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Identification and Age of Neoformed Paleozoic Feldspar (Adularia) in a Precambrian Basement Core from Scioto County, Ohio, USA

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Abstract. Fourteen core samples of Precambrian granitic gneisses from a well drilled in the Green Township, Scioto County, Ohio were studied to determine the origin of alkali feldspar in these rocks. The well intersected the basement at a depth of 1,700 m and penetrated 11.3 m of Precambrian crystalline rocks. Petrographically the samples in the upper 6.4 m of the basement core show evidence of severe alteration by the presence of hematite, limonite and chlorite and by the absence of plagioclase. Alkali feldspars from this part of the core are turbid, have a low 2 V of about 10°, are highly enriched in K, have low Na and Rb concentrations, lack cathode luminescence, and form a straight line on a Rb–Sr isochron diagram yielding a date of 599±69 Ma. Core samples from below 6.4 m appear relatively fresh and unaltered. Alkali feldspar from this portion of the core is orthoclase, shows uniform blue luminescence and gives a Rb–Sr date of 1,162±11 Ma. These results indicate that feldspars in the lowest part of the core are primary minerals that crystallized during the Grenville Orogeny, whereas the K-feldspar in the top of the core is of low-temperature secondary origin. The formation of this feldspar is explained as a consequence of chemical weathering of primary feldspar during late Precambrian time to clay minerals that were later reconstituted under low-temperature hydrothermal conditions as K-feldspar (adularia) by reactions with brines derived from the overlying Mt. Simon Formation of Cambrian age.

Introduction

The Precambrian basement rocks of Ohio are covered by a thick sequence of Paleozoic sedimentary rocks and are therefore accessible only by deep drilling. The basement rocks of Ohio have been divided into two major lithologic provinces (Bass 1960; Janssens 1973; Botoman 1975). In eastern Ohio the basement is composed of amphibolite-grade metamorphic rocks and igneous rocks similar to those of the Grenville Province of Canada. They consist of gneiss, amphibolite, marble, granite, quartz monzonite, syenite, diorite and gabbro. In western Ohio the basement rocks are composed of rhyolite, trachyte, andesite, granite, shale, argillite, dolomite, limestone and quartzite. The north-south trending boundary between these two lithologic provinces is located in western Ohio along the Cincinnati Arch (Fig. 1).

Gonterman (1973) conducted a petrographic study of several cores that penetrated the Precambrian basement of Ohio. He noted an abundance of salmon-colored feldspar in the upper part of many of the cores which he described as buff colored in thin section, optically negative with a small 2 V angle, having an index of refraction of about 1.525 and birefringence of about 0.01. He suggested that this mineral is probably the low-temperature K-feldspar adularia.

Faure and Barbis (in press) reported Rb–Sr whole-rock dates for basement samples from several localities in Ohio. Samples from Sandusky County yielded a date of approximately 1.2 Ga whereas samples from Lake County and Richland County gave anomalously low dates of approximately 560 Ma. They noted that the samples which gave anomalously low dates contain an abundance of the salmon-colored feldspar described by Gonterman (1973) while the Sandusky County samples do not.

In addition, Faure and Barbis (in press) reported Rb–Sr dates for thirteen whole-rock samples from the basement core drilled at Scioto County Ohio, which is the object of the present study (Fig. 1). They observed that the samples formed two linear arrays of points on a Rb–Sr isochron diagram. The whole-rock samples from the upper 7.7 m of the core define a straight line whose slope gives a date of 699±16 Ma with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7101±0.0007. Samples from below 7.7 m form a second line giving a date of 1,173±41 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7048±0.0012. This difference was assumed to reflect the effects of alteration of the upper part of the basement rocks in Scioto County that is suggested by the presence of the salmon-colored feldspar. Faure and Barbis (in press) also suggested that the date for the lower section of the core, where adularia is not present, is a reliable measure of the *age* of these rocks and indicates that the basement of Ohio is the southward extension of the Grenville Province of the Canadian Precambrian shield. On the other hand, they suggested that the 699±16 Ma date of the samples from the upper 7.7 m is *not* the age of the rocks but reflects the presence of neoformed adularia in the basement rocks of Scioto County and that it is interme-

