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Geochronology of Precambrian Rocks of the Teton Range, Wyoming

Note: This paper is dedicated to Aaron and Elizabeth Waters on the occasion of Dr. Waters' retirement.

ABSTRACT

The oldest rocks in the Teton Range are complexly deformed interlayered biotite gneiss, plagioclase gneiss, amphibole gneiss, and amphibolite. Also, within these rocks, there are concordant bodies of strongly lineated quartz monzonite gneiss, here named the Webb Canyon Gneiss, which may be of volcanic origin. Coarse metagabbro, here named the Rendezvous Metagabbro, is intrusive into the layered gneiss sequence and was metamorphosed and deformed along with the enclosing rocks.

These older rocks are cut by discordant plutons and swarms of undeformed dikes of quartz monzonite and associated pegmatite. The quartz monzonite, which makes up much of the central part of the Teton Range, is here named the Mount Owen Quartz Monzonite.

The youngest Precambrian rocks are undeformed dikes of slightly metamorphosed tholeiitic diabase.

A Rb-Sr whole-rock isochron on the Webb Canyon Gneiss and the Rendezvous Metagabbro indicates that these rocks were metamorphosed 2,875 $\pm$ 150 m.y. ago. The initial Sr. ratio of 0.700 suggests that the original rocks are probably not significantly older than the metamorphism. The Mount Owen Quartz Monzonite has a whole-rock isochron age of 2,495 $\pm$ 75 m.y. and an unusually high initial ratio of 0.732. Plagioclase-microcline isochrons from two samples of the quartz monzonite indicate partial re-equilibration of the Rb-Sr system during a thermal event 1,800 m.y. ago.

The age of the diabase dikes has not been definitely determined, but biotite in the wall rocks of one major dike has a K-Ar age of 1,450 m.y. This suggests that the dike was emplaced during or prior to a thermal event 1,300 to 1,500 m.y. ago that was responsible for resetting many of the previously reported K-Ar mineral ages throughout the range.

The geochronologic record in the Teton Range is very similar to that elsewhere in the Wyoming Precambrian province. Major metamorphic events with ages between 2,700 and 2,900 m.y. have been identified in the Bighorn, Beartooth, Little Belt, and Granite Mountains. Post-tectonic granitic rocks with ages of 2,500 to 2,700 m.y. have been found in the Wind River Range and the Granite Mountains. Later thermal events have affected Rb-Sr systematics of rocks in the Beartooth Mountains, Wind River Range, and Granite Mountains, as well as in the Teton Range at about the same time as major episodes of regional metamorphism in terranes flanking the Wyoming province in southwestern Montana and in the Front Range in Colorado.

INTRODUCTION

The Teton Range (Fig. 1) in northwestern Wyoming affords some of the northwesternmost exposures of ancient continental crust in the central Rocky Mountains. The Precambrian rocks of the Tetons are part of a terrane exposed in most of the uplifts in Wyoming and north-central Montana that has yielded metamorphic and plutonic ages greater than 2.5 b.y., similar to those in the Superior province of the Canadian Shield. This terrane has been referred to as the Wyoming province (Engel, 1963; Condie, 1969).

The Teton Range is a fragment of a large northwest-trending Laramide uplift that was sundered in late Pliocene or Pleistocene time by a zone of major north-south normal faults along which the eastern edge of the Teton block was uplifted and the floor of Jackson Hole was dropped. The total displacement on the fault zone is estimated to be as much as

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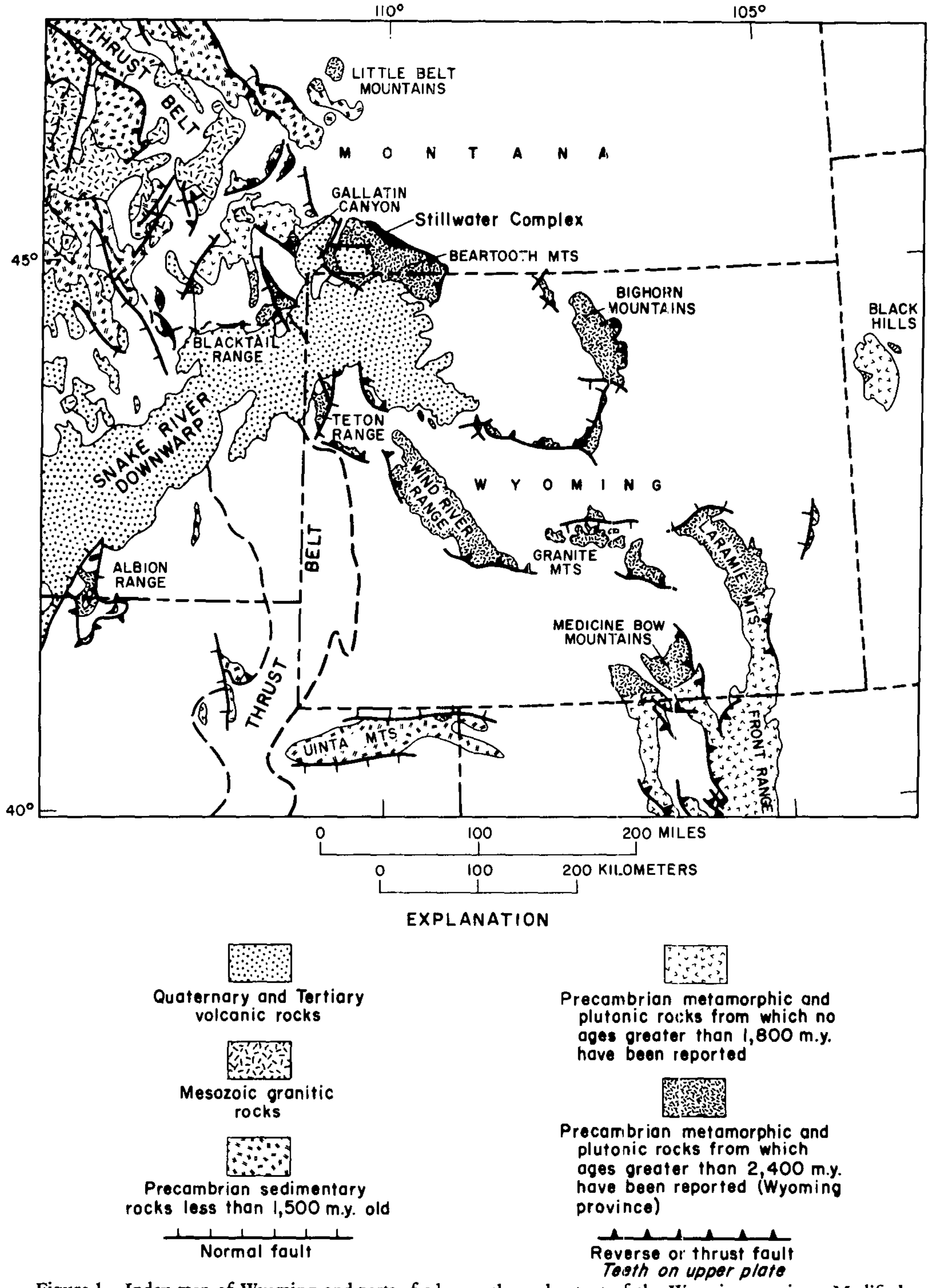


Figure 1. Index map of Wyoming and parts of adjacent states showing outcrop areas of Precambrian rocks and extent of the Wyoming province. Modified from King (1969).

30,000 ft (Love and Reed, 1968). Although the area of exposed Precambrian rocks in the Teton Range is only about 170 sq mi (Fig. 2), the precipitous eastern face of the range provides a nearly continuous vertical cross section with a maximum relief of nearly 7,000 ft (Fig. 3). Problems of exposure in a geologic sense are less critical than those of exposure in a mountaineering sense.

Since 1962, mile-to-the-inch scale geologic mapping of the Precambrian rocks of the Tetons has been completed as part of a U.S. Geological Survey project to produce a geologic map of Grand Teton National Park and vicinity, and several nontechnical accounts of the geology of the Teton Range have been published (Reed, 1963; Love and Reed, 1968; U.S. Geol. Survey, 1971). In the present paper, we report the results of an investigation of the geochronology of the Precambrian rocks of the Tetons that was carried on in conjunction with the mapping program.

GEOLOGY OF THE PRECAMBRIAN ROCKS

Metamorphic Rocks

Layered Gneiss and Migmatite. The oldest rocks in the Teton Range are complexly deformed layered biotite and amphibole gneisses, amphibolites, and migmatites that are believed to be of Precambrian W age in the interim classification recently adopted by the U.S. Geological Survey (James, 1972). The sequence commonly contains lenses and layers of light-gray to white quartz-plagioclase gneiss, and in several places pods of layered magnetite iron-formation a few feet thick and a few tens of feet long have been found. No identifiable quartzite has been found in the gneiss sequence. The occurrences of quartzite reported by Horberg and Fryxell (1942) have all proved to be either light-colored plagioclase gneiss, sheared quartz veins, or downfaulted slices of Flathead Quartzite.

