aqueous or alcoholic solutions of electrolytes. In such cases $-\Delta v_x$ increases as the charges on the ions increase and as the ionic radius diminishes. A reservation must be made about this statement. Liquids, it is now recognized, possess a peculiar type of structure due primarily to the presence of directed cohesive forces between the molecules. A solute, particularly a highly polarizing one, may affect the structure of a liquid in such a way as to produce anomalous volume-changes.

A semi-empirical equation summarizing the effects of factors (a) to (d) on the volume-change on mixing was developed.

These considerations have led to two conclusions of direct geochemical interest. The solubilities of sparingly soluble substances such as the sulfates, sulfides, fluorides, carbonates, or hydroxides of the alkaline earths, the rare earths, or the heavy metals in water are undoubtedly increased by hydrostatic pressure and the increase is significant. For example, a rise of hydrostatic pressure from atmospheric to 1000 atmospheres increases the solubility of calcite in water by over 50 per cent of its value at one atmosphere and the same rise of pressure increases the solubility of calcium sulfate by roughly the same amount.

On the other hand, in systems containing solid silicate minerals and molten silicates the compressibilities of the components are close together and small. Unless the structural effects in the liquids play a predominant role we may conclude, therefore, that the solubilities of the minerals in the liquid silicates are probably lowered by increase of pressure. In other words, a silicate liquid in equilibrium with a solid phase will contain less and less of that solid as the hydrostatic pressure increases.

[This paper is to be published in an expanded form in the American Journal of Science.]

Geophysical Laboratory,
    Carnegie Institution of Washington,
        Washington, D. C.

TEMPERATURES IN A SINKING ZENOLITH

T. S. Lovering

(Abstract)

A zenolith may sink or float or remain stationary in a magma depending on the relative densities of the inclusion and the melt. If the density of the two differ perceptibly, the rate at which the zenolith moves through the magma will be a function of its diameter and its difference in density.

The experimental work of Rouse shows good agreement with the formula given by Rubey for the general case of the movement of spheres through liquids. Calculations were made with Rubey's formula for spheres of different diameters whose density was 0.23 greater than that of the liquid which was assumed to have a density of 2.29 and a viscosity ranging from 38,000 to 135 poises. The densities chosen seem ones that may be reasonably assumed for an igneous rock near its melting-point and the viscosities are those that have been experimentally determined for basalt in the temperature-range between 1,150° and 1,400° C. When the calculations have been graphed for representative viscosities it is found that, for the conditions assumed, an inclusion about 60 cm (2 feet) in diameter will sink about 1 km per day in a basaltic mass having a viscosity of 38,000 poises, equivalent to a temperature 1,150° C. In the same melt a zenolith 200 cm (6-1/2 feet) in diameter would sink about ten km a day neglecting the length of time necessary to acquire terminal velocity. An inclusion two cm in diameter would only sink one meter in a day in the same magma but a temperature rise of 50° C would change the viscosity to 3,200 poises and accelerate its fall 125 times.

The change of temperature in a sinking zenolith depends on many complex factors. If there is a chemical reaction between the inclusion and the magma, it may be perceptibly exothermic or endothermic. If heat is evolved, as it may well be with certain types of inclusions, the reaction will be self-propelling and complete solution would result whether the inclusion were large or small. If heat were absorbed during the reaction, a condition that seems unlikely, the temperature would rise more slowly in the mass than normal but complete solution could still take place. The chemical action would be conditioned by the temperature-distribution in the zenolith and either solution or melting would be closely related to the rate of temperature-increase

caused by conduction. If chemical reaction were slow, the assimilation of an inclusion would be due chiefly to a temperature-rise sufficient to cause fusion. In general, this temperature probably would be close to that of the magma. Although the special conditions which may be properly assumed for individual masses are innumerable, the general case of an unreactive zenolith initially at a lower temperature than the magma is instructive.