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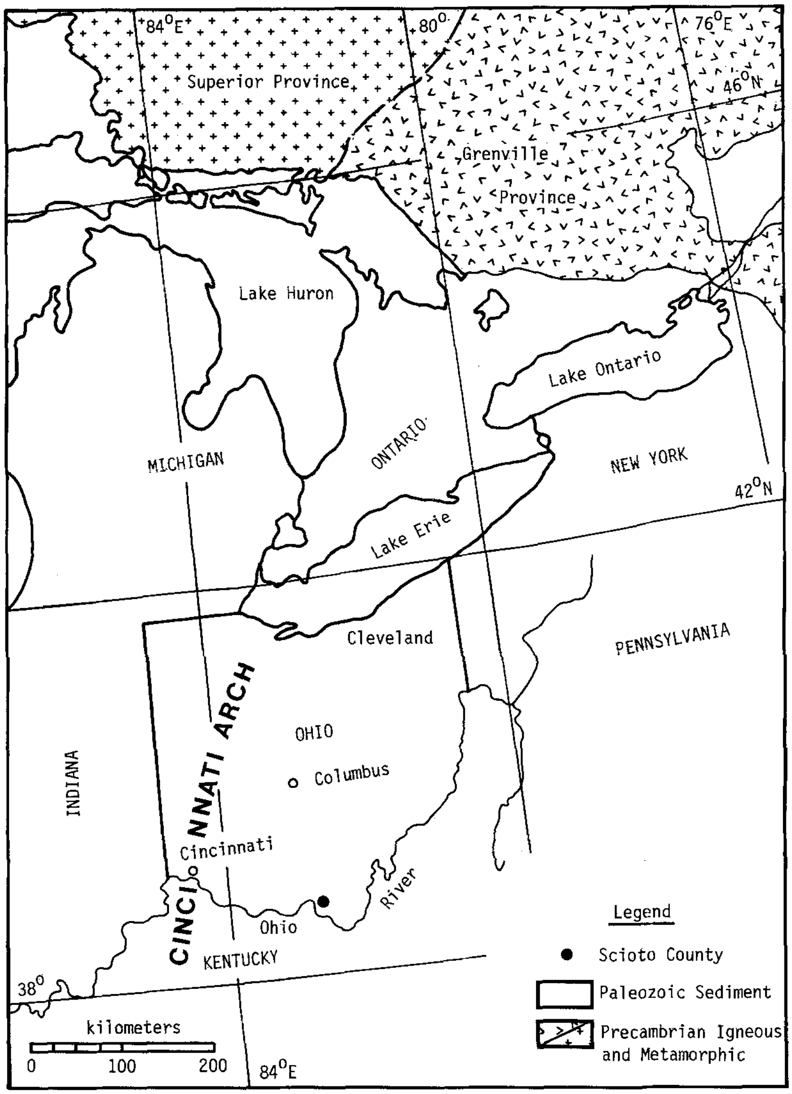

Fig. 1. Location of the Scioto County core in southern Ohio in relation to the Grenville Province of Canada (After Faure and Barbis, in press)

diate between the age of the basement (approximately 1.2 Ga) and the age of the adularia. The adularia could have formed by reactions between chemical weathering products that formed during Precambrian time and brines associated with the deposition of sandstones of the Mt. Simon Formation during the Cambrian period (Faure and Barbis, in press).

The purpose of this study is to confirm the presence of low-temperature K-feldspar (adularia) in the upper part of the Scioto County core and to date it by the Rb–Sr method in order to determine the time of its formation. The Scioto County core was chosen for this investigation because it apparently consists both of an altered upper portion and an unaltered lower portion. This core, therefore, also provides an opportunity to study the effects of chemical weathering and subsequent reconstitution of the weathering products. The new data to be presented here include chemical analyses and Rb–Sr dating of K-feldspar concentrates, as well as cathode luminescence and electron microprobe scans of individual feldspar grains. This study is based on the same suite of samples examined previously by Gonterman (1973), Barbis (1978), Mensing (1982) and by Faure and Barbis (in press).

Analytical Methods

Alkali feldspar concentrates from 14 samples from the Scioto County core were prepared by means of magnetic and heavy liquid separations. Rb and Sr concentrations were measured by X-ray fluorescence. Ca, Na and K concentrations were determined by atomic absorption spectrophotometry using a Perkin-Elmer model 303 spectrophotometer. $^{87}Sr/^{86}Sr$ ratios were measured by mass spectrometry using a Nuclide Corporation model 6-60-S mass spectrometer. Cathode luminescence was used to distinguish primary feldspar from low-temperature feldspar with a Nuclide Corporation Luminoscope Model ELM-2B. Scanning electron micrographs were taken using a Cambridge S4-10 scanning electron microscope and an Ortec X-ray spectrometer. The details of the analytical methods were described by Mensing (1982).

