UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Mid-Tertiary shearing in the two-mica Ibapah stock, western Utah

by

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Open-File Report 86-0151

1986

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards; the stratigraphic nomenclature has previously been approved.

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ABSTRACT

The Ibapah stock in the Deep Creek Range of western Utah is a mineralogically zoned one- to two-mica, peraluminous monzogranite that invaded the enclosing upper Proterozoic and lower Paleozoic sedimentary rocks in mid-Tertiary time. Errorchrons and calculated model isochrons from Rb-Sr data indicate large initial 87/86 Sr values, and suggest that the magma was derived in large part from the underlying continental crust.

Major zones of shearing produced cataclastites and protomylonites along the east side of the stock. Cross cutting relations indicate that vertical, north-northwest-trending shears cut north-dipping, east-trending shears. The trend of the range changes from a north-northwesterly direction to a northeasterly orientation at the point where the east-trending system traverses the range. Therefore, the easterly set of shears may reflect a pre-uplift fault system that influenced the subsequent development of the range-bounding faults. Based upon anomalously young K-Ar dates, the later structural event may have taken place during early Miocene time.

INTRODUCTION

The Ibapah stock in western Utah (fig. 1) is one of a number of peraluminous plutons that were emplaced within a north-northeast-trending belt of metamorphosed sedimentary rocks in the eastern Great Basin. The stock occupies the entire central part of the Deep Creek Range of western Utah and separates predominantly Proterozoic rocks to the south from predominantly upper Proterozoic and Cambrian rocks to the north (fig. 1; Bick, 1966). The sedimentary rocks were metamorphosed to staurolite grade during a regional event of Mesozoic age (Misch and Hazzard, 1962), but most primary sedimentary features were preserved. Synmetamorphic deformation produced large-scale folds and thrust faults in the Proterozoic and Paleozoic rocks (Rodgers, 1985; Bick, 1966), but none has been reported to extend into the Ibapah stock.

The results of the present field and related isotopic studies document that the Ibapah stock is an unmineralized one- to two-mica pluton of probable mid-Tertiary age that was derived from the lower crust, and that major shear zones cut and deform the intrusive body. Anomalously young early Miocene potassium-argon ages for the stock may reflect this deformation, which was accompanied by the intrusion of andesite dikes. The deformation documents one or more episodes of faulting that may be related to mid-Tertiary deformation reported in the southern part of the range by Rodgers (1985).

INTRUSIVE ROCKS

Almost all of the intrusive rocks in the central Deep Creek Range are primary phases of the Ibapah stock. Associated with and intruded into the stock are several small intrusive plugs and dikes of various compositions which are aerially much less extensive (fig. 1).

Ibapah stock

The Ibapah stock is a light-gray, coarse-grained, porphyritic to subporphyritic monzogranite to granodiorite. Oriented phenocrysts of microcline define uncommon flow foliation. Xenoliths are sparse except in contact zones or near roof pendants; they range from a few centimeters to a meter in length and include hornblende diorite and biotite monzogranite.