The most common mineral assemblages in the gneisses are

quartz + oligoclase or andesine + biotite ± garnet ± potassium feldspar

in the biotite gneisses and

quartz + andesine or labradorite + hornblende ± biotite ± garnet

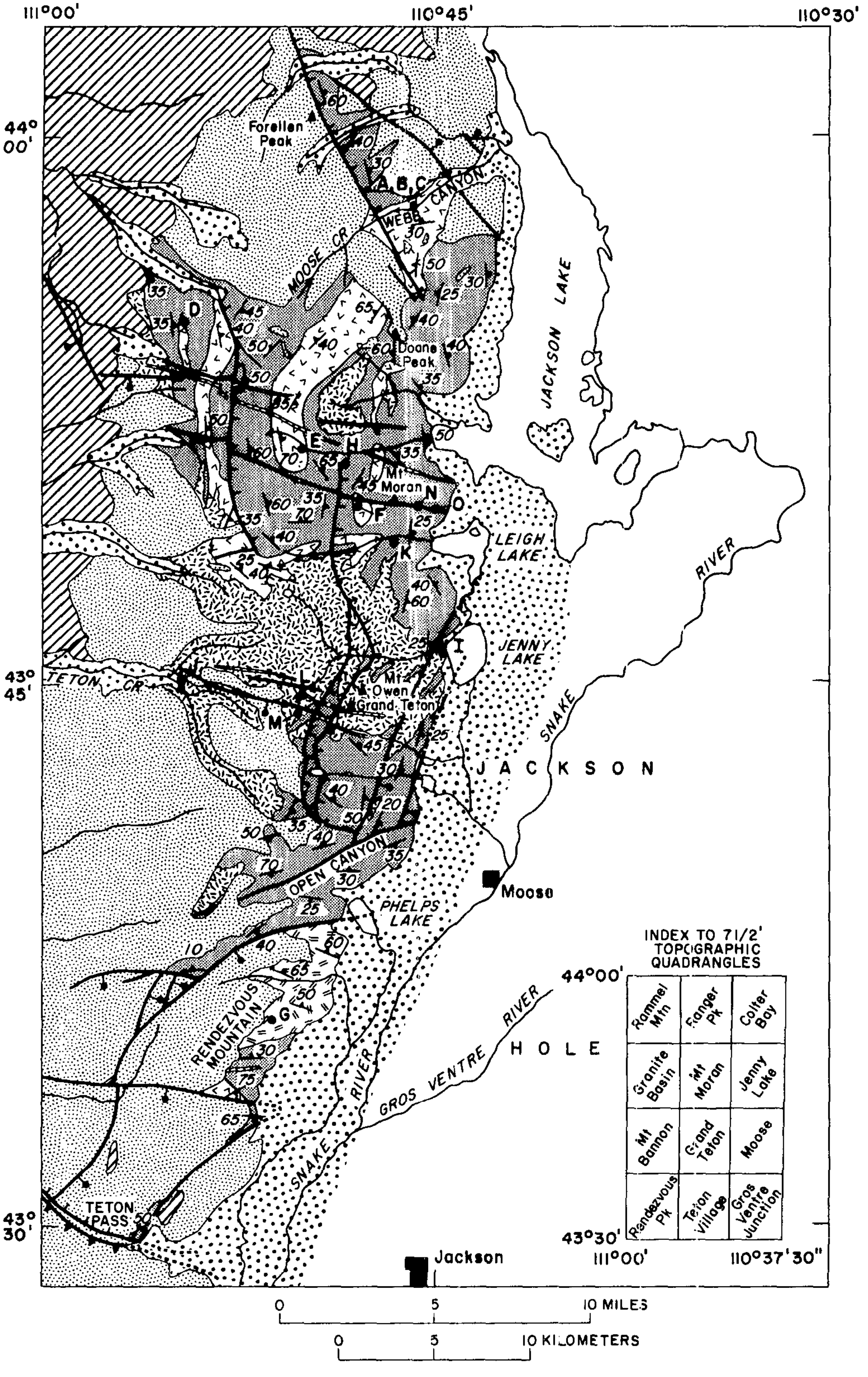
in the amphibole gneisses and amphibolites. Thin layers of amphibole schist interleaved with the gneisses locally contain actinolite, anthophyllite, and cummingtonite in association with quartz, andesine or labradorite, biotite, and garnet. In a few places in the northern part of the range, the gneisses contain cordierite and gedrite. Primary muscovite is rare or absent and no alumino-silicate minerals have been found. The rock reported as sillimanite schist by Reed (1963) on the basis of study of the hand specimens has proved by thin section study to be anthophyllite schist.

In broad areas adjacent to the larger masses of Mount Owen Quartz Monzonite (Fig. 2), the biotite gneisses are lighter colored, less conspicuously layered, and contain abundant potassium feldspar in porphyroblasts, in quartzo-feldspathic folia, and in small grains intergrown with quartz and plagioclase throughout the rock. These migmatitic effects are apparently related to the emplacement of the quartz monzonite and are superimposed on the older metamorphic assemblages.

Most of the gneisses display some degree of alteration or retrogression, including chloritization of ferromagnesian minerals, sericitization of feldspars, and partial decalcification of plagioclase. Some rocks are barely altered, whereas others are almost completely altered.

The conspicuous layering in much of the gneiss sequence (Fig. 4) suggests that most of the gneisses are supracrustal. Some, such as the iron formation and the local layers of marble, are clearly metasedimentary, but the vast bulk of the sequence could be derived from volcanic or volcaniclastic rocks. The mineral assemblages suggest that the rocks were metamorphosed in the amphibolite facies, and the occurrence of cordierite may indicate metamorphism of the low-pressure or low-pressure–intermediate type described by Miyashiro (1961). The scarcity of primary muscovite and the absence of alumino-silicate minerals is probably due to the absence of rocks of pelitic composition.

Webb Canyon Gneiss. The name "Webb Canyon Gneiss" is here proposed for a medium- to coarse-grained strongly foliated nonlayered biotite-and-hornblende–bearing gneiss of quartz monzonitic composition that forms several large concordant bodies in the northern part of the Teton Range. Rb-Sr data discussed below show that the rock is of Precambrian W age (James, 1972). The map pattern suggests that the largest body of Webb Canyon Gneiss



111°00'
110°45'
110°30'
44° 00'
43° 45'
43° 30'
Forellen Peak
WEBB CANYON
MOOSE CR
Doane Peak
JACKSON LAKE
Mt Moran
LEIGH LAKE
JENNY LAKE
TETON CR
Mt Owen
Grand Teton
SNAKE
JACKSON
OPEN CANYON
PHELPS LAKE
Moose
RIVER
GROS VENTRE RIVER
HOLE
RENDEZVOUS MOUNTAIN
SNAKE RIVER
TETON PASS
Jackson
INDEX TO 71/2' TOPOGRAPHIC QUADRANGLES
44°00'
43°30'
111°00'
110°37'30"
Rammel Mtn
Ranger Pk
Colter Bay
Granite Basin
Mt Moran
Jenny Lake
Mt Bannon
Grand Teton
Moose
Rendezvous Pk
Teton Village
Gros Ventre Junction
0
5
10 MILES
0
5
10 KILOMETERS

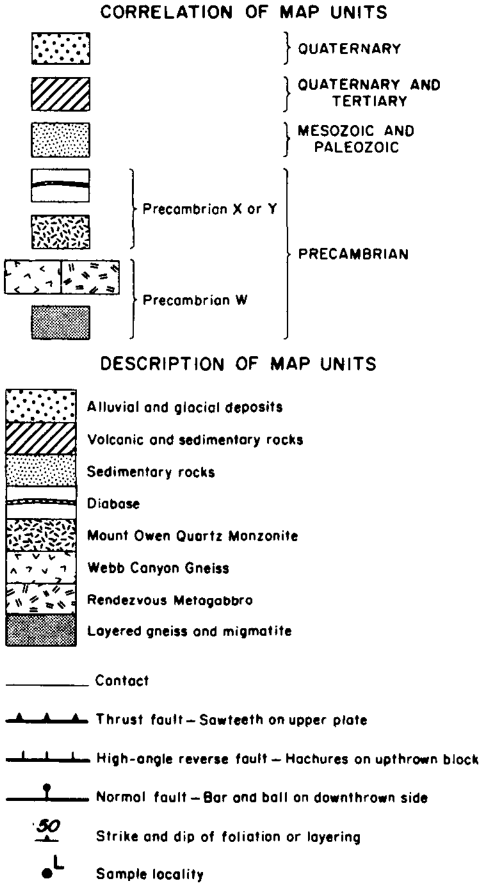


Figure 2. Generalized geologic map of the Precambrian rocks of the Teton Range showing sample localities.

is exposed in the core of an isoclinal fold and that the smaller discontinuous bodies lie at a different stratigraphic horizon. However, the structure is so complex that other interpretations are possible. The type locality is designated as the lower parts of the cliffs on the northwest side of Moose Creek in the lower part of Webb Canyon 1.9 mi S. 78° E. of Owl Peak in the Ranger Peak 7½′ quadrangle, Wyoming (Fig. 2, sample loc. A, V, and C).

The type locality is near the northeast end of the largest exposed body of Webb Canyon Gneiss in the Teton Range. The contact of the body with layered biotite and amphibole gneisses to the northwest lies about midway up the cliffs. The contact strikes approximately east-west and dips 20° to 40° north, parallel to foliation in the Webb Canyon Gneiss and layering in the layered gneisses.

The Webb Canyon commonly contains layers of amphibolite a few inches to several hundred feet thick. Several thick amphibolite layers are conspicuous in the gneiss at the type locality. Contacts of these amphibolite layers are knife-sharp.

Contacts of the Webb Canyon Gneiss with the enclosing rocks are commonly marked by a layer of similar amphibolite. Where amphibolite is absent, contacts with the layered biotite gneisses are gradational over a few tens of hundreds of feet, and the Webb Canyon Gneiss becomes finer grained and rudely layered near the contact.

