Precambrian rocks of the Albuquerque country

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PRECAMBRIAN ROCKS OF THE ALBUQUERQUE COUNTRY

J. PAUL FITZSIMMONS
University of New Mexico

ABSTRACT

Precambrian rocks are found in the cores of the mountain ranges of the Albuquerque country. Medium-grade regionally metamorphosed rocks, including quartzite, quartz-mica schist, greenstone, and metarhyolite, generally with northeast trend and steep dip, are the country rocks in which microcline granite and more or less related dike rocks (pegmatites, aplites, lamprophyres) have been emplaced. Quartz-feldspar gneiss is present in many localities, contiguous to the granite. Both gneiss and granite have been modified by potash metasomatism. Radioactive measurements indicate an age of 1,350 million years for the granite and suggest that the Precambrian rocks of the Albuquerque country were deformed, metamorphosed, and invaded by granite during the Mazatzal revolution.

INTRODUCTION

Of Paleozoic and younger rocks one may ask, for any specified area: are they present? For Precambrian rocks, this question is superfluous. Precambrian rocks are everywhere present. The question is rather: are they exposed? Rocks of other ages may be missing entirely, having never been deposited or having been eroded away after deposition, but one needs merely to probe deeply enough, if the rocks are not at the surface, to be sure of encountering Precambrian formations. The pre-eminence attained by this world-wide distribution, however, is offset by extensive burial beneath some or all of the representatives of later ages. Probing, theoretically very neat and tidy, is expensive and time consuming, and it is not comparable with a full view of the rocks. One does not gain full enjoyment or understanding of a symphony by hearing three isolated measures from widely spaced parts of the composition. At best he may get some notion of the key, the tempo, the constituents of the orchestra; but keys may change between measures, tempos may increase or decrease, and all instruments do not play incessantly. Similarly, a few probes will not give complete information about the basement rocks. No system of indirect observation can substitute for good outcrops.

In the Albuquerque country, Precambrian rocks crop out on the steep western slopes of the faulted Sandia, Manzanita, and Manzano Mountains, in smaller masses in faulted zones within these ranges, on the steep western slopes and along the crest of the faulted Nacimiento and San Pedro Mountains, in a few small faulted zones east of the main mass of Precambrian rock in these mountains, on the steep eastern slope of the Lucero uplift (in one small area), and in the core of the domal Zuni Mountains.

ROCKS

This Precambrian terrane is represented chiefly by a sequence of regionally metamorphosed rocks, clastic sedimentary and volcanic, in which large volumes of granitic rocks have been emplaced. Locally there is moot evidence of thermal metamorphism and of retrogressive metamorphism, but the dominant process has been regional.

Quartzite is one of the most abundant metamorphic rock types, particularly in the Sandia-Manzano zone. In places it consists almost exclusively of quartz, but much of it exhibits some admixture—sericite, biotite, kyanite (rare), apatite, magnetite, hematite, feldspar; the contacts are commonly gradational into quartz-feldspar gneiss or into quartz-mica schist. The gradational zones to quartz-feldspar gneiss may be due to original increase of feldspar in the clastic sediments, to produce arkosic sandstone, or they may be due to feldspathization during or attendant upon regional metamorphism. The gradations to quartz-mica schist are probably due to gradual increase of original clay admixture. That the quartzite is metamorphosed sandstone there can be no doubt: cross-lamination has been observed in many places. But a clastic source for the feldspar has not been established beyond question.

Foliation in the quartzite is displayed by streakings of the admixtures: stringers of sericite, lenses and bands of hematite flakes, and zones of discoloration too nebulous to define microscopically. The color of the quartzite ranges from white through light gray to dark gray. Locally, greenish and reddish zones are observed, but these are minor.

The quartzite is generally resistant and forms prominent ridges. It forms the backbone of the ridge crossing U. S. Highway 66 at "Dead-man's curve" in Tijeras Canyon. It also forms the constriction at Abo Pass on U. S. Highway 60 at the south end of the Manzano Mountains.

Quartz-mica schists, ranging from micaceous quartzites to rocks with mica predominating, are widespread constituents of the Precambrian terrane. They are the dominant rock at the north end of the Sandia Mountains, are present in Tijeras Canyon, and are found at many places in the Manzanita and Manzano Mountains (as well as in the Los Pinos Mountains farther to the south). Mica-rich varieties are not abundant. Both biotite and muscovite may be present, the former very rarely occurring without the latter. The grain size in some of these rocks is so fine that it were better to call the rocks phyllites. They commonly display a sheen, a crumpled or crenulated surface, and few megascopically identifiable minerals; the microscope shows the principal minerals to be quartz and sericite. Accessories are generally oligoclase-andesine, biotite, epidote, garnet, chlorite, magnetite, and rare apatite and zircon.