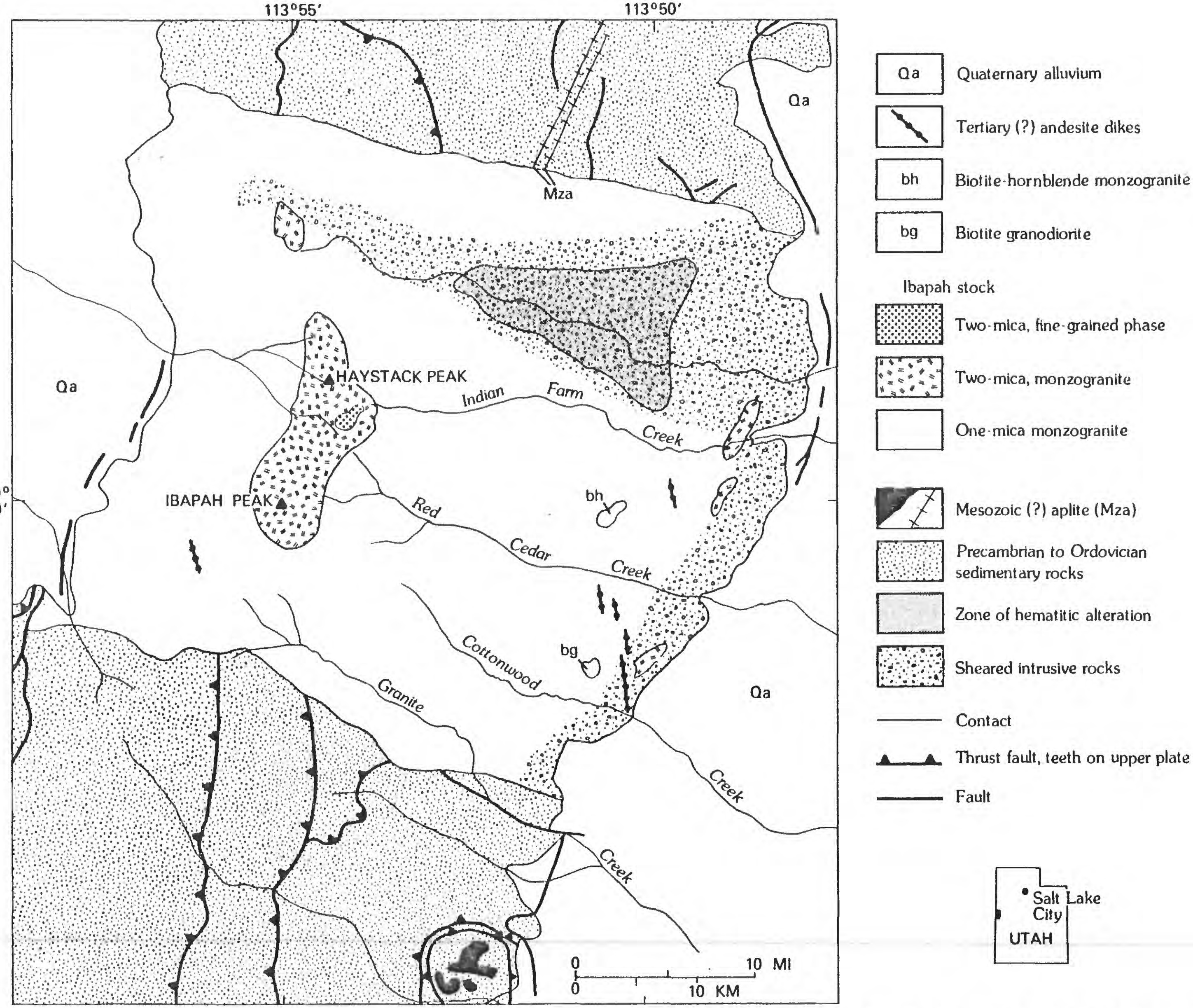

Figure 1. Generalized geologic map of the central Deep Creek Range, Utah, showing the distribution of the intrusive phases of the Ibapah stock, the zone of hematitic alteration in the stock, and the region of sheared intrusive rocks. Geology of the terranes surrounding the stock modified from Bick (1966). Mesozoic age for aplite assumed from Rodgers (1983), but age is not known absolutely.

Microcline, plagioclase, quartz, biotite, and muscovite are the major minerals in the stock (table 1). Perthitic microcline phenocrysts are as much as several centimeters long. Allanite, sphene, zircon, apatite, and magnetite are variably present as accessory minerals.

The distribution of biotite and muscovite constitute the major petrologic variation in the stock. Biotite is the only mica in most of the rocks in the outer part of the pluton (fig. 1). In contrast, muscovite is extremely common, locally to the exclusion of biotite, in the inner part of the body. Two-mica rocks are also scattered throughout the outer biotite-rich region of the pluton. Sphene and allanite are absent in rocks containing primary muscovite, but none of the other major or accessory minerals varies with muscovite.

