

Rb-Sr WHOLE-ROCK AGE DETERMINATION ON PARTS OF THE MANHATTAN SCHIST AND ITS
BEARING ON ALLOCHTHONY IN THE MANHATTAN PRONG, SOUTHEASTERN NEW YORK

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ABSTRACT

Basement rocks (Fordham Gneiss, Yonkers Gneiss, Pound Ridge Granite) and cover rocks (Lowerre Quartzite, Inwood Marble, Manhattan Schist) make up most of the bedrock in the Manhattan Prong. Parts of the Manhattan Schist are structurally above the basement cover sequence. Regional stratigraphic and structural relationships in the Manhattan Prong suggest that parts of the Manhattan Schist are Cambrian in age and are allochthonous relative to the underlying Cambrian and Ordovician autochthonous cover rocks. A Rb-Sr whole-rock isochron of 554 ± 59 m.y. from Member C of the Manhattan Schist in White Plains, New York is interpreted to indicate that parts of the Manhattan Schist are no younger than Cambrian. It is presumably older than some of the underlying rocks it structurally overlies, thus supporting an allochthonous origin for Member C. This result is corroborated by field studies in the type-locality of the Manhattan Schist.

INTRODUCTION

The Manhattan Prong lies southeast of the Hudson Highlands and east of the Hudson River (Fig. 1) and may be considered as an extension of the Northern Appalachian crystalline complex extending southwest from Connecticut into New York State (Lobeck, 1922). Precambrian and Paleozoic crystalline rocks that underlie this region have been classically divided into three major stratigraphic units known as the Fordham Gneiss, Inwood Marble, and Manhattan Schist (Merrill, 1890). West of the Hudson River, Triassic and Jurassic sedimentary and igneous rocks of the Newark Basin dip gently toward the west and unconformably overlie the crystalline rocks. In western Connecticut and southeastern New York, several mappable units of schist, amphibolite, and gneiss, known as the Hartland Formation, the Hutchinson River Group, and part of the Manhattan Schist, constitute a eugeosynclinal terrane along the eastern edge of the Manhattan Prong (Baskerville 1982; Hall 1968a, 1968c; Merguerian 1983a, unpub. data; Seyfert and Leveson 1969).

A number of subdivisions have been mapped within each of the three classic units of Manhattan Prong stratigraphy (Hall, 1966, 1968a; Merguerian, unpub. data). One result of the correlation and interpretation of the regional stratigraphy is a proposal that parts of the Manhattan Schist constitute an allochthonous Cambrian sequence that was juxtaposed with Cambrian and Ordovician Inwood Marble and autochthonous portions of the Manhattan Schist (Hall, 1968a, 1968b; Merguerian, unpub. data). The main aims of this paper are to report Rb-Sr isotopic data from Member C of the Manhattan Schist exposed in White Plains, N.Y., to evaluate the interpretation that it is Cambrian and therefore allochthonous, and to present structural and stratigraphic data from the type-locality of the Manhattan Schist in further support of an allochthonous schist model.

GENERAL GEOLOGIC RELATIONS

Basement gneisses in the Manhattan Prong include numerous mappable units within the Fordham Gneiss (Hall, 1966, 1968a, 1968c; Ratcliffe, 1968a), the Yonkers Gneiss, and the Pound Ridge Granite (Prucha et al., 1968; Scotford, 1956). Rb-Sr isotopic studies of

