GEOCHEMICAL DATING OF IGNEOUS AND METAMORPHIC ROCKS IN ARIZONA

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INTRODUCTION

Large areas of igneous and metamorphic rocks are exposed in the Colorado Plateaus and in the Sonoran Desert and Mexican Highlands sections of the Basin and Range province. In the Colorado Plateaus province they are exposed in the Grand Canyon and at the south end of the Defiance Uplift (DuBois, 1958; Lance, 1958). They are also reported from a few "wildcat" wells drilled on the Colorado Plateau. All of the outcrops in the Colorado Plateaus province and most of those in the broad belt of the Central Highlands subprovince are of older Precambrian age. Precambrian metasediments are also reported in the Altar Valley region near Caborca in Sonora, Mexico. South and west of this belt, throughout much of the Sonoran Desert subprovince, the igneous and metamorphic rocks are at least in part post-Paleozoic.

The Precambrian metasediments of the Grand Canyon, central Arizona and southern Arizona, have been called the Vishnu, Yavapai and Pinal "schists" or "series", respectively (Anderson and Creasey, 1958; Lance, 1958; 4). The general structural trends in the three areas are similar and Wilson (1939) suggested that a single widespread orogeny, the Mazatzal revolution, metamorphosed the older Precambrian sediments producing the Vishnu, Yavapai and Pinal schists. There is no definite evidence for further significant orogenic disturbances until post-Paleozoic time. Locally, post-Paleozoic orogenies are unquestioned (Ransome, 1919; Gilluly, 1956), but the age of the orogenies, whether Nevadan, Laramide, or both, is open to question. Some of the orogenies may possibly be Santa Lucian, or of lower Upper Cretaceous age (Taliaferro, 1944; Curtis, Evernden and Lipson, 1958).

The ages, or probable ages, of the orogenies mentioned above have been deduced by the use of classic stratigraphic relationships -- superposition and sequence of intrusion. Geochemical dating is a comparatively new tool in the area and the dates presented here are all which are currently available.

A number of these dates were obtained under the current program of geochemical investigation at the University of Arizona. The geochemical program is investigating 1) the possibility of more than one major older Precambrian orogeny in Arizona; 2) the possible existence of igneous and metamorphic bodies of post-Mazatzal and pre-Mesozoic age; 3) the number, extent and age of post-Mesozoic orogenies; and 4) the age of specific rock units, such as the Catalina gneiss (DuBois, 19, 20) whose age is discussed as possibly Precambrian (?), Cretaceous (?), or Tertiary (?).

DATING TECHNIQUES

Several geochemical dating techniques, such as the rubidium-strontium, the potassium-argon, the uranium-lead, the isotopic lead and the alpha-lead methods, have been developed. The multiplicity of available techniques has the advantage of allowing cross checks on samples from the same rock by different methods on different minerals which respond differently to perturbing influences.

Pertinent data regarding geochemical ages for crystalline rocks in Arizona are given in tables 2 and 3 and the sample locations are also shown on figure 10. Alpha-lead dates shown in table 3 have been determined by the Petrology and Geochemistry section of the U. S. Geological Survey and the Department of Terrestrial Magnetism of the Carnegie Institution of Washington (Tilton and others, 1957). Table 2 summarizes the Rb-Sr (rubidium-strontium) and K-A (potassium-argon) data available for crystalline rocks in Arizona. The ages of samples 11 through 14 were determined by the Carnegie group (Aldrich and others, 1957). The ages of samples 1 through 7 are the first results of an inter-laboratory investigation by Lamont Geological Observatory, Columbia University and the Geochronology Laboratories of the University of Arizona. The mass spectrometric analyses were made by Dr. Bruno Giletti at Lamont. The argon analyses for samples 1 through 7 will not be available until after the completion of the Geochronology Laboratory gas source mass spectrometer.

The K-A and Rb-Sr ages, particularly the latter, represent a closer approximation to the actual age of mineral genesis that the alpha-lead dates. The alpha-lead dates are semi-quantitative in the absence of isotopic checks on the presence of initial lead. Investigation to date has shown that the dominant perturbing influence is lead loss. However, the Precambrian alpha-lead dates shown in table 3 probably are reliable minimum ages. For example, both mica and zircon from the Bagdad granite were analyzed. The mica (sample 12) yielded an age of 1, 390 m. y. (million years) by the Rb-Sr method and 1, 410 m. y. by the K-A method. In contrast, the zircon (sample 19) yielded an alpha-lead age of 675 m. y. However, the Pb^{207}-Pb^{206} isotopic age of the zircon was 1, 210 m. y. (Tilton and others, 1957). The alpha-lead age was apparently perturbed by lead loss and a reasonable conclusion is that both zircon and mica from the Bagdad granite were formed about 1,400 m. y. ago.