Colors of the schist range from pinkish gray through silvery gray (particularly the phyllitic rocks) to dark gray. Many are stained brown or yellowish brown on weathering surfaces. Exposures are generally poor because of rapid disintegration along foliation planes and secondary fractures.

Quartz-feldspar gneisses are found in Tijeras Canyon and are very abundant in the Nacimiento Mountains. Banded gneisses are not common. Most of the gneisses are lenticular, with undulatory planes of foliation; augen gneisses are characteristic. The augen are mostly pink microcline. Oligoclase-andesine is an abundant feldspar in these rocks, exceeding the microcline in many places, but it occurs in finer grains and is more uniformly spread throughout the rock. The quartz shows moderate straining and has sutured borders. Accessories are biotite, less hornblende and epidote, and occasional sphene, apatite, zircon, and magnetite. The predominant color is pink, but may be anything from pinkish gray to bright red.

In Tijeras Canyon this rock has a composition re-

markably similar to that of the contiguous "Sandia granite," except that microcline is not so abundant and does not show the sieve structure so characteristic of this mineral in the granite. Also the plagioclase in the gneiss is cleaner, less altered, than in the granite.

Some quartz-feldspar gneiss consists almost exclusively of these two minerals (or three, for two kinds of feldspar are invariably present), with only minor amounts of other minerals. In some varieties, however, biotite forms up to ten percent of the rock. In none of these rocks does hornblende form the dominant mafic constituent.

Lodewick (1960) found rounded (eroded) zircons in the gneiss in Tijeras Canyon and, on this basis, postulated a metasedimentary origin. This is a significant position in view of the similarity of mineral composition of the gneiss to composition of the adjacent granite.

Erosional forms on the gneiss greatly resemble granitic terrain: moderately resistant rounded knolls and undulating uplands. Such landscape is typical in the Nacimiento Mountains.

Greenstone is a term used to designate a rather diverse assemblage of rocks, most of which are more or less metamorphosed flows, sills, dikes, and tuffs of the basaltic or basalt-andesitic kindred. Clastic rocks may be included, but more by virtue of propinquity than of consanguinity. The greenstone consists mostly of foliates, though in places the foliation is feeble and inconspicuous; chlorite schists and epidote amphibolites are perhaps the most typical members. Locally one may find, on microscopic examination, some traces of the character of the original rocks—saussuritized plagioclase, and altered, but not wholly obscured, pyroxene—but generally, though the grade of metamorphism is moderate, relict textures have been destroyed. Commonly, where one might expect to find amphibolite, he finds hornblende schist, that is, a rock containing quartz and little or no feldspar. Some of the rocks of Tijeras Canyon contain both plagioclase and quartz, though the former is generally more abundant than the latter. Intercalated rocks of rather insignificant volume include metasilts and metashales, which have now the structures and compositions of quartz phyllites and slates.

The general hue of the greenstone is very dark green. Local zones are somewhat lighter, especially among the chlorite schists, but the deviation from dark green is not marked. Small localized zones of greenstone are found among other types of metamorphic rocks, but there are also large continuous masses, one of the largest forming much of the south side of Tijeras Canyon, below the ledge of Madera limestone, and extending southward into the Manzanita Mountains. The units of the greenstone are not generally resistant, decomposing readily and eroding easily. Where exposed on slopes they are protected by more resistant cap rock.

Metarhyolite has been reported from a number of places in the Precambrian terrane of the Albuquerque country. The evidence for calling some of this rock metarhyolite is flimsy: perhaps nothing more than fine grain size and general composition. But there appears to be sufficient evidence (of relict structures and of enduring minerals) that metarhyolite is present in considerable volume, apart from the doubtful masses. A characteristic feature of the varieties of this rock is a rather high content of quartz, generally 50 to 80 percent, a rather curious phenomenon when it is recalled that high quartz content in such

rocks as gneiss is frequently considered a criterion for sedimentary origin. Quartz in excess of 50 percent is not typical of rhyolites.

However, many investigators have reported considerable thicknesses of metarhyolite in the Albuquerque region: Reiche (1949) in the North Manzano Mountains, Stark (1956) in the South Manzano Mountains, and Bruns (1959) in Tijeras Canyon. Harbour (1960) has indicated over a thousand feet of such rock in the Franklin Mountains, far to the south, and Just (1937), Montgomery (1953), Barker (1958), and Muehlberger (1960) have mapped similar rocks in the Petaca and Picuris region in northern New Mexico. Metarhyolite is also an important constituent of possibly correlative rocks in central Arizona (Wilson, 1939). Flawn (1956) has reported a great northeast-trending belt of rhyolitic and related rocks (Panhandle volcanic terrane) in the covered basement of eastern New Mexico and the Texas panhandle, but he has stated that these rocks are virtually free of metamorphic effects.