Description of the Core

The core was drilled in Green Township of Scioto County, Ohio. It intersected crystalline Precambrian rocks at a depth of 1,700 m and penetrated 11.3 m of the basement. The core is granitic in composition and has a medium-to coarse-grained gneissic texture. Gonterman (1973) divided the core into three sections based on lithologic changes at about 6.4 m and 7.7 m below the unconformity. In the upper 6.4 m, samples are medium-to coarse-grained gneisses that are extensively altered. Mineral constituents include alkali feldspar, biotite, magnetite, apatite, chlorite, hematite and limonite. Calcite and dolomite are present as veinlets filling fractures in the rock. A major constituent (approximately 60%) of the rock in the upper zone is the salmon-colored feldspar described by Gonterman (1973). As observed in thin section, many feldspar grains contain clear patches within a turbid feldspar matrix. The clear patches are concentrated near the central part of most grains and often form elongate parallel lamellae. The clear areas are believed to be remnants of primary feldspar, while the turbid feldspar matrix is of low-temperature origin (adularia). The primary feldspar has a 2 V of approximately 40°, is optically negative and has been identified as orthoclase. The cloudy surrounding matrix is generally buff- to yellow-colored in plane light, has a consistently low 2 V of 5° to 10° and is also optically negative. These two feldspars have distinctly different luminescent properties which will be discussed later.

The intermediate zone (6.4 to 7.7 m) is composed of medium- to coarse-grained gneisses, similar in texture and fabric to the overlying section, but different mineralogically. The rock in this section contains oligoclase, K-feldspar, biotite, hornblende, apatite, chlorite, calcite, dolomite, anhydrite, hematite, limonite and magnetite. Alteration and fracturing is minor compared to the overlying rocks. K-feldspar consists of large grains of perthitic orthoclase showing little evidence of alteration.

In the lower zone (> 7.7 m) the rocks appear relatively fresh. The samples are medium- to coarse-grained gneisses with broad mineralogical bands (> 10 cm). Mineral constituents in this interval include alkali feldspar, plagioclase, quartz, hornblende, biotite, magnetite and apatite plus very minor amounts of secondary minerals including carbonates, iron oxides and anhydrite. Alkali feldspar in this section consists of perthitic orthoclase. Most grains are fresh, but a few show minor amounts of replacement along grain boundaries.

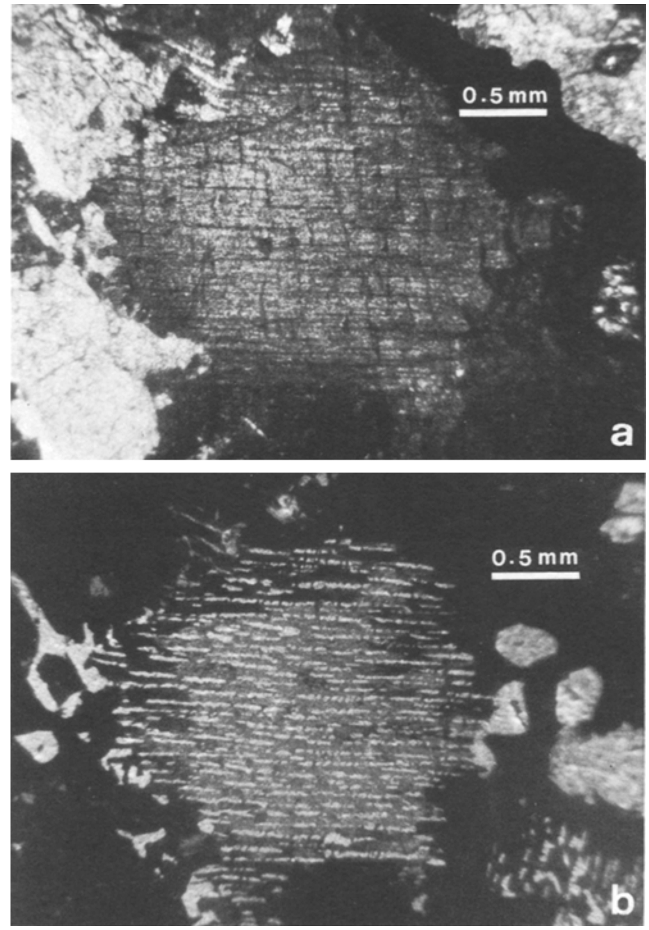

Plate 1 a and b. Photomicrographs of an alkali feldspar grain in sample R-39 under crossed polars (**a**) and cathode luminescence (**b**). Replacement of primary luminescent feldspar by neoformed nonluminescent adularia has occurred at the perimeter of the grain and has extended toward the grain interior parallel to cleavage resulting in bands of luminescent lamellae. The core of the grain is composed of luminescent primary feldspar indicating that the grain has undergone only a moderate amount of replacement (× 62.5)

