Reports

Ancient Granite Gneiss in the Black Hills, South Dakota

Abstract. *Granite gneiss, with an age of approximately 2.5 billion years, in the Black Hills, South Dakota, provides a link betweeen ancient rocks in western Wyoming and Montana and in eastern North and South Dakota and Minnesota. The discovery suggests that early Precambrian rocks covered an extensive area in northcentral United States and were not restricted to several small nuclei.*

A granite gneiss that is exposed over an area of about 5 square kilometers along the northeast periphery of the Precambrian core of the Black Hills, South Dakota, has petrographic characteristics and a structural setting which suggest that it is a very ancient rock. Preliminary rubidium-strontium and uranium-thorium-lead data point to an age as great as 2.5 billion years for this rock and thus indicate that it corresponds in age to the Algoman granites of the Superior province in Minnesota and Ontario (*1*). The granite gneiss is along Little Elk Creek, about 3 miles north of Nemo, Pennington County, South Dakota.

The Precambrian rocks of the Black Hills may be divided into three broad categories that differ in lithology and in apparent age. The youngest are the pegmatites and granite in the Harney Peak region of the southern portion and the pegmatites in a much smaller area near Tinton in the northwestern portion. Pegmatites of the Harney region have been dated at 1.6 billion years (*2, 3*). The next youngest rocks consist of schists and several bodies of amphibolite. These are the dominant rocks throughout the 100-km length of the Precambrian core of the Black Hills, but all that is definitely known of their age is that they are older than the pegmatites. In the southern Black Hills the schists were metamorphosed during the emplacement of the Harney Peak granite to high-rank rocks containing abundant sillimanite. Elsewhere the metasediments are chiefly schists and phyllites that consist mainly of mica, chlorite, carbonate minerals, and quartz. The most detailed descriptions have been published by Redden (*4*) for a part of the southern Black Hills, and by Noble and others (*5*) for the Lead area in the northern Black Hills.

The oldest rock in the Black Hills is the granitic gneiss that is the subject of this paper. The observations and analytical data reported in this paper are based on samples collected from exposures along Little Elk Creek in S1/2 sec. 3, T3N, R5E.

The rock is predominantly gneissic in structure, cataclastic in fabric, and granitic in composition. Foliation, moderately to well developed, is evident chiefly from biotite crystals in parallel orientation distributed in layers and lenses separated by feldspar and quartz. The dominant minerals are oligoclase, microcline, and quartz, but these are accompanied by abundant biotite and muscovite.

The two published geologic maps of this locality both show that the gneiss is entirely surrounded by Paleozoic rock (*6, 7*). Along the southwest side of the gneiss, flat-lying Paleozoic rocks cover an area 3 km wide and conceal the contact between the gneiss and the Precambrian rocks of the rest of the Black Hills. Thus the age relationship between the gneiss and the other Precambrian rocks cannot be readily ascertained from their structural relationships. Runner (*7*) stated that the granite in the Nemo area is clearly intrusive into the Precambrian sedimentary rocks; however, we have not seen the field relationships that support this interpretation.

The predominant Precambrian rocks of nearby areas are micaceous and chloritic schist and phyllite, quartzite, banded iron-formation with hematite and magnetite, and siliceous marble, together with intrusive bodies of massive amphibolite. The deformation and metamorphism of these rocks doubtless accompanied the development of at least part of the metamorphic character of the gneiss. Whether the gneiss is intrusive into these rocks or was the basement on which they were deposited is an open question. We believe that the gneiss is one of the oldest rocks in the area.

Three samples (5 to 15 kg) of the total-rock gneiss were analyzed for rubidium and strontium in an effort to determine its age of emplacement. One of the samples also has been used to obtain zircon for U-Th-Pb isotopic ages and minerals for a Rb-Sr isochron age of metamorphism (from a diagram of Rb^{87}/Sr^{86} plotted against Sr^{87}/Sr^{86}). Standard techniques of isotope dilution and mass spectrometry were used for all determinations. The analytical uncertainty in determinations of concentrations is approximately ± 1 percent, and of isotopic compositions, ± 0.4 percent. All strontium data have been normalized to a Sr^{86}/Sr^{88} ratio of 0.1194.

The Rb-Sr analyses of the total rock (Table 1) may be used in two ways to

Table 1. Sr^{87}/Sr^{86} and Rb^{87}/Sr^{86} atom ratios and rubidium and strontium concentrations for some rocks and minerals from granite gneiss in Little Elk Canyon, Black Hills, South Dakota.