the Fordham Gneiss indicate that the Fordham Gneiss units were deposited about 1300 m.y. ago and recrystallized about 1100 m.y. ago (Mose, 1982). Rb-Sr isotopic studies on the Yonkers Gneiss and lithically similar and probably equivalent Pound Ridge Granite Gneiss indicate that these units, although part of the basement, are significantly younger than the metamorphic event recorded by the Fordham Gneiss. Long (1969) determined a whole-rock Rb-Sr isochron of 563 ± 30 m.y. for the Yonkers Gneiss. (All Rb-Sr whole-rock ages in this report have been calculated using a Rb decay rate of 1.42×10^{-11} yr⁻¹, Steiger and Jager, 1977.) Detailed mapping (Hall, pers. comm.) has revealed truncation of subunits in the Fordham Gneiss along the Yonkers Gneiss contact which may be due to faulting, an unconformity, or a cross-cutting intrusive relationship. The radiometric data taken in conjunction with the discontinuity at the Yonkers Gneiss contact indicates that the Yonkers is either a metamorphosed Late Precambrian intrusive body or a volcanic unit that was deposited unconformably on the Fordham. Mose and Hayes (1975) determined a Rb-Sr whole-rock isochron age of 579 ± 21 m.y. for the Pound Ridge Granite, and suggested that it and the Yonkers Gneiss formed from the consolidation of migmatitic fluids that intruded the older Fordham Gneiss. All of the above predominantly gneissic units are grouped together as basement rocks in Fig. 1 because they are unconformably overlain by the basal lower Paleozoic Lowerre Quartzite and subunits of the Inwood Marble (Hall, 1968a). An erosional interval occurred after the formation of the Yonkers Granite and the Pound Ridge Granite. The resulting erosion surface was submerged and overlain by the eugeosynclinal pre-metamorphic protoliths of the Lowerre Quartzite and Inwood Marble. Unfortunately, these relationships have not been documented in New York City due to a lack of critical exposures.

The basal Lowerre Quartzite outcrops north of New York City and consists of quartz-feldspar granofels, quartzite, and feldspathic schist, which is overlain successively by several members of the Inwood Marble (Hall, 1966, 1968a). In the Manhattan Prong (Fig. 1), the Inwood Marble consists of clean dolomitic marble with minor quartzite, schist, and calcite marble. Together the basal Lowerre and Inwood sequence mark a portion of an extensive carbonate bank that developed on the submerged Precambrian crust (Fordham Gneiss) in

the vicinity of the eastern edge of the continent of North America during the Cambrian and Early Ordovician (Rodgers, 1968).

Merrill (1890, 1902) originally named the Manhattan Schist of New York City during folio mapping conducted by the U.S. Geological Survey. Further work by many researchers have defined the lower Paleozoic stratigraphy of the New York City area (c.f. - Berkey, 1910, 1911; Fettke, 1914; Gratacap, 1909; Hobbs, 1905; and Prucha, 1956). Recently, detailed bedrock mapping of outcrops and newly-created construction excavations on Manhattan Island by Merguerian (unpub. data) indicates that in its type-locality the Manhattan Schist is composed of three lithologically distinct schistose and gneissic tectono-

stratigraphic units (Merguerian, 1983b). Two of these are allochthonous and form southward-topping sequences that structurally overlie the Fordham-Inwood basement-cover sequence. Locally, above the Inwood Marble in Manhattan and the Bronx occurs interlayered calcite marble and rusty-weathering schist (lower schist unit in Fig. 1). Similar interlayered schist and calcite marble occur in White Plains, N.Y., where the unit is designated Manhattan Member A by Hall (1968b). Based upon regional lithologic correlation, the lower schist unit is considered to be a metamorphosed equivalent of the middle Ordovician Walloomsac Formation. In White Plains, the base of Member A is in contact with subunits of the Inwood Marble and the Fordham Gneiss basement and thus is interpreted to rest unconformably upon them, and is correlated with a widespread Middle Ordovician unconformity (Hall, 1968a). Thus the Lowerre Quartzite, Inwood Marble and lower schist unit (Member A) of the Manhattan Schist are interpreted to constitute the miogeosynclinal autochthonous cover rocks of the region (Fig. 1).

Structurally above the Fordham-Inwood-lower Manhattan Schist sequence occurs the middle schist unit of the Manhattan Schist. This is a lithologically distinctive assemblage of massive rusty- to maroon-weathering quartz-plagioclase-biotite-muscovite gneiss and schist with subordinate garnet, tourmaline, and magnetite with thin but conspicuous layers and lenses of sillimanite+quartz+magnetite (Merguerian, 1981, 1983b). Also included in this unit is subordinate muscovitic schist and discontinuous amphibolite. The middle schist unit, which underlies the hilly central and northern parts of Manhattan Island (Fig. 1), is lithostratigraphically equivalent with Cambrian rocks of the Hoosac Formation in western Massachusetts, parts of the Waramaug Formation in western Connecticut, and Hall's (1968b) Members B and C of the Manhattan Schist in White Plains, N.Y. (Merguerian, 1981, 1983a). In White Plains, N.Y., Member C of the Manhattan Schist consists mainly of metamorphosed pelitic rocks that are now schist, schistose gneiss, and granofels. Some amphibolite layers are also present and are locally extensive enough near the lower contact of Member C to be mapped as a separate unit (Member B) of the Manhattan Schist.