In weathering characteristics, the metarhyolite is somewhere between the schists and the gneisses. Indeed, the rock is fundamentally a schistose to gneissose quartz-feldspar rock with varying, but generally minor, proportions of muscovite and biotite.

Granite is perhaps the most abundant type of Precambrian rock in the Albuquerque country, at least in surface exposures. There are undoubtedly many individual bodies of granitic rock, but the compositional variations are not great. The rock is generally rather coarse grained, though fine-grained varieties are locally present. Much of it is porphyritic, or, what is more likely, porphyroblastic. Large insets of microcline, ranging up to three inches across, are fairly common and abundant. All weathered granite takes on brownish or yellowish brown hues, but in fresh cuts the granite of the region ranges from a medium gray to red. Some areas consist almost exclusively of gray granite. In this variety the microcline, as might be expected, is gray. Quartz is commonly blue. Elsewhere the granite is pink or red, chiefly because of coloration in the microcline. The relation of one variety of granite to the other is not everywhere systematic, but some generalizations may be drawn. In the Sandia Mountains the rock immediately underlying the late Paleozoic strata along the crest of the range is characteristically red. Downslope the granite becomes pinker in hue, not so deeply colored, and at the base gray granite is typical. There are no sharp contacts marking these as distinct units, and the gradation is not persistent or invariable. Furthermore, red granite may be found in localized zones in the midst of gray granite. Mineralogically there is little difference between megascopic color varieties. One feature alone seems rather systematic. Secondary epidote is widely present throughout the other outcrop areas of Precambrian granite in the Albuquerque country. It is much more abundant, however, in the red granite. Or, perhaps it would be nearer the truth to say that red granite that is localized in predominantly gray granite is almost always accompanied by abundant epidote. Microcline is generally the dominant feldspar. It appears to engulf minerals, or to invade them, or to occupy interstitial zones that resemble late filling less than late invasion or late replacement. Except in definitely weathered specimens, it appears to be fresh everywhere in the rock. Albite or albite-oligoclase is invariably present, usually in lesser amounts than the mi-

crocline. It always appears cloudy or dirty by virtue of alteration to clay or other secondary minerals. Quartz is abundant, commonly forming 30 to 35 percent of the rock, and is characteristically strained. Extinction in this mineral is not merely undulatory, but aggregate-undulatory; that is, what appears in plain light to be a large quartz grain proves to be an aggregate of many small units, each with its particular undulatory pattern. The composite picture is one of extremely uneven extinction. Biotite is the common mafic mineral and is present everywhere, but the content is generally less than 10 percent, mostly less than 5 percent. Hornblende is rarely present, though there is some indication locally that the biotite is secondary after hornblende. Sphene is ubiquitous as an accessory, usually occurring in reddish brown euhedral wedge-shaped crystals. Apatite also is almost universally present. Magnetite is the common opaque mineral, though ilmenite is also present, and, at least in Tijeras Canyon, pyrite also. The fairly recent road cuts of Tijeras Canyon have exposed rocks fresher than can generally be found in other Precambrian areas of the Albuquerque country. It is in these fresh rocks that pyrite may be seen. It is never found in rocks long exposed at the surface, because of its great susceptibility to weathering. It may very well be that pyrite is present in most of the granite of the Albuquerque country, but that it eludes our scrutiny because it remains only in fresh rock below the surface.

Statistical work on a number of orogenic zones about the world, particularly in Fennoscandia, Greenland, Canada, and Sierra Leone, indicates that different phases of granitic rocks are associated with stages of orogenic development. Early kinematic, late kinematic, and post-kinematic granitic rocks have been distinguished. The synkinematic rocks are generally granodioritic or dioritic in composition, predominantly gray in color, and mostly gneissic. Post-kinematic rocks are more frequently pink or reddish, have more potash than soda, and are generally directionless.

It is not easy to fit the granitic masses of the Albuquerque country into this scheme. The first question is: are there two (or more) granites? or is there but one? And if there is but one, to which stage does it belong? More detailed work needs to be done to bring the full illuminating light of understanding into focus on this problem, but present data appear to indicate but a single granitic phase, at least in respect to the orogenic classification outlined above. Firstly, the mineral content, while not perfectly homogeneous, does not vary greatly; it attests to a single process of petrogenesis. Secondly, the color variation, however suggestive it may appear, does not permit any profound orogenic interpretation at this time. In its relation to the crest of the mountain, that is, toward the ancient erosion surface, it suggests an association with weathering or some other surface phenomenon, though I am not prepared to say that this is so. A knowledge of what the color is, where it lies, what causes it is imperative before any decision can be made on this matter. It is not yet clear whether the color is due to staining, to primary incorporation of matter, or whether it is due to cooling history or crystallization history (and thus not directly related to chemistry in the sense normally suspected).

