Volcanic and Structural Controls of Mineralization in the Dos Cabezas Mountains of Southeastern Arizona

U.S. GEOLOGICAL SURVEY BULLETIN 1676

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and SCOTT D. BIRMINGHAM

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Volcanic and Structural Controls of Mineralization in the Dos Cabezas Mountains of Southeastern Arizona

By Harald Drewes, Dean P. Klein, *and* Scott D. Birmingham

Abstract

The Dos Cabezas Mountains, about 50 km southeast of Willcox, Ariz., have been the site of a moderate amount of base- and precious-metals mining and have a strong potential for the discovery of additional mineral deposits. This encouraging evaluation has been obtained from the combined results of geologic mapping, geochemical sampling, and geophysical surveys. These results have also led us to identify some general objectives and some specific targets for exploration in the central part of the mountains.

Geologic mapping indicates that the central part of the mountains is underlain by a volcano-plutonic field of dacitic to rhyolitic (granodioritic to granitic) composition of Late Cretaceous-Paleocene age. Much of the remaining volcanic field consists of dacitic-flow breccia and breccia pipes. Several granitoid stocks, some porphyry masses, and assorted aphanitic to porphyritic dikes intrude the volcanic pile. Very locally the volcanic pile is underlain by Mesozoic sedimentary rocks; in most places Precambrian crystalline rocks make up the basement. Breccia pipes containing clasts of Paleozoic or Mesozoic sedimentary rocks suggest that such rocks also underlie concealed parts of the volcanic pile. An area of such an igneous system, especially one having this age, composition, and alteration intensity, offers a prime general target for mineral exploration.

Faults have had a major control in the distribution of the volcano-plutonic rocks. The Apache Pass fault zone is a major northwest-trending, steeply dipping, diversely and recurrently reactivated basement structure, forming the southwest side of the volcano-plutonic field. Magmatic and hydrothermal fluids probably migrated upward along deeper levels of this fault zone. A subordinate fault splaying off the Apache Pass fault zone lies near the northeast side of the field. A ring-dike system lies along part of this splay fault and follows the margin of the field where it diverges from the subordinate fault. Other subordinate faults trend northeast, offsetting the Apache Pass fault zone and probably guiding fluid movement in shallower levels. Still other faults are inferred to underlie alluvium or some of the volcanic rocks, and one of these faults appears to mark a subsurface change from a thin to a thick sequence of the volcanic pile. The known and inferred collapse of part of the volcano-plutonic field between the Ivanhoe and Elma mines and Howard Peak, combined with the evidence of many breccia pipes and other known intrusive rocks in the area, suggests that this area was the major volcanic center. Faults and other structures, then, are seen as the major avenues of guiding the movement of fluids at deep to moderate depths and to sites of rocks that may have accumulated ore deposits.

Rocks favorable to mineralization include Paleozoic and Mesozoic sedimentary rocks and some of the dacitic breccia. These are particularly good host rocks where they lie near the borders of stocks and where they are faulted. From regional relationships, we find stocks of Late Cretaceous-Paleocene age to be most commonly associated with mineralization. Furthermore, the occurrence of these favorable host rocks at a transitional structural level between plutonic and volcanic environments is propitious for mineralization.

Geochemical sampling, mainly of mine dumps and prospects, shows that base and precious metals are widely dispersed. In some places, silver is seen to occur with lead, and elsewhere it occurs with copper. High silver values occur mainly in the north-central part of the area and along the southwest strand of the Apache Pass fault zone. Silver occurs as commonly with copper alone as it does with lead, with which it presumably appears as argentiferous galena. Gold occurs in pyritiferous quartz veins or argentiferous galena in widely dispersed sites. Copper appears nearly throughout the volcanic field. Zinc is also widespread, but is more erratic in its presence than is copper. Lead is more common in the northwestern and northeastern parts of the volcanic field than elsewhere. Quartz veinlets and propylitic alteration are widespread, and locally intense clay mineral alteration is also present. In summary, there are many signs that hydrothermal fluids migrated through the sedimentary and volcanic rocks of the central Dos Cabezas.

