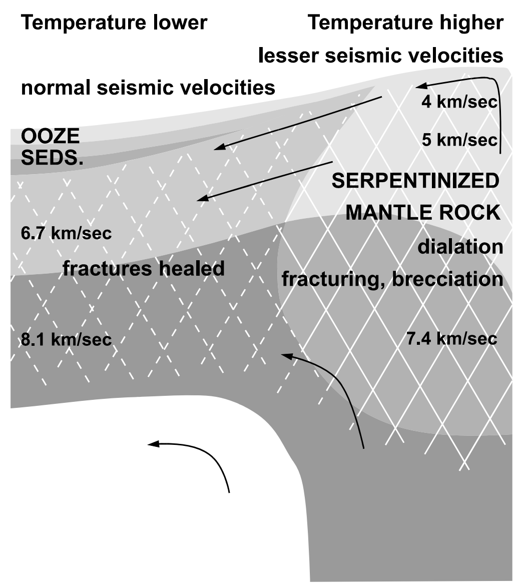

Figure g2.1 The flow to one side of an oceanic ridge (that mirrors the flow on the other side) after a figure that Hess drew in 1960 and published in his *History of the Ocean Basins* 1962 in which he made a case for his (as Dietz named it in 1961) "hypothesis of sea-floor spreading:

"The mid-ocean [*sic*] ridges could represent the traces of the rising limbs of convection cells, while the circum-Pacific belt of deformation and volcanism represents descending limbs. The Mid-Atlantic Ridge is median because the continental areas on each side of it have moved away from it at nearly the same cm/yr rate. This is not exactly the same as continental drift. The continents do not plow through oceanic crust [*see* Topic *i10*] impelled by unknown [*sic*] forces; rather they ride passively on mantle material as it comes to the surface at the crest of the ridge and then moves laterally away from it. On this basis the crest of the ridge should have only recent sediments on it, and away, basal sediments increasingly older on its flanks; the whole Atlantic Ocean and possibly all of the oceans should have little sediment older than Mesozoic.

"On the system here suggested any sediment upon the seafloor ultimately gets incorporated in the continents. New mantle material with no sedimentary cover on it rises and moves outward from the ridge. The cover of young sediments it acquires in the course of time will move to the axis of a downward-moving limb of a convection current, be metamorphosed, and probably eventually be welded onto a continent.

"Assuming a rate of 1 cm/1000 yrs one might ask how long, on the average, the present seafloor has been exposed to deposition if the present thickness of sediment is 1.3 km. The upper 0.2 km would not yet have been compacted and would represent 20 million years of deposition. The remaining 1.1 km now compacted would represent 240 million years of accumulation or in total an average age of the seafloor of 260 [the now-known average is closer to 100] million years."[1]