The stock is generally texturally homogeneous except in a small area along the range crest in the center of the stock where the monzogranite is fine grained, equigranular, and mineralogically identical to nearby coarser grained rocks. Foliation is not apparent, and talus and glacial deposits obscure any contact relations. The groundmass of nearby coarse-grained two-mica rocks is finer grained than elsewhere in the stock, suggesting that the melt quenched or cooled more quickly in the central region of the stock. This central area is 2 km higher than the base of the range, and the textures may identify an upper-level vent area in the magma chamber. Some parts of the stock are coarse-grained but equigranular, but intrusive contacts could not be found between these and porphyritic rocks.

Major-oxide analyses of the one- and two-mica phases of the Ibapah stock demonstrate that the entire stock is peraluminous and siliceous (table 2). Trace-element concentrations are also generally similar throughout the stock (Cadigan and others, 1979).

The intrusive contact between the Ibapah stock and the surrounding rocks is visible only along the northern and southern borders of the pluton, as normal faulting truncated the eastern and western margins of the stock. Bick (1966) demonstrated that the northern and southern contacts parallel major transverse faults in the Deep Creek Range, and he concluded that two of the faults controlled the intrusion of the stock. However, the contact as now exposed is clearly intrusive. Partially assimilated country rocks contaminate the monzogranite along the southern contact, and contact metamorphism produced local hornfels and hematitic alteration and pyrrhotite flooding in the metasedimentary rocks. The stock is more equigranular near the contact, and flow-banding, schlieren, and injection into the host rocks are common. Broad, intrusion-related folding is apparent along the contact. Small isolated plugs of monzogranite south of the southern contact are finer grained than the main stock and contain abundant aplite dikes and quartz veins.

The Ibapah stock was emplaced after the country rocks were folded, faulted, and metamorphosed during regional deformation. Bick (1966), Rodgers (1983, 1985), and Nelson (1966) placed the intrusion of the stock after regional deformation. Furthermore, multi-stage, small-scale structures, presumably related to the pre-intrusive deformational events, are preserved in many of the pendants and inclusions of the country rocks in the stock and along the contacts.

Other intrusive phases

Small bodies of porphyritic hornblende-biotite monzogranite and equigranular biotite granodiorite cut the Ibapah stock (fig. 1); other bodies may be present, but, because of their small size, may have been missed during

Table 1. Modal analyses of rocks of the Ibapah stock

[All modes based upon counts of 800-1100 points.

Values in volume percent]

	Two-mica phase		
Sample no.	N-1	N-6	N-39
Quartz	26	33	24
Plagioclase	16	42	40
K-feldspar	51	20	32
Biotite	0	2.9	2
Muscovite	8	2.5	1
Ilmenite	<0.5	<0.5	<0.5
Sphene	0	0	0
Allanite	0	0	0
Apatite	<0.5	<0.5	<0.5
Zircon	<0.5	<0.5	<0.5
Chlorite	0	0	<0.5

	One-mica phase			
Sample no.	W-26	N-17	N-35	N-38
Quartz	27	29	26	37
Plagioclase	32	46	48	28
K-feldspar	38	14	18	20
Biotite	2	9	7	14
Muscovite	0	0	0	0
Ilmenite	<0.5	1	1	1
Sphene	<0.5	1	0	1
Allanite	0	0	0	<0.5
Apatite	<0.5	<0.5	<0.5	<0.5
Zircon	<0.5	<0.5	<0.5	<0.5
Chlorite	<0.5	0	<0.5	0

Table 2. Major-oxide analyses, in percent, and CIPW norms of one- and two-mica phases of the Ibapah stock

[Major oxide analyses by single-solution whole-rock method; analysts: H. Smith and J. Reid]

