NEWS AND VIEWS

New Ways with Volcanoes?

THE article by Dr David R. Waldbaum on page 534 of this issue seems well designed to put a cat among the geological pigeons. One way and another, many of the processes considered to take place within the crust of the Earth entail a marked change of pressure. This is most obvious when volcanic material reaches the surface from a substantial depth beneath it, but it is now clear that transformations of the same kind must occur when material is added to tectonic plates at mid-oceanic ridges and, conversely, when the edges of the plates are reincorporated into the Earth's crust at subduction trenches. The question that Waldbaum seeks to answer is whether conventional thermodynamics can be used to predict changes of temperature likely to accompany these pressure changes.

It is only fair to say that the issue is exceedingly complicated, not least of all because of the difficulty of defining with sufficient clarity the conditions under which these thermodynamic changes take place. The nub of Waldbaum's conclusion is that there must be many circumstances in which a decrease of the pressure to which some part of the Earth's crust is subjected will be accompanied by an increase of temperature. Such an effect would of course provide a neat explanation of the ways in which igneous material moving upwards towards the surface of the Earth remains molten or at least plastic.

How does all this come about? Waldbaum falls back, quite properly, on a discussion of the application to the materials of the Earth's crust of the Joule–Kelvin effect, best known for its importance in refrigeration processes, when cooling is brought about by the adiabatic throttled expansion of a gas. Liquid CO_2 at ambient temperature can, for example, be converted directly to dry ice at $-80°$ C by this means. For every gas, however, there is at a given pressure an inversion temperature above which throttled expansion results in a temperature increase. (The inversion temperature decreases with increasing pressure.) As Waldbaum points out, the extrusion of a solid substance under similar circumstances will result in a rise in its temperature. In physical terms, the work of extrusion is converted into heat either by direct viscous dissipation or by dissipation as kinetic energy. Since the internal energy of a solid is not strongly dependent on pressure, the heat produced during extrusion must raise its temperature.

It is important to know how closely this chain of argument applies to the processes which go on in the Earth's crust. On the face of things, at least, the pressures within the mantle are great enough to satisfy the interests of most thermodynamicists. Given that the so-called adiabatic gradient for the materials of which the Earth's crust is made may amount to as much as 1 K for each kilobar, it is obviously also possible to think of circumstances in which solid materials are made molten simply by changes of pressure. The chances are, however, that there need to be refinements of the simple picture that suggests itself —the possibility that solids under high pressure at great depths in the crust or mantle could be induced to fly upwards as liquids whenever decreases of pressure took place. Moreover, much depends on whether phenomena such as convection in the mantle, described, for example, by Turcotte and Oxburgh (*J. Geophys. Res.*, **74**, 1458; 1969), can be properly regarded as adiabatic processes. Waldbaum says that even if friction, viscosity and turbulence are ignored in these discussions, the circumstances are such that the ratio $(\partial T/\partial P)_H$ is greater than the ratio $(\partial T/\partial P)_S$, so that the temperature must increase. Where most discussion of Waldbaum's article will be concentrated is on the supposition that these processes are strictly adiabatic or isenthalpic in the sense of the Joule–Kelvin equation.

Only a close definition of what precisely is meant by constant enthalpy—the old-fashioned heat content—is sufficient to resolve the difficulty. Does the definition of the enthalpy of a material include kinetic and gravitational energy, or are these quantities excluded? If the Joule–Kelvin equation should be applied only when changes of gravitational and kinetic energy can either be ignored or compensated for, there is obviously a possibility that the estimates of Joule–Kelvin heating which Waldbaum has made are substantially too great. Obviously it would be valuable to see a closer discussion, along the lines already provided by Mackenzie (*J. Geophys. Res.*, **72**, 6261; 1967) among others of the departures from hydrostatic equilibrium of the pressure differences within convecting regions of the crust and mantle of the Earth. Another difficult, requiring further examination is that there may be many circumstances in which it may be invalid to assume that convection is an adiabatic process. Certainly those parts of the Earth's crust where gravity measurements suggest that convection is rapid are also places at which the heat conduction anomalies are most marked.

For practical purposes, what Waldbaum has predicted is that there will be circumstances in which the process of viscous dissipation within a convecting fluid could result in an increase of temperature in the rising parts of the fluid. This is the hare that thermodynamicists are invited to chase. More immediately, however, it does seem clear that Joule–Kelvin heating of a solid may be important in processes of rapid change as in the impact of meteorites or the effects of seismicity beneath the surface. The process also may be important in the formation and intrusion of kimberlites as well as in violent volcanic eruption. How much more widely applicable may be Joule–Kelvin heating in tectonic processes remains to be seen.