Geophysical surveys, including aeromagnetic and gravity

studies, indicate the presence of subsurface structural features and help to show the configuration of structural features exposed at the surface. Blind stocks or dikes are suggested by the surveys at several sites along the Apache Pass fault zone or within the area of the volcanic field, where they are of potential economic interest. Blind stocks or dikes are also indicated along the southwestern foothills, where they are of lesser significance chiefly because the associated exposed dikes are of mid-Tertiary rather than Late Cretaceous-Paleocene age. The geophysical signature of the volcanic field indicates that the field may be thickest near the breccia pipes and that the volcanic rocks may thin abruptly, perhaps through subsurface faulting, between the Ivanhoe and Elma mines. Finally, the surveys show that the sedimentary rocks of the Apache Pass fault zone decrease in dip southwestward, where they apparently diverge from the steeply dipping fault planes of the extensive Apache Pass zone.

The close geographic association of a magma type that has an age and composition commonly found with mineral deposits in the region, a major fault zone, favorable host rocks, and abundant signs of past movement of hydrothermal fluids, all exposed at an optimum depth in an ancient volcano-plutonic system contribute to our belief that more mineral deposits may be found in the Dos Cabezas Mountains. Primary targets for further exploration studies include the geophysically inferred stocks of the volcanic field and the mapped and inferred structural zones near stocks and near the central part of the volcanic field. Secondary targets include sedimentary rocks believed to underlie some of the central part of the volcanic field, some of the breccia pipes, parts of the Apache Pass fault zone farther from known or inferred stocks of Paleocene age, parts of the southwestern belt of sedimentary rocks where geophysical anomalies and Tertiary dikes converge, and the western extension of the fault zone beneath an apparently shallow alluvial cover.

INTRODUCTION

The central part of the Dos Cabezas Mountains of Cochise County in southeastern Arizona, from which some $2 million worth of base and precious metals has been produced, has considerable potential for additional mineral deposits. New deposits are likely to be blind ore bodies; they could include sulfide replacement, stockwork, and disseminated copper and molybdenum deposits. Less likely, they may also include small auriferous quartz-vein deposits.

The evaluation of the mineral potential of the Dos Cabezas is largely based on similarities in lithologic and structural controls between known deposits in the area and certain deposits in nearby mining districts. It is also based on a widespread, but erratic, geochemical dispersion of many metals. Furthermore, the mountains are sites of geophysical anomalies that have some intriguing relationships to known, projected, and speculative geologic features. Together, these relationships suggest that the Dos Cabezas warrant further geologic, geochemical, and geophysical investigation aimed at searching for certain kinds of mineral deposits.

Geographic Setting

The Dos Cabezas Mountains lie immediately southeast of Willcox in the southeast corner of Arizona (fig. 1). The mountains are usually given less attention than neighboring ranges because they are lower and less extensive. Both Interstate Highway 10 and the Southern Pacific Railroad skirt the northeast side and northwest end of the mountains. Access to the mountains is mainly from the paved State Highway 186 and the village of Dos Cabezas to the southwest and from an unpaved county road and Bowie to the northeast. Like the mountains themselves, the Teviston and Dos Cabezas mining districts in the Dos Cabezas Mountains are less well known than the more productive districts of nearby ranges, such as the Courtland-Gleeson districts.

The Dos Cabezas Mountains are a small, but rugged, extension of the higher and broader Chiricahua Mountains to the southeast and the equally large and extensive Pinaleno Mountains to the north. Apache Pass, separating the Dos Cabezas from the Chiricahua Mountains, is mountainous but low and short; Railroad Pass, separating the Dos Cabezas from the Pinaleno Mountains, is a broad low saddle that resembles a slightly raised intermontane valley. Between these passes the Dos Cabezas are about 35 km long and 10–15 km wide, trending northwest near Apache Pass and west-northwest near Railroad Pass. Dos Cabezas Peaks are 8,354 ft high, but most of the range is only about 7,000 ft high, and the northwestern third of the range rarely exceeds 6,000 ft.