The origin of the Webb Canyon Gneiss is uncertain. No primary textures or structures are preserved. Chemically the rock closely resembles an alkalic granite or rhyolite; its texture and grain size suggest that it may be a plutonic rock, but the lack of intrusive relations and the continuity and extent of the concordant amphibolite layers within it seem to preclude an intrusive origin. It therefore seems most likely that the gneiss is derived from felsic volcanic rocks, either flows or tuffs interlayered with flows or sills of basalt that were metamorphosed to produce the amphibolite layers.

Rendezvous Metagabbro. We suggest the name "Rendezvous Metagabbro" in this report for the coarse-grained mafic rock that is exposed between Open Canyon and Rock Springs Canyon in the southern part of the Teton Range. The unit is believed to be of Precambrian W age on the basis of Rb-Sr data discussed below (James, 1972).

The type locality is designated as the freshly blasted outcrops between elevations 8,400 and 9,000 ft in the small valley on the east slopes of Rendezvous Mountain, just north of the aerial tramway at the Jackson Hole ski area (Fig. 2, sample loc. G). The type locality is about 1.6 mi N. 65° W. of the lower terminus of the tramway in Teton Village, Teton Village 7½′ quadrangle, Wyoming. The rock is nonlayered and very weakly foliated. Typically it has a blotchy appearance due to irregular clots of dark-green hornblende 1 inch to several inches across set in a matrix of light-gray plagioclase. Similar rock that occurs in pods in the layered gneisses north of Phelps Lake was aptly described by Bradley (1956) as "leopard diorite." The rock typically consists of about 60 to 70 percent finely twinned plagioclase (about An_{75}) and 25 and 35 percent hornblende. A few plagioclase grains are faintly

Figure 3. Oblique aerial photograph of the east face of Mount Moran. Direction of view is northwest. Vertical relief from bottom to summit, as pictured, is about 3,400 ft. Country rock is predominantly migmatitic biotite gneiss. Light-colored dikes, most of which dip gently to the north (right), are Mount Owen Quartz Monzonite and related pegmatite. Prominent dark band is a diabase dike 100 to 150 ft thick. Light-gray cap on summit is Flathead Quartzite of Cambrian age that rests unconformably on the dike. Sample locality N is about midway up the lowest outcrop of the dike visible in the photograph. Photograph by Austin Post.

zoned. Commonly the plagioclase is partly sericitized and decalcified. The hornblende, which probably replaces original pyroxene, is partly jacketed with actinolite and locally is partly altered to chlorite and epidote. A few small grains of quartz occur as poikilitic inclusions in hornblende and between the larger plagioclase grains, and scattered small flakes of reddish-brown biotite are intergrown with the hornblende.

The northern contact of the metagabbro is marked by a fault. On the west, the rock passes beneath Paleozoic sedimentary rocks; on the east, it passes beneath surficial deposits (Fig. 2). The contact between the metagabbro and migmatitic biotite gneiss to the south is sharp

A

B

Figure 4. Photographs of layered gneiss. A. Thinly layered biotite gneiss, amphibole gneiss, and amphibolite west of Static Peak, about 2 mi northwest of Phelps Lake (Fig. 2). B. Interlayered plagioclase gneiss (white), biotite gneiss (medium gray), amphibole gneiss and amphibolite (dark gray) displaying rootless isoclinal folds and sheared-out layers. About 1.5 mi northwest of Doane Peak (Fig. 2).

and concordant. The metagabbro near the contact is finer grained and lighter colored. The gneiss near the contact is highly contorted and contains pods of metagabbro a few inches to a few feet across. The intrusive nature of the metagabbro is confirmed by the widespread occurrence of similar lenses and pods, presumably boudinaged sills or dikes, in the enclosing layered gneisses, and by the occurrence of angular inclusions of biotite gneiss in the main body of metagabbro.

Deformation of the Metamorphic Rocks. The layered gneisses display at least two generations of folds (Reed, 1963). The earliest folds are rootless isoclines with axial planes and limbs parallel to layering. The largest isoclines observed have limbs a few tens of feet long, but much larger ones may be present. Some layers are contorted by isoclinal folds, whereas other layers above and below are not contorted (Fig. 4B). This suggests that many of the layers are limbs of sheared-out isoclines and that, although the layers probably reflect original compositional differences, their original sequence has been completely obliterated by shearing parallel to layering.

Superimposed on the early isoclines are more open folds with diverse axial orientations. The folds may belong to several generations, but analyses of the structures have not yet been completed and therefore a sequence has not been worked out.

Foliation in the gneisses is parallel to the layering, and mineral lineations are generally parallel to axes of the younger folds. This suggests that amphibolite-grade metamorphism was synchronous with the younger folds. Parallelism between foliation and lineation in the Webb Canyon Gneiss and similar structures in the enclosing rocks indicates that the Webb Canyon was deformed at the same time as the enclosing rocks.

The Rendezvous Metagabbro does not display any conspicuous lineation, but the rude foliation is parallel to that in the nearby migmatitic gneisses. The occurrence of boudins and deformed layers of metagabbro in the surrounding layered gneisses suggests that the original gabbro was emplaced prior to or during deformation and metamorphism of the gneisses.

Younger Intrusive Rocks

Mount Owen Quartz Monzonite. Much of the central part of the Teton Range is underlain by an irregular pluton of light-colored quartz monzonite and associated pegmatite for which we here propose the name "Mount Owen Quartz Monzonite." Isotopic data discussed below indicate that the rock could be Precambrian X or Precambrian W (James, 1972). The rock is named from its exposures on the slopes of Mount Owen, but the type locality is designated as the more easily accessible exposures along the trail in the South Fork of Cascade Canyon at elevation 8,880 ft, 1.9 mi due west of the summit of Mount Owen, Grand Teton 7½′ quadrangle, Wyoming (Fig. 2, sample locality L).

Typically the Mount Owen Quartz Monzonite is a medium- to fine-grained light-colored rock consisting of 30 to 40 percent quartz, 20 to 30 percent potassium feldspar, 25 to 35 percent plagioclase, 5 percent or less biotite, and a trace of muscovite. The potassium feldspar is microcline and microperthite; the plagioclase is generally finely twinned unzoned sodic oligoclase.

The rock is generally nonfoliated but locally displays a faint foliation marked by biotitic streaks that is believed to be a flow structure. Except near fault zones the quartz monzonite is unsheared, but in many specimens the biotite is partly altered to chlorite or fringed with secondary muscovite and the feldspars are slightly clouded and contain small granules of clinozoisite.

Dikes, pods, and irregular bodies of pegmatite ranging in thickness from a few inches to several tens of feet are common throughout much of the main mass of the Mount Owen Quartz Monzonite. Locally they comprise a quarter or more of the rock mass. The pegmatites contain irregular masses of gray quartz, subhedral crystals of milky white oligoclase, and blue-gray microcline as much as 2 ft long, muscovite in plumose aggregates or tabular books as much as 3 in. across, and long flat blades 1 to 2 in. across and as much as 1 ft long. Generally an individual pegmatite body contains muscovite or biotite, but not both. A few pegmatites contain garnet crystals as much as 6 inches in diameter (Love and Reed, 1968, Fig. 25).

The contacts of the Mount Owen Quartz Monzonite are highly irregular and difficult to depict on a geologic map. Blocky inclusions of wall rocks a few feet to several feet across are common throughout the pluton (Fig. 5A). As the margins are approached, these inclusions become more and more abundant until one

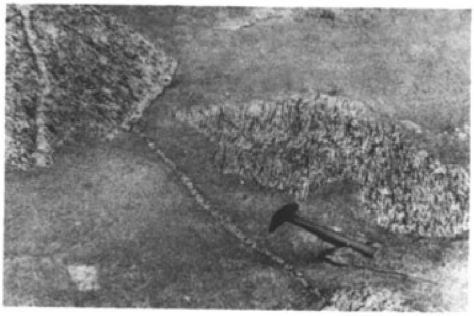


Figure 5A. Angular inclusions of strongly foliated Webb Canyon Gneiss in Mount Owen Quartz Monzonite. Note rotation of the foliation in the blocks. Light-colored slightly sheared quartz-feldspar dike in inclusion at upper left is truncated by contact; small biotite pegmatite dike (left of hammer) cuts across both the inclusions and the quartz monzonite, although it is inconspicuous in the inclusions because of similarity in grain size. About 3 mi northwest of sample locality M (Fig. 2).

Figure 5B. Network of dikes of Mount Owen Quartz Monzonite and related pegmatite cutting migmatitic biotite gneiss on the north face of the West Horn of Mount Moran. Note rude layering in gneiss dipping about 60° E. (left). Face is about 700 ft high.

passes imperceptibly from quartz monzonite and pegmatite containing abundant inclusions of wall rocks into wall rocks containing myriad cross-cutting dikes of quartz monzonite and pegmatite. Many of the dikes in the wall rocks are composed partly of pegmatite and partly of fine-grained quartz monzonite. The finer grained rock may occupy either the center or the margins of an individual dike. Dikes of quartz monzonite cut dikes of pegmatite and vice versa, indicating a complex, overlapping order of emplacement.

The wall rocks for as much as 5 mi from the contacts of the main pluton are cut by smaller plutons and laced with swarms of quartz monzonite and pegmatite dikes, many of which are emplaced along low-dipping joint sets (Figs. 3 and 5B). The dikes become less and less abundant farther from the main pluton, and only a few dikes are found cutting the gneisses in the northern and southern ends of the range.