The pertinent factors that must be considered in evaluating the significance of the age data shown in tables 2 and 3 are listed below:

1. Rb-Sr and K-A experimental errors are probably well within ±5%, with the exception of samples 3 and 6. Experimental error for samples 3 and 6 is about 30% standard deviation because the radiogenic strontium content of sample 3 is only 0. 4% and of sample 6, only 0. 6% of the total strontium content.

2. Alpha-lead dates for the Precambrian zircons are probably minimal due to lead loss.

3. Geologic factors, such as the duration and possible multiplicity of diastrophic disturbances, weathering and alteration, will affect chemical relationships within the minerals that compose rock. Specific minerals and specific chemical relationships within a given mineral may respond differently to identical geologic conditions.

4. The age of the minerals composing a rock and the age of the rock itself are not necessarily identical.

5. The expression "the age of the rock" is a matter of definition and it must be specified whether it refers to the age of sedimentation, diagenesis, mobilization or metamorphism.

GEOLOGIC SIGNIFICANCE OF DATED SAMPLES

The ages listed in tables 2 and 3 are discussed briefly with respect to their geologic environments.

Samples 1, 2, and 11 represent mica separates from a pegmatite, gneiss and

Table 2: Rubidium-strontium and potassium-argon ages of mineral separates from igneous and metamorphic rocks of Arizona

Sample number	Type of Rock and Location	Mineral dated	Rb-Sr age (m. y.)*	K-A age (m. y.)	Laboratory
1	Pegmatite in Vishnu schist, Kaibab Trail, Grand Canyon	muscovite	1, 550	--	Arizona-Lamont
2	Migmatite zone in Vishnu schist, Bright Angel Trail, Grand Canyon	biotite	1, 390	--	Arizona-Lamont
11	Gneiss, Zoroaster Creek, Grand Canyon	mica***	1, 370	1, 390	Carnegie Inst.
3	Granite, U. S. Highway 66, near Valentine	biotite	1, 300**	--	Arizona-Lamont
4	Diana granite, Arizona Magma Mine, Chloride	biotite	1, 350	--	Arizona-Lamont
5	Chloride granite, 1/2 mile north of Chloride	biotite	1, 210	--	Arizona-Lamont
12	Lawler Peak granite, Bagdad	mica***	1, 390	1,410	Carnegie Inst.
13	Pegmatite in Lawler Peak granite, Bagdad	mica***	1, 500	1,410	Carnegie Inst.
6	Yavapai schist, Prescott	biotite	490**	--	Arizona-Lamont
14	Pegmatite, Wickenberg	mica***	1, 300	1, 160	Carnegie Inst.
7	Oracle granite, near Campo Bonito Mine, Oracle	biotite	1, 450	--	Arizona-Lamont

Note: Final absolute calibration of mass spectrometric analyses for Arizona-Lamont Rb-Sr dates is not complete and there may be minor changes in the final dates.

* m. y. (million years)
** 30%; see text.
*** exact mineral identification not given

migmatite zone, respectively, collected within a few miles of the Phantom Ranch at Grand Canyon. The age spread is from 1,370 m.y. to 1,550 m.y. This spread of 180 m.y. is not a result of experimental factors alone because the two determinations of the muscovite in sample 1 check closely and there is excellent agreement between Rb-Sr and K-A ages for the mica separate from the gneiss (sample 11). The age spread is probably due to mineralogic-geologic interrelationships which are impossible to evaluate without further investigation.

The validity of the age given for the granite collected 35 miles east of Chloride (sample 3) is open to question because the sample had a low radiogenic strontium content. Nonetheless, the data tend to confirm a probable Precambrian age for this granite. Paleozoic rocks overlie similar-looking granite a few miles north and east of the sampled locality.