Together, the Dos Cabezas, Chiricahua, and Pinaleno Mountains separate the broad intermontane San Simon Valley to the east from the equally broad Sulfur Springs Valley to the west. The San Simon Valley drains north into the Gila River, and near the Dos Cabezas the valley is about 3,700 ft above sea level. However, the Sulfur Springs Valley drains into the closed basin of Willcox Playa, which lies about 500 ft above the San Simon Valley. As a result of this difference in local base level of erosion, the northeast flank of the Dos Cabezas is incised by some long, deep canyons whereas the southwest side is less rugged. Likewise, the eastern ends of Apache and Railroad Passes have longer grades than the western ends. While this cross-range asymmetry seems to be a minor topographic feature of the area, it has been a contributing factor in bringing access to the Elma mine (fig. 2), located at mid-flank on the northeast side of the Dos Cabezas, across the crest of the range from Dos Cabezas village.

In contrast to the higher, broader, forested Chiricahua and Pinaleno Mountains, with their running

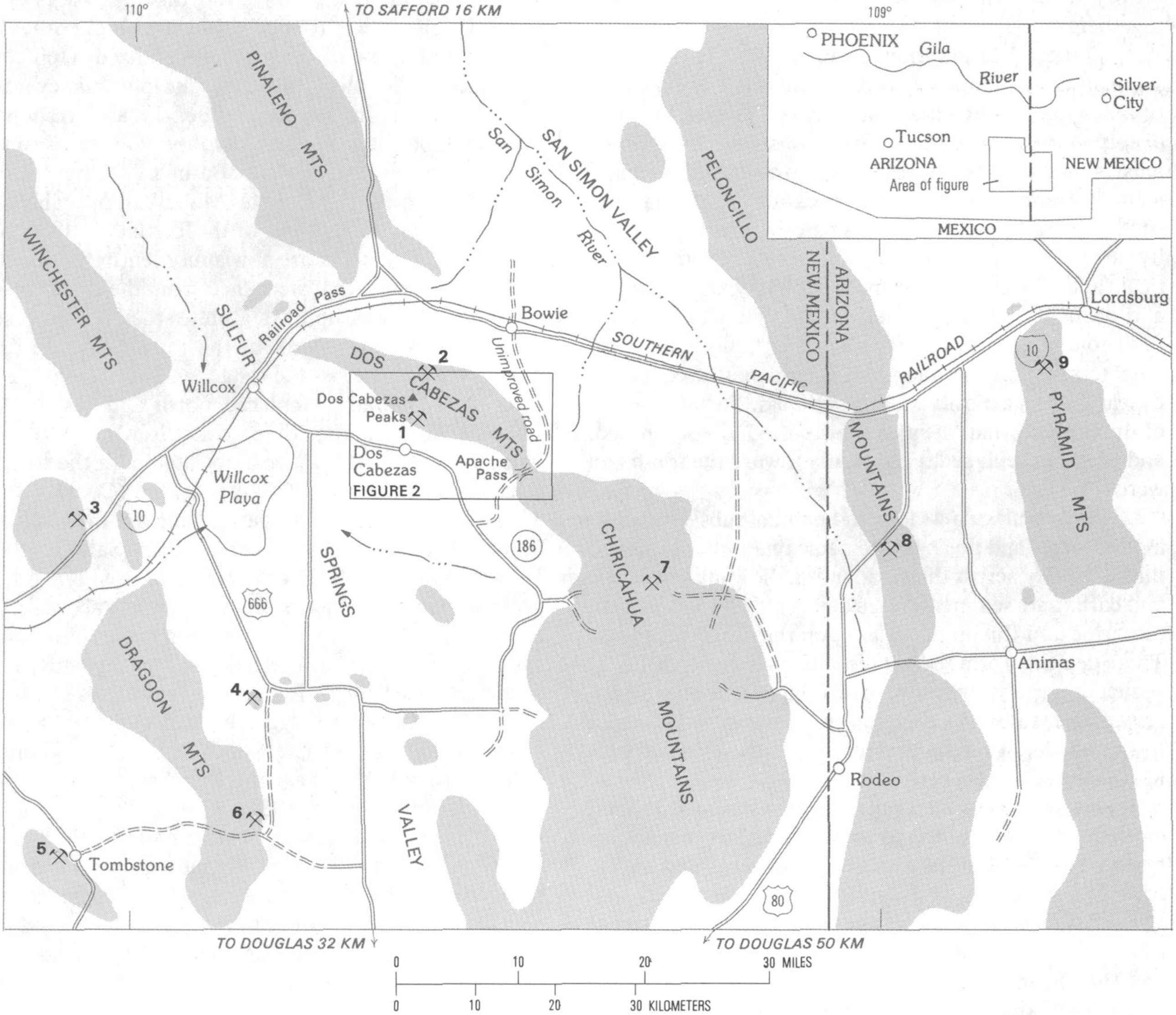


Figure 1. Location of Dos Cabezas Mountains, the mining districts and camps of adjacent ranges, and area of figure 2. Sites of mining camps or districts: 1, Dos Cabezas; 2, Johnson; 3, Pearce; 4, Tombstone; 5, Cortland-Gleason; 6, Hilltop; 7, Granite Pass; and 8, Lordsburg.

water, recreational sites, and summer homes, the lower narrower Dos Cabezas Mountains are covered largely by brush, scrubby pinyon pine and juniper, and grass and cactus vegetation. Despite these fairly austere conditions of vegetation and surface water, the Dos Cabezas have extensive rangeland and at times have been the site of considerable mining activity.

Geologic Setting

The geologic development of the Dos Cabezas Mountains has much in common with that of the surrounding region (Drewes, 1980, 1981; Drewes and others, 1985), but at several geologic times the site of the mountains lay along borders of diverse depositional or tectonic terranes that give the local geologic record some unique features. On the whole, the geologic study has shown the presence of general features favorable to accumulation of ore deposits, but that study must be more detailed in order to help locate sites that may contain mineral deposits of