Some have suggested that the local zones of red granite in the gray granite are actually late intrusions, whether immediately later or much later. This may be true, but it appears strange that both the gray granite and the red granite contain similar inclusions—xenoliths—of metamorphic country rock. If the red granite invaded a zone of gray granite, what happened to the gray granite? If the later rock digested the earlier rock, either by piecemeal stoping or by replacement, where did the inclusions come from? And why are there no inclusions of gray granite—merely of the metamorphic rock? The red granite appears to be due to a later process than the initial emplacement of the gray granite, but it would seem that this process may have been a milder one than the emplacement of a completely new rock.

No dogmatism will be displayed here regarding the origin of these granitic masses. It is doubtful that sufficient data are yet at hand to permit such presumption. Lodewick (1960) found euhedral zircons in the granite and, because of this, proposed that the Sandia granite is igneous. The conclusion may be valid, but not solely from this evidence. It is known that zircons will form in a metamorphic environment if the physicochemical conditions are suitable. Rounded zircons may present a very cogent argument for sedimentary origin, but euhedral zircons, however suggestive their presence, do not uniquely define igneous origin. There is, on the opposite side, evidence that metasomatic replacement has occurred on a rather grand scale, within the granite, within inclusions, and within some of the contiguous foliated rocks. But it will still be contended, with justification, that the demonstration of metasomatic replacement in contact zones, or even throughout an entire granitic mass, does not constitute proof that the granite as a whole is a metasomatic body. And there, for the moment, the matter lies. The most obvious metasomatic phenomenon in the Precambrian rocks of the Albuquerque area is the growth of microcline porphyroblasts. Large crystals of microcline, precisely like those in the granite proper, are found scattered through xenoliths of schist; indeed, in places they may actually pierce the contact, extending into both the granite and the xenolith. With no great strain to the mind, even the unimaginative mind, one may fancy that he sees these porphyroblasts caught in the process of growing. Even within the granite, with no reference to the relation of the microcline to xenoliths or to country rock, one may observe peculiarities in this mineral that attest to a "birth date" later than the formation of the rest of the rock. These peculiarities include sieve structure (numerous inclusions of quartz and altered plagioclase), invading stringers and embayments into both quartz and plagioclase, and interstitial positions much more suggestive of invasion than of passive filling (that is, the interstices are "open," not "closed"; linear, not confined; continuous, not isolated).

If the above-indicated observations reflect actual historical events, and if but one granitic phase is present (despite the titillating enigma of the red coloration), the process of granite emplacement was probably synkinematic. Without the secondary microcline the rock would be granodioritic or tonalitic, and hence, if the scheme is valid, synkinematic. Many feldspathized (microcline) synkinematic granites have been noted in other orogenic zones, and this possibility for the Sandia granite is thus an acceptable one to many students of the problem.

Xenoliths in the granite offer a tantalizing challenge to the curious. In the Sandia Mountains these are observed in most parts of the granitic mass, though they are more abundant in some zones than in others. The zones of greater abundance, however, cannot yet be related to any

systematic distribution of country rock, contacts, erosion surfaces, or to any other known point of reference.

The xenoliths are of several kinds, obviously reflecting the country rock from which they came, but correlations on this evidence cannot be made. The xenoliths are not numerous enough, and continuations of the xenolithic zones into the country rock cannot be followed, because of lack of outcrops (truncation by fault zones or by covers of younger rocks). The xenoliths range in size from minute to two or three feet in length, and, exceptionally, to six or eight feet in length. A black, mildly schistose rock is very common as an inclusion. It consists of quartz, biotite, andesine, abundant hornblende, and porphyroblasts of microcline. Epidote is generally present. Quartzite xenoliths are also found, though not in such abundance. They too contain porphyroblasts of microcline and abundant epidote.

The xenoliths are generally flattened and elongate, but nearly spherical forms are not rare. In most places one needs to exert his imaginative faculties to discern any pattern of orientation of the xenoliths, but in a few zones a definte pattern may be observed over distances up to one hundred feet and more, and here the plane of the xenoliths appears to be horizontal.