To further complicate matters, an upper schist unit forms most of the bedrock of the southern third and western side of Manhattan Island and consists of dominantly well-layered, muscovitic schist, gneiss, granofels, and amphibolite. The upper schist unit is in uncertain contact with the middle schist unit but highly flattened rocks from the contact zone suggest that the contact is a ductile fault (Merguerian, unpub. data). The rocks are identical to, and therefore considered correlative with, the Cambro-Ordovician Hartland Formation of the Bronx, N.Y. (Baskerville, 1982) and western Connecticut (Merguerian, 1983a). Thus rocks classically mapped as the Manhattan Schist form different tectonostratigraphic units (lower, middle, upper) in the southern terminus of the Manhattan Prong (Fig. 1).

Detailed mapping and petrographic studies on Manhattan Island indicate that the middle schist unit is in mylonitic contact both with subunits of the autochthonous Inwood Marble and

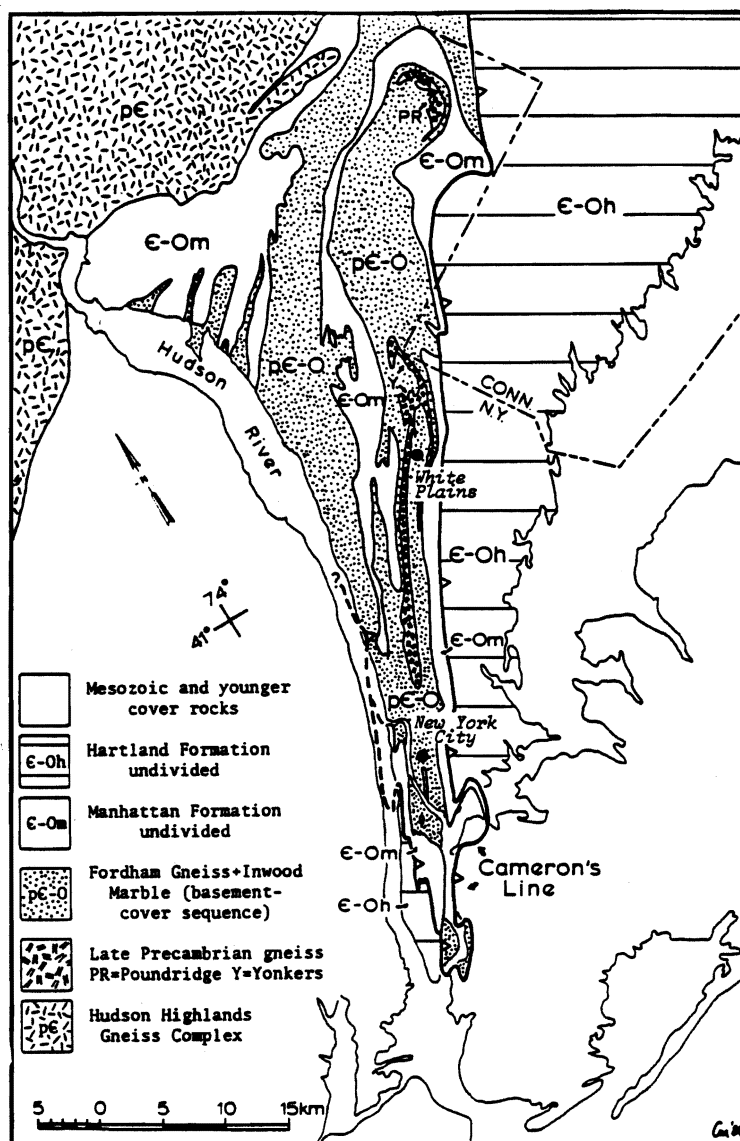


Figure 1- Simplified geologic map of the Manhattan Prong showing the distribution of Precambrian to Lower Paleozoic metamorphic rocks. Most intrusive rocks have been omitted and map contacts are from various sources mentioned in the text. In the type-locality of the Manhattan Schist Formation in New York City the rocks have been subdivided into a lower unit (included in pe-O), a middle unit (E-Om), and an upper unit (E-Oh) (Merguerian, unpub. data).