economic value. Perhaps the most favorable aspect of the Dos Cabezas block is the juxtaposition, along an ancient but reactivated fault zone, of Paleozoic and Mesozoic host rocks favorable for replacement ore deposits, and a transition zone between stocks and volcanic rocks of a single magmatic suite of Late Cretaceous-Paleocene age. A review of the geologic history of the area shows how these features were brought together.

During Precambrian time, a thick sequence of sedimentary and volcanic rocks accumulated in the area of the present Dos Cabezas Mountains. These rocks were deeply buried, metamorphosed, intruded by granitic masses, and locally folded, to form the crystalline basement terrane typical of southeastern Arizona and southwestern New Mexico. This basement terrane was cut by extensive, northwest-trending, steeply dipping or vertical faults on which movement probably was recurrent and probably was largely left lateral. The Apache Pass fault zone (fig. 1) is one of these master faults in the basement terrane; another fault of this kind may lie concealed beneath gravel deposits of Railroad Pass. Toward the end of the Precambrian, the area was uplifted, deeply eroded, and partly peneplaned, particularly toward the south and west.

As a result of a widespread gradual subsidence during Paleozoic and much of Mesozoic times, the sea spread intermittently across the area, and shallow marine clastic and carbonate sediments were deposited alternately with estuarine and fluvial material upon the basement rocks. These deposits form several disconformable depositional sequences, the youngest of which lapped upon a Pennsylvanian(?) to Early Cretaceous upland that was centered to the northeast of the present site of the Dos Cabezas Mountains.

By Late Cretaceous time, the area was raised again, eroded, and then deformed and intruded by magmas in response to events of the Cordilleran orogeny. Regionally, rocks were folded and faulted in response to east-northeast-directed compressive stress, but that deformational style is less obvious in rocks of the Dos Cabezas and the terrane to the north and east than in the rocks to the south and west. Apparently the allochthonous terranes (overthrust plates) terminated near the southern part of the Dos Cabezas Mountains area against a series of left-lateral strike-slip or oblique-slip faults.