In the South Manzano Mountains, Dorman (Stark, 1956) noted inclusions somewhat similar to those found in the Sandia Mountains, but exhibiting more systematic orientation. Dorman was able to measure strikes and dips on a number of these inclusions, and his observations indicate that the strike of the xenoliths diverges about 20° from the strike of the foliation in the country rock. His solution to this discrepancy is that "the granite was emplaced by injection and that its inclusions and schlieren are fragments of the country rock carried along in the flowing mass." It is not easy to see why flow lines, if they occur, should diverge appreciably from the contact (and the contact appears to parallel the foliation in the area indicated). Even more uncongenial to my mind is the attempted resolution of this view with any concept of emplacement of granitic masses. If the granite be magmatic and flow into an open chamber, then there might be current for orientation of inclusions torn from the sides of the chamber. Or, if the magma forcibly thrust the country rock aside, the movement might occur at some appreciable rate and produce flow orientation. But if piecemeal stoping be the mode of emplacement (and there is no evidence that the country rocks have been pushed aside to make room for the granite mass, nor, certainly, any evidence that a cavity was excavated first), how great a current can be postulated for invading magma? Piecemeal stoping entails downward movement of stoped blocks, a movement contrary to any possible current of invasion. The question may be asked here: if the granite is magmatic, what mechanism of emplacement would produce sufficient current, at an angle of 20° to the contact, to orient included blocks? It would seem, on investigating trends among the foliated rocks, that a divergence of 20° is no greater than frequently measured between members of a foliated sequence where no problem of separate origin (because of divergence) could possibly arise. Trends among schists and gneisses are not uniform and consistent, and I think, in view of the still meager data, that we should not ignore the possibility that the indicated trend of xenoliths may be relict trends of the rocks that occupied the site before the granite was emplaced.

The granite weathers in typical fashion, producing spheroidally weathered boulders, which clutter the surface, form tor-like hummocks, or stand poised on "tiny feet," tempting man and nature alike to thrust them from their pedestals. The xenoliths are, as a rule, more resistant than the host granite, and stand out as knobs on the weathered surfaces.

Dike rocks in the Precambrian terrane may be assigned to one of three types: pegmatite, aplite, and lamprophyre. Spatially they have little relation to each other. Aplites appear to be most widespread of this group. Pegmatites are localized, but are very abundant in a few areas. Lamprophyres tend to be somewhat localized and somewhat uncommon, but a few dikes persist over distances greater than any of the pegmatites or aplites.

Pegmatites are very abundant in the rincon, or outer prong, in the Juan Tabo area at the north end of the Sandia Mountains. A few occur in Tijeras Canyon and others are to be found wherever granitic masses occur. They are not confined to the granite. In fact, in the Juan Tabo area they are much more abundant in the metamorphic rocks adjacent to the granite, though some are completely within the granite, and some cut across the contact. Most are merely aggregates of quartz and feldspar, commonly intergrown in graphic structure. Microcline is the dominant feldspar, but oligoclase is generally present. Muscovite is practically absent in some pegmatites, but may constitute up to eight percent of the mass, locally forming books up to one inch across. Schorlite is generally absent, but is present in some pegmatites in amounts up to three or four percent. Other constituents are rare: ilmenite, magnetite, and garnet.

The pegmatites are mostly pinkish white, pink microcline and white quartz being intimately intergrown in parts of the mass, occurring in segregated zones in other parts. The longest pegmatite dike observed is about half a mile long (in the Juan Tabo area of the Sandia Mountains). Most are but a few feet long (up to a hundred feet) and are rather irregular in outline. In the Juan Tabo area the largest number of pegmatite bodies have a northwesterly trend, at right angles to the foliation of the metamorphic rocks. A few pegmatites, especially in the northern part of the Juan Tabo area, parallel the foliation.

Aplites are mostly pink dike rocks, consisting almost exclusively of quartz and feldspar, with very minor muscovite or, less commonly, biotite, and generally exhibiting sharp straight contacts. Quartz-feldspar dikes might be better terminology, because many do not have typical aplitic, or sugary-grained, texture. The grain size may vary markedly within short distances, or it may be fairly uniform and persistent. Some dikes have coarse-grained or medium-grained margins and fine-grained interiors. Many cut across xenoliths. The width of the dikes ranges from a fraction of an inch to several inches, rarely to as much as one foot.

Aplites appear to be confined to granitic terrane. In Tijeras Canyon most trend approximately east, though other trends may also be observed.

Lamprophyres are not abundant, but a few of them persist for considerable distances. One, a spessartite (euhedral hornblende with minor oligoclase-andesine and diopsidic pyroxene), may be traced from south of Tijeras Creek, near the entrance to Tijeras Canyon, northward across U. S. Highway 66, over the ridge into Embudo Canyon and beyond, a distance of over two miles. The width of this dike is variable; in places it practically pinches

out, elsewhere swells to twenty feet and more. Grain size is very erratic, displaying no particular relation to contact or interior. Coarse-grained zones alternate with fine-grained zones, suggesting a streaming action of multiple or spasmodic intrusion. The rock in this dike is very fresh, but it is found only in Precambrian granite and, for this reason, has been assigned to the Precambrian. Another type of lamprophyre in Tijeras Canyon may be referred to as mica trap (possibly a minette or kersantite). It weathers so readily that fresh samples are practically unattainable, but the shiny biotite phenocrysts, however altered, are readily visible and diagnostic. The age of this rock is uncertain. It has been considered Precambrian in Tijeras Canyon, where it cuts only Precambrian rock, but a very similar dike rock may be seen on the Sandia Crest road, just above Doc Long's picnic area, cutting the Pennsylvanian Madera limestone.