interlayered schist and calcite marble of the lower schist unit (Merguerian, unpub. data, 1983b). Thus lithostratigraphic and structural data strongly suggest that probable Cambrian rocks of the middle schist unit occur physically above Cambro-Ordovician rocks of the basement cover sequence on Manhattan Island.

Similarly, although Members B and C in White Plains are structurally above other units (Hall, 1968a and 1976), they are interpreted to have initially been feldspathic shales, siltstones, and sandstones as well as some mafic lavas deposited during the Cambrian as an eastern facies of the Lowerre Quartzite and part of the Inwood Marble. If this interpretation is valid, it suggests that Members B and C are allochthonous in concert with relationships established farther south on Manhattan Island (Fig. 1). They were apparently juxtaposed with autochthonous rocks which are partly time equivalents (Lowerre and lower part of the Inwood) and partly younger than (upper part of the Inwood and Member A of the Manhattan) the allochthonous rocks. In addition to such deep-seated thrust faulting, which is believed to have occurred during the middle Ordovician Taconic orogeny (Hall, 1968a), the entire section of basement, autochthonous rocks, and allochthonous rocks was subjected to protracted metamorphism, and intrusion during the Taconic orogeny (Hall, 1968a; Ratcliffe, 1968b). Episodes of folding and metamorphism during the Acadian and Alleghanian orogenies also affected the rocks in the region (Brock and Brueckner, 1978; Clark and Kulp, 1968; Grauert and Hall, 1974; Hall, 1968a; Long and Kulp, 1962), thus the orogenic history of the region is highly complex.

A minimum age of about 360 m.y. has been determined from K-Ar analyses done on micas from the Manhattan Schist collected from a number of localities in the Manhattan Prong (Clark and Kulp, 1968; Long and Kulp, 1962). The actual range in ages determined by these K-Ar studies is 375 m.y. to 406 m.y. (Long and Kulp, 1962) and 330 m.y. to 440 m.y. (Clark and Kulp, 1968). The meaning of these ages is debatable. It is reasonable to conclude that the spectrum of K-Ar ages either represents the various local times of uplift and cooling of the rocks subsequent to the Taconic orogeny (Dallmeyer and Sutter, 1976) or that it represents the domain effects of Acadian metamorphism (Brock and Brueckner, 1978; Brock and Mose, 1979; Clark and Kulp, 1968; Grauert and Hall, 1974; Long and Kulp, 1962). In either case, these data indicate that the Manhattan Schist is no younger than approximately 440 m.y. (Late Ordovician).

The Manhattan Schist is intruded by several igneous plutons which have yielded radiometric dates that provide important constraints on the minimum age of the Manhattan Schist. A Rb-Sr whole-rock age of 359 ± 21 m.y. has been determined for the Peekskill Granite (Fig. 1) which intruded the Manhattan Schist (Mose et al., 1976). The Croton Falls Complex intruded Manhattan Schist Unit C (Fig. 1) and has yielded a Rb-Sr whole-rock age of 387 ± 37 m.y. (Brock and Mose, 1979). The Cortlandt Complex (Fig. 1) intrudes foliated subunits of the Manhattan Schist and K-Ar data on igneous biotite of the pluton yields an age of roughly 435 m.y. (Long and Kulp, 1962). Thus radiometric data from plutonic rocks also only indicate that the Manhattan Schist and all the New York City Group have a minimum age of about 435 m.y. (Late Ordovician). The data do not prove (or disprove) that unit C is Cambrian. Only if the age of deposition of Manhattan C were shown to be Cambrian or late Precambrian could the thrusting interpretation be supported. For this reason, an attempt was made directly to date the metasedimentary unit C.