During Paleocene time, probably late in the Cordilleran orogenic event, granitic magmas moved upward through the basement rocks along the fault zones and were emplaced into the cover rocks as stocks or erupted on the surface to form andesitic to rhyolitic volcanic rocks. Concurrently with magmatic activity, these fault zones were reactivated, in many segments as dip-slip or oblique-slip faults and in some segments as left-lateral strike-slip faults. The site of the future Dos Cabezas Mountains became such a major volcano-plutonic complex. In the central high part of the present Dos Cabezas, dacite to rhyolite breccia masses with subtle variations from one another appear to make a nested series of volcanic throats and pipes. Some of these breccia masses were intruded by plutonic rocks, and along the northeast margin of the volcanic pile are segments of an elongate intrusive feature resembling a ring dike. All rocks of the volcanic pile are strongly propylitized or otherwise altered, and a few of them are mineralized. Uplift and deep erosion followed these volcano-plutonic events.

Beginning in Oligocene time, the area responded through block faulting and rhyolitic volcanism to tensional conditions that mark the Basin-and-Range tectonic event. The present Dos Cabezas Mountains probably were formed during the last half of the Tertiary Period, with uplift along faults that are now almost entirely concealed by gravel deposits that were shed from the raised block. During this time of uplift, a granite stock was emplaced along the northeast flank of the range, rhyolite dikes typically spread across the range, and auriferous quartz veins were probably emplaced north and east of Dos Cabezas Peaks and perhaps also elsewhere. Rhyolite volcanic rocks that may be associated with the tectonic event are found north of Railroad Pass (Cooper, 1960; Thorman, 1979, unpub. data), and another volcanic center occurs southeast of Apache Pass (Sabins, 1957b; Drewes, 1982a). Similar volcanic rocks are known from drilling to underlie some of the San Simon Valley (Sabins, 1957b; Drewes, 1982b). A volcanic terrane of unknown age or composition is inferred from a magnetic survey to underlie the valley a few tens of kilometers southwest of the Dos Cabezas village. In Railroad Pass a small olivine basalt flow of late Miocene age is the youngest volcanic rock known near the Dos Cabezas Mountains (Erickson and Drewes, 1984).

The youngest geologic events recorded in the area are of continued erosion of the mountains and deposition in the intermontane basins. Pediments were developed along parts of both mountain flanks and may underlie all of the flanks, where they could provide areas for potential blind ore deposits.

Mineralization Setting

The mineral deposits and areas of known mineralization of the Dos Cabezas Mountains resemble those found in the central part of the Peloncillo Mountains (fig. 1, site 8) and Lordsburg mining district (site 9), 40–70 km to the east and also resemble aspects of the Johnson (site 3) and Courtland-Gleeson (site 4) mining districts 50–70 km to the west and southwest. Straddling the central part of the range, the Teviston mining district (site 2) lies on the northeast flank and the Dos Cabezas mining district (site 1) lies on the southwest flank (fig. 2). Most ore production has come from only a few mines in these districts. The mineral deposits in these districts include base- and precious-metal veins, replacement bodies, disseminated occurrences, and skarn deposits. Many of the deposits are found along the Apache Pass fault zone, especially near stocks and dikes; others occur in dacitic breccia masses believed to mark the root zone of a volcanic pile.

These kinds of deposits and structural or lithologic controls are typical of mineral occurrences in nearby mountains, which have produced at least a moderate amount ($1–10 million) of lead, copper, zinc, silver, or gold. For example, base metals and silver were mined from vein and replacement bodies in strongly faulted Paleozoic and Mesozoic rocks near northwest-trending strike-slip faults in the central Peloncillo Mountains, 40 km east of the Dos Cabezas (fig. 1, site 8). Some of these deposits are near an Oligocene granite stock, near rhyolite dikes or plugs, or in the root area of a Paleocene to Eocene andesitic to dacitic volcanic pile (Armstrong and others, 1978; Drewes and Thorman, 1980a, 1980b; Elston, 1963; Gillerman, 1958; Lindgren and others, 1910; Richter and Lawrence, 1983).