Cathode Luminescence

Cathode luminescence was utilized to distinguish the different kinds of feldspar in the Scioto County core. Kastner (1971) demonstrated that feldspars of high-temperature origin show blue or red luminescence. Kastner and Siever (1979) later suggested that feldspars of low-temperature origin do not luminesce due to their chemical purity. Luminescence is produced when enough impurities and defects, which act as luminescent centers or activators, are present in a crystal. Low-temperature phases exclude impurities and therefore do not contain a sufficient number of activators for luminescence to be induced. Samples from the lowest section of the Scioto County core (> 7.7 m) display uniform bright blue to blue green luminescence throughout the feldspar grains. This result confirms the hypothesis that the feldspar in the lowest section of the core is unreplaced and of primary origin.

Feldspars in the rocks above a depth of 7.7 m have luminescent properties that are markedly different from those in the lower section. They display very non-uniform, discontinuous luminescence throughout the grains. Most grains are composed of small luminescent (in a blue hue) patches and/or lamellae of feldspar within a non-luminescent feldspar matrix. The nonluminescent matrix corresponds to the turbid feldspar discussed previously, whereas the luminescent patches and lamellae constitute the clear feldspar. Some of the smaller feldspar grains are composed entirely of turbid non-luminescent feldspar with no remnants of primary material remaining.

Plates 1 and 2 depict pairs of photomicrographs illustrating the luminescent properties of some of the feldspars in the upper zone of the core. Plate 1 shows a feldspar grain exhibiting a relatively moderate amount of replacement. By comparing Plate 1 a with 1 b it is apparent that the grain boundary was completely replaced and that replacement extended toward the interior of the grain along cleavage planes leaving remnants of luminescent primary feldspar as parallel lamellae. The luminescent lamellae are not parallel to cleavages in all grains which indicates that twinning and/or exsolution lamellae may also have controlled replacement. Plate 2 depicts another feldspar grain that shows two directions of luminescent lamellae. In

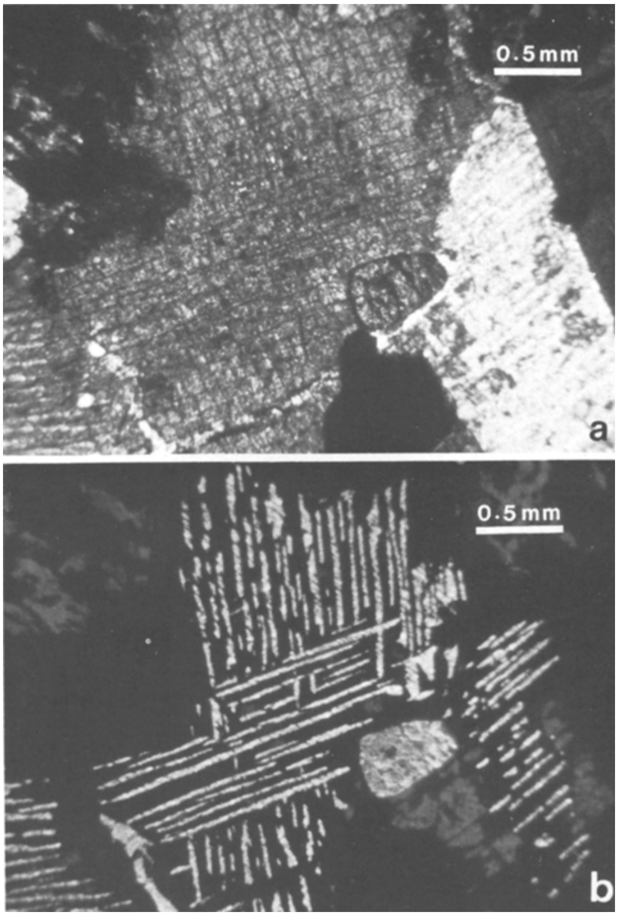

Plate 2a and b. Photomicrographs of an alkali feldspar grain in sample R-42 under crossed polars (**a**) and cathode luminescence (**b**). The grain boundary is composed of adularia and replacement has extended into the interior of the grain. Remnants of primary feldspar form two sets of parallel luminescent lamellae indicating that replacement was crystallographically controlled (× 62.5)

Plate 2 the entire grain boundary is non-luminescent and replacement has extended into the interior of the crystal along cleavage planes. This grain is somewhat more extensively replaced than that shown in Plate 1 which has retained a luminescent core whereas that of Plate 2 has not.