Sample no.	DCN-17 Porphyritic biotite monzogranite	DCN-34 Porphyritic biotite monzogranite	DCN-39 Equigranular two-mica monzogranite
SiO_2	73.2%	72.3%	72.5%
Al_2O_3	14.7	14.1	14.7
Fe_2O_3	0.57	1.2	0.93
FeO	0.48	0.8	0.64
MgO	0.26	0.74	0.41
CaO	0.99	1.2	1.5
Na_2O	4.1	3.6	3.8
K_2O	4.5	4.4	4.8
H_2O+	0.37	0.60	0.39
H_2O-	0.11	0.25	0.09
TiO_2	0.10	0.28	0.15
P_2O_5	0.08	0.08	0.04
MnO	0.05	0.07	0.01
CO_2	0.06	0.06	0.04
F	0.06	0.04	0.06
Sum	100.00	100.00	100.00
CIPW Norms			
Quartz	30.2	31.6	28.6
Corundum	1.66	1.60	0.82
Orthoclase	26.8	26.3	28.5
Albite	35.0	30.8	32.3
Anorthite	3.98	5.06	6.67
Enstatite	0.65	1.86	1.03
Forsterite	0.34	0.15	0.18
Magnetite	0.83	1.76	1.35
Ilmenite	0.19	0.54	0.29
Apatite	0.19	0.19	0.10
FR	0.11	0.07	0.12
Calcite	0.02	0.07	0.05

traverses through the stock. Both show reduced grain size and flow segregation or swirl patterns near intrusive contacts. Biotite and hornblende compose 34 volume percent of the monzogranite, and accessory minerals in both rock types include zircon, allanite, magnetite, and abundant corroded sphene.

Dikes of aplite, pegmatite, and andesite cut the Ibapah stock. The aplite dikes are ubiquitous and locally extend into the metasedimentary rocks. The dikes cut the Ibapah stock and all other intrusive phases except the andesite.

Thin pegmatite dikes are much less common than aplite dikes. Dikes in the southwestern part of the stock contain radio-quality quartz crystals and beryl (Thomson, 1973). Small veins of quartz and blue beryl were noted during the present study near the biotite granodiorite plug.

The andesite dikes are vertical and consistently strike N15-20^{o}W (fig. 1). The rocks are fine grained, dark, and composed of plagioclase feldspar, pyroxene, and quartz phenocrysts set in a groundmass of pyroxene, potassium feldspar, and plagioclase; epidote and chlorite are common alteration minerals. The dikes are 1-5 m wide, and strike lengths locally exceed a kilometer. The dikes are restricted to the eastern and southern portions of the stock; one dike, near Birch Canyon 15 km south of the stock, cuts the metasedimentary rocks. Trace-element analyses of the andesite dikes show enhanced concentrations of Ba, Co, Ni, Sr, V, and Zr in comparison with the enclosing monzogranite (Wallace, unpub. data, 1978). One sample north of Cottonwood Canyon contains 11 ppm Sn; the dike south of Birch Canyon contains 18 ppm Sn.

Alteration and vein mineralization

Approximately 15 km^2 of the northeastern part of the pluton are altered to hematite (fig. 1). Much of the hematite is in abundant microfractures in felsic minerals, especially feldspars, and all felsic minerals have a haze of orange-iron-oxide alteration. The altered rocks are friable; most grains are slightly broken and quartz is severely strained. Some primary biotite has been altered to magnetite and chlorite, with somewhat later hematite. The transition from red to unstained monzogranite spans about 5 m without any apparent change in the original lithology. The hematite is therefore a product of post-crystallization alteration of an isolated part of the Ibapah stock, and it does not obviously reflect an separate intrusive event.

Weak propylitic alteration is common, especially near major zones of shearing and in places near the northern and southern intrusive contacts. Biotite is weakly altered to chlorite, muscovite, magnetite, and epidote. The feldspars are dusted with fine-grained sericite and, locally, somewhat coarser muscovite. The latter occurrence is distinct from primary magmatic muscovite.