Description	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86} *	Rb (ppm)	Sr (ppm)
	Sample 14(A)†			
Total rock	0.885	6.061	79.7	38.1
	Sample 14(B)1‡			
Total rock	.764	1.614	129	232
	Sample 14(B)2‡			
Total rock	.788	2.341	126	156
Plagioclase	.751	0.424	31.2	213
Microline	.806	3.170	176	161
Biotite	2.050	75.72	590	22.6

* Decay constant: Rb^{87}, 1.47×10^{-11} yr^{-1}. † Sample 14(A) is strongly foliated gneiss from SW1/4, sec. 3, T3N, R5E. ‡ Sample 14(B) is weakly foliated gneiss from SE1/4, sec. 3, T3N, R5E. Two separate specimens were collected at this site.

Table 2. Analytical results for zircon from sample 14(B)2 of granite gneiss Little Elk Canyon, Black Hills, South Dakota.

Conc. (ppm)	Isotopic abundance* (%)	Age (10^6 yr)
U, 479.8	Pb^{204}, 0.056	U^{238}/Pb^{206}, 1675
Th, 315.6	Pb^{206}, 72.15	U^{235}/Pb^{207}, 2100
Pb, 172.7	Pb^{207}, 12.63	Pb^{207}/Pb^{206}, 2550
	Pb^{208}, 15.16	Th^{232}/Pb^{208}, 1560

* The isotope ratios of the common lead used to correct for the nonradiogenic lead present in the zircon are $Pb^{206}/Pb^{204} = 18.51$, $Pb^{207}/Pb^{204} = 15.72$, and $Pb^{208}/Pb^{204} = 38.44$. Decay constants: $U^{238} = 1.54 \times 10^{-10}$ yr^{-1}; $U^{235} = 9.72 \times 10^{-10}$ yr^{-1}; $Th^{232} = 4.88 \times 10^{-11}$ yr^{-1}. Atomic ratio $U^{238}/U^{235} = 137.7$. The percentages are based on the number of atoms.

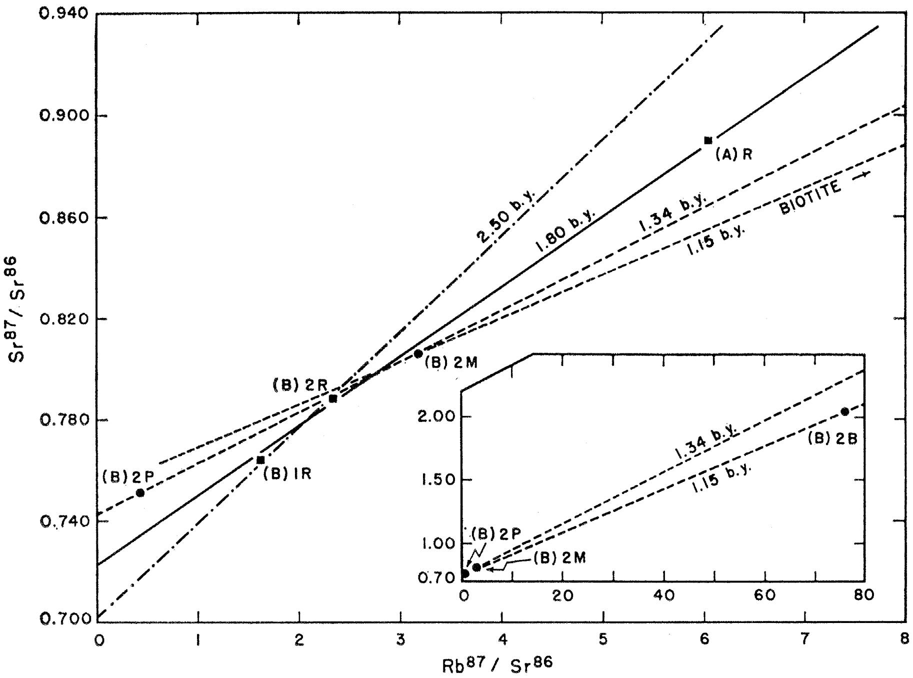

Fig. 1. Rb^{87}/Sr^{86}–Sr^{87}/Sr^{86} diagram for some rocks and minerals from granite gneiss in Little Elk Canyon, Black Hills, South Dakota. The solid line shows the least-squares isochron fit to the three total-rock samples. The dot-dash line represents a 2.50-billion-year isochron calculated for an initial Sr^{87}/Sr^{86} ratio of 0.702. The two dashed lines bound the plagioclase, microcline, and biotite data for sample 14(B) 2. *P*, plagioclase; *M*, microcline; *B*, biotite; and *R*, total rock.