Luminescence generally increases with depth even though replacement of primary feldspar by adularia is not uniform. The extent of replacement of individual grains is probably related to composition (plagioclase or K-feldspar), grain size and to the density and proximity to fractures within the rock. The uppermost samples (< 6.4 m) show extensive and sometimes complete replacement of primary K-feldspar and plagioclase. The samples from the intermediate zone (from 6.4 m to 7.7 m) are characterized by less replacement than those from the overlying section. Many grains in this zone have luminescent cores, though grain boundaries are almost always replaced. Feldspar grains in the lowermost section of the core, below 7.7 m, show uniform luminescence in blue-green colors with little or no evidence of replacement.

Elemental Variations with Depth

Concentrations of K, Na, Ca, Rb and Sr in 14 alkali feldspar concentrates are listed in Table 1. The most significant

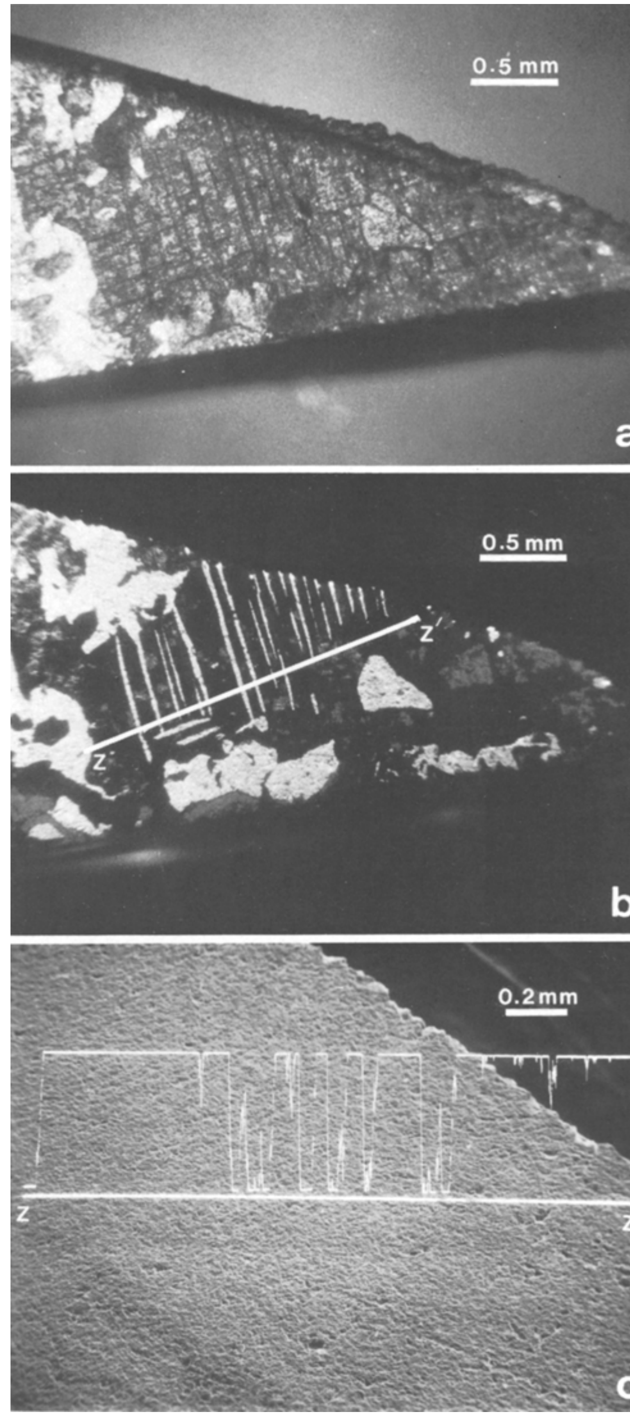

Plate 3a–c. Photomicrographs of an alkali feldspar grain in sample R-43 in plane-polarized light at × 62.5 (**a**), cathode luminescence at × 62.5 (**b**), and in the scanning electron microscope at × 100 (**c**). The pattern above the baseline (Z − Z′) in 3c represents the relative concentrations of K along the baseline. Comparing 3b with 3c illustrates that the non-luminescent portions of the feldspar grain are enriched in K which confirms the identification of adularia

finding is the enrichment in K and depletion in Na and Rb of the feldspars from the uppermost section of the core compared to those taken at depths of more than 6.4 m (Fig. 2). The 9 alkali feldspar samples from the lower zones of the core (> 6.4 m) have an average K concentration of