Likewise, a large amount ($10–100 million) of copper, lead, zinc, silver, and gold was produced from the Lordsburg and Animas mining districts in the Pyramid Mountains, 70 km east of the Dos Cabezas Mountains (fig. 1, site 9). These metals were obtained mainly from vein deposits in a Paleocene granodiorite stock and its Upper Cretaceous to Paleocene andesite volcanic host rocks (Anderson, 1957; Clark, 1970; Flege, 1959; Lasky, 1939; Lindgren and others, 1910; Thorman and Drewes, 1978; Richter and Lawrence, 1983; U.S. Bureau of Mines, 1978), which also appear to have been the root zone of a volcanic pile of late Cordilleran orogeny time, but one exposed at a deeper structural level.

The features of the mineralized areas of the Dos Cabezas Mountains also have aspects in common with those at Johnson Camp, part of the Cochise mining district in the Little Dragoon Mountains, 50 km west of the Dos Cabezas (fig. 1, site 3). Base metals were produced in a moderate amount from veins, disseminated deposits, and replacement deposits in deformed Paleozoic metasedimentary rocks near a Paleocene granitic stock (Cooper and Silver, 1964; Keith, 1973).

Similar geologic features occur in the Courtland-Gleeson mining camps, 70 km southwest of the Dos Cabezas Mountains (fig. 1, site 6). Base-metal deposits there are also of moderate or large size and include replacement and skarn deposits largely in deformed Paleozoic sedimentary rocks. Some vein, disseminated, and stockwork deposits also occur in an andesitic to dacitic host rock that contains large blocks of the sedimentary rocks and in some Jurassic granite. These rocks are intricately faulted on low-angle structures that probably include both thrust and glide faults of tectonic and volcano-tectonic origin (Gilluly, 1956; Keith, 1973; Drewes, 1981).

This review of the setting of the Dos Cabezas Mountains suggests that the mineral occurrences there are typical of many other areas in southeastern Arizona and southwestern New Mexico. Indeed, in similar magmatic and structural settings, similar mineral occurrences should be expected. At several of these mineral occurrences near the Dos Cabezas, considerably more production has taken place and is focused on porphyry copper deposits. Some of the geological, geochemical, and geophysical features of the Dos Cabezas Mountains are viewed to be suffiently favorable for the location of more ore deposits and perhaps also for large-tonnage low-grade types of deposits. These features are described in the following sections.

GEOLOGY

The central part of the Dos Cabezas Mountains, that part in which most signs of mineral enrichment are found, is underlain by large bodies of igneous rock and by some metamorphic and sedimentary rocks, shown on figure 2. While most of the large igneous bodies are massive, a few of these bodies, and, especially the sedimentary rocks, have a marked northwest-trending structural grain. Deformation of rocks of the central Dos Cabezas is mostly minimal, but locally folds and faults are abundant, and the intensity of faulting is particularly marked along the Apache Pass fault zone. This fault zone, some structures splaying off it, and the tilt of major structural blocks away from the fault zone, which has oriented bedding parallel to it, provide much of the northwest grain of the area. Additionally, faults probably lie along both flanks of the range, controlling its physiographic trend and enhancing the structural grain. The following description of these rocks and structures focuses mainly on features believed to be germane to the occurrence of mineral deposits.

Stratigraphy and Petrography

The rocks of the central Dos Cabezas Mountains include more Precambrian units and fewer Paleozoic and Mesozoic units than occur in most nearby ranges, and the Tertiary rocks are largely of early Tertiary age (table 1 and detailed maps of Drewes, 1984, 1985) rather than mid-Tertiary age. However, not all rock units or formations within these suites are equally important to an assessment of the mineral potential of the area. Most significant perhaps are some of the older of the Paleozoic formations, the Upper Cretaceous and Paleocene dacitic and andesitic breccia bodies and granitic stocks, and the mid-Tertiary dikes and veins.