Carbonate rocks are conspicuously absent in the Precambrian terrane of the Albuquerque country. Calcite is present in several rocks as a secondary mineral and there are a few small localizations of calcite that may be primary, but marbles or lime-silicate rocks are virtually absent.

STRUCTURAL FEATURES AND METAMORPHISM

The foliated metamorphic rocks of the Sandia-Manzanita-Manzano zone have a general northeasterly trend; that is, the foliation has this trend. A similar trend has been observed in the Nacimiento Mountains, but fewer details on this area are available. Bedding, where it may be observed, may diverge from the foliation, but not greatly. Dips are mostly steep, and may be either to the northwest or to the southeast, in places changing within short distances. In Tijeras Canyon the foliation of the greenstone complex on the south side of the canyon dips uniformly to the southeast; the foliation in the gneiss and associated rocks on the north side of the Tijeras fault dips to the northwest. Drag folds may be observed in places and larger fold structures within the Precambrian foliates have been observed, but exposures along the strike are of insufficient length to permit delineation of regional Precambrian structures. The general northeasterly trend, however, is a fact of great significance. A similar trend has been observed in possibly correlative Precambrian rocks in Arizona (in the Grand Canyon, in central and southern Arizona, and elsewhere). It is probable that sediments accumulated in Precambrian time in a geosynclinal zone continuous into what is now Arizona, indeed occupying much of the territory that is now New Mexico and Arizona, and that these sediments were deformed and metamorphosed in a single major event, the concomitant forces acting at right angles to this general northeasterly trend.

There is no clear-cut evidence for more than one episode of metamorphism involving the Precambrian rocks. This, of course, does not mean that such evidence may not yet be found. And it is not meant to imply that local processes of contact metamorphism were not effective. But major transformation by contact metamorphism about the borders of the large granitic masses, if it occurred, can hardly be said to represent a separate episode, since the granitic rocks were surely begotten by the rogenesis that produced the regional metamorphism.

Regional metamorphism (dynamothermal) of the Precambrian rocks was generally low to medium grade, although local zones of higher grade are indicated by the presence of sillimanite. Potash feldspar is generally considered an index of high grade in progressive metamorphism

of argillaceous sediments, but there is evidence that the microcline in the quartz-feldspar gneiss is due to potash metasomatism (in association with the adjacent granitic masses) and, as such, is not proof that these rocks attained high-grade dynamothermal metamorphism. There is ample proof that such feldspathization may occur in mesozonal (medium-grade) environments. The assignment of metamorphic grade in the Albuquerque country is thus not a simple task. Chlorite schists in the greenstone complex suggest low-grade metamorphism. Epidote in schists and amphibolites marks medium grade. Chlorite tends to disappear in medium-grade rocks, and epidote disappears in high-grade rocks. The relation of low-grade to medium-grade rocks is not yet sufficiently clear to designate isograds or to discover any other systematic pattern in the trend of metamorphism. Faulting has been responsible for some juxtaposition of rocks of different grade, but it is not certain that all such anomalous associations can be explained in this way. Some mineral changes are related to the contact zone of the granitic masses. Such changes have been called contact metamorphism by some, but in view of the metasomatism known to occur in the contact zone, the changes that are spatially related to this contact may indicate advancing fronts of metasomatism. Fronts of this kind may, of course, result from contact metamorphism. But, until the granitic rocks can be definitely proved to be magmatic, it may be presumptuous to designate the mineral changes as contact effects.

The disregard of some prismatic and platy minerals for foliation planes, as observed for some sillimanite and mica, has been considered by a number of investigators to be indication of an episode of thermal metamorphism superimposed on earlier dynamothermal metamorphism (whether the thermal metamorphism be contact metamorphism or something else). This seems hardly justifiable. Foliation in metamorphic rocks is due to dynamothermal processes, the combined effects of shearing and elevated temperatures, and it strains the imagination to suppose that both effects cease at precisely the same "geologic instant." Shearing movements and the influx of heat are seldom so nicely adjusted that they rise and fall with the same phase of the moon. It is customary for one to outlast the other. If shearing outlasts heat inflow, then foliated rocks should display some cataclastic features unhealed by recrystallization (since this process is contingent upon the heat). If temperatures remain high after shearing has ceased, then minerals tend to grow with little or no regard for foliation, and unoriented minerals are formed. These are but natural consequences of the dying stages of dynamothermal metamorphism, and should not be interpreted as separate events.

GEOLOGIC HISTORY

The Precambrian history of the Albuquerque country remains to be written. What we now know represents but a few isolated scenes from a pageant that stretched across a temporal interval at least five times the length of all remaining geologic time. There are too many gaps in the record of that remote era.