Hydrothermal mineral deposits are rare, small, and widely scattered. Galena, pyrite, chalcopyrite, tourmaline, magnetite, calcite, and iron oxides are variously present in small veins with quartz gangue. Detectable amounts of tin are present in a thin quartz-magnetite vein near the central equigranular two-mica monzogranite, as well as in several of the andesite dikes. Small veins of quartz with tourmaline or beryl are present, and the stock itself contains slightly elevated concentrations of uranium in comparison with granitic rocks of similar composition (Cadigan and others, 1979).

Age and isotopic data

Rodgers (1985) reported a 39 m.y. age (U-Pb isochron date on zircons; D. W. Rodgers, oral commun., 1985) for the pluton. As part of the present study, four unaltered samples of the Ibapah stock were collected near the mouth of Indian Farm Creek (fig. 1) for Rb-Sr analysis and dating; two others were previously collected by Donald E. Lee. The isotopic data (fig. 2) are scattered and therefore provide only an approximate age assignment of 124 ± 36 m.y. for the pluton, substantially older than the zircon age. The scatter in the Rb-Sr data is typical of other similar plutons in the region (Best and others, 1974), and conflicting ages for individual plutons has been reported elsewhere in the eastern Great Basin (Lee and others, in press).

The isochron (perhaps more realistically called an "errorchron") derived from the Rb-Sr data shows an initial $^{87}Sr/^{86}Sr$ ratio of 0.7123 (fig. 2). Calculated model isochrons, using an age of 39 m.y. and the Rb-Sr composition of each sample, suggest initial ratios between 0.7148 and 0.7218, with an average of 0.7197. The ratios are consistent with derivation of the magma from the lower continental crust. The variable compositions could reflect either heterogeneity at a single source or contamination of the magma by an isotopically distinct source after initial magma generation (Farmer and DePaolo, 1983). Lee and others (1981) reported a $d^{18}O$ value of +9.6 permil for one sample (GR-91), a value somewhat lower than would be expected for a peraluminous magma that was generated entirely from continental crust (O'Neil and others, 1977).

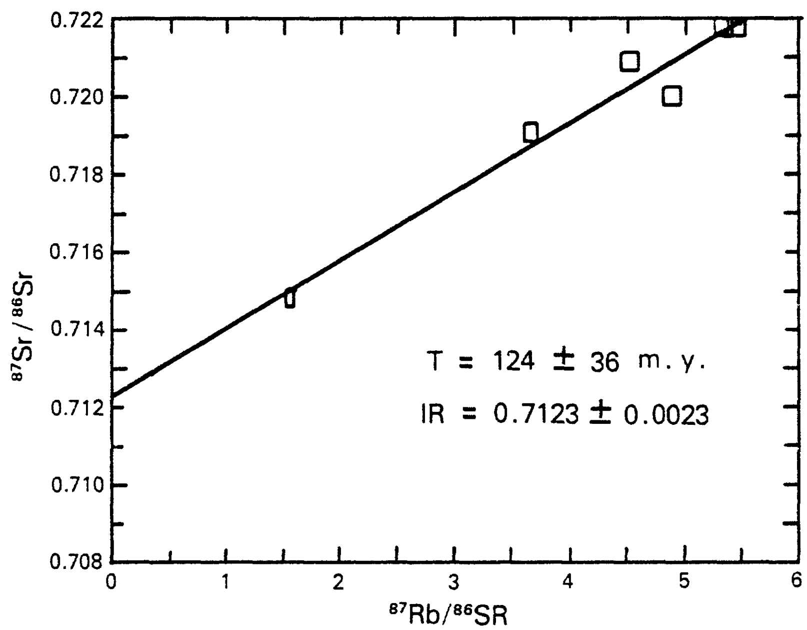

Figure 2. $^{87}Sr/^{86}Sr$ vs. $^{87}Rb/^{86}Sr$ plot of samples from the Ibapah stock. Samples with "DC-" designation collected for this study; GR-91 and GR-92 collected by Donald E. Lee. Regression line gives an age of 124 ± 36 m.y. Rectangles represent error for each sample. All analyses by Ronald W. Kistler. T = age of intrusion based on linear regression; IR = initial ration based on intercept at $^{87}Sr/^{86}Sr$ at zero.