interpret the age. One method begins with the assumption that the granite at the time of crystallization had a Sr^{87}/Sr^{86} ratio of 0.702, similar to that commonly found for early Precambrian granites in Minnesota and Ontario. The calculations then yield ages of 2.02, 2.56, and 2.45 billion years for samples 14(A), 14(B) 1, and 14(B) 2, respectively. The other method is to define a least-squares isochron from the analytical data. This isochron is a poorly defined line that indicates an age of 1.80 billion years and an initial Sr^{87}/Sr^{86} ratio of 0.723. Though one can argue that these rocks may originally have had a high Sr^{87} content due to some even more ancient crustal history, it is more likely that subsequent redistribution of strontium under open system conditions, which tends to reduce variations in isotopic composition, has decreased the slope of the isochron and increased the apparent initial Sr^{87}/Sr^{86} ratio. In any case, the Rb-Sr data indicate that this rock or its precursor has been part of the crust for no less than 1.8 billion years, and probably for several hundred million years longer.

The zircon data (Table 2) also suggest an ancient age for the gneiss. Despite the discordance in the ages, which shows a need for further work to interpret the behavior of the U-Th-Pb system in the zircons, the commonly accepted diffusion models indicate an age greater than 2.5 billion years from this single analysis. More than half the zircon crystals are euhedral, and the remainder are subhedral or fragmented but not rounded. None of the zircons appears to be detrital.

The age of metamorphism of this gneiss is of as much interest as its initial age. In an effort to date the metamorphism, Rb-Sr analyses have been made of plagioclase, microcline, and biotite from one of the samples, and the compositions are plotted in Fig. 1. If metamorphism had completely homogenized the strontium and the system were closed thereafter, these analyses, when plotted on the graph, would generate a straight line with a slope that would indicate the age of metamorphism. No well-defined line can be drawn through the three points, and ages calculated from pairs of minerals range from 1.15 to 1.35 billion years. The intrusion of the Harney Peak granite and its associated pegmatites, which have been dated at 1.6 billion years, may have contributed to the metamorphism of the gneiss. If so, the minerals became open systems at some later time. The most obvious possibility is during the early Tertiary, when rhyolite and quartz monzonite were intruded in the northern Black Hills; some exposures are within 3 miles of the gneiss locality.

This gneiss is probably contemporaneous with rocks of the Superior province of the Canadian Shield, where the ages are generally 2.5 billion years or older. The areal distribution of rocks in northcentral United States that are known to be of similar age is shown in Fig. 2. Recent work has extended the

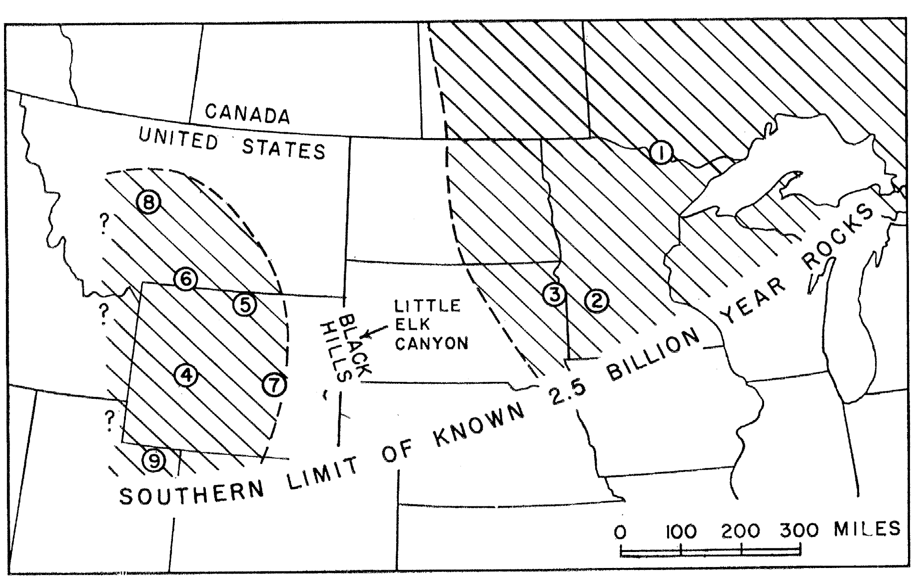

Fig. 2. Distribution of 2.5-billion-year-old rocks in northcentral United States. 1, Minnesota-Ontario (*1*); 2, Minnesota River Valley (*1, 9*); 3, Milbank, South Dakota (*1*); 4, Wind River Mountains (*11*); 5, Bighorn Mountains (*11, 12*); 6, Beartooth Mountains (*12*); 7, Casper Mountains (*13*); 8, Little Belt Mountains (*14*); 9, Uinta Mountains (*16*). Subsurface data (*8, 10*) have been used to delineate the boundary in North Dakota and Manitoba.