If a zenolith is falling through the magma at appreciable speed, the liquid moving past it brings fresh supplies of heat at approximately constant temperature to the surface of the body. If we may neglect the thermal gradient in the melt, it can be assumed that the surface of the
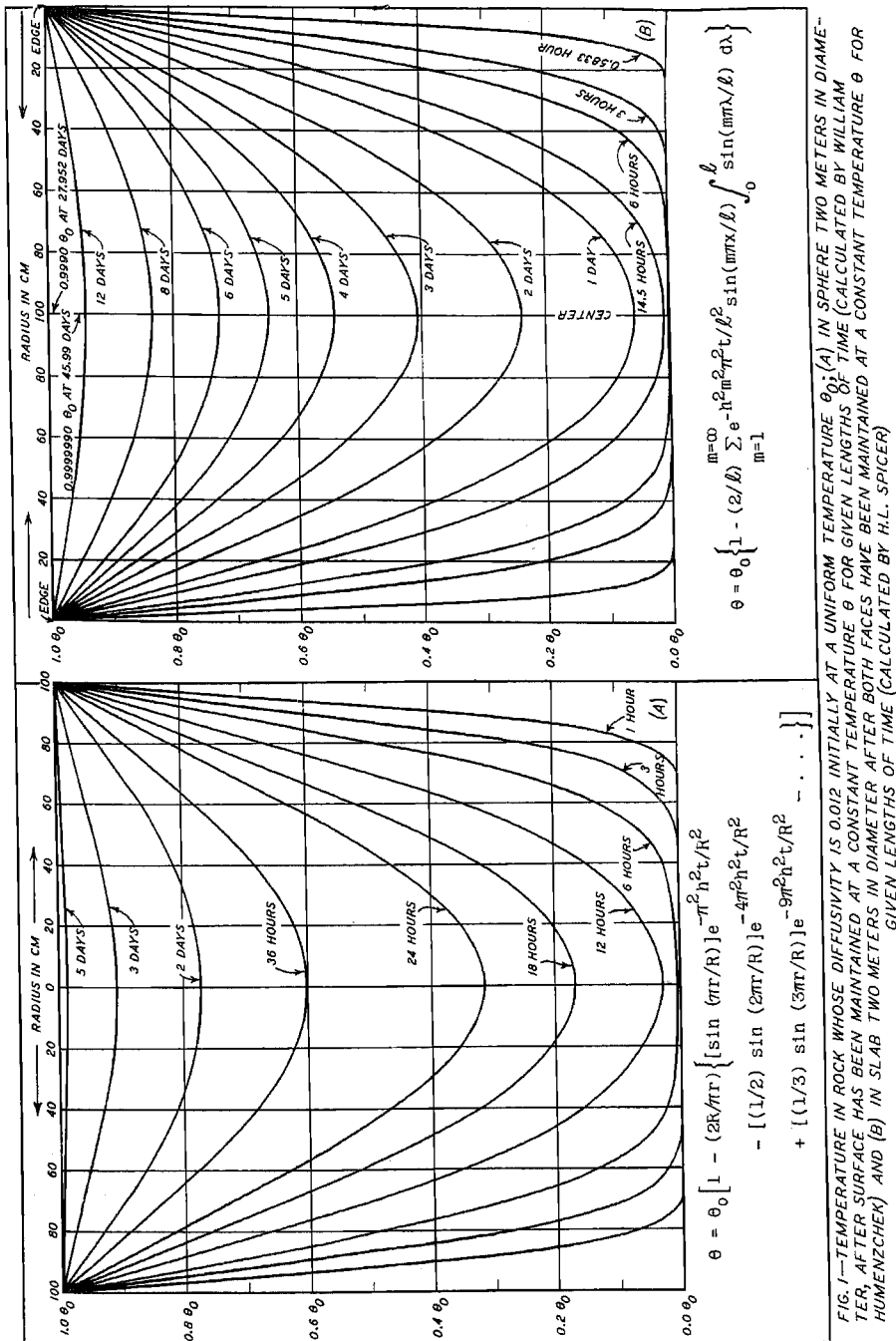

$$\theta = \theta_0 \left\{ 1 - (2/\ell) \sum_{m=1}^{m=\infty} e^{-h^2 m^2 \pi^2 t/\ell^2} \sin(m\pi x/\ell) \int_0^\ell \sin(m\pi\lambda/\ell) \, d\lambda \right\}$$

$$\theta = \theta_0 \left[1 - (2R/\pi r) \left\{ [\sin (\pi r/R)] e^{-\pi^2 h^2 t/R^2} \right. \right.$$
$$- [(1/2) \sin (2\pi r/R)] e^{-4\pi^2 h^2 t/R^2}$$
$$\left. \left. + [(1/3) \sin (3\pi r/R)] e^{-9\pi^2 h^2 t/R^2} - \ldots \right\} \right]$$