Specimens were collected for study from an approximately 100 m long excavation in Member C of the Manhattan Schist south of the intersection of Jackson Avenue and Central Park Avenue in the northern part of the Mt. Vernon 7 1/2' quadrangle (Fig. 1). It is the same locality from which samples were collected for the Rb-Sr study on adjacent, small (about 2 cm thick), whole-rock slabs and their minerals made by Grauert and Hall (1974). The isochrons resulting from the small whole-rock slab study were interpreted to represent the climax of the last metamorphic event at 335 m.y. when local strontium isotopic homogenization took place within the 10 cm diameter volumes represented by the slabs. Biotite - whole-rock chords from these samples correspond to ages ranging from 310 m.y. to 320 m.y. These ages are interpreted to indicate the approximate time that biotite became a closed system to rubidium and strontium (Grauert and Hall, 1974). The modified whole-rock slab age of about 335 m.y. is only slightly younger than the 360 m.y. K/Ar ages common from rocks in this region (Long and Kulp, 1962) and it is reasonable to conclude that they are related to the same event. These interpretations lend weight to the argument that metamorphism was important in this region during the Acadian orogeny and that ages younger than 430 m.y. are not simply cooling ages related to post-Taconic uplift (Grauert and Hall, 1974).

The present study was undertaken in the hope of identifying the time of deposition or diagenesis of Member C of the Manhattan Schist. This age might be determined if strontium isotopic homogenization had been achieved or closely approached in the volume or rock exposed at the approximately 100 m long and 5 m high collecting locality at the time of diagenesis and not during subsequent Taconic or Acadian metamorphism.

SAMPLE PREPARATION AND ANALYTICAL TECHNIQUE

Eight 5 to 15 kg samples were collected, crushed and individually split into 10 g portions that were then powdered. Each powder was split into a 0.2 g to 0.3 g portion for isotopic analysis. ^{84}Sr and ^{87}Rb spikes, ultrapure HF, HClO_4 , and HCl, and teflon beakers were used in each analysis and the solutions were passed through pyrex cation-exchange resin columns to obtain Rb and Sr fractions.

The mass spectrometer analyses were done at Florida State University using a 12 inch radius of curvature, 60° sector, single focusing mass spectrometer with a triple-filament source, Faraday cup collector, vibrating reed electrometer and an expanded scale strip-chart recorder. The Eimer and Amend standard SrCO_3 had been analyzed 22 times prior to and during this study at Florida State University and yielded an average $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.7080 ± 0.0002 (1 σ) when $^{86}\text{Sr}/^{88}\text{Sr}$ is normalized to 0.1194, so no correction of the strontium isotopic data from the samples had to be made to correct for machine fractionation. The ^{87}Rb blanks averaged 1.3 ng and the ^{86}Sr blanks averaged 4.1 ng, and these are insignificant values compared to the Rb and Sr concentrations in the samples.

Four analyses of National Bureau of Standards standard K-feldspar (NBS -70a feldspar) that were performed over the course of this study are summarized in Table 1. The data are in close agreement with those reported by Compston et al. (1969) and by DeLaeter and Abercrombie (1970). This agreement indicates that there are no major systematic errors in the isotope tracer calibrations.

^{87}Rb (ppm)	^{86}Sr (ppm)	$^{87}\text{Rb}/^{86}\text{Sr}$ (atomic ratio)	Analysis
149.5	5.983	24.70	1
150.7	6.059	24.59	2
149.7	6.026	24.56	3
149.5	5.992	24.67	4
149.8	6.015	24.63	average
0.6	0.035	0.07	std. dev.
150	6.01	24.7	Compston et al. (1969)
148	6.13	23.9	DeLaeter and Abercrombie (1970)

Table 1. Analyses of NBS-70a standard K-feldspar

All the Sr isotopic compositions were calculated from analyses of sample Sr and spike Sr mixtures. The $^{85}\text{Rb}/^{87}\text{Rb}$ ratio was taken to be 2.593; the decay constant used for ^{87}Rb is $1.42 \times 10^{-11} \text{ yr}^{-1}$ (Steiger and Jager, 1977).