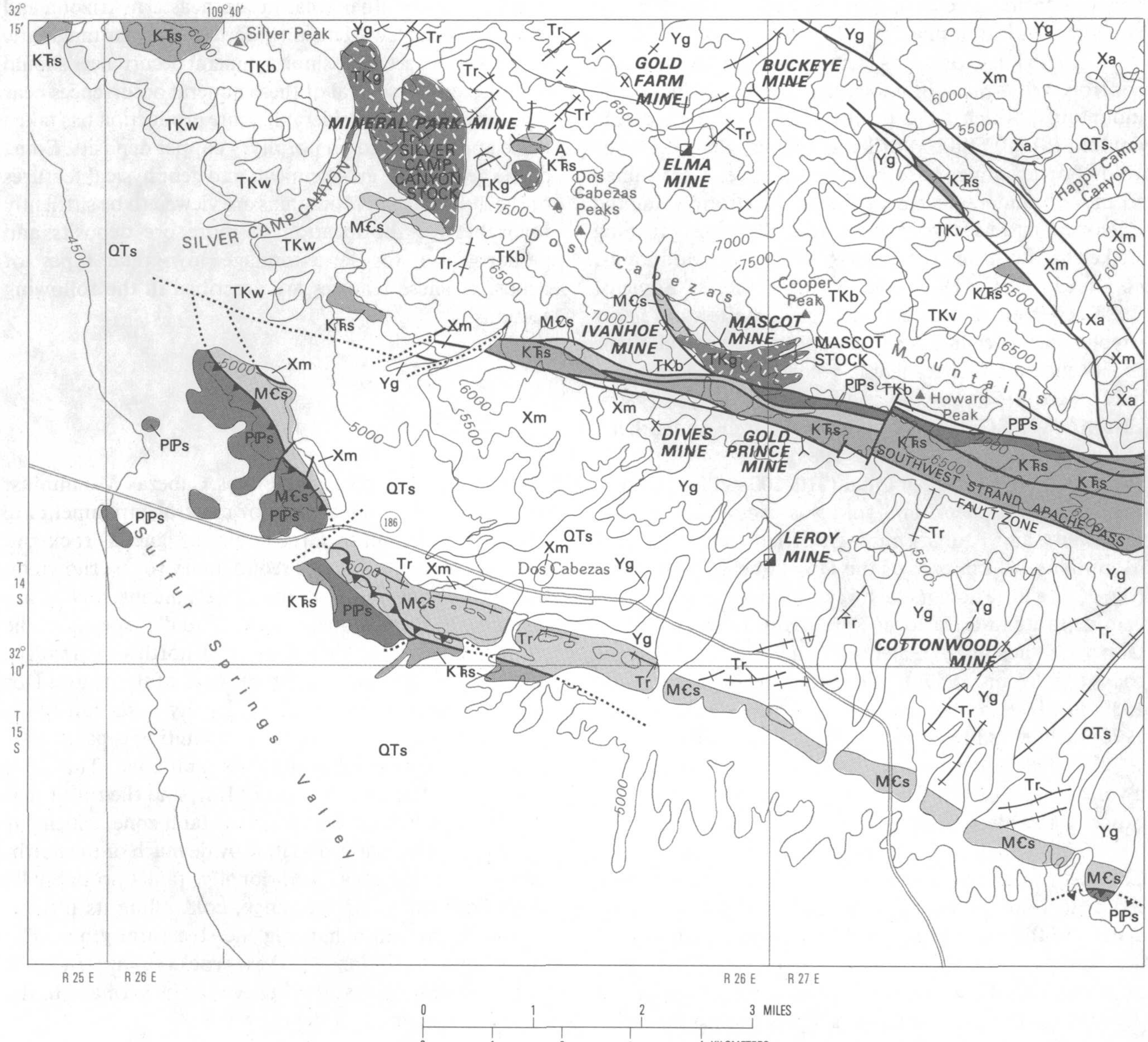
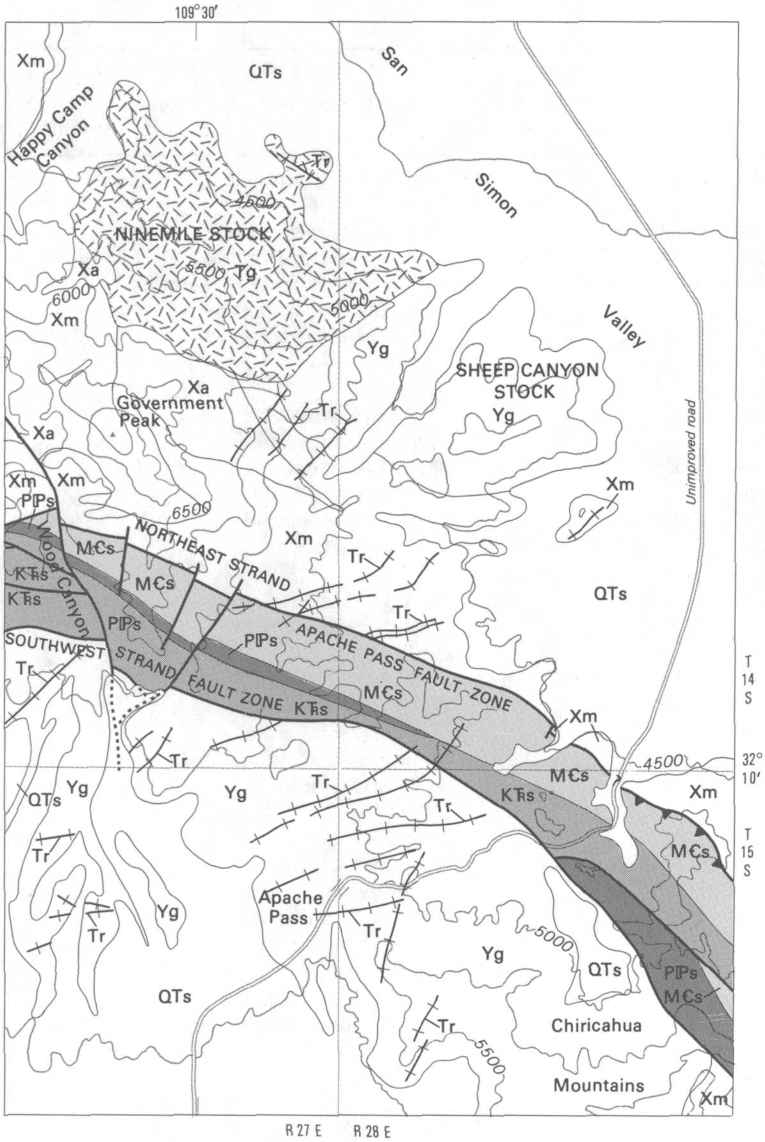