FIG. I--TEMPERATURE IN ROCK WHOSE DIFFUSIVITY IS 0.012 INITIALLY AT A UNIFORM TEMPERATURE θ_0; (A) IN SPHERE TWO METERS IN DIAMETER, AFTER SURFACE HAS BEEN MAINTAINED AT A CONSTANT TEMPERATURE θ FOR GIVEN LENGTHS OF TIME (CALCULATED BY WILLIAM HUMENZCHEK) AND (B) IN SLAB TWO METERS IN DIAMETER AFTER BOTH FACES HAVE BEEN MAINTAINED AT A CONSTANT TEMPERATURE θ FOR GIVEN LENGTHS OF TIME (CALCULATED BY H.L. SPICER)

zenolith is maintained at constant temperature unless the movement is so slow that the chilling effect of the inclusion is perceptible in the approaching magma. At the end of one second the chill due to a large zenolith 1,000° C cooler than the surrounding magma would cause a fall in temperature of only 0°6 C at a distance of 0.5 cm and would be entirely negligible at a distance of one cm. Thus it would seem that a body falling at the rate of one cm per second would have its surface maintained at the temperature of the melt. Even with the simplifying assumption that the surface is maintained at a constant temperature, it is impossible to calculate the temperature-distribution for bodies of all shapes. Calculations were made for the sphere and the slab and most all other shapes would lie between these two extremes. If the temperature-distribution is graphed for a body of a given diameter, this same curve applies to other similar bodies of larger or smaller diameter providing the coordinates are suitably changed. The time at which a given temperature-distribution is reached changes with the square of the diameter. Thus if a temperature-curve is plotted for an inclusion at the time t, the same curve will hold for a similar inclusion whose diameter is ten times as great at the time $\overline{10}^2$ t, if the distance-coordinates of the curve are revalued at one-tenth those of the original curve. The heating of the inclusion is measured in percentage of the difference in temperature of the magma and the inclusion--it is independent of the actual temperature-difference at the start. This is equivalent to saying that the center of an inclusion originally 100° C below that of the melt will have risen 50° C at the time that the center of an inclusion originally 1,000° C cooler than the melt has risen 500° C.

The heating curves of the sphere and the slab show that small bodies would quickly achieve the temperature of the magma. In a basaltic magma at 1,200° C a spherical inclusion 25 cm in diameter (10 inches) would sink at a rate of 2.5 cm per second and would be at essentially the temperature of the magma in two hours, when it would have moved only about 180 meters.
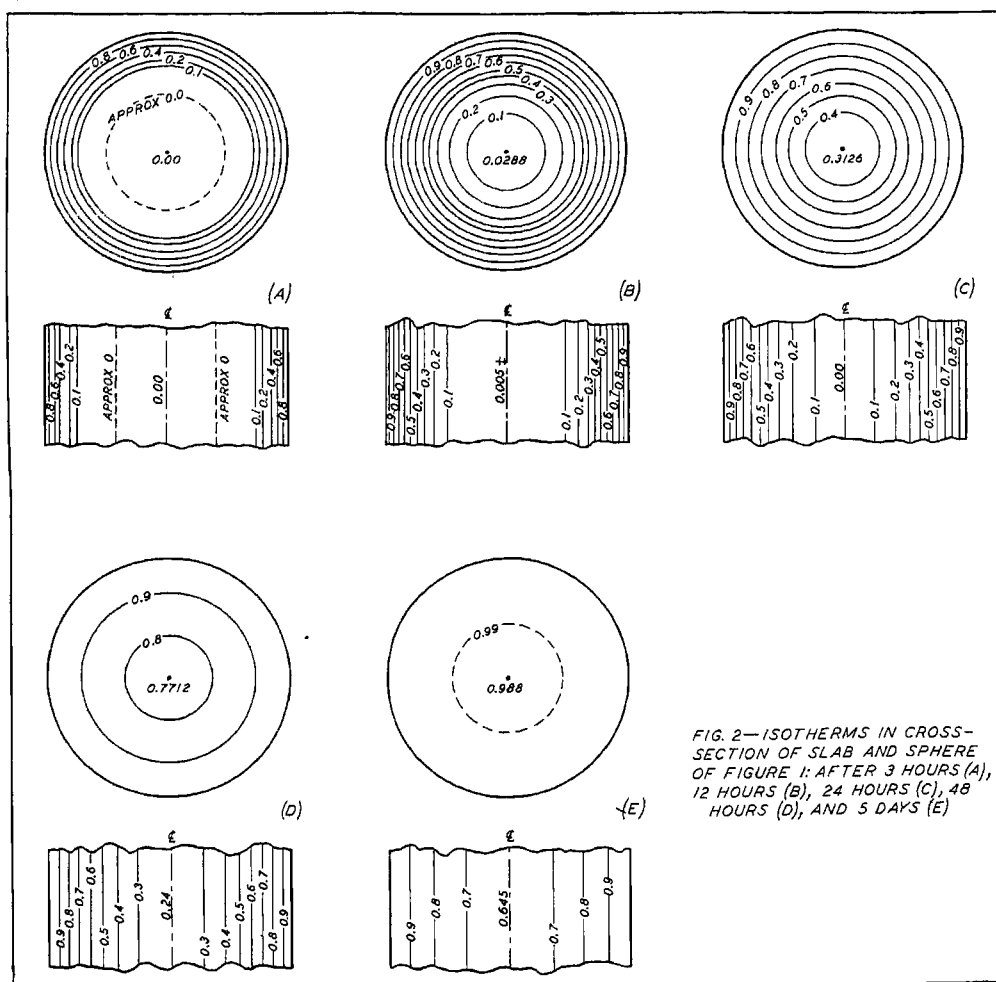