The story (what story there is) is in the rocks, but how many rocks there are, how many episodes of accumulation, how many intervals of erosion—these are questions easy to ask and hard to answer.

Stratigraphers have their problems with correlation among the fossiliferous or potentially fossiliferous strata, but the Precambrian geologist, deprived at the start of any

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hope of correlation by fossils, both through the dearth or absence of life in the Precambrian seas and through the obliterating effects of metamorphism, and faced with the task of comparing isolated masses of rock that formed great distances apart and have since been modified by various degrees of metamorphism and unknown degrees of metasomatism, is presented with a labor that Hercules was fortunate in being spared.

In areas of continuous outcrops, such as continental shields, rock units may be traced for some distance, through various changes in lithology, though even here exposures are not always good and the picture at best is but two dimensional. In the southwestern part of the United States, which is no shield area, where Precambrian outcrops are isolated in the cores of mountains, tracing is out of the question (though, with more data from well samples of basement rock, where such information is available, we may approximate this technique), and it is necessary to resort to other means. The most promising is radioactive dating. However, this is a statistical method, and one or two measurements hardly suffice to outline the events of two or three billion years.

One age determination (really a dual determination—1,300 million years by the K-A method and 1,340 million years by the Rb-Sr method) of the Sandia granite indicates an age on the order of 1,300-1,350 million years (Aldrich and others, 1957). This age is in agreement with determinations for Precambrian rocks in the Sangre de Cristo Mountains (near Mora and near Dixon) as well as for Precambrian rocks of similar occurrence in Colorado (Aldrich and others, 1957). It is also comparable with the age determined for rocks in the Vishnu schist at the bottom of the Grand Canyon and for other primitive Precambrian rocks of southern Arizona (Giletti and Damon, 1961).

If the value 1,350 million years is valid for the Sandia granite, the metamorphic rocks that are hosts for the granite are yet older. If the granite is synkinematic the metamorphic rocks are not much older, and all the Precambrian rocks may be on the order of 1,350 million years old (though it must be remembered that sedimentary rocks may accumulate for many millions of years before they are metamorphosed). If the granite is post-orogenic, then the metamorphic rocks may be considerably older than the granite, but they still belong to the same orogenic cycle. The date 1,350 million years probably more or less fixes the orogenic movements of the southwestern part of the United States and is the age of the Mazatzal revolution.

The Mazatzal revolution, however, represents something of a midpoint in our history of the Precambrian. Sediments and volcanic rocks accumulated for countless

ages before, the record of which is partially and dimly preserved in the rocks, and erosion acted for perhaps a billion years after (before deposition of the Paleozoic sedimentary rocks now observed on top of them), the record of which has been irrevocably removed.

Of published reports, Reiche's (1949) postulates the greatest number of Precambrian events in the Albuquerque country. His study of the Manzanita and North Manzano Mountains led him to propose the following sequence of events: accumulation of several thousand feet of basic to intermediate tuffs and lavas, with intercalated clays and silts; accumulation of clays, silts, and fine well-sorted sands (at least 7,500 feet thick); moderate deformation and subsequent erosion; renewed subsidence and accumulation of more clastics, rather more quartzose than previous deposits (a total of more than 4,000 feet); accumulation of more than 5,000 feet of predominantly rhyolitic lavas and ash; emplacement of dikes and granitic bodies, and strong deformation with attendant metamorphism, changing the basic lavas and tuffs to greenstones and chloritic schists, the quartz sandstones to quartzite, the clays and silts to phyllites, schistose grits, and schists, and the rhyolite to a moderately schistose quartz-feldspar mass; and erosion, lasting well into the Paleozoic, until Mississippian and Pennsylvanian rocks were deposited on the deeply weathered surface.

It may be said, in regard to this chronicle, that the evidence for assigning the greatest age to the parent rocks of the greenstone is insubstantial. Reiche assumed that the sedimentary sequence indicated in the above list was deposited on the basic lavas and tuffs, but he admitted that this relationship could not be verified. At another place he stated that all observed contacts of the greenstone complex are either intrusive or faulted, a statement somewhat at variance with his view that the greenstone is derived from flows and tuffs. There is also some doubt concerning the existence of two separate sequences of clastic rocks, separated, as indicated, by an unconformity. A variance of trends is observed, but faulting and folding may be responsible for this. The remaining events are rather well established and conform to the record of neighboring areas. Stark (1956), for instance, outlined the geologic history of the South Manzano Mountains in the following form: deposition in a marine environment of approximately 7,000 feet of sands (now the Sais quartzite), shales and siltstones (now the Blue Springs schist), and more sands (now the White Ridge quartzite); emergence, tilting to the east, and erosion; extrusion of the Sevillita rhyolite (about 5,000 feet); intrusion of basic igneous sills; folding and metamorphism; intrusion of granite (Monte Largo stock); invasion of vein quartz and development of quartz reefs; cross folding, faulting, and

development of regional schistosity; intrusion of Priest granite; erosion.

