

(Continued from p. 34)

applied intermittently to the fine grains subjected to the 'grinding' actions in each of these types of apparatus.

That a real pressure component is operative in the action of the mortar assembly was shown by increasing or reducing the weight of the pestle-head assembly by means of a suitable weight or counterpoise to twice or one-sixth the normal weight. Thus, although about 20 per cent conversion of calcite to aragonite was achieved by only 13 hr. of grinding under normal weight, and about 5 per cent in the same time under half the normal weight, more than 100 hr. under the one-sixth weight failed to produce detectable amounts of aragonite. Presumably the greatly reduced weight of pestle is not sufficient to generate pressures greater than 3,000 bars on the calcite, leaving it still in its equilibrium field. Another example is the litharge-massicot transition of lead oxide in which litharge is the low-pressure (and also low-temperature) form. The action of the light-weight pestle (under nitrogen) will drive massicot readily to the stable litharge (this being merely the effect on kinetics due to bond breakage), but if litharge is the starting material no change to massicot is observed. To accomplish the latter the heavier pestle is necessary, presumably since only then is enough pressure available to reach the massicot field. On the other hand, the heavy pestle will produce some litharge when acting on massicot, because all values of pressure up to the maximum must be encountered, since the apparatus of necessity produces a whole 'spectrum' of pressures. A similar example was found on grinding a mixture of the samarionite and valentinite forms of Sb_2O_3 .

Thus it is clear that the stresses causing fracture generally operate to accelerate reactions, although the effect is larger in some pairs of structures than in others. Superimposed on this kinetic effect is a hydrostatic pressure effect. Detailed verification of the separability of the 'stress' and pressure effects has been effected⁵ in an uniaxial high-pressure device⁶ so modified that a slow continuous oscillating displacing shear action by the movement of one piston through 2° of arc is applied to samples (of the above compounds) simultaneously subjected to high pressures and temperatures. It is sufficient to mention here that it has been established that stresses in the form of displacing shear do not alter equilibrium pressures of transitions (within the experimental limits), although they do contribute enormously to the rates of such reactions.

Burns and Bredig² have already pointed out that the possibility of phase transformations taking place on grinding must be taken into account in explaining discrepancies in the behaviour of calcium carbonate. Our results show that: (1) 'grinding' or mixing, in both 'automatic mortars' and 'Wig-L-Bug'-type shakers not only can introduce appreciable amounts of surface and strain energy but also can quite generally cause the formation of high-pressure phases; (2) the effective maximum in the 'spectrum' of hydrostatic pressures obtained in such instruments is not less than about 15,000 bars; (3) in addition to the quasi-hydrostatic pressures exerted, the shearing stresses causing the breakage of bonds and/or the storage of strain energy result in a very marked acceleration on the kinetics of such transformations.

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¹ Zastavsky, A. I., Kondrashov, Y. A., and Tolkachev, S. S., *Doklady Akad. Nauk.*, **75**, 559 (1950). Bode, H., and Voss, E., *Z. Elektrochem.*, **60**, 1053 (1956).

² Burns, J. H., and Bredig, M. A., *J. Chem. Phys.*, **25**, 1281 (1956). At the time of oral presentation (see ref. 5) of this work, Prof. J. Goldsmith directed our attention to his work with J. C. Jamieson on the grinding of magnesian calcites, etc., reported orally at the American Crystallographic Association, Milwaukee meeting, 1958.

³ MacDonald, G. J. F., *Amer. Min.*, **41**, 744 (1956). Jamieson, J. C., *J. Chem. Phys.*, **21**, 1385 (1953). Clark, S. P., *Amer. Min.*, **42**, 564 (1957).

⁴ Dachille, F., and Roy, R., *J. Amer. Ceram. Soc.*, **41**, 78 (1959).

⁵ Dachille, F., and Roy, R., oral presentation, Geol. Soc. Amer., Pittsburgh meeting, November 3 (1959).

⁶ Dachille, F., and Roy, R., *Z. Krist.* (in the press).

Strontium-90 in the 'Mixed Layer' of the Atlantic Ocean

OCEANOGRAPHY and marine geochemistry have only relatively recently been able to take advantage of isotopic tracer techniques; unfortunately, the conceptual framework devised for isotope studies in biochemistry and physiology is not readily applicable to systems of very large spatial extension.

In considering the significance of the ocean reservoirs in the geochemistry of carbon dioxide, and in using the distribution of carbon-14 to derive rates of ocean mixing in both vertical and horizontal planes, it has been conventional¹ to divide the oceans into shallow surface reservoirs assumed to be well mixed, and deep reservoirs assumed to be only slowly renewed from the surface. Since, in some applications, the quantitative expression of this picture is extremely sensitive to the assumed depth of the surface reservoir, and to its rate of renewal from below, it seems important to point out that these parameters are measurable by using relatively short-lived radioisotopes, which are added to the system at the surface. In the case of the Atlantic Ocean, North and South, this condition is well met by radioactive strontium-90 from bomb test fall-out. To the Atlantic, strontium-90 has been added, measurably, only as fall-out to the ocean surface. In this form the isotope is wholly soluble in water²; and in sea water, the dilution of the radioisotope by both stable strontium and stable calcium in solution is so great that neither biological nor chemical processes produce significant changes in strontium-90 concentration. Thus, its vertical transport depends wholly on vertical movement of the water in which it is dissolved.

As a part of an extended study of the marine geochemistry of long-lived radioisotopes from fall-out, we are obtaining a number of series of measurements of the change in strontium-90 concentration with depth in the ocean. Some of these measurements, together with descriptions of the methods employed, have been published³. We now present (Table 1) seven series of strontium-90 analyses, all but one previously unreported. These series agree in showing very significant concentrations of radiostrontium at depth in the open ocean, both north and south of the equator. The number of analyses is still too few to justify very precise integration of the curves of strontium-90 versus depth, but an average concen-

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