Armstrong (1970) obtained K-Ar ages of 18.7 m.y. for the Ibapah stock, 17 m.y. for schist in the metamorphic sequence, and 28.7 m.y. for a pegmatite related to the stock. In light of the Rb-Sr and Rodgers' (1985) dates, these ages probably reflect resetting by an early Miocene event, such as shearing and deformation in the stock, or uplift.

INTERNAL STRUCTURES

Several prominent sets of joints cut the stock, and post-crystallization shear zones locally obliterated all igneous textures. The shear zones are younger than the joints, and they locally parallel some of the joint systems.

Joints

The most prominently displayed joints are in the northwestern and east-central sections of the stock, but limited exposures are ubiquitous throughout the pluton. The dominant orientations of the joint sets in the stock fall into groups of N60^{o}E to due north (DN), N35-45^{o}W, and DN-N25^{o}E, similar to groupings defined by Bick (1966), and into less distinct or more widely scattered groups of N70-75^{o}W and N15-30^{o}W. Two sets generally predominate in any particular area of the stock: in the east-central region between Indian Farm Creek and Cottonwood Creek, the major joint sets strike N70-75^{o}E and N20-25^{o}E; in the northwestern area, the joints strike N16^{o}E and N15^{o}W. The east and west range fronts strike N20^{o}E, as do uplift-related Holocene fault scarps in the alluvial fans, and joints with a similar orientation may be related to uplift of the range.

Shear zones

Much of the eastern part of the Ibapah stock was pervasively sheared and altered. The most intense deformation was along the eastern flank of the range where the original granitic texture has largely been obliterated (fig. 1). Major shear zones also form a west-pinching wedge of deformation into the northern core of the pluton. Cross cutting relationships document more than one episode of shearing.

Deformation produced discrete, intensely cataclastized shear zones to diffuse stockwork-like systems of small shears and fractures. The discrete shear zones are common north of Indian Farm Creek where shear zones, 50-200 m apart, cut the intrusive rocks. This area of shearing tapers westward towards the crest of the range 7 km to the northwest, where it is a narrow zone of diffuse shears with chloritic alteration. The structures strike N70-85^{o}E and dip moderately to steeply to the northwest; rare slickensides rake 20^{o}NW. The zones are several centimeters to a meter or more thick, and they are laterally persistent for as much as 4 km. The shear zones are composed of cataclastite to protomylonite (based upon Wise and others, 1984) with associated chlorite; primary cohesion is present along some faults, and fluxion structures locally are visible in thin sections and in outcrops. The resulting structures form resistant brownish-green zones that stand out in notable relief in the unbroken stock. The footwall contact of each shear zone grades down from granulated to relatively unbroken monzogranite over a few centimeters. Thin fractures and shears in the footwall strike to the north and dip steeply to the east. In contrast, the upper surface of each shear zone is sharp to indistinct and, in the latter case, gradually grades from protomylonitic to strongly fractured to relatively unfractured monzogranite.

The southernmost shear zones in the vicinity of Indian Farm Creek form a right-stepping en echelon pattern that separates the large region of sheared rock to the north from pristine monzogranite to the south; shears south of this boundary are limited to granitic rocks at the immediate range front. The fresh rocks to the south are cut by a prominent set of vertical joints that parallels the shears. Evidence of shearing was not noted along the joints, although the en echelon shears along the boundary evolve laterally into joint-like features.

