and that of Childs and Collis-George (3) for Poiseuille permeability. Recently Marshall (4) has used this concept of two-plane interaction in determining diffusive flow; however, he has not recognized basic differences between gas diffusion in wet and dry porous systems.

The nature of the coefficients k_1 and k_2 is being considered and will probably introduce a factor varying between 0.8 and 1.2 in the end result. A value of about 0.85, when applied to the data of Fig. 1, results in very close agreement between the experimental data and the computed values.

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Clay Mineral Composition of Borate Deposits and Associated Strata at Boron, California

Abstract. X-ray analyses of samples from lacustrine deposits in the Kramer borate district of California show that montmorillonite is the dominant clay mineral, and that illite is abundant in red siltstones, common in green and gray borate-barren claystones, and sparse in borate-bearing rocks. Kaolinite is present only in red siltstones. The distribution of clay minerals is related to the geologic history of borate deposition.

Throughout much of the Cenozoic era, a "boron-rich province" existed in California, southern Oregon, and western Nevada (1). Boron-rich waters resulting from volcanism collected in playa basins and formed segregated calcium and sodium borate beds in many places in the boron province. Such deposits are geochemically distinct from magnesium-rich borate deposits of marine origin.

As a part of a more encompassing project (2), samples of borates and associated lake clays were collected in the Kramer district at the open-pit mine of the Pacific Coast Borax Company, Boron, Calif. The objectives were to determine the relationships between clay minerals and borate minerals and to relate effects of environmental factors on clay mineral formation, stability, and diagenesis.

In the Kramer district (3) Quaternary alluvium and fanglomerates are underlain by Upper Miocene and Pliocene red playa sediments and green and gray lacustrine claystones and siltstones. Various sodium and calcium borates characterize the various layers in the lacustrine sequence, and thick beds of sodium borates are interbedded with claystone (4). An olivine basalt (Upper Miocene?) occurs beneath the lacustrine sediments.

Various borate minerals are associated together in specific units. Ulexite ($NaCaB_5O_9 \cdot 5H_2O$) and colemanite ($Ca_2B_6O_{11} \cdot 5H_2O$) nodules in claystone matrices are widely scattered in beds above and below the main borax-tincalconite-kernite unit. Colemanite, probably a secondary mineral after primary ulexite (5), is most common near the top of the borate-bearing beds. Borax ($Na_2B_4O_7 \cdot 10H_2O$), tincalconite ($Na_2B_4O_7 \cdot 5H_2O$), and kernite ($Na_2B_4O_7 \cdot 4H_2O$) occur in three main layers interbedded with claystones that collectively form a lentil about 1 mile in diameter in the center of the larger ovate sodium-calcium borate basin. Borax represents the primary precipitate, and tincalconite and kernite are secondary after borax (5). Less common are probertite ($NaCaB_5O_9 \cdot 5H_2O$), inderite ($Mg_2B_6O_{11} \cdot 15H_2O$), inyoite ($Ca_2B_6O_{11} \cdot 13H_2O$), howlite [$Ca_2SiB_5O_9(OH)_5$], and sassolite ($H_3BO_3$) (6).

Forty-five channel samples were collected from various clayey borate beds and from over- and underlying evaporite-barren beds. Borate and clay mineral compositions were determined by direct-recording x-ray diffractometer analyses by standard powder and oriented-sample techniques.

Montmorillonite and illite are, with few exceptions, the only clay minerals present, and the former is the dominant mineral in all of the samples studied. The ratio of the intensity of the unheated 10-A diffraction peak to the gain in intensity of the 10-A peak after heating to 450°C is used as a measure of the illite-to-montmorillonite ratio. Terms used to describe the amount of illite present are abundant, common, sparse, and trace, depending on whether the illite to montmorillonite ratio is 1:1 to 1:2, 1:2 to 1:4, 1:4 to 1:16, and less than 1:16, respectively. Grouping into these ratios is subject to considerable error, but it is desirable to use semi-quantitative limits of some kind in order to compare relative clay mineral abundances in different rock units. Kaolinite and vermiculite-chlorite are found in trace amounts only and do not complicate the quantitative scheme.

Illite is abundant in the red sandy siltstones and is common in borate-barren green and gray claystones above and below the borate units. However, ratios of montmorillonite to illite in the barren claystones are variable, illite ranging between sparse and abundant. Illite is invariably sparse in the borate beds and associated claystones. Kaolinite is present only in red sandy siltstone and probably represents a weathering product of feldspar. A vermiculite or degraded chlorite was found in minor amounts in the upper ulexite-claystone unit.

Influx of terrigenous illite and illite-like mica apparently remained rather constant during the life of the playa lake. Increased increments of montmorillonite derived during the pulsating episodes of volcanism caused a decrease in the illite-montmorillonite ratio. The more saline volcanic waters caused clay to flocculate and permitted deposition of thick sodium borate beds. Clay entering the basin flocculated immediately and was deposited around the edges of the basin. However, during times of low salinity, clay minerals stayed in suspension longer, permitting deposition in all parts of the basin. In laboratory suspensions, flocculation occurred only in samples with high borate content.

The presence of kaolinite in the red playa sediments, as well as the absence of this mineral in underlying green and gray claystones, is noteworthy. In the latter case, kaolinite was either absent in the detritus from the source rocks (7) or has been altered by diagenesis to another mineral in the high pH environment. It is hoped that further investigation will explain the distribution of kaolinite (8).

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References and Notes

1. W. C. Smith, *Bull. Geol. Soc. Am.* 69, 1707 (1958).
2. This project was made possible by National Science Foundation grant G-5659, and by the recipient of the grant, J. B. Droste. I am indebted to Droste for guidance; to G. S. Gordon of the U.S. Borax Research Corp., D. M. Cooper, W. H. Wamsley, and W. J. Diffley of the Pacific Coast Borax Co. for their cooperation; and to D. J. McGregor, W. N. Melhorn, and J. L. Harrison for their comments on the manuscript.
3. H. S. Gale, *Calif. J. Mines Geol.* 42, 325 (1946).
4. Pre-Quaternary rocks referred to in this paper have been called Ricardo formation by H. S. Gale (3), but have recently been included in the Tropico group by T. W. Dibblee, Jr. [*Bull. Am. Assoc. Petroleum Geologists* 42, 136 (1958)].
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6. G. L. Smith, H. Almond, D. L. Sawyer [*Am. Mineralogist* 43, 1068 (1958)] reported an occurrence of sassolite in the Kramer district; however, I did not find this mineral.
7. Elsewhere in this issue, J. B. Droste studies the clay mineral composition of playa surfaces and concludes that the type of clay mineral present is strictly a function of source rather than a matter of diagenesis.
8. This report is published with the permission of the State Geologist, Indiana Geological Survey.

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