Undeformed dikes of quartz monzonite and pegmatite cut cleanly through complexly folded layered gneisses, and angular rotated blocks of wall rock are widespread as inclusions in the main pluton, showing clearly that the Mount Owen Quartz Monzonite was emplaced after the folding and metamorphism of the enclosing rocks.

Contacts of individual dikes with the wall rocks and of individual inclusions with the quartz monzonite are generally very sharp. There is no evidence of local contact metamorphic effects on the wall rocks and only local evidence of digestion of inclusions. Apparently the Mount Owen Quartz Monzonite was emplaced in rather brittle country rocks by some combination of dilation of fractures and magmatic stoping, without appreciable deformation of the wall rocks.

Diabase. The youngest Precambrian rock in the Teton Range is tholeiitic diabase which forms a series of west-northwest-trending dikes that cut all the other Precambrian rocks but which are unconformably overlain by the basal beds of the Flathead Quartzite of Middle Cambrian age. The largest dike is prominently exposed on the east face of Mount Moran (Fig. 3). It is about 150 ft thick and has been traced along strike for almost 10 mi, completely across the Teton Range. The vertical extent of the exposures on Mount Moran is more than 5,000 ft. The prominent dikes exposed on the Grand Teton and on Middle Teton are 40 to 60 ft thick; other dikes range in thickness from a few inches to several tens of feet. Isotopic data discussed below suggest that the dikes are of Precambrian X or Precambrian Y age (James, 1972).

The diabase consists essentially of subcalcic augite, sodic labradorite (An_{50-55}), pigeonite, and opaque ores, and contains a few small grains of brown hornblende and biotite. Most of the dikes have chilled margins a few inches thick that consist of a very fine-grained, dark felted groundmass containing subhedral phenocrysts of pyroxene and euhedral laths of plagioclase; some of these display a flow orientation parallel to the walls (Fig. 6).

Whereas the dikes are undeformed (except for shearing along faults), most of the diabase exhibits some evidence of incipient alteration or metamorphism. Plagioclase is partly altered to sericite and pyroxene is locally converted to chlorite, epidote, and bluish-green amphibole. In some specimens, the pyroxene is almost completely converted to amphibole, but the plagioclase is little altered.

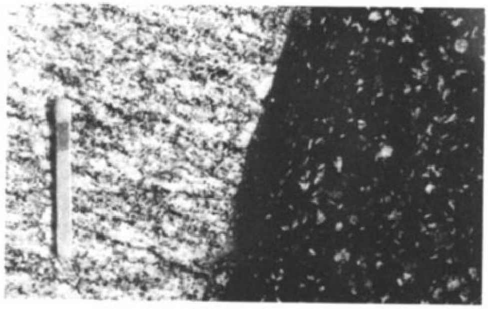


Figure 6. Sawed slab showing chilled margin of diabase dike. Average grain size of diabase in center of dike is about the same as that of the larger phenocrysts of plagioclase and pyroxene in the chilled margin. Paper match shows scale. South wall of 20-ft-thick dike in Garnet Canyon about 2 mi southeast of summit of Grand Teton (Fig. 2).

ISOTOPIC STUDIES

Analytical Methods

Rb and Sr analyses were carried out using procedures similar to those described by Peterman and others (1967, 1968). Preliminary x-ray fluorescence analyses for Rb and Sr were made using the technique described by Doering (1968). Measurements of isotopic ratios were made on a 6-in., 60°, single-focusing mass spectrometer using triple filament surface ionization. Precision of results is believed to be about the same as that quoted by Peterman and others (1968): for individual Rb determinations, ±1.5 percent at the 95-percent confidence level; for individual Sr determinations, ±2.2 percent at the 95-percent confidence level; for Rb/Sr ratios by isotope dilution, ±2.7 percent; for Sr^{87}/Sr^{86} ratios calculated from measurements on spiked samples, about ±3 percent; and for Sr^{87}/Sr^{86} ratios measured on unspiked samples, ±0.15 percent. All Sr^{87}/Sr^{86} ratios were normalized to a value of Sr^{86}/Sr^{88} = 0.1194. In all Rb-Sr calculations, the following constants were used:

$Rb^{87}\lambda_\beta = 1.39 \times 10^{-11}$/yr, corresponding to half life of $Rb^{87} = 50 \times 10^9$ yrs. Rb^{87} = 0.283 g/g Rb.

Rb-Sr ages quoted from the literature have been recalculated using the 50×10^9 yr half-life if the original authors used a different value.

Ar extractions were made using the fusion technique described by Dalrymple and Lanphere (1969). Potassium contents of biotites were determined by flame photometry; all other potassium contents were determined by isotope dilution.

The following constants were used in the K-Ar calculations:

$$K^{40}\lambda_\epsilon = 0.584 \times 10^{-10}/\text{yr}$$
$$\lambda_\beta = 4.72 \times 10^{-11}/\text{yr}$$
$$K^{40} = 1.19 \times 10^{-4} \text{ moles/mole K}.$$

All sample localities are indicated on Figure 2. Detailed locations and petrographic descriptions are available.[1]

Age of the Webb Canyon Gneiss and Rendezvous Metagabbro

The results of Rb and Sr analyses of five whole-rock samples of Webb Canyon Gneiss, one sample of plagioclase gneiss in the layered gneiss sequence adjacent to the Webb Canyon Gneiss, and three samples of Rendezvous Metagabbro are given in Table 1. Taken alone, the five analyses of the Webb Canyon Gneiss define a whole-rock isochron with an age of 2,790 ± 400 m.y. and an initial Sr^{87}/Sr^{86} ratio of 0.703 ± 0.017 (model 4 of McIntyre and others, 1966). No meaningful independent isochron could be calculated for the three Rendezvous Metagabbro samples because of their low Rb/Sr ratios.

Although the age relation between the Webb Canyon Gneiss and the Rendezvous Metagabbro is uncertain, field relations show that both they and the enclosing gneisses have

[1] This material (NAPS no. 01969) may be obtained by writing to Microfiche Publications, Div. of Microfiche Systems Corp., 305 East 46th St., New York, New York 10017, enclosing $5 for photocopies, or $1.50 for microfiche. Make checks payable to Microfiche Publications.

TABLE 1. WHOLE-ROCK RUBIDIUM AND STRONTIUM ANALYSES

Sample locality*	Field no.	Rb (ppm)	Sr (ppm)	Rb^{87}/Sr^{86}	(Sr^{87}/Sr^{86})†	Age (m.y.)
		Plagioclase gneiss adjacent to Webb Canyon Gneiss				
A	986A	13.7	282.7	0.140	0.7062*	
		Webb Canyon Gneiss				
B	984A	35.7	76.9	1.35	0.7756§	
C	985A	41.6	60.9	1.98	0.7770§	
D	1181A	67.1	78.5	2.50	0.8079§	
E	416	63.0	52.2	3.56	0.8464§	2875 ± 150
F	437	78.3	128.5	5.03	0.8991§	
		Rendezvous Metagabbro				
G	1294A	11.5	144.7	0.232	0.7082§	
G	1294B	23.0	151.8	0.438	0.7192§	
G	1294G	39.0	167.5	0.675	0.7265§	
		Mount Owen Quartz Monzonite				
H	421	104.9	68.1	4.54	0.8915§	
I	R-1	173.2	65.3	7.91	1.016	
J	TC-1	210.2	58.8	10.75	1.110	
K	542	161.6	38.9	12.60	1.181	2495 ± 75
L	847	172.6	29.1	17.83	1.346	
M	962	215.0	33.0	20.12	1.456	

**Sample localities are shown on Figure 2.*

†Normalized to Sr^{86}/Sr^{88} = 0.1194.

§Indicates determinations made on unspiked sample; all other determinations made on spiked samples.

undergone the same episodes of high-grade regional metamorphism and deformation. We have therefore also calculated a single composite isochron (Fig. 7) for all of the Webb Canyon Gneiss and Rendezvous Metagabbro analyses, plus the analysis of the plagioclase gneiss in the layered gneiss sequence. This yields an age of 2,875 ± 150 m.y. with an initial Sr^{87}/Sr^{86} ratio of 0.700 ± 0.002 (model 4 solution of McIntyre and others, 1966). The slope of this isochron and therefore the age is dependent largely on the analyses of the Webb Canyon Gneiss; the initial Sr^{87}/Sr^{86} ratio is controlled principally by the metagabbro and plagioclase gneiss analyses.

Because all the rocks included have undergone extensive recrystallization during high-grade regional metamorphism, we interpret the isochron age to be the approximate date of the metamorphism. K-Ar ages of 2,780 and 2,800 m.y. on hornblende from amphibolite interlayered with biotite gneisses on Mount Moran (Table 4) are in accord with this interpretation. The isochrons constructed for both the Webb Canyon Gneiss alone and for the composite samples show scatter in the data which exceeds the experimental error. The basic assumptions of the Rb-Sr dating method are that all the samples started with the same Sr^{87}/Sr^{86} ratio and subsequently retained all of their Rb and Sr. The departure of the data points from a straight line by more than the experimental error shows that one or the other of these assumptions is not strictly correct. However, the reasonable initial ratio and the agreement with other geochronologic results in nearby areas suggest that the isochron age is probably meaningful to within the stated uncertainty.

The initial Sr^{87}/Sr^{86} ratio (the y-intercept of the isochron line) is an indication of the source and history of the strontium in the rocks. The Sr^{87}/Sr^{86} ratio in the mantle 2.9 b.y. ago is inferred to have been between 0.700 and 0.701 (Hedge and Walthall, 1963; Hedge, 1966). Because the initial Sr^{87}/Sr^{86} ratio in the Webb Canyon Gneiss and Rendezvous Metagabbro is in the same range as mantle strontium 2.9 b.y. ago, we conclude that unless substantial increases in Rb/Sr ratios occurred during metamorphism, the original rocks were removed from the mantle only shortly before the episode of high-grade regional metamorphism dated by the isochron.