The Rb-Sr age and initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio on the isochron diagram were calculated using the York Model I regression treatment in the REGROSS program described by Brooks et al. (1972). There is no allowance for the use of individual errors in the $^{87}\text{Rb}/^{86}\text{Sr}$ and the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in this program. The one-standard-deviation experimental error in $^{87}\text{Rb}/^{86}\text{Sr}$ was derived from an exami-

SAMPLE	$^{87}\text{Sr}/^{86}\text{Sr}^*$	^{86}Sr (ppm)	^{87}Rb (ppm)	$^{87}\text{Rb}/^{86}\text{Sr}$ (atomic ratio)
MD 1	0.7232	17.337	19.925	1.136
MD 2	0.7276	13.926	28.572	2.028
MD 3	0.7205	23.624	25.624	1.087
MD 4	0.7147	41.129	14.923	0.359
MD 5	0.7225	27.720	28.046	1.000
MD 6	0.7216	21.430	22.754	1.050
MD 7	0.7283	14.716	30.569	2.053
MD 8	0.7279	16.557	30.466	1.820

*Atomic ratio, assuming $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$

Table 2. Analytical data from samples of Manhattan Schist, Member C

nation of duplicate analyses done over the past five years and was calculated to be 2 percent. The one-standard-deviation experimental error in $^{87}\text{Sr}/^{86}\text{Sr}$ was derived from multiple analyses of the Eimer and Amend standard SrCO_3 and was calculated to be 0.03 percent. The one-standard-deviation experimental errors used in the REGROSS program to calculate the Rb-Sr age in this paper were 2 percent for $^{87}\text{Rb}/^{86}\text{Sr}$ and 0.05 percent for $^{87}\text{Sr}/^{86}\text{Sr}$. The errors assigned to the age and initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio are given at the 68 percent confidence level (1 sigma). The age and initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio are $554 \pm 59 \text{ m.y.}$ and 0.7129 ± 0.0003 , respectively. The isotopic data are presented in Table 2 and the isochron is shown in Figure 2.

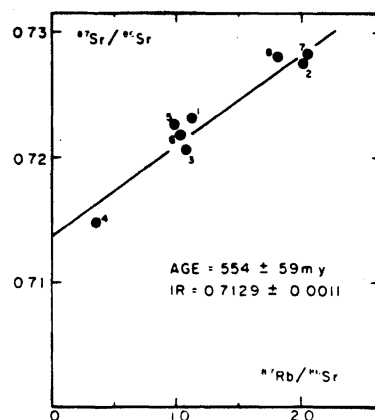


Figure 2. Rb-Sr isochron diagram showing the distribution of data points derived from samples of Unit C in the Manhattan Schist

DISCUSSION

Interpretation of Rb-Sr ages of metamorphosed sedimentary rocks is helped by a familiarity with information gained from the use of this technique on sedimentary rocks, particularly those formed from fine grained sediments. In theory a Rb-Sr isochron age of deposition or diagenesis determined on a sedimentary rock should define the time of isotopic equilibration between strontium in the ancient marine sediment and strontium in its interstitial sea water, providing such equilibration is ever achieved. Rocks with some detrital grains that retain an isotopic ratio related to the source terrane could possibly yield a Rb-Sr isochron age between the age of the source rocks and the time of deposition and diagenesis of the sedimentary rock being studied. This "provenance age" effect should not be as severe a problem in dating fine grained sedimentary rocks such as shales although Whitney and Hurley (1964) reported such a situation in their study of shale from the Hamilton Group. Bofinger and Compston (1967) made new calculations from the data presented by Whitney and Hurley (1964) and argued that the isotopic age of these shales actually coincides with the time of deposition and diagenesis. Brookins et al. (1970) report an "excess age" for the Lower Permian Eskridge shale which yields a Mississippian-Pennsylvanian Rb-Sr age. Although this is of concern, many published Rb-Sr ages determined with shales correspond to deposition and/or diagenesis (Allsopp and Kolbe, 1965; Bofinger and Compston, 1967; Bofinger et al., 1968; Bonhomme, 1982; Bonhomme et al., 1982; Chaudhuri and Brookins, 1969; Cingolani and Bonhomme, 1982; Faure and Kovach, 1969; Kralik, 1982; Moorbath, 1969; Morton and Long, 1982; Pringle, 1973).

