FORMATION OF CLAY MINERALS

By ROBERT H. S. ROBERTSON
16 Kirklee Road, Glasgow.

[Read 6th November, 1953]

Among early observers of the origin and occurrence of clay minerals were those geologists who described the hydrothermal alteration of felspar in granite to kaolinite and of some basic igneous rocks to fuller's earth. There were speculations into the origin of bauxite and laterite and of the effect of weathering on various rocks and minerals in different climates. Little progress, however, was made until clay minerals could be identified by X-ray diffraction and other methods.

Modern studies (Grim, 1953) of the formation of clay minerals begin with Noll's hydrothermal synthesis of montmorillonite (1930), pyrophyllite, kaolinite, and mica (1936); since then, most of the clay minerals have been synthesised from their oxides, though attapulgite and hydrated halloysite have not yet been made in the laboratory. Even to-day not enough experimental observations have been made to allow really convincing phase-rule diagrams of these hydrated systems to be made.

As it takes one hour to form kaolinite from its oxides at 300°C and 11½ hours at 200°C (Noll, 1936), between these limits the rate of reaction is doubled for every 15°C rise. If this relation held at lower temperatures it would take 60 years for kaolinite to form at 15°C. Sedletsky (1937) synthesized montmorillonite at room temperature in 4 years, but much quicker syntheses of clay minerals have been achieved by Caillère and Hénin (1948) by an electrolytic method, and by Stresse and Hofmann (1941) who boiled hydrated silica in a solution of magnesium chloride and boiled the product again after adding potassium hydroxide, calcium hydroxide, or sodium hydroxide. The rate of formation of clay minerals in relation to temperature and concentration of reactants gives scope for much future research.

Hydrothermal attack on minerals in the laboratory has been restricted almost entirely to felspars; and atmospheric weathering of rock chips in the lysimeter has also been confined to comparatively few types of rock. Accurate observations of the weathering products of rocks, collected from the field, continue to provide a rich harvest of results. Another line of study has been to observe the effect of weathering of the same kind of rock, such as basalt, in different climates.

Many observations have been made of natural transformations of minerals into clays and it would be tedious to enumerate them. There have also been many observations of one clay mineral being transformed into another, and many of these have been effected in the laboratory. These studies have led to genetical series of transformations from rock-forming minerals, through different types of
FORMATION OF CLAY MINERALS

clay minerals, to rocks consisting essentially of uncombined oxides. Not only are attempts being made to understand the thermodynamics of these changes but also the methods by which the oxides are transported within the rock mass. It is necessary to know how some of the more insoluble oxides are peptized, perhaps by sodium silicate, and carried as a sol to the higher levels as in the formation of laterite.

The molecular state of silica gel, with or without the presence of small amounts of sodium oxide, is of importance with regard to its mode of reaction with alumina, magnesia and other oxides. The degree of polymerisation and the effect of ageing of these gels is of interest not only to the clay mineralogist but also to the applied chemist in industry, since mixed gels are made synthetically for use as catalysts, adsorbents, and in pharmaceutical preparations. Some of these materials have cation exchange properties, although they are not usually crystallised. Layer lattice minerals are, however, comparatively easily made by substituting nickel for aluminium, a fact of importance in catalysis. It is perhaps rather strange that these "nickel clays" have not been found in nature.

Attention has been drawn recently by Jacks (1953) to Russian work on the effect of lichen and other lowly plants in weathering fresh rock surfaces. There appears to be some evidence of clay formation both within and without the organism. It is also thought by some that glauconite is essentially formed in the presence of organisms or organic matter (e.g., Hendricks and Ross, 1941). The role of biological weathering is clearly worth further study, possibly by inoculated lysimeters. There is even a possibility that inhaled mineral dust may be transformed into clay minerals in the human lung (Robertson, 1952).

The formation of clay minerals can therefore be seen to be of interest to many groups of scientific workers. The geologist is interested in the evidence it provides of past climates, of volcanicity and palaeogeography, particularly from the Tertiary onwards. We have evidence of Pleistocene deep weathering in many isolated places; of the kaolinisation and lateritisation of the Antrim basalt; of the deep Permian weathering of the Carboniferous rocks, and of the rather strange conditions which produced attapulgite in the Miocene more commonly than at other times in America, France, North Africa and Syria.

Inorganic chemists are interested in the molecular state and reactions of the sols and gels, which in certain circumstances produce clay minerals. Physiologists keep in contact with work on clay minerals for evidence of mineral changes in the soil, the plant, and the human being. There is no need to stress the importance of this work to the soil scientists, for it is they who have drawn the most complete picture of clay formation from parent rock in relation to climate, topography including drainage, temperature, and the nature of organic cover.

In recent years, studies of the formation of clay minerals have proved to be of great value to industrialists who wished to trace the
variations in quality of clay mineral deposits both laterally and in
depth, and mining engineers are finding that the course and degree
of hydrothermal argillification is in certain circumstances a guide to
mineralisation. Oceanographers are also beginning to disentangle
the complex origin of clay minerals found in marine deposits; there
are those clay minerals which are essentially detrital in origin but
which undergo changes on their way to their place of deposition, and
there are further changes which take place thereafter.

I have tried to review the main methods of study of the formation
of clay minerals and the very different approaches to the subject
which exist. The ramifications of this subject are vast and the harvest
of knowledge awaiting the researcher in these fields is considerable.

References

Soc. Amer., 61, 275-348.

[This paper contains the essence of the introductory lecture to the discussion,
"Formation of clay minerals"—EDITOR].