Age and Strontium Composition of the Mount Owen Quartz Monzonite

Six whole-rock samples of the Mount Owen Quartz Monzonite (Table 1) define an isochron (Fig. 8) with an age of 2,495 ± 75 m.y. and

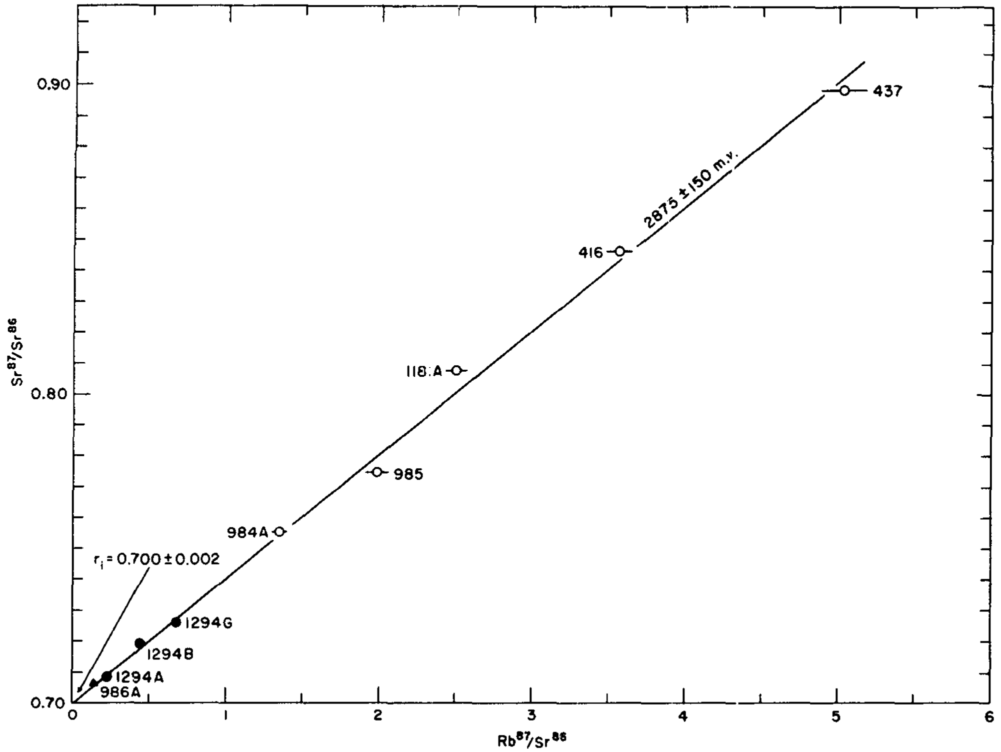


Figure 7. Rb-Sr isochron diagram for whole-rock samples of Webb Canyon Gneiss (open circles), Rendezvous Metagabbro (solid circles), and plagioclase gneiss (triangle). Horizontal lines through circles indicate analytical uncertainty in Rb^{87}/Sr^{86}.

an initial Sr^{87}/Sr^{86} ratio of 0.732 ± 0.009 (model 1 of McIntyre and others, 1966). The age is consistent with preliminary Pb^{207}/Pb^{206} isotopic ages on four separates of zircon from the sample from locality J which range from 2,420 to 2,510 m.y. However, the zircons contain appreciable amounts of common lead and are highly discordant, making a unique interpretation of their isotopic ages difficult.

The initial Sr^{87}/Sr^{86} ratio is extremely high for a Precambrian rock. There is a possibility that this is a result of postcrystallization disturbance of the isotopic system. So-called "rotated isochrons" characterized by a reduced age and an anomalously high apparent initial ratio arising during postcrystallization metamorphism have been documented by Zartman and Stern (1967) and Zartman and Marvin (1971). However, both the very close fit of the points to the isochron (Fig. 8) and the apparent agreement between the isochron age and the Pb^{207}/Pb^{206} ages on zircon are difficult to explain on the basis of isochron rotation. The anomalously high initial Sr^{87}/Sr^{86} ratio is probably real, and we interpret the isochron age as being close to the age of emplacement of the quartz monzonite.

If the high initial Sr^{87}/Sr^{86} ratio is an isotopic characteristic of the magma, the magma could not have been derived directly from the mantle, which 2.5 b.y. ago should still have had a Sr^{87}/Sr^{86} ratio of between 0.700 and 0.701 (Hedge and Walthall, 1963; Hedge, 1966).

Evidently the anomalous strontium was derived from crustal rocks, either at the present level of exposure or at deeper levels. We have determined Rb and Sr concentrations and Rb-Sr ratios on a number of samples of the wall rocks of the Mount Owen and have calculated their Sr^{87}/Sr^{86} ratios and radiogenic Sr^{87} contents 2.5 b.y. ago on the assumption that they would plot on the same isochron as the Webb Canyon Gneiss and Rendezvous Metagabbro. The results are summarized in Table 2 and Figure 9. Of the 33 samples analyzed, only one would have had a Sr^{87}/Sr^{86} ratio higher

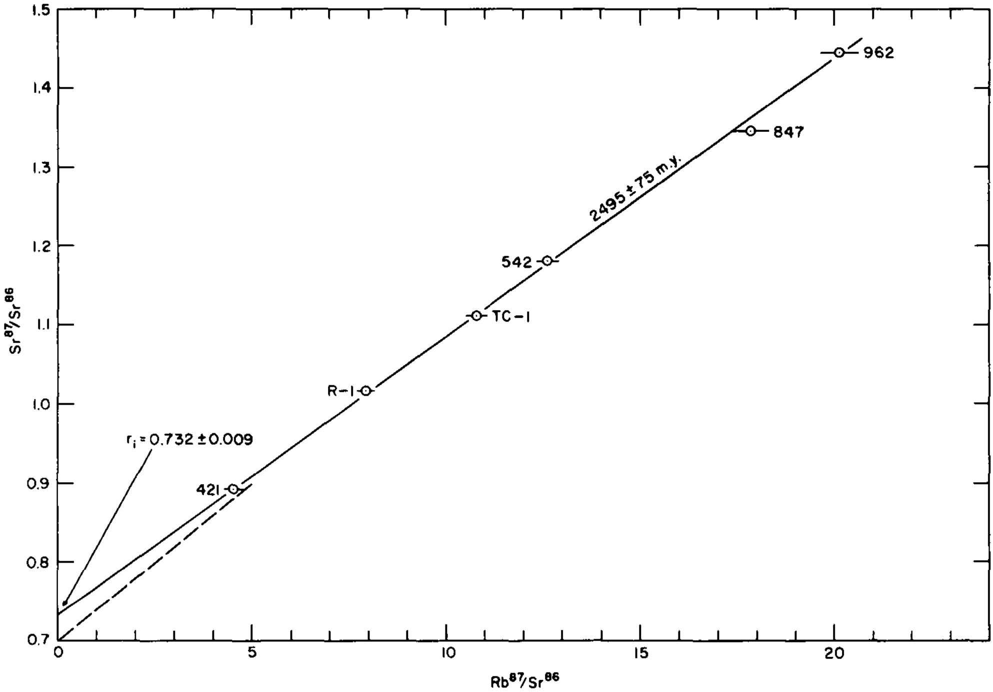


Figure 8. Rb-Sr isochron diagram for whole-rock samples of Mount Owen Quartz Monzonite. Horizontal lines through circles indicate analytical uncertainty in Rb^{87}/Sr^{86}. Dashed line is Webb Canyon Gneiss–Rendezvous Metagabbro whole-rock isochron from Figure 7.

than that of the Mount Owen Quartz Monzonite. This strongly suggests that the anomalous strontium in the Mount Owen was not derived from the wall rocks by any process such as large-scale digestion of inclusions or replacement of wall rocks. This result is in accord with the field evidence and with the bulk chemistry of the rocks.

The high Sr^{87}/Sr^{86} ratio in the Mount Owen would appear to be the result of either (1) incorporation of strontium representative of crustal rocks with Sr^{87}/Sr^{86} ratios much higher than those of the present wall rocks, or (2) selective incorporation of radiogenic Sr^{87} through some process involving isotopic fractionation, perhaps partial anatexis or hydrothermal flushing of radiogenic strontium, or (3) some combination of (1) and (2).