A major shear zone obliquely truncates the southeastern boundary between hematitic and fresh monzogranite (fig. 1). The hanging walls of several shear zones just to the south crudely grade northward (up into the hanging wall) from sheared white monzogranite into the red phase, creating a colorful but erratic patchwork of altered and unaltered monzogranite. The hematitic alteration appears to antedate the major episode of deformation, and the isolated patches represent faulted slivers of the altered monzogranite.

The northeastern range front lacks unsheared or unaltered monzogranite. Most of the rocks retain a vague granitic texture, but they are severely altered to chlorite and are densely laced with thin, chlorite-filled shears and fractures; as a result, the entire area has an olive green hue. Discrete, wide shear zones are absent, and deformation is distributed over the myriad of thin shears and fractures. The major shear orientation along the range front strikes DN-N20°W and dips very steeply to the northeast. Within a kilometer of the range front, the major east-trending shear zones curve to N60°E and are nearly vertical, and they are extremely diffuse and subordinate to the north-northwest-trending system. To the west and north of Indian Farm Creek, shears in the east-trending system are cut and offset in a right-lateral direction by vertical, closely spaced fractures that strike DN-N15°W. This fracture set becomes more common and well defined eastward towards the range front.

The shear zones south of Indian Farm Creek are principally restricted to a 2-km-wide belt along the eastern margin of the stock and range front. Major shears along the range front south of Red Cedar Creek strike N32-37°E and dip 32°NW; minor shears strike due north and dip steeply to the west. Shear zones in the southernmost part of the stock strike either N44-70°E and dip 50-85°NW or strike N10°W and dip 80°W. All northeast-trending structures displaced aplite and pegmatite dikes several centimeters to tens of meters in a predominantly left-lateral direction. Slickensides on a N10°E, 80°SE shear surface north of Cottonwood Creek rake 56° to the northeast.

Shear zones and andesite dikes north of Cottonwood Creek are mutually cross cutting. A major andesite dike that extends north-northwesterly from the mouth of Cottonwood Canyon is not displaced by any shear zones, although several thin shears pass through the dike and chlorite-filled hairline fractures, parallel to the large dike, cut the monzogranite. This relationship suggests that the north-northwest-trending shear system in part controlled the emplacement of the dike.

DISCUSSION

This study concentrates on the Ibapah stock and does not discuss the metasedimentary rocks into which it was intruded. Petrological characteristics of the stock and structures that modified the crystalline rocks have been identified and should be considered in future geologic analyses of the range.

The Ibapah stock is a two-mica, S-type granite (Chappell and White, 1974) that was derived in large part from partial melting of the crust. Other S-type granites in western Utah and eastern Nevada (Lee and others, 1981; Best and others, 1974; Farmer and DePaolo, 1983) share chemical and physical characteristics with the Ibapah stock: peraluminous composition, normative corundum, high initial Sr ratio, ilmenite and locally abundant muscovite, and the association with uranium, tungsten, tin, and other trace elements. Possible crustal sources include Paleozoic miogeoclinal sediments or, more likely, the crust that underlies the sedimentary rocks (Farmer and DePaolo, 1983).

A mid-Tertiary age of intrusion for the Ibapah stock is consistent with the ages of numerous other intrusions in the region (Moore and McKee, 1983). However, many two-mica plutons in the eastern Great Basin are of Jurassic to Cretaceous age, including the nearby Kern Mountains pluton (71-75 m.y.; Lee and others, in press), whose disrupted Rb-Sr systematics are similar to those found in the Ibapah stock.

The depth of emplacement of the stock is largely unknown. Unlike the Mesozoic stocks emplaced in the Egan and southern Snake Ranges (Gans and Miller, 1983), the Ibapah stock intruded the lower Paleozoic section after the Mesozoic deformation had considerably thickened the supracrustal section (Bick, 1966; Rodgers, 1985). Therefore, the thickness of the section above the youngest intruded formation (at least 2.6 km; Bick, 1966), is not an adequate estimate of the actual thickness of overlying rocks. Recent studies have shown that the presence of muscovite does not impose a minimum depth of emplacement (Miller and others, 1981). Most of the other muscovite-bearing plutonic rocks in the region were intruded at depths as great as 7 km (Gans and Miller, 1983), and possible venting in the upper part of the Ibapah pluton suggests a relatively shallow depth of emplacement.