Clearly, strontium isotopic homogenization can be achieved, or closely approached, in the rock at the time of deposition and diagenesis, even though Sr in sediments does not equilibrate readily with strontium in sea water (Biscaye and Dasch, 1971; Cordani et al., 1978; Dasch et al., 1966; Dasch, 1969; Faure, 1977; Murthy and Beiser, 1968). It is likely that the equilibration of strontium isotopes occurs during diagenesis, if it occurs at all, and the equilibration process only operates when ionic transport can occur in pore water solutions (Bath, 1974; Dasch, 1969). Gebauer and Grunfelder (1974) have pointed out that all of the detrital clay minerals are stable up to 150°C during the early and middle stages of diagenesis. Hence, development of authigenic clay minerals with a homogeneous strontium isotopic composition will only be achieved in the later stage of diagenesis.

This is supported by oxygen isotope studies on shales (Yeh and Savin, 1977). It also seems likely that homogenization of strontium isotopes should continue until authigenic clay minerals cease to form. Perry and Turekian (1974) studied a Miocene shale and showed that the destruction of detrital minerals is accompanied by the formation of authigenic clay minerals during diagenesis. The newly formed clay minerals were found to incorporate strontium that is released from the breakdown of detrital minerals and strontium from interstitial sea water. Both diagenesis and strontium isotope homogenization were found to be incomplete but a clear trend toward homogenization was observed with increase in depth of burial. An isochron determined on a Pennsylvania clay by Hoffman et al. (1974) using samples collected from the finest size fraction with the greatest percentage of authigenic minerals corroborates the findings of Perry and Turekian (1974). It is thus reasonable to conclude that if a shale yields a linear or near linear array of points on an isochron diagram, then isotopic homogenization was achieved, or closely approached, during diagenesis and the isochron probably represents an age of diagenesis. It might also be inferred that the initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of an isotopically homogenized shale is the result of a combination of strontium from detrital grains, authigenic grains and interstitial sea water. In such a case the calculated initial ratio is in part a measure of the age and the Rb/Sr ratios in the source rock(s) from which the detritus was derived, and in part the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of the intergranular sea water.

Graywackes and other coarse grained clastic sedimentary rocks should be more resistant than pelitic rocks to strontium isotopic homogenization during diagenesis. However, the matrix of the graywackes and other coarse clastics is composed largely of clay minerals, and most of the rubidium, radiogenic strontium and bound water is in the matrix. Relatively little is in the allogenic quartz and plagioclase. Thus a graywacke with a pelitic matrix would be expected to yield a whole-rock Rb-Sr isochron age which is close to the time of deposition and diagenesis, especially if the detrital material was uniformly distributed over the area selected for Rb-Sr study (Cordani et al., 1978).

An important study has been made of the Lowerre Quartzite and the Poughquag Quartzite (actually sandstone) which are Cambrian units in southeast New York (Hall, 1968a). Spanglet et al. (1978) found that linear arrays of data points generated on Rb-Sr isochron diagrams may be related in some rocks to the age of the source area and in other cases to the time of deposition. In the first case, five samples containing 87 to 93% quartz (Lowerre Quartzite in Paleozoic sillimanite zone in the Manhattan Prong) yield an isochron age of 942 ± 70 m.y. which approaches the age of the source area (about 1000 m.y.). However, six samples containing 52 to 60% quartz (unmetamorphosed Poughquag Quartzite with 1 to 7% hematite and the remainder clastic feldspars and micas) yield a best-fit line with an apparent age of 590 ± 40 m.y. which approximates the time of deposition (about 570 to 550 m.y.). One might conclude from this case that quartz-rich psammitic rocks will yield an age representing the age of the provenance terrane, but that pelitic rocks, either shales or coarser grained rocks with a pelitic matrix, will yield an age representative of the time of diagenesis.