Table 1. Analytical data for alkali feldspars from the Scioto County core

Sample	Depth below Unconformity, M	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	K wt.%	Na wt.%	Ca ppm
R-40F	4.57	65.1	324.3	0.57 ± 0.016	0.7101 ± 0.00030 0.7096 ± 0.00018	7.76	2.69	216
R-41F	5.03	72.9	239.6	0.88 ± 0.012	0.7127 ± 0.00022	9.74	1.56	185
R-42F	5.64	77.8	123.9	1.81 ± 0.057	0.7193 ± 0.00058	10.68	0.70	435
R-39F	5.94	68.8	162.6	1.22 ± 0.008	0.7161 ± 0.00028	10.60	1.19	194
R-43F	6.40	67.3	146.2	1.33 ± 0.026	0.7180 ± 0.00044	10.77	0.59	480
R-44F	6.86	45.3	472.8	0.27 ± 0.007	0.7100 ± 0.00020	6.56	3.27	449
R-45F	7.47	19.5	648.8	0.08 ± 0.002	0.7075 ± 0.00016	3.35	4.72	723
R-51F	7.92	113.3	540.9	0.60 ± 0.005	0.7164 ± 0.00013	6.37	3.38	404
R-50F	8.69	131.3	447.4	0.85 ± 0.006	0.7200 ± 0.00015	6.89	3.08	298
R-52F	8.69	105.5	460.8	0.66 ± 0.002	0.7179 ± 0.00024	5.86	3.68	471
R-53F	9.45	153.1	122.2	3.65 ± 0.037	0.7722 ± 0.00027 0.7724 ± 0.00025	7.35	2.92	149
R-54F	10.05	174.9	174.5	2.91 ± 0.017	0.7540 ± 0.00022	8.12	2.38	93
R-55F	10.36	135.6	156.9	2.51 ± 0.022	0.7477 ± 0.00017 0.7474 ± 0.00018	5.66	1.94	110
R-56F	10.97	182.2	212.7	2.48 ± 0.006	0.7478 ± 0.00020	7.34	2.63	135

The Eimer and Amend $SrCO_3$ isotope standard has an average $^{87}Sr/^{86}Sr$ ratio of 0.70813 ± 0.00006. The reproducibilities are $\pm 0.097\%$ for K, $\pm 0.035\%$ for Na, and ± 12 ppm for Ca. The analytical errors of the $^{87}Rb/^{86}Sr$ are $1\bar{\sigma}$ based on triplicate determinations. The uncertainties of the $^{87}Sr/^{86}Sr$ ratios are $1\bar{\sigma}$ calculated from sets of six scans each

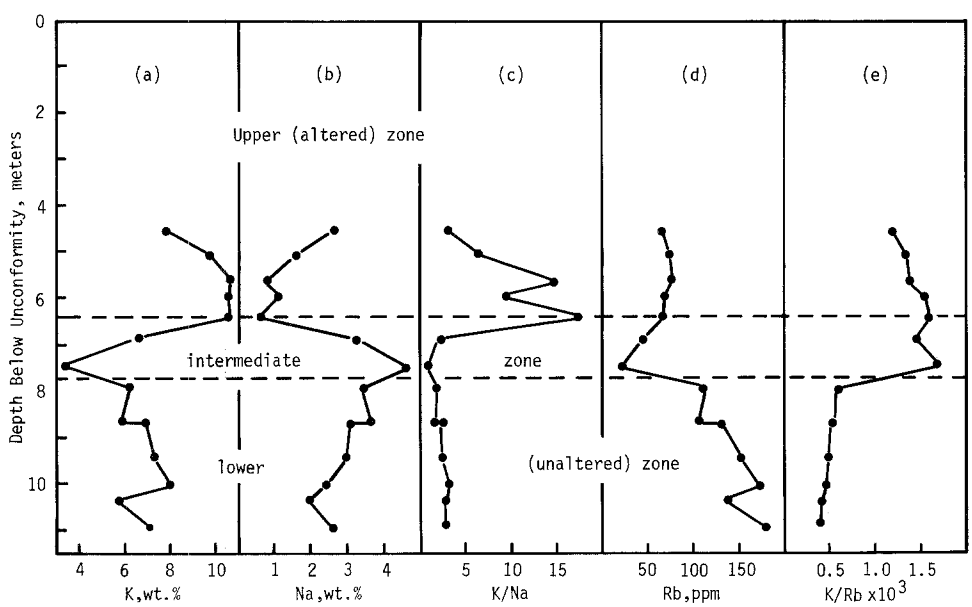

Fig. 2a–e. Variations of the concentrations of Na, K and Rb in K-feldspar as a function of depth in the basement core from Scioto County.
a Variation of K in weight percent;
b Variation of Na in weight percent;
c Variation of the K/Na ratio
d Variation of Rb in parts per million;
e Variation of the K/Rb ratio in K-feldspar

