tration process is further facilitated.

It has been demonstrated in the field that a segregation of early-formed olivine crystals occurs in the center of the Muskox dike, and by studying the model we have found that this is an expected condition during flowage of a solid-fluid mixture. The geological significance of the process remains to be explained.

In the simple case of the Muskox dike, flowage adequately explains both the concentration of olivine toward the center and its cryptic zoning (the rise of Mg/Fe ratio in olivine toward the center). At the time of intrusion, the first olivines with the highest Mg/Fe ratio started to crystallize. As the magma flowed and cooled these crystals migrated away from the walls, leaving the residual fluid depleted in Mg relative to Fe. Succeeding crystals became relatively more rich in iron as the process proceeded. The chemical evolution is similar in principle to that occurring during normal gravitative crystallization, except that separation of crystals occurs across the gravity field rather than vertically within it. Thus the process may be considered as the flow analogue of gravitative differentiation.

The chemical or cryptic zoning of minerals by flowage differentiation is best developed among the first formed crystals and becomes more complex as crystallization proceeds. In the Muskox dike, both orthopyroxene and plagioclase show cryptic zoning which can be interpreted as being due to flowage. However their rims show zoning due to chemical reaction with interstitial liquid and this tends to mask the earlier zoning due to flowage. Final crystallization of the interstitial liquids produces mineral compositions related to the local site of crystallization rather than to the dike as a whole.

Where double, parallel, olivine-rich (picrite) zones occur in the center of the dike, several explanations are possible. Obstructions in the conduit, sudden swelling, turbulence, or pulsating conditions of flowage will cause the simple flow pattern to break into several parts. However, in general these effects will only modify the shape of the central mass of crystals by breaking or bending it, but will not destroy it completely.

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Dome-Shaped Volcanic Gas Vents in Arizona

Abstract. *Dome-shaped fossil gas vents on one of the Hopi Butte diatremes attest to escape of gas during the closing stage of volcanic activity.*

Dome-shaped fossil gas vents occur on top of one of the Hopi Buttes, the Dilkon diatreme, 3.2 km (2 miles) west and 1.6 km north of Dilkon Trading Post. Late Pliocene volcanic activity formed the Hopi Butte diatremes, and the mafic lava is monchiquite (an igneous rock composed of olivine, pyroxene, and mica in a matrix of analcime).

The Dilkon diatreme is 90 to 120 m (300 to 400 feet) high, is roughly circular and has a diameter of approximately 0.4 km at the top. The butte is largely made up of monchiquite which toward the top grades into a rock composed of well-rounded balls of monchiquite ranging in size from a few centimeters to 0.6 m in diameter, in a matrix of agglomerate (accumulations of volcanic eject). Capping the butte is about 3 m of thinly layered tan limestone which was deposited in a shallow lake within the diatreme. Around the edges of the diatreme the limestone dips inward 15 to 20 degrees, indicating postdepositional sinking or collapse of the central volcanic vent; the fossil gas vents (Fig. 1) are found in the limestone and cover most of the upper surface of the butte.

The dome-shaped fossil vents were formed by vertically rising gas that quietly escaped from below. The dome shape generally persists downward into the underlying limestone layers and only locally was turbulence sufficient to destroy completely the thin bedding of the then still-unconsolidated limestone. Vesicular channelways that carried the rising gases lie within the dome-shaped structures and the limestone immediately below (Fig. 2).

Both thin sections and slabs cut through the domes were examined microscopically for organic material; none was observed. After solution of the limestone in acid, the residue (about 10 percent of sample) was analyzed

Fig. 1. Fossil dome-shaped volcanic gas vent domes on exposed surface of diatreme.

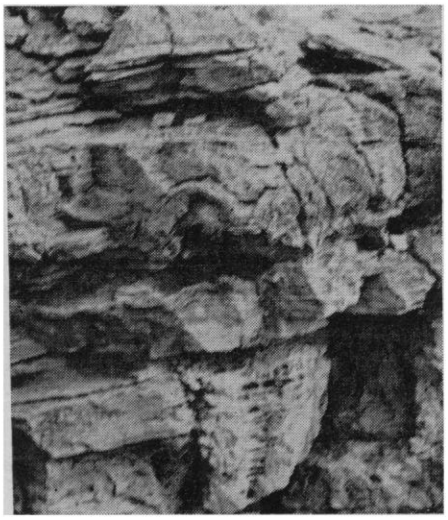

Fig. 2. Layered limestone transected by fossil gas channels. See vertical channel near the center of the photograph.

by x-ray diffraction and proved to be mostly quartz and goethite; x-ray fluorescence revealed chiefly Ca, Fe, and Mn, and traces of Sr and K. The iron occurs as oxide giving the tan color to the limestone. The manganese occurs as secondary pyrolusite dendrites.