FIG. 2—ISOTHERMS IN CROSS-SECTION OF SLAB AND SPHERE OF FIGURE I: AFTER 3 HOURS (A), 12 HOURS (B), 24 HOURS (C), 48 HOURS (D), AND 5 DAYS (E)

Even in a very fluid magma (basalt at 1,400° C) this inclusion would only sink 2,000 meters before it reached the temperature of the melt. A spherical inclusion two meters in diameter would sink at 13 cm per second in a magma of 38,000 poises viscosity--equivalent to basalt at 1,150° C. The temperature at the center of this inclusion would rise much more slowly than in the small one and it would sink four or five km before the temperature at the center began to rise perceptibly.

Certain modifying factors should be considered. In general, the temperature of the magma would not be uniform and would increase with depth. This thermal gradient would correspond with a decrease in viscosity which would hasten the movement of a zenolith accordingly. If volatiles were present, the chemical activity of the magma would probably be greater but the viscosity would be less and the descent of a zenolith more rapid. It seems probable that the rate of solution would be slow compared with the rate of descent in an active magma and conversely magmas sufficiently viscous to cause slow movement of moderate-sized zenoliths would be relatively inactive chemically.

Consideration of the factors briefly sketched suggests that active assimilation would take place chiefly through the digestion of small fragments in any portion of a magmatic chamber exposed to view. Most zenoliths two feet or more in diameter would probably sink to the bottom of even moderately large magmatic chambers before they were appreciably assimilated unless an exothermic chemical reaction took place between the magma and the zenolith.

Department of Geology,
    University of Michigan,
        Ann Arbor, Michigan

NOTES ON THE EGERSUND ANORTHOSITE, NORWAY

Robert Balk

(Abstract)

Located in the extreme southern part of Norway, the region has been described in part by F. K. Kolderup, and is now under investigation by Professor Tom. F. W. Barth of Oslo. Among the outstanding features of the rock are straight, sharp dikes of massive medium-grained anorthosite, the rocks of which are indistinguishable from their wall-rocks, but they cut the foliation of the wall-rocks at high angles. Equally remarkable are discordant dikes, up to three feet thick, of coarse, pegmatitic texture, composed megascopically of plagioclase (probably calcic andesine), pyroxene, and ilmenite. Preliminary examination by Barth and the writer in the field failed to reveal any hydroxyl-bearing minerals or quartz. Some dikes are so rich in ilmenite that they constitute commercial ore. These dikes raise the question as to what volatiles are capable of precipitating the above mineral associations.

Mount Holyoke College,
    South Hadley, Massachusetts