their operation at least several metres of sediment, but the new lithosphere in ridge zones has had little time to develop a sediment cover. Measurement is therefore limited to the small isolated basins where sediment has begun to form, which are by definition not typical of the whole region. Moreover, the rugged ridge topography, which allows such sediment pools to grow and which is itself the product of variable thermal expansion, distorts the flow of heat and thus introduces geographical variations that are difficult to correct for. Small wonder, therefore, that heat flow data from ridges, though generally high as predicted by plate tectonics, are both highly scattered and subject to systematic errors which generally do not even permit calculation of a true mean value.

Nor is that all. Some of the systematic deviations (for example, the conspicuously low heat flow often found on ridge flanks) are so great that it is impossible to account for them either by topographic distortion or as the result of the accumulation of cold sediment. This has led several workers to suggest that an important influence on the distribution and variation of heat flow in the vicinity of oceanic ridges is hydrothermal circulation in the igneous upper crust—an idea put forward many years ago by Elder (in *Terrestrial Heat Flow*, edit. by Lee, W. H. K., American Geophysical Union, 1965) but promoted particularly vigorously in recent years by Lister (*Geophys. J.* **26**, 515; 1972 and subsequent articles). Lister's point is that heat advected from the crust by hydrothermal circulation which has open access to the ocean water will not be recorded by measurements limited to sediment pools. Average heat flow values obtained from ridge zones will therefore almost always be too low to be consistent with otherwise reasonable models of lithospheric accretion which ignore hydrothermics. Only when there is a complete sediment cover forming a continuous impermeable barrier between the igneous crust and the open ocean will the measured average heat flow begin to approach the true value of heat lost by the oceanic lithosphere.

The existence of hydrothermal circulation is now widely accepted, having been demonstrated to be the most likely explanation for the heat flow distributions revealed by several studies since 1972. A particularly striking confirmation of Lister's basic ideas, however, has now been reported by Davis and Lister (*J. geophys. Res.* **82**, 4845; 1977) who have obtained 104 heat flow results from a 110 km square area centred on the point where the Juan de Fuca ridge meets the transform (Sovanco fracture zone) that offsets it from the Explorer ridge to the north. In the southern section of this area lies the northern end of the Juan de Fuca ridge with its young lithosphere (0–1.8 Myr old), whereas to the north of the fracture zone lies the older crust (3.3–3.6 Myr) which has spread from the Explorer ridge. In other words, the test area includes two quite distinct zones between which the effects of hydrothermal circulation, if any, may be compared.

Throughout the area as a whole the heat flow observations, made at roughly 10 km intervals, were highly variable, ranging from 1.4 to 15.9 μcal $cm^{-2}\,s^{-1}$ and having no obvious correlation with either topography or sediment cover. Moreover, this variability and lack of correlation were equally evident in eight measurements made specially at 2 km intervals. From this evidence alone it seems necessary to invoke hydrothermal circulation throughout the test area.

But the consequences of the circulation differ significantly between the two subzones. The overall picture is mirrored south of the fracture zone where the sediment distribution over the Juan de Fuca ridge and ridge flanks is intermittent and the sediment, where it exists at all, is thin. The heat flow variability is far too great to be explained solely in terms of topographic distortion or sedimentary accumulation. Where there is no sediment cover there must be open circulation between the hydrothermal waters in the igneous lithosphere and the ocean waters above, leading to an underestimate of the true heat flow by the actual measurements made in sedimentary areas. This is confirmed by plotting the measured mean heat flow against the reciprocal of the square root of the age of the lithosphere. The point thus produced lies way below the line derived from other Pacific heat flow provinces where there is no hydrothermal circulation.

North of the Sovanco fracture zone, on the other hand, the basement of the east flank of the Explorer ridge is completely covered with thick flat-lying sediment. The heat flow here is still variable, but rather less so than in the south of the test area; and there is now a distinct inverse correlation between heat flow and the corresponding sediment thickness. In principle, both the variability and the correlation could be explained either by topographic distortion (by which heat tends to converge towards areas where, because of topographic variations in the basement, the sediment is thinner and hence its insulating effect smaller) or by the cooling influence of sedimentary deposition. Indeed, the presence of the heat flow–sediment thickness correlation in particular points strongly towards just such explanations. Calculations show, however, that even in this zone these effects are insufficient.

So it is necessary to invoke hydrothermal circulation even though in this case there is a complete sediment cover. But this is not to say that the sediment cover has no effect. On the contrary, it prevents the hydrothermal waters in the igneous lithosphere venting to the ocean and thus eliminates the false measurement of heat flow inevitable in the case of the Juan de Fuca ridge zone. The measured average heat flow is thus the true heat flow; and this is confirmed by the fact that the former plots precisely on the Pacific heat flow–lithospheric age curve.

In summary, then, what Davis and Lister have shown, above all, is that artificially low values of measured heat flow are entirely consistent with the effects of hydrothermal circulation but that such circulation does not give rise to artificially low values of measured heat flow in all circumstances. Although hydrothermal circulation will always produce scatter of heat flow, a false average value will result only when the hydrothermal waters can vent to the ocean. Incidentally, such venting will, not surprisingly, also lead to a reduction in the average temperature of the hydrothermal waters themselves. Thus Davis and Lister estimate that temperatures at the top of the igneous crust range from 300 °C to 100 °C below the few well-sedimented sections of the Juan de Fuca ridge but from 200 °C to below 25 °C where there is no sediment cover. □

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A hundred years ago

THE vessel was at this time in the neighbourhood of Terra del Fuego, about 140 miles from Magellan's Straits, when early in the morning it narrowly escaped collision with an island where no trace of land appeared on the charts. The vessel hove-to until daylight, when the captain proceeded with a boat's crew to the new island, which had gradually diminished in size since the first observation. Around the conical rocky mass the water was hissing, and although no smoke appeared, it was found to be too highly heated to permit of landing. The sinking continued slowly, until at eight o'clock the island was completely submerged, and an hour later the vessel passed over the spot where it had disappeared.

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