$6.38 \pm 0.45\%$, whereas the 5 samples from the upper zone (<6.4 m) have much higher K concentrations, rising to 10.77% with an average value of $9.91 \pm 0.56\%$ (Fig. 2a). The Na concentrations of the alkali feldspars from the lowest zones of the core (>6.4 m) have an average value of $3.11 \pm 0.26\%$ whereas those from the uppermost zone have significantly reduced Na concentrations with an average value of $1.34 \pm 0.37\%$ (Fig. 2b). The K enrichment and Na depletion of the alkali feldspar from the uppermost zone of the core is further illustrated by the K/Na ratio (Fig. 2c) which increases abruptly from an average value of 2.2 ± 0.2 in the lowest sections of the core up to 18.0 (sample R-43F), with an average value of 10.2 ± 2.8 in the upper section. In addition, the K-feldspars in the upper zone have low Rb concentrations (Fig. 2d) and high K/Rb ratios (Fig. 2e) relative to the alkali feldspar from the lower zone. The Rb concentrations decrease from an average of 142.2 ± 11.0 ppm for alkali feldspar from the lowest section of the core (<7.7 m) to an average of 59.5 ± 7.7 ppm for K-feldspar from the upper 7.7 m (Fig. 2d). Figure 2e depicts the abrupt increase of the K/Rb ratio from an average of 486±24 in the lower section to an average of 1,456±66 for feldspar in the upper zone. The concentrations of Ca and Sr in the feldspars vary irregularly down the core with high values in the intermediate section between 6.40 m and 8.69 m. The range of concentrations for Sr is from 122 ppm to 540 ppm and that for Ca is from 93 ppm to 723 ppm. The Ca/Sr ratios are constant at about 0.84±0.23 except for two samples (R-42F, R-43F) whose Ca/Sr ratios are 3.5 and 3.28 respectively. In general, the K-feldspar in the upper part of the core contains significantly reduced concentrations of chemical impurities (Na, Rb, Ca and Sr) which is characteristic of feldspar formed at low temperature, according to Kastner and Siever (1979) and Ali and Turner (1982).

X-Ray Line Graphing of Potassium

In order to correlate the chemical results with the observed luminescence of the K-feldspar in the upper zone of the Scioto County core, the relative variations of K content across such a feldspar grain were compared with the luminescence of the same grain. Plate 3 consists of three photomicrographs of the same alkali feldspar grain in a thin-section chip of sample R-43. Plate 3a is in plane-polarized light, Plate 3b shows cathode luminescence and Plate 3c is a scanning electron micrograph. The baseline (Z−Z′) constructed in Plate 3c depicts the line on the specimen surface that was analyzed for K. The pattern above the baseline represents the relative concentration of K in the sample along the baseline. The results show that there is a fluctuation of the K-concentration in the K-feldspar grain along Z−Z′. In general, areas of high K content do not luminescence because they are composed of adularia. This result confirms the interpretation of the chemical variations and optical properties that the K-feldspar in the upper part of the core is adularia.

Rb−Sr Dating

The 14 alkali feldspar concentrates were analyzed for dating by the Rb−Sr method (Table 1). A plot of the data on a Rb−Sr isochron diagram forms two distinct linear arrays of points (Fig. 3, lines A and B). Dates were calculated by the method of York (1969) and the computer program of Faure (1977) using $\lambda^{87}Rb = 1.42 \times 10^{-11} a^{-1}$. Line A is formed by feldspar samples from the bottom section of the core (>6.4 m) and gives a date of 1,162±11 Ma with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7061±0.0002. Sample R-53F was excluded from the calculation because it does not fit the line within analytical uncertainty. Faure and Barbis (in press) also excluded the whole-rock sample of R-53 from their calculations for the same reason. Apparently this sample has been disturbed by some process that did not affect the other samples in the same way. The date based on the feldspar samples that form line A is in good agreement with the 1173±41 Ma date for the whole-rock samples from the same section of the Scioto County core (Faure and Barbis, in press). These results indicate that the whole-rock and alkali feldspar samples in the lowest portion of the Scioto County core have remained closed to Rb and Sr for 1162 Ma since the Grenville Orogeny.