Other inferences can be made from Rb-Sr studies of metamorphosed sedimentary rocks. Many Rb-Sr ages for low-grade metasedimentary rocks seem to correspond to the time of deposition-diagenesis (Compston and Pidgeon, 1962; Fairbairn et al., 1969; Obradovich and Peterman, 1968; Pringle, 1973), but others are thought to correspond to slaty cleavage formation (O'Nions et al., 1973;

Pringle, 1973) or metamorphism (Bofinger et al., 1970; Clauer and Kroner, 1979; Gebauer and Grunefelder, 1974; Gorokhov et al., 1982; Peterman, 1966). Similarly, studies of high-grade metasedimentary rocks have yielded ages which seem to correspond to the time of deposition (Bell, 1968; Spanglet et al., 1978), metamorphism (Bickerman et al., 1975; Borsi et al., 1973; Hills et al., 1968; Sturt et al., 1975; Weber et al., 1975) or post-metamorphic uplift (Bickerman et al., 1975; Fullagar and Dietrich, 1976).

In some studies of high-grade metasediments (and metavolcanics), the metamorphic event is thought to be responsible for "resetting" the Rb-Sr system, usually by syn-metamorphic Sr isotopic homogenization, and "secondary isochrons" have been generated to date the metamorphic event. In this technique, samples are collected from a volume of rock within which isotopic homogenization occurred (Field and Raheim, 1980). The volume of isotopically homogeneous rock has been estimated to be adjacent slabs of compositionally banded gneiss (Cameron et al., 1981; Collerson et al., 1982), 10+ meter in diameter "sample sites" (Mose, 1982), 10-250 meter in diameter "stations" (Gray and Compston, 1978), and several 100 to several 1000 meters in diameter "areals" (Kohler and Muller-Sohnius, 1980). Schistosity development may determine the distance over which Sr isotopic homogenization can occur (Black et al., 1979).

From the preceding brief discussion, it should be clear that unanimity has not been reached about the significance of Rb-Sr isochron ages obtained from metasedimentary rocks like Unit C in the Manhattan Schist. It does appear that if metasedimentary rocks, particularly those of pelitic origin, yield to a Rb-Sr whole-rock isochron, the calculated age probably corresponds to the time of deposition, diagenesis, metamorphism, or post-metamorphic uplift. A more useful way to characterize the age is to note that the Rb-Sr isochron age is probably not older than the time of deposition or not younger than the time of uplift. This observation is useful in this study of the Manhattan Schist. This test of the Rb-Sr system in samples of Manhattan Schist, Unit C, yield an age corresponding to Cambrian time. This age does not correspond to the time of metamorphism or uplift, known by other studies to be Ordovician and younger in age (Dallmeyer and Sutter, 1976). It seems most likely that the Cambrian age for Unit C corresponds to the time of deposition and/or diagenesis of the sedimentary protolith for Unit C. This being the case, the age supports the field studies cited earlier in which Unit C is thought to be allochthonous material, thrust over younger metasedimentary strata in the Manhattan Prong.

CONCLUSION

A Rb-Sr whole-rock isochron age of 554 ± 59 m.y. was obtained from the samples of Member C of the Manhattan Schist from White Plains, N.Y. This is believed to be a minimum age for the time of deposition and diagenesis of these rocks and indicates that they are not younger than Cambrian. The interpretation that Member C of the Manhattan Schist is allochthonous and consists of Cambrian or Late Precambrian rocks that have been juxtaposed at depth with Cambrian and Ordovician autochthonous rocks in the Manhattan Prong is thus supported by this age determination. The Rb-Sr data of this study, together with structural and stratigraphic data, strongly supports the concept that parts of the Manhattan Schist are allochthonous lithostratigraphic units. Although the rocks dated in this study may have been deposited and subjected to diagenesis somewhat earlier than 554 ± 59 m.y. ago, we believe that the age probably approximates their time of deposition, and that strontium isotopic homogenization was not achieved during the subsequent Paleozoic metamorphic events.

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