The stock differs from other stocks of similar chemical affinities by its mineralogical variations that define regions of muscovite-biotite and biotite (+ sphene) monzogranite which are otherwise identical. The absence of intrusive contacts between these mineralogical regimes suggests that the variations are the products of syngenetic processes. The two-mica rocks may represent the original magma composition that was peripherally contaminated by assimilated country rocks. Alternatively, the mutual exclusion of muscovite and sphene and the coincident presence of biotite and sphene may reflect a decrease in the oxygen fugacity in the muscovite-rich region of the magma chamber during crystallization.

The multi-stage shear zones in the pluton record a major tectonic episode that is younger than the mid-Tertiary age of the Ibapah stock. Andesite dikes were intruded during the later stages of this event, and their north-northwest orientation suggests a generally N80^{o}E direction of extension. This is corroborated by lateral offset along east-northeast-trending faults, and by the orientation of slickensides on north-northwest-trending fault surfaces. Cenozoic normal faults related to uplift of the range parallel the range fronts (Nolan, 1935; Bick, 1966; this study), and major joint sets in the stock parallel the normal faults along this segment of the range. However, the andesite dikes, which have orientations similar to many of the north-trending shear zones, trend away from the immediately adjacent range fronts and so were not likely emplaced along faults related to uplift of the range. Therefore, much of the north-trending shear system may be completely unrelated to and older than uplift-related normal faults.

A major north-trending, east-dipping normal fault is exposed along the eastern flank of the range north (Bick, 1966) and south of the stock (Rodgers, 1983). This fault has the same strike as the younger set of faults in the pluton but dips much more gently to the east. Rodgers (1985) suggested that the fault segment south of the stock formed after emplacement of the stock during the third and last stage of deformation in the southern part of the range. This deformation also involved westward rotation of the range by as much as 40 degrees during mid-Tertiary extension.

The orientation of the Deep Creek Range changes from N10^{o}W north of the Ibapah stock to N40^{o}E south of Indian Farm Creek; the bend is located approximately where the east-northeast-trending shear system cuts through the range. The coincidence of the bend and the location of this shear system resembles similar bends in Holocene normal faults that reacted to pre-existing structures in the basement (Zoback, 1983). This would imply that the shear system predated uplift of the range. Furthermore, it is unlikely that the east-northeast-trending shear system is a direct product of normal faulting along the range front because it is best developed some distance from the range front, and because it has a very different orientation and inferred direction of movement. Using the major area of hematitized monzogranite as a reference, the slivers of altered monzogranite in the hanging walls of the east-trending faults indicate components of both dip-slip and left-lateral movement, roughly consistent with the few observed slickensides. Coupled with the west-pinching wedge of deformation, this suggests that the stock south of this zone moved southeastward and relatively up. Therefore, all of the shears in the stock are probably older than the age of Basin-Range-type uplift of the range, and the early Miocene K-Ar ages from the stock may reflect this deformational event and (or) attendant intrusion of the dikes.

ACKNOWLEDGMENTS

Tom Nash and Rob Zech were part of the original team that mapped the Ibapah stock during the evaluation of the Deep Creek emergency withdrawal area in 1978, and their observations and comments provided an excellent foundation for subsequent studies. Barb Nevins assisted during additional field work in 1983. Ron Kistler provided Rb-Sr analyses of the samples collected for this study, and Zell Peterman provided the regression diagram for the isotopic data. Margo Toth, Myron Best, M. E. Bickford, and Don Lee provided thorough and thoughtful reviews.

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