If a process of preferential extraction of radiogenic strontium from rocks like the

TABLE 2. AVERAGE Rb AND Sr CONTENTS AND Rb-Sr RATIOS FOR VARIOUS ROCK TYPES AND ESTIMATED Sr^{87}/Sr^{86} RATIOS AND RADIOGENIC Sr^{87} CONTENTS 2.5 B.Y. AGO

Rock type	Number of samples	Rb (ppm) Average	Rb (ppm) Range	Sr (ppm) Average	Sr (ppm) Range	Rb/Sr Average	Rb/Sr Range	Estimated Sr^{87}/Sr^{86} 2.5 B.Y. ago	Estimated radiogenic Sr^{87} 2.5 B.Y. ago (ppm)
Biotite Gneiss	14	68	16 to 149	220	56 to 917	0.309	0.047 to 2.68	0.7049	0.107
Amphibolite	3	12	5 to 17	98	86 to 119	0.122	0.063 to 0.192	0.7019	0.018
Rendezvous Metagabbro	7	23	8 to 43	185	167 to 207	0.124	0.040 to 0.217	0.7019	0.035
Webb Canyon Gneiss	9	69	35 to 105	87	57 to 109	0.793	0.445 to 1.74	0.7127	0.109
Mount Owen Quartz Monzonite	12	201	116 to 368	44	18 to 74	4.57	1.57 to 12.51	0.732	--

Rb and Sr contents and Rb/Sr ratios determined by x-ray fluorescence methods similar to those described by Doering (1968) using samples analyzed by isotope dilution methods (Table 1) as standards. Analyst, W. P. Doering.

present wall rocks were operative, the volume of rock involved can be estimated. Assuming the magma originally contained 44 ppm strontium (Table 2) with a Sr^{87}/Sr^{86} ratio of about 0.703 (typical of 2.5-b.y.-old granitic rocks), the equivalent of 0.13 ppm of pure Sr^{87} must be added to raise the ratio to 0.732. This would require *complete* extraction of radiogenic Sr^{87} from a volume of rock with radiogenic Sr^{87} contents like the biotite gneisses or Webb Canyon Gneiss slightly greater than the volume of the Mount Owen Quartz Monzonite or *partial* extraction from correspondingly greater volumes.

Later Events

The only Precambrian events in the geologic record subsequent to the emplacement of the Mount Owen Quartz Monzonite are (1) intrusion of the diabase dikes, (2) widespread incipient low-grade metamorphism of the dikes and the older rocks, and (3) local shearing and alteration along fault zones.

In an attempt to evaluate the effect of later events on the mineral ages, we have studied the Rb-Sr systematics in the major mineral phases in two typical samples of the Mount Owen Quartz Monzonite and have made a detailed K-Ar study of the large diabase dike exposed on the east face of Mount Moran (Fig. 3). Analytical data on the major minerals from whole-rock samples of Mount Owen Quartz Monzonite from localities J and M are given in Table 3 and plotted in Figure 10. Whole-rock analyses of the same samples are given in Table 1. If no redistribution of Rb or Sr had taken place since crystallization of the quartz monzonite, all of the data points for the individual minerals would plot on the whole-rock isochron. The fact that most of the minerals do not fit the whole-rock isochron shows that significant redistribution of these elements has occurred. However, the excellent fit of the whole-rock analyses to the isochron in Figure 8 shows that the redistribution did not affect volumes of rock as large as the whole-rock samples (1 to 5 kg).

The plagioclase and microcline data from each of the rocks define mineral isochrons (Fig. 11) whose slopes correspond within analytical uncertainty to an age of about 1,800 m.y. Each line passes through the corresponding whole-rock point, but, as has been pointed out by Naylor and others (1970), this is required by material balance since most of the

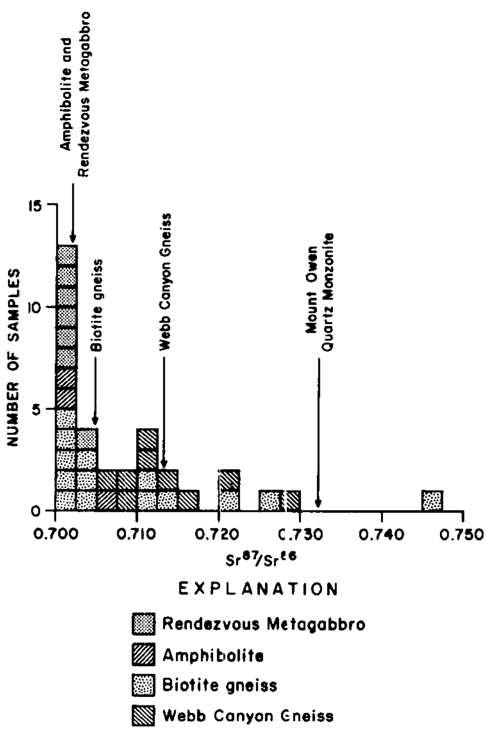


Figure 9. Estimated Sr^{87}/Sr^{86} ratios of various wall rocks at the time of emplacement of the Mount Owen Quartz Monzonite. Data from Table 2. Average values for various rock types are indicated by vertical arrows.

Rb and Sr in the rocks are contained in the feldspars. The muscovite from locality M lies nearly on the whole-rock isochron, indicating that the mineral did not participate in any later re-equilibration, but the muscovite for locality J lies close to the feldspar isochron, showing that it did participate. Both biotite points fall well below the mineral isochrons. The apparent ages of the biotites are 1,440 and 1,550 m.y.

Table 4 summarizes K-Ar ages in and adjacent to the diabase dike on Mount Moran (Fig. 3). All the samples from locality N were collected along a single horizontal traverse northward from the center of the dike at an elevation of about 9,700 ft where the dike is 110 ft thick. The sample from locality O came from near the center of the dike at elevation 8,100 ft. Hornblende from locality B came from a segregation pegmatite in the Webb Canyon Gneiss that is unrelated to the Moran dike but is included for comparison.

Hornblende from the wall rocks has ages

TABLE 3. RUBIDIUM AND STRONTIUM DATA AND APPARENT AGES OF MINERALS FROM MOUNT OWEN QUARTZ MONZONITE

Sample locality*	Mineral	Rb (ppm)	Sr (ppm)	Rb^{87}/Sr^{86}	$(Sr^{87}/Sr^{86})n$†
M	Plagioclase	40.0	56.5	2.10	0.9808§
M	Microcline	539.3	47.2	33.06	1.761
M	Muscovite	643.5	40.8	54.62	2.720
M	Biotite	636.9	60.3	33.44	1.662
J	Plagioclase	20.5	50.1	1.24	0.8754
J	Microcline	409.0	75.2	16.62	1.278
J	Muscovite	551.2	17.5	118.9	3.852
J	Biotite	1,189.2	39.1	108.0	3.032

*Sample localities are shown on Figure 2.
†Normalized to Sr^{86}/Sr^{88} = 0.1194.
§Indicates determination made on unspiked sample; all other determinations made on spiked samples.

ranging from 2,800 m.y. to 2,600 m.y. The older age corresponds very closely to the time of regional metamorphism inferred from the Webb Canyon Gneiss–Rendezvous Metagabbro whole-rock isochron. The lower age is found within 2 ft of the dike contact and may be due to partial Ar loss from heating of the wall rocks during intrusion of the dike. The difference, however, is only slightly greater than analytical uncertainty, and hornblende from the Webb Canyon Gneiss well removed from any known diabase dike is even younger.

The three ages for biotite from the wall rocks (1320, 1350, and 1450 m.y.) are analytically indistinguishable, and all lie in the same range as biotite from elsewhere in the Teton Range. No further decrease in the apparent age of the wall-rock biotite was found even within 5 ft (0.045 dike widths) of the contact. Rock from the chilled margin of the dike has an apparent age of 775 m.y., whereas plagioclase from near the center of the dike has apparent ages of 583 and 396 m.y.

The results are ambiguous as to the time of

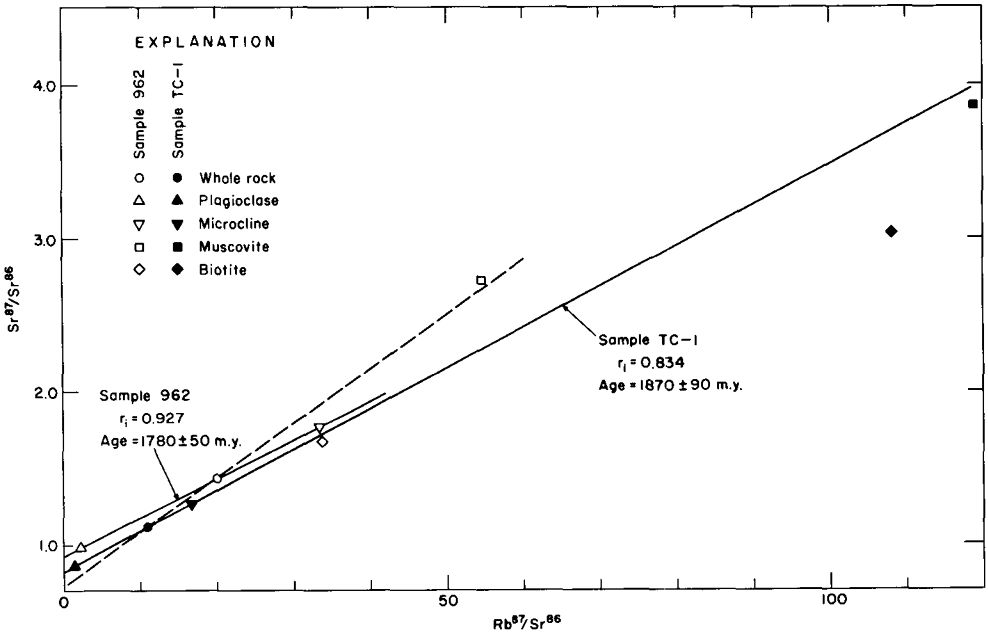


Figure 10. Rb-Sr isochron diagram for minerals from Mount Owen Quartz Monzonite samples from localities J and M. Dashed line is whole-rock isochron from Figure 8. Solid lines are plagioclase-microcline isochrons for each sample.

