The 600 brushes measured extend over about a degree or two of 2 theta, brushes on the Ab-rich side being somewhat more extended. The disposition of brushes for *h*00 and 00*l* indicates an increase of β for the Ab-rich phase and a decrease for the Ab-poor phase relative to the principal and supposedly original phase. This is in accord with requirements."

"An initially homogeneous fragment was annealed at 500° C. After this treatment it yielded a *b*-axis oscillation pattern showing brushes similar to those described above."

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AGE OF AUTHIGENIC BIOTITE IN THE UTICA SHALE[1]

G. H. BEALL, *Department of Geology and Geophysics, Massachusetts Institute of Technology, Cambridge, Mass.*

Biotite suspected to be of authigenic origin has recently been reported in the bottom few feet of the Utica shale where it overlies the Trenton limestone near L'Epiphanie, Quebec, 25 miles north of Montreal (Clark and Stevenson, 1960). It occurs as scattered, euhedral, pseudohexagonal, thin books averaging 0.4 mm in diameter and 0.1 mm in thickness, and makes up as much as one per cent of the shale just above the Trenton-Utica boundary.

Factors suggesting authigenic development of the mica crystals in-

[1] M.I.T. Age Studies No. 35.

clude their almost perfect euhedralism, the lack of fraying of the edges, absence of any alteration, and the presence of abundant carbonaceous inclusions.

The composition of the shale in the zone of biotite occurrence is not unusual. Quartz, detrital plagioclase and some muscovite, authigenic dolomite, and carbonaceous granules are enclosed with the biotite in a clay matrix. The shale is black and silty, and is of the normal euxinic facies. There has been no regional metamorphism in this section of the St. Lawrence Lowland, and no evidence of contact metamorphism exists in the exposure itself. There is, however, a 40-foot thick basic sill a quarter of a mile west of the outcrop within the Trenton limestone and across a large fault. This sill, at least 75 feet below the base of the Utica formation, is presumably of Monteregian or Lower Cretaceous age, like other similar sills in the Montreal area.

Since authigenic biotite has not, to the knowledge of the writer, previously been described, it would be useful to be able to eliminate possible detrital and metamorphic origins. The former can be ruled out from the textural observations listed above, but the latter would be possible despite the lack of observable contact metamorphic effects in the rock as a whole.

The only igneous activity known in the Montreal and surrounding St. Lawrence Lowland areas is that of the Monteregian basic and alkaline stocks and associated dikes and sills. The period of this activity has been determined at M.I.T. to be from 90 to 130 million years in age, based on numerous age determinations by both the strontium-rubidium and argon-potassium methods (Fairbairn *et al.*, in preparation). If the biotite in the Utica shale developed from high temperatures caused by a nearby Monteregian sill, the age of the biotite should be Monteregian or Lower Cretaceous. If, on the other hand, it is authigenic, the age should approximate the known Upper Ordovician age of the Utica shale.

From about three pounds of the shale supplied by Professor T. H. Clark of McGill University, Montreal, a few grams of a concentrate containing 63 per cent biotite and 37 per cent shale were separated. Ages determined using this concentrate by both argon-potassium and strontium-rubidium methods with the appropriate data are listed on next page.

These results would tend to confirm an authigenic origin for the biotite in the Utica shale. The argon-potassium age of 402 m.y., a Silurian age, is perhaps slightly young for authigenic biotite in an Upper Ordovician sediment deposited at about 450 m.y., but there is the possibility of argon loss due to diffusion, particularly if the local temperature in the shale rose appreciably over 100° C. during the Monteregian igneous

Age Data on Biotite Concentrate from Utica Shale

Argon-Potassium

Sample Number	%K	Radiogenic Ar^{40}/K^{40}	Air Correction	Age, m.y.
B 4055	3.69	0.0262	19%	402±25
R 4055 (Whole rock)	0.6±0.2			

Strontium-Rubidium

Sample Number	Rb (ppm by wt.)	Sr (ppm by wt.)	Radiogenic Sr^{87}	Age, m.y.
B 4055	147.8	115.2	0.34	550±75

period. In any event, a Monteregian metamorphic origin for the biotite can be ruled out.

The strontium-rubidium age of 550 m.y., a Cambrian age, is almost surely too high for the biotite. This date can be easily explained by the fact that the majority of the strontium in the biotite concentrate is contributed by the 37 per cent shale particles, 115 ppm being generally too high a strontium concentration for pure biotite. This is not surprising considering the presence of detrital feldspar, clay minerals, and dolomite within the shale. Because the age calculation is based on the assumption of an average Sr^{87}/Sr^{86} ratio of 0.712 in the materials of the concentrate at the time of formation of the biotite, the age will likely appear high. For example, it would appear 100 m.y. too high if the actual initial Sr^{87}/Sr^{86} ratio in the materials of the concentrate averaged 0.718 instead of 0.712. Considering the amount of detritus likely of Grenville origin in the shale, such an initial ratio would be quite possible.

The problem of the development of biotite under authigenic conditions presumably at temperatures below 100° C. and under the reducing conditions of the euxinic environment is an interesting one. Biotite generally forms during increasing metamorphism from chlorite and muscovite. This reaction forms the boundary between the chlorite-muscovite and muscovite-biotite subfacies of the greenschist facies. This "reaction" is really a series of reactions, one for each Fe/Mg ratio in the chlorite, and this series is generally thought to take place in nature at temperatures over 200° C. Iron-rich biotites would be stable at the lowest temperatures at any fixed pressure and activity of water. The biotite in the Utica shale, however, is a normal Fe-Mg biotite intermediate between end members phlogopite, annite, eastonite and siderophyllite, according to the optical properties.

For biotite to form at the expense of or instead of chlorite and muscovite at temperatures less than 100° C. in an authigenic environment, it would appear that unusual conditions must prevail. These conditions must be such as to cause a reduction in the temperature of reactions of metamorphism and dehydration by favoring the higher grade or dehydrated assemblages.

The favoring of relatively dehydrated mineral assemblages at temperatures below the usual region of stability can be caused by a low activity of water, *i.e.* a high concentration of dissolved materials in the fluid phase associated with the mineral assemblages. Normally close to unity during progressive metamorphism of water-rich sediments, the activity of water in the fluid phase in a euxinic environment, where decaying organisms and general reducing conditions may cause considerable hydrogen sulfide, ammonia, methane and other materials to dissolve in the fluid, may be reduced considerably.

A low activity of water could perhaps lower the temperature range of the chlorite+muscovite=biotite series of reactions sufficiently to bring it into the authigenic range, thus explaining the possible development of biotite in sediments before metamorphism.

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THE PREPARATION OF SMALL POWDER SAMPLES FROM THIN AND POLISHED SECTIONS

K. L. Williams, *Department of Geology, Australian National University, Canberra, A.C.T.*

The *x*-ray powder diffraction method is a valuable tool for the identification of minerals in thin and polished sections. Many methods have been employed to extract the small powder samples, the most common being the use of modified dental or micropercussion drills, or of diamond- or carbide-tipped pencils. Although these techniques are suitable for