Superior province into eastern North and South Dakota and Minnesota, by use of both outcrop and subsurface samples (*1*; *8–10*). Rocks of this same age have been found in the Wind River, Bighorn, Beartooth (*11, 12*), Casper (*13*), and Little Belt mountains (*14*) of western Wyoming and Montana; these have been interpreted as either a detached segment of the Superior province or a separate continental nucleus (*15*).

Much of the Precambrian basement lying between these two areas is not exposed and, until the present, only ages of 1.7 billion years or younger have been reported from the Black Hills (*2, 3*) and from drill core samples in eastern Montana and western North Dakota (*8, 10*). These data are compatible with the interpretation that subsequent geologic events obliterated evidence for Superior rocks in this region, if indeed they ever existed. The discovery of an ancient gneiss in the Black Hills, midway between the two areas of known Superior rocks, makes this interpretation obsolete. It also allows the prediction that additional discoveries of rocks of this age will be made by analyzing drill cores from basement rocks at other localities between the Bighorn Mountains and eastern South Dakota.

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17. Publication authorized by the director, U.S. Geological Survey. We acknowledge the helpful discussions of S. S. Goldich and J. C. Ratte, who accompanied Zartman and Norton in collecting the samples. Marcia Newell aided in the analysis required for the U-Th-Pb age determinations.

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Persistence of DDT in Soils of Heavily Sprayed Forest Stands

Abstract. *Soils from DDT-sprayed forest stands in New Brunswick and Maine contained DDT residues. The residues increased in successive samplings between 1958 and 1961, although no new spray was applied. The increase suggests that DDT residues may persist for several years in tree canopies but are ultimately carried into the soil.*

Persistence is an important characteristic contributing to the usefulness of DDT as an insecticide. Yet this very characteristic contributes significantly to the deleterious side effects of DDT applications, including the potential contamination of man's food chain, and raises important questions concerning the movement and storage of insecticide residues in nature. Such questions are especially pertinent in areas where DDT has been applied from airplanes during several years and residues may have accumulated. One of the most extensive aerial spraying operations ever undertaken has been directed toward the control of the spruce budworm (*Choristoneura fumiferana* Clem) in Maine and eastern Canada during the past decade (*1*). The study reported in this paper was an effort to determine the extent to which DDT residues have persisted in soils of forest stands heavily sprayed as a part of this program.

A total of four stands were sampled: three in northcentral New Brunswick and a fourth in northern Maine. The New Brunswick stands had been sprayed at various times since 1952; the Maine stand was sprayed experimentally for this study. All stands consisted of second growth fir, *Abies balsamea* (L) Mill., and spruce, *Picea rubens* Sarg. and *P. glauca* (Moench) Voss.

Several sampling points were selected along a line of travel through each stand. The line of travel was arranged to traverse gradients such as slopes and to avoid obvious heterogeneities in the vegetation and soil. Samples were taken from each soil horizon 10 meters in the cardinal directions from the point selected on the line of travel; thus each sample consisted of four subsamples. The organic layers, the A_{00} and the A_0 horizons, were sampled separately on the basis of area, 464.5 cm^2 (one-half of 1 ft^2) being obtained from each subsample point. Analyses from these organic horizons could then be expanded directly to kilograms of DDT per hectare. A composite sample of approximately 2 liters was obtained for each sampling point from each of the mineral horizons.

To calculate the total amount of DDT in the mineral horizons, a single soil pit was dug in each stand and a profile description was recorded. Three "undisturbed" samples were removed in 6.4-cm (2½-in.) diameter steel cylinders from each mineral horizon, and volume weight was determined from these. Determinations of DDT were expressed as DDT per unit weight of soil (air-dry) and were expanded to a land area basis by using the total weight-per-hectare of soil in each horizon. Benzene extraction and the Downing-Norton modification of the Schechter technique were used for the DDT analyses (*2*). Control samples were from unsprayed areas. Recovery of known quantities of DDT applied to these soils was 95 percent or higher. Standard errors were calculated for the means of samples from each horizon in each stand.

Stand 1 was near the Budworm City Airport and was sprayed in 1952 with 0.89 kg of DDT per hectare (1 lb/acre) (*3*) and in the following years through 1958 with 0.45 kg per hectare. Total dosage during the 6-year period was 3.57 kg per hectare. Soils were sampled in 1958, 1960, and 1961. The samples collected in 1958 were from six sampling points, those collected in 1960 were from five points, and those in 1961 from two points. Total amounts of DDT in the soil profile increased annually in the samples of 1958 through 1961 (Table 1), although there was no application of DDT after the original sampling in 1958. In that year the soil profile contained about 0.45 kg of DDT per hectare. In 1960 the profile contained about 1.5 kg per hectare, approximately three times the amount of 1958;