TABLE 4. POTASSIUM-ARGON AGES FROM THE TETON RANGE, CHIEFLY FROM THE DIABASE DIKE ON MOUNT MORAN AND ITS WALL ROCKS

Material	K_2O* (percent)	Ar^{40} radiogenic† (moles x 10^{-9}/gm)	Ar^{40} radiogenic (percent)	Age ±2σ (m.y.)
	Pegmatite in Webb Canyon Gneiss, sample locality B§			
Hornblende	1.711*	13.90	99	2580 ± 25
	Wall rocks of diabase dike, Mount Moran, sample locality N§			
Hornblende 0.7 ft from dike	0.620*	5.308	98	2,650 ± 25
Hornblende 2.0 ft from dike	0.523*	4.311	99	2,600 ± 80
Hornblende 10 ft from dike	0.519*	4.535	99	2,800 ± 90
Hornblende 20 ft from dike	0.638*	6.010	99	2,780 ± 80
Biotite 5 ft from dike	0.96	3.094	75	1,450 ± 90
Biotite 40 ft from dike	6.20	17.58	99	1,320 ± 50
Biotite 100 ft from dike	7.65	22.20	88	1,350 ± 50
	Diabase from dike on Mount Moran, sample locality N§			
Whole rock from chill zone	0.809*	1.142	90	775 ± 50
Plagioclase near center of dike	1.209*	0.7862	88	396 ± 6
	Diabase from dike on Mount Moran, sample locality C§			
Plagioclase near center of dike	1.331*	1.343	96	583 ± 8

*Indicates determination by isotope dilution, W. H. Henderson, analyst; all other determinations by flame photometer, Violet Merritt, analyst.
†H. H. Mehnert and R. F. Marvin, analysts.
§Sample localities are shown on Figure 2.

emplacement of the dike. The plagioclase ages are in conflict with the field relations, for the same dike is overlain unconformably by the Cambrian Flathead Quartzite (Fig. 3). The 775-m.y. age on the chilled margin is geologically permissible and agrees approximately with whole-rock K-Ar ages on the chilled margin of a similar dike in the Beartooth Mountains reported by Hanson and Gast (1967) and Condie and others (1969). Condie, however, found a wide range of whole-rock K-Ar ages of the chilled margins of diabase dikes elsewhere in the Wyoming province.

If the 775-m.y. whole-rock age is accepted as the age of the dike, there is no explanation for the consistency of the biotite K-Ar ages in the wall rocks. According to the model of Hanson and Gast (1967, Fig. 8) a dike 110 ft thick and having an initial temperature of 1,100°C will heat the wall rock 5 ft away to a maximum temperature of nearly 700°C and will keep it above 300°C—the estimated minumum temperature required for complete loss of Ar from biotite—for more than 100 yrs. This should be reflected by a significant decrease in the apparent age of the biotite near the contact. We suggest that the dike was emplaced during or before the time recorded by the biotite K-Ar ages. According to this interpretation, the *minimum age* of the dike is 1,450 ± 90 m.y., the oldest apparent age of biotite in the wall rocks, and the *maximum age* is 2495 ± 75 m.y., the age of the Mount Owen Quartz Monzonite.

K-Ar and Rb-Sr mineral ages from the Teton Range available in the literature (Giletti and Gast, 1961; Menzie, 1966; Giletti, 1968) are summarized in Figure 11. Except for two Rb-Sr ages on muscovite from pegmatites, none of the mineral ages approaches those that are inferred from the whole-rock Rb-Sr isochrons. Muscovite ages scatter all the way from 2,500 to 1,390 m.y. without any significant maxima in distribution.

K-Ar and Rb-Sr biotite ages tend to cluster in the range 1,100 to 1,500 m.y. A single Rb-Sr age for microcline from a pegmatite is close to the age indicated by our plagioclase-microcline isochrons.

While data from the Teton Range do not conclusively demonstrate an 1,800 m.y. thermal event, events at about that time have been identified elsewhere in the Wyoming province and in adjacent regions. Such an event may be responsible for re-equilibration of the Rb-Sr systems indicated by our plagioclase-microcline isochrons for the Mount Owen Quartz Monzonite. Most of the Rb-Sr and K-Ar ages on biotite and some of the K-Ar ages on muscovite are appreciably younger than the 1,800 m.y. These lower ages indicate either a prolonged interval of high temperature following an 1,800 m.y. event or a distinctly younger and less intense thermal event.

The conspicuous chilled margins displayed by the diabase dikes suggest that the dikes were emplaced in relatively cool wall rocks and thus are compatible with the interpretation of a later episode of reheating. If so, the local low-grade metamorphism of the dike rocks and chloritization and sericitization of some of the minerals in the older rocks may also date from this time. We suggest that a distinct thermal event occurred between 1,330 and 1,500 m.y. ago and that the younger biotite and muscovite ages (Fig. 11) reflect slow uplift and cooling following the thermal maximum. Local shearing and alteration along Precambrian fault zones were concurrent with or postdated this event.

REGIONAL INTERPRETATION

Figure 12 is a summary of the Precambrian geochronology of the Teton Range and of selected other areas in and adjacent to the Wyoming province. Catanzaro (1967) summarized much of the earlier data and, although considerable new data are now available, many of the conclusions he presented are not substantially changed.

Ages greater than 3,000 m.y. have been reported in several areas in the Wyoming province. Giletti (1966, 1968) found a single Rb-Sr age of 3,260 m.y. for granitic gneiss from the Blacktail Range, Montana, and K-Ar ages of 3,220 and 3,270 m.y. on biotite from granitic gneiss in the Gallatin Canyon, Montana. Heimlich and Banks (1968) have reported K-Ar ages of 3,100 and 3,180 m.y. on biotite from one body of quartz diorite and 3,060 m.y. on biotite from a schist skialith in another body of quartz diorite in the Bighorn Mountains. In view of the uncertainties inherent in single Rb-Sr and K-Ar age determinations in complex metamorphic terranes, the significance of these scattered ages will be in doubt until they are confirmed by further geochronologic studies.

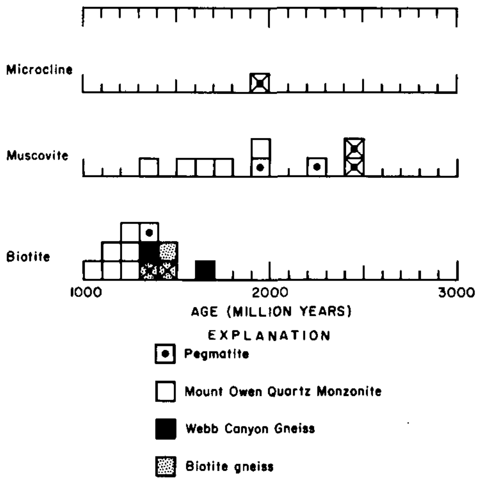


Figure 11. Histogram of K-Ar and Rb-Sr mineral ages from the Teton Range reported by Giletti and Gast (1961) and Menzie (1966). Boxes with X's are Rb-Sr ages; all others are K-Ar ages.

The only other ages older than 3,000 m.y. are discordant isotopic ages on apparently detrital zircon from metasedimentary schists, hornfels (Nunes and Tilton, 1971) and granitic paragneiss (Catanzaro and Kulp, 1964; Catanzaro, 1968) in the Beartooth Mountains. These ages suggest a source terrane for at least some of the metasedimentary rocks of the Wyoming province that is older than 3,140 m.y. (assuming an episodic lead loss model) or 3,300 m.y. (assuming a continuous diffusion model).

Ages in the range 2,500 to 2,900 m.y. are found throughout the Wyoming province and have generally been interpreted as indicating an episode of intense regional metamorphism, migmatization, and emplacement of plutonic rocks.

The northernmost exposures of rocks from which ages in this range have been reported are in the Little Belt Mountains, Montana, where Catanzaro and Kulp (1964) and Catanzaro (1968) have found that zircons from migmatitic gneisses have discordant ages that can be interpreted by a continuous diffusion model as 2,700 m.y. and which they suggest may date an episode of intrusion and migmatization.

Metamorphic rocks in the Beartooth Mountains, Montana, have yielded a Rb-Sr whole-rock isochron age of 2,730 ± 150 m.y. (Powell and others, 1969), whereas zircon from the Stillwater Complex has nearly concordant Pb^{207}/Pb^{206} ages of 2,750 m.y. (Nunes and Tilton, 1971). Brookins (1968) has obtained a whole-rock Rb-Sr age of 2,660 m.y. for the late synkinematic or postkinematic Crevice Mountain Granite in the southern Beartooth Mountains in Wyoming.