Near Chloride, in northwestern Arizona, a younger granite, called the Ithaca Peak granite by Thomas (1949) and the Chloride granite by Dings (1951), intrudes the older Diana granite (Thomas, 1949). Dings assigned the younger granite a Precambrian(?) age and Thomas suggested it might be Mesozoic (?). The Rb-Sr method gives an age of 1,350 m.y. for the Diana granite (sample 4) and an age of 1,210 m.y. for the Chloride granite (sample 5). Both rocks are Precambrian. However, the significance of the difference in the ages cannot be determined from the two Rb-Sr dates alone. The ages for the mica separates from these granites are younger than the ages for the three mica separates from rocks of the Grand Canyon Vishnu series. The significance of this difference is also not now known.

The alpha-lead data on the zircon separate from the Bagdad granite (sample 19) has already been discussed. It has been pointed out that the lead isotopic age (1,210 m.y.) is much closer than the alpha-lead age (675 m.y.) to the Rb-Sr and K-A ages

Table 3 - Alpha-lead ages of zircon separates from igneous and metamorphic rocks of Arizona

Sample Number	Rock type and Location	Alpha-Lead (m.y.)	Laboratory
15	Government Canyon granodiorite, Prescott	930	U.S.G.S.
16	Quartz monzonite porphyry, San Manuel	119*	U.S.G.S.
17	Johnny Lyon granodiorite, Johnny Lyon Hills, east of Tucson	615 815	U.S.G.S.
18	Quartz diorite, Jerome	1,050	U.S.G.S.
19	Granite, Bagdad	675	Carnegie Inst.

*Approximate value; see text

obtained for mica separates from this granite (sample 12). These Rb-Sr and K-A ages are also close to those obtained for an intrusive pegmatite from the same area (sample 13). These ages, which range from 1, 390 m. y. to 1, 550 m. y. fall well within the 1, 370 m. y. to 1, 550 m. y. range for the Vishnu series at Grand Canyon.

The lead-alpha dates for the Government Canyon granodiorite at Prescott and the quartz diorite at Jerome (samples 15 and 18) confirm the Precambrian age of these rocks. The correct age is probably significantly greater. The low age obtained for the biotite separate from the Yavapai schist in the same area (sample 6) is not significant because the radiogenic strontium content was low. The Rb-Sr ratio for this sample may have been influenced by a basic dike which cuts across the schist in the road cut from which this sample was obtained.

The apparent age of the mica separate from the pegmatite at Wickenberg (sample 14) is similar to the apparent age of the Chloride granite.

The Rb-Sr age of 1,450 m.y. for the Oracle granite biotite separate (sample 7) falls midway between the limits for the Vishnu series and confirms the existence of an orogeny of "Vishnu" age as far south as Tucson. The alpha-lead dates for the zircon separates from the Johnny Lyon granodiorite (Silver, 1955) (sample 17), about 50 miles east of Tucson, suggest a southward extension of this orogeny. This hypothesis will be tested by Rb-Sr and K-A dating of the Johnny Lyon granodiorite, the Pinal schist which occurs at least as far south as the Bisbee area, and the Altar schist from Caborca, Mexico.

The alpha-lead data for the zircon separate from the quartz monzonite porphyry at San Manuel (sample 16) indicates a Nevadan or Santa Lucian age. However, it is only a single determination, and it is difficult to evaluate its significance because the zircon was very low in lead content (David Gottfried, personal communication, 1959).

CONCLUSIONS

The few geochemically dated samples available at this time tend to confirm the older Precambrian age of Wilson's Mazatzal revolution. Aldrich, Wetherill and Davis (1957) apparently demonstrate an essentially contemporaneous orogenesis within the Rocky Mountain belt in New Mexico, Colorado and Wyoming. The extent of igneous and metamorphic rocks of this age has yet to be determined.

The present data, however, do not rule out the possibility of several closely spaced periods of orogeny within the Mazatzal revolution. There is ample time within the spread of from about 1, 200 m. y. to 1, 550 m. y. for two or more periods of orogeny. The Paleozoic Taconic and Acadian revolutions of the Appalachian region occurred within a period of 150 m.y. On the west coast, three orogenic periods, Nevadan, Santa Lucian and Laramide, developed within a shorter period of time. The presence of similar structural trends in apparently similar rocks in different areas is not sufficient evidence to limit their deformation to a single period of orogeny. On both the east and west coasts of North America, orogenies have developed along similar trends in different areas and at different times. It will be difficult to date closely spaced orogenies in older Precambrian times because with the increasing ages of the orogenic periods, the relative age differences decrease and the influences of relatively trivial perturbing factors increase. Nonetheless, the existence of closely spaced older Precambrian orogenies may eventually be demonstrated by combined geologic, mineralogic and geochemical investigations.