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Note

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Strontium Fixation by Lime Contained in Soils

Abstract. *The suitability of soils for the disposal of radioactive strontium waste products is determined in part by the amount and properties of calcium carbonate in the soil. Analyses of the strontium ion concentrations in the effluent solution of soil columns and x-ray diffraction patterns suggest that a fraction of the strontium ions is precipitated as strontium carbonate.*

The incorporation of radioactive waste products from nuclear plants into the soil is one of the proposed solutions for the disposal of these wastes. The suitability of soils for retaining radioactive waste containing strontium-90 is determined both by the composition and concentration of the waste and by soil properties such as cation exchange capacity and *p*H.

Many soils in arid and semiarid regions contain high concentrations of calcium carbonate which might increase the capacity of the soil for retaining strontium ions. We are now reporting on the adsorption process of strontium ions.

Two soils were used. The clay content of soil No. 1 was 1.5 percent and that of soil No. 2 was 47.0 percent, both determined by the Sudan method (*2*). The cation exchange capacities, measured in soil columns with a solution of CsCl containing Cs^{137}, were 1.00 and 13.7 meq per 100 g for soil Nos. 1 and 2, respectively. Soil No. 1 contained 26 percent carbonates and 0.9 percent "active" lime. The carbonates percentage of soil No. 2 was 24.2 and the active lime content in it was 13.8 pecent. The carbonates were determined gasometrically (*3*) and the active lime by Drouineau's method (*4*). The *p*H of a water-saturated soil paste (*5*) of soil No. 1 was 8.9 and that of soil No. 2 was 8.2. The gypsum content (*5*) was 0.025 and 0.030 percent in soil Nos. 1 and 2, respectively.

Soil columns were prepared by packing the soil samples in glass cylinders (10 cm by 2.5 cm in diameter) closed at the bottom by a plastic sponge. A solution of $0.01N$ $SrCl_2$ containing 10^{-2} μc per ml of Sr^{85} was supplied to the surface from a Mariotte bottle which maintained a constant head. Constant-volume fractions of the effluent were collected by means of a syphon and transferred to plastic containers for counting. The radioactivity was measured with a sodium iodide scintillation counter. Two flow rates of the solution through the soil columns were used for each soil, 2 to 4 cm per hour and 20 cm per hour. With soil No. 2, these high flow rates were achieved by mixing the soil with pure quartz sand. Each experiment was carried out in triplicate at a constant temperature of 22° ± 0.1°C.

Figure 1 shows the curves relating the strontium concentration in the effluent to the volume, for the two soils.

Both curves approach values of c/c_0 (concentration of effluent to that of influent at a given volume) less than unity, the values being 0.78 and 0.69 for soils Nos. 1 and 2, respectively. These values were independent of the flow rates. The concentrations (c/c_0) of the effluent could not be raised even by the passage of two to three times the volume required to attain the asymptotic value. The constant effluent value of less than unity was presumably caused by precipitation of the strontium ion.

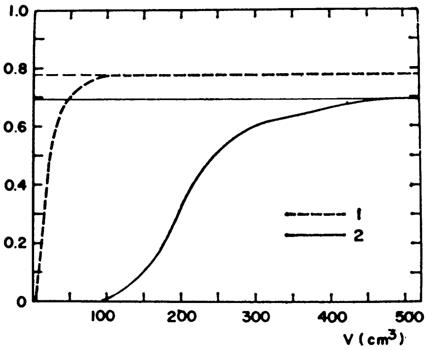

Fig. 1. The relation of the effluent concentration to the volume. (The quantity c/c_0 is the ratio of the concentration of the effluent at a given volume to that of the influent.)

Strontium may be precipitated in the soil as its sulfate, phosphate, or carbonate salt. In the soils investigated, the low concentration of soluble sulfates and of phosphates soluble in dilute acid, $0.01N$ HCl (a few parts per million), could not account for the relatively large amounts of strontium inactivated.

Thus, by elimination, it appeared that the reaction:

$$Sr^{++} + CaCO_3 \rightleftarrows SrCO_3 + Ca^{++}$$

took place in the fixation and resulted in final values of c/c_0 smaller than unity.

To check the foregoing assumption that strontium is precipitated as carbonate, portions of each of the two soil samples were washed with either NaCl or $SrCl_2$, and the x-ray diffraction pattern of their clay fraction was determined. Sodium carbonate was used as the dispersing agent. The surplus electrolyte was removed, and the water in the clay suspension was replaced by a solution of one part glycerol and two parts ethanol (*6*). A Philips x-ray diffractometer model PW 30 with a copper tube was used for the analysis.

The data showed a remarkable diminishing intensity of the $CaCO_3$ line and appearance of $SrCO_3$. It seems that the appearance of $SrCO_3$ was caused both by the aforementioned reaction and by the precipitation of exchangeable Sr with the carbonate associated with the dispersing agent. That the suggested reaction is taking place is shown by the disappearance of $CaCO_3$. Thus, part of the strontium is being fixed, in these soils, by reaction with $CaCO_3$. The differences between the curves for the two soils (Fig. 1) would suggest that