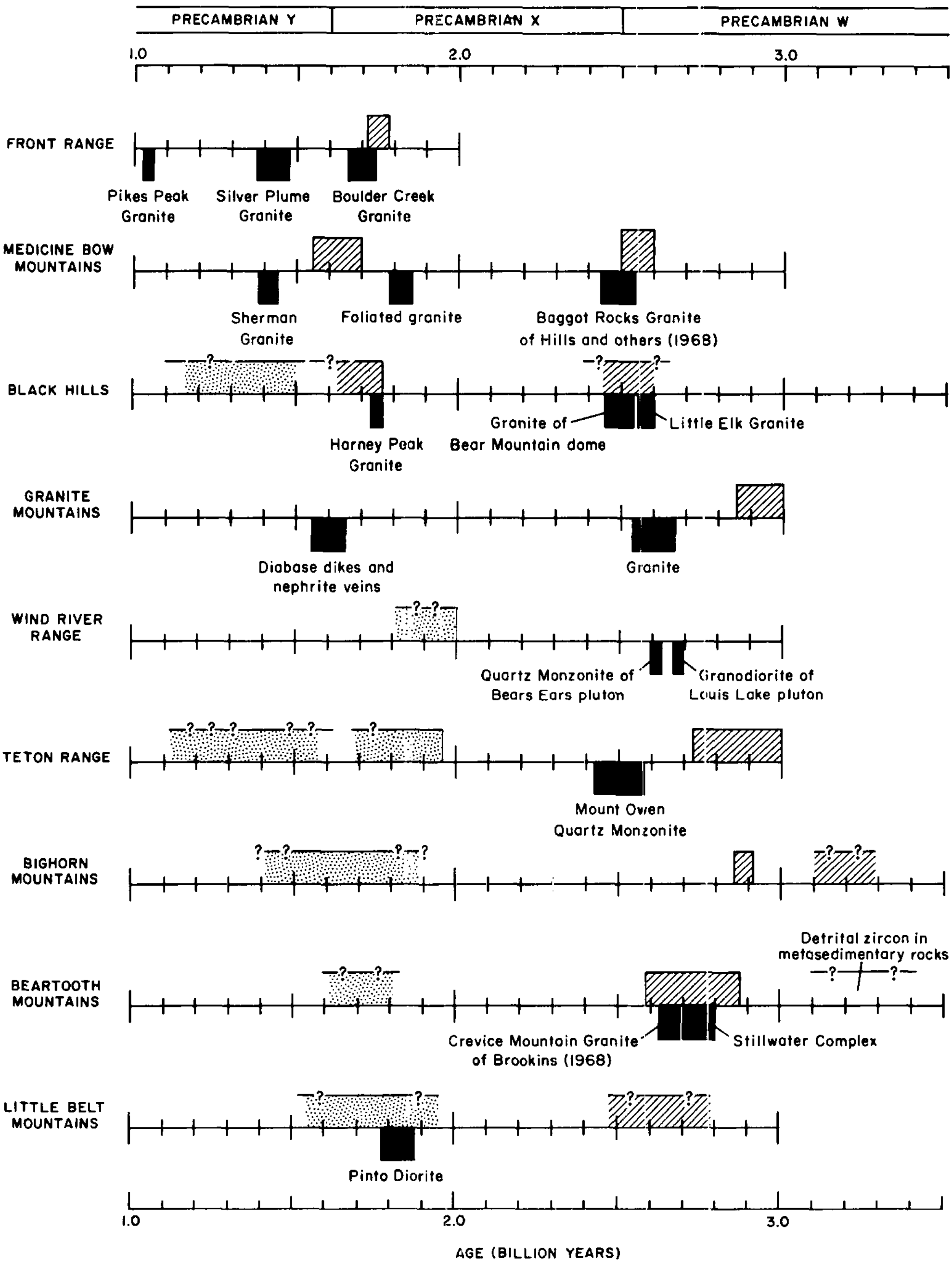


Figure 12. Summary of Precambrian geochronology of selected areas in and adjacent to the Wyoming province. Sources of data are cited in text. Solid boxes below time lines indicate intrusive events. Lined boxes above time lines indicate principal metamorphic episodes; stippled boxes indicate re-equilibration of isotopic systems without significant metamorphism. Lengths of boxes indicate analytic or geologic uncertainties.

Basement rocks exposed in the cores of the gneiss domes in the Albion Range, Idaho, have a whole-rock isochron age of 2,610 ± 300 m.y. (Armstrong and Hills, 1967; Armstrong, 1968). These rocks have undergone amphibolite facies regional metamorphism during the Mesozoic, and therefore their Precambrian history is difficult to decipher, but they represent the westernmost known occurrence of rocks of the Wyoming province.

Heimlich and Banks (1968) obtained concordant Pb-U ages of 2,930 m.y. on monazite from a quartz monzonite gneiss in the northern Bighorn Mountains which they believe is of metasomatic origin. Zircons from the same rock have Pb^{207}/Pb^{206} ages of 2,820 to 2,830 m.y. Heimlich and Banks suggest that the zircons may be detrital and that they have been reset during a metamorphic event that led to formation of the gneiss. The same authors found a maximum K-Ar age of 2,780 m.y. on biotite from nonmigmatitic metasedimentary gneiss in the southern part of the Bighorn Mountains.

Rb-Sr whole-rock isochron ages of 2,825 ± 80 m.y. on paragneisses and orthogneisses in the Granite Mountains have been reported by Peterman and others (1971) and interpreted as dating major regional metamorphism. Granite from small postkinematic plutons has a Rb-Sr whole-rock isochron age of 2,610 ± 70 m.y. In the nearby Wind River Range, Naylor and others (1970) have found ages on zircons that suggest primary ages of 2,607 ± 15 m.y. and 2,687 ± 15 m.y. for the apparently postkinematic Bears Ears and Louis Lake plutons.

Hills and others (1968) have found a whole-rock isochron age of 2,550 ± 50 m.y. for gneisses from the northern part of the Medicine Bow Mountains. They interpreted this as dating a metamorphic event, but concluded on the basis of the initial Sr ratio that the rocks are not more than 200 m.y. older than the metamorphism. Zircon concordia and whole-rock Rb-Sr isochron ages indicate that their late synkinematic and postkinematic Baggot Rocks Granite was emplaced 2,400 to 2,480 m.y. ago.

Rocks comparable in age to those of the Wyoming province have also been identified in the Black Hills, South Dakota. Zartman and Stern (1967) reported a Pb-U concordia age of 2,560 m.y. for the Little Elk Granite in the northeastern Black Hills, and Ratté and Zartman (1970) found a whole-rock Rb-Sr age of about 2,500 m.y. for granite in the Bear Mountain dome in the west-central part of the Black Hills. These granitic rocks, which appear in the cores of gneiss domes, seem to be part of a metamorphic terrane that is older than the bulk of the surrounding Precambrian rocks and that forms a link between the Wyoming province and the Superior province of the Canadian shield (Zartman and others, 1964).

Thus the inferred episode of migmatization and metamorphism in the Bighorn Mountains, the major metamorphism and emplacement of the Stillwater complex in the Beartooth Mountains, a possible episode of intrusion and migmatization in the Little Belt Mountains, and the major regional metamorphism in the Granite Mountains are synchronous or nearly so with the principal regional metamorphic episode in the Teton Range. Except for the 3,000-m.y.-old detrital zircon identified in the Beartooth Mountains, there is no direct evidence of the original age of the rocks affected by these metamorphic episodes. The inference from the initial Sr composition that many of the rocks in the Teton Range are not much older than the metamorphic event may also apply to some or all of the rocks elsewhere in the Wyoming province. Late synkinematic and postkinematic granitic rocks with ages 100 to 300 m.y. younger than the principal metamorphic events have been identified in the Beartooth Mountains, Granite Mountains, and Wind River Range, as well as in the Teton Range.

The principal metamorphic event and the late synkinematic to postkinematic granite in the northern Medicine Bow Mountains all seem to be somewhat younger than those recorded farther north and west. Metamorphic events associated with emplacement of the older granitic rocks in the Black Hills and the poorly dated Precambrian metamorphism in the Albion Range may be comparable in age to the metamorphism in the Medicine Bow Mountains. Although the evidence is far from conclusive, ages of rocks in the Wyoming province may decrease toward the western, southern, and eastern margins.

The effects of younger thermal events like those recorded by mineral ages in the Teton Range are widespread elsewhere in the Wyoming province. Brookins (1968) found an 1,850-m.y. potassium-feldspar whole-rock isochron for the Crevice Mountain Granite in the Beartooth Mountains and K-Ar ages of 1,180 m.y. for potassium feldspar, 1,650 m.y. for biotite, and 1,820 m.y. for muscovite. He interpreted these ages as indicating a metamorphic episode 1,600 to 1,800 m.y. ago which may have produced the slightly granulated texture in the granite. Nunes and Tilton (1971) found evidence of disturbance of the Pb-U system in apatite from the Stillwater Complex about 1,600 m.y. ago.

In the Wind River Range, Naylor and others (1970) found evidence of disturbance of the Rb-Sr systems in the 2,600- to 2,700-m.y.-old granitic rocks less than 2,000 m.y. ago. They noted no obvious petrographic evidence of this disturbance, but mineral isochrons were appreciably affected, and one biotite–whole rock isochron is as young as 1,680 m.y. In the Granite Mountains, K-Ar and Rb-Sr mineral ages indicate that diabase dikes similar to those in the Teton Range and associated nephrite veins were emplaced about 1,600 m.y. ago (Peterman and others, 1971).

No large intrusive bodies that might be related to the 1,600 to 1,800 m.y. events have been identified in the central part of the Wyoming province, but intrusions in this age range have been found in several areas near the margins of the province, and they are widespread in the flanking terranes. They include the 1,820-m.y.-old Pinto Diorite in the Little Belt Mountains (Woodward, 1970), the 1,740-m.y.-old Harney Peak Granite in the Black Hills, South Dakota (Riley, 1970), the 1,820-m.y.-old granitic rocks in the southern Medicine Bow Mountains (Hills and others, 1968) and the 1,700-m.y.-old Boulder Creek Granite and related rocks in the Front Range, Colorado (Peterman and others, 1968). In most of these areas, the granitic rocks seem to be nearly synchronous with episodes of medium- and high-grade regional metamorphism.

The hypothesized 1,300 to 1,500 m.y. thermal event in the Tetons has not been generally recognized elsewhere in the Wyoming province, although mineral ages within this range do occur in the Black Hills (Aldrich and others, 1958; Zartman and others, 1964). To the south of the Wyoming province, this interval includes emplacement of the Sherman Granite in the Medicine Bow Mountains (Hills and others, 1968) and the Silver Plume Granite in the Colorado Front Range (Peterman and others, 1968).

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