The second line (Fig. 3, line B) is formed by alkali feldspars from the *upper* section of the core (<6.4 m) and gives

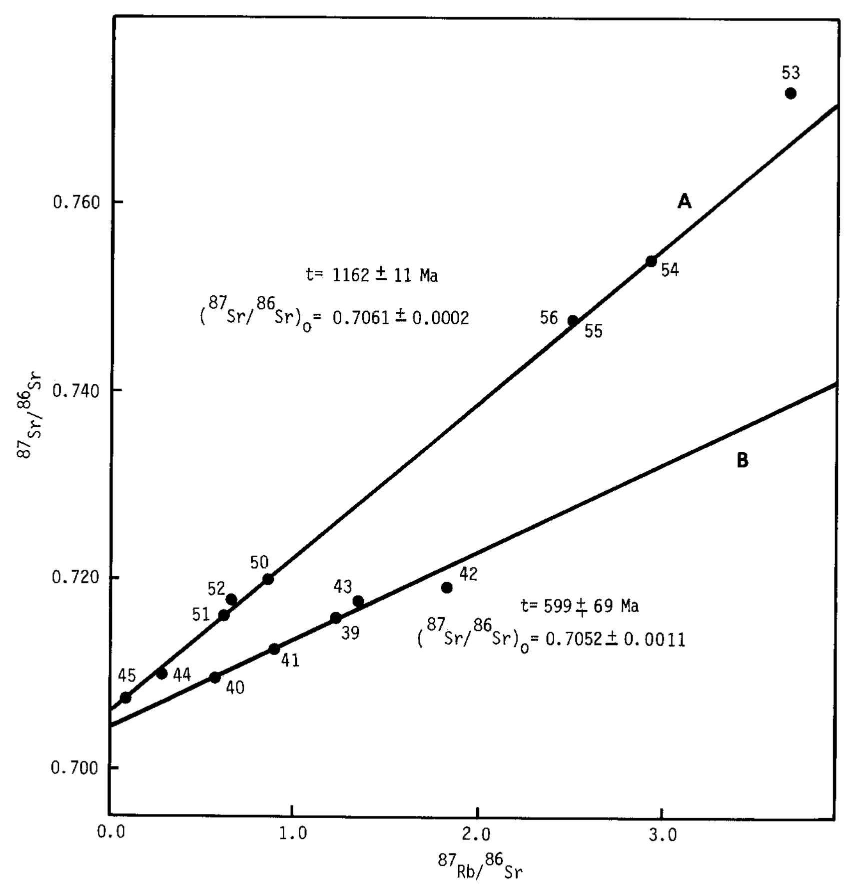

Fig. 3. Rb−Sr isochron diagram for K-feldspar concentrates of granitic basement rocks from Scioto County, Ohio

a Cambrian date of 599±69 Ma with an initial ratio of 0.7052±0.0011. Therefore, the date is consistent with the hypothesis of Faure and Barbis (in press) that interstitial brines derived from the Cambrian Mt. Simon Sandstone provided an environment favorable for the formation of adularia from previously formed weathering products. The date may be an overestimate of the age of the adularia, because line B is probably a mixing line between neoformed adularia and remnants of old, primary alkali feldspar. Line B, therefore, may have had a positive slope at the time of formation of the adularia. Inclusions of primary feldspar were observed by cathode luminescence as shown in the Plates.

Summary

The presence of low-temperature K-feldspar (adularia) in the granitic gneisses of the Precambrian basement of Scioto County, Ohio, has been clearly demonstrated. This illustrates that the formation of low-temperature feldspars is not restricted to sedimentary rocks, but that such feldspars may also occur in igneous and metamorphic rocks in subsurface.

Weathering of basement rocks during Precambrian time may have formed clay minerals which later reacted with low-temperature hydrothermal brines derived from the overlying Mt. Simon Formation to form K-feldspar. The solutions apparently percolated through fractures in the upper portion of the basement and supplied the potassium and silica necessary for the neoformation of adularia. Rb–Sr dating indicates that the adularia is probably younger than 599±69 Ma, which is consistent with the hypothesis that it could have formed during the Cambrian period.

This study indicates that fictitious Rb–Sr whole-rock isochrons (mixing lines), such as the 699 Ma date of the altered rocks reported by Faure and Barbis, may result from the presence of neoformed feldspar. Similar low-temperature feldspars may be present in basement rocks elsewhere in the world. For example, red and turbid ^{18}O-rich feldspars have been reported by Shieh (in press) from the upper 70 m of a long core of basement rocks in northern Illinois. It seems likely that other isotopic systems may also be affected by such alteration processes.

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