Stark finds no traces of the earliest events recorded by Reiche. This by no means signifies that such events did not take place. But, since the evidence is much less than overpowering, it is well to set our beliefs accordingly. Some of the later events chronicled by Stark are also supported by little evidence in adjoining areas. Again this does not disprove their validity, but it does urge caution in using them as keys to unlock the history of every Precambrian exposure.

We may take it as established, then, that there was a period of accumulation of clastic sediments, markedly quartzose, preceded by or possibly accompanied by accumulations of basic to intermediate igneous rocks, and followed by accumulation of rhyolitic rocks. This period of accumulation was followed by deformation, metamorphism, and emplacement of granitic masses and associated rocks (aplites, pegmatites, and, possibly, lamprophyres). Erosion followed. Erosional intervals probably occurred locally at various times and places within the zones of accumulation, but there is no evidence that the entire region was raised and lowered to produce widespread traceable unconformities. Basic dikes and related hypabyssal masses were injected at various times.

The kinds of rocks and the sequence of events here depicted correspond fairly well with the rocks and events of central Arizona (Wilson, 1939). In Arizona, however, there followed, after a period of erosion, another period of accumulation (coarse and fine clastics and limestone). In the Albuquerque country there are no known rocks that record any comparable event. Nor, so far as known, is there any record northward in New Mexico of extensive deposits of Precambrian sediments after the orogeny that produced the deformation and metamorphism and prepared the scene for the emplacement of granitic rocks.

REFERENCES

Aldrich, L. T., Wetherill, G. W., and Davis, G. L., 1957, Occurrence of 1,350 million-year-old granitic rocks in western United States: Geol. Soc. America Bull., v. 68, p. 655-656.

Barker, Fred, 1958, Precambrian and Tertiary geology of the Las Tablas quadrangle, New Mexico: New Mexico Bur. Mines and Mineral Res. Bull. 45, 104 p.

Bruns, J. L., 1959, Petrology of the Tijeras greenstone: Univ. New Mexico unpub. master's thesis, 119 p.

Ellis, R. W., 1922, Geology of the Sandia Mountains: Univ. New Mexico Bull. 108, geol. ser., v. 3, no. 4, 45 p.

Flawn, P. T., 1956, Basement rocks of Texas and southeast New Mexico: Univ. Texas Pub. 5605, 261 p.

Giletti, B. J., and Damon, P. E., 1961, Rubidium-strontium ages of some basement rocks from Arizona and northwestern Mexico: Geol. Soc. America Bull., v. 72, p. 639-644.

Harbour, R. L., 1960, Precambrian rocks at North Franklin Mountain, Texas: Am. Assoc. Petroleum Geologists Bull., v. 44, p. 1785-1792.

Hayes, P. T., 1951, Geology of the Precambrian rocks of the northern end of the Sandia Mountains, Bernalillo and Sandoval Counties, New Mexico: Univ. New Mexico unpub. master's thesis, 54 p.

Just, Evan, 1937, Geology and economic features of the pegmatites of Taos and Rio Arriba Counties, New Mexico: New Mexico Bur. Mines and Mineral Res. Bull. 13, p. 44.

Lambert, P. W., 1961, Petrology of the Precambrian rocks of part of the Monte Largo area, New Mexico: Univ. New Mexico unpub. master's thesis, 108 p.

Lodewick, R. B., 1960, Geology and petrology of the Tijeras gneiss, Bernalillo County, New Mexico: Univ. New Mexico unpub. master's thesis, 63 p.

Montgomery, Arthur, 1953, Precambrian geology of the Picuris Range, north-central New Mexico: New Mexico Bur. Mines and Mineral Res. Bull. 30, 89 p.

Muehlberger, W. R., 1960, Precambrian rocks of the Tusas Mountains, Rio Arriba County, New Mexico, in New Mexico Geol. Soc. Guidebook of Rio Chama country, 11th Field Conf.: p. 45-47.

Reiche, Parry, 1949, Geology of the Manzanita and North Manzano Mountains, New Mexico: Geol. Soc. America Bull., v. 60, p. 1183-1212.

Stark, J. T., 1956, Geology of the South Manzano Mountains, New Mexico: New Mexico Bur. Mines and Mineral Res. Bull. 34, 49 p.

Stark, J. T., and Dapples, E. C., 1946, Geology of the Los Pinos Mountains, New Mexico; Geol. Soc. America Bull., v. 57, p. 1121-1172.

Wilson, E. D., 1939, Precambrian Mazatzal revolution in central Arizona: Geol. Soc. America Bull., v. 50, p. 1113-1164.

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