Figure 2(above and facing page). Generalized geologic map of the Dos Cabezas Mountains.

Precambrian Rocks

Crystalline rocks of Precambrian age are widely exposed and make up the basement suite of the Dos Cabezas Mountains (fig. 2; pl. 1). The oldest formation is a thick sequence of abundant phyllite, metagraywacke, and metavolcanic rocks and of some interbedded metaquartzite and conglomerate that collectively are known as the Pinal Schist (fig. 2). The Pinal underlies moderately large areas on both sides of the Apache Pass fault zone, although these areas are not continuous across the fault zone. Furthermore, masses of Pinal closest to one another across the fault zone vary in dominant lithology or internal structural style. From these signs of apparent displacement of the Pinal terranes, the Apache Pass fault zone appears to have had a considerable lateral component of movement. Not only are these rocks structurally informative, but their lithologic diversity has strongly influenced their geophysical signatures, and so they are described here in some detail.

Most Pinal rocks are of somber appearance in outcrop, underlying moderately steep to gentle slopes that have numerous small brownish-gray rock ledges and knolls, rocky gulleys, and a general veneer of phyllitic detritus. The metaquartzite is an exception, for it is usually nearly white and underlies moderately bold to extremely bold outcrops. The typical Pinal rock is fine grained and has a phyllitic foliation parallel to the few relicts of



CORRELATION OF MAP UNITS

QTs	QUATERNARY AND TERTIARY
Tr, Tg	TERTIARY
TKg, TKw, TKb, TKv	TERTIARY TO CRETACEOUS
KTRs	CRETACEOUS TO TRIASSIC
PIPs	PERMIAN AND PENNSYLVANIAN
M€s	MISSISSIPPIAN TO CAMBRIAN
Yg	MIDDLE PROTEROZOIC
Xa, Xm	EARLY PROTEROZOIC

DESCRIPTION OF MAP UNITS

QTs **Sediments (Quaternary and Tertiary)**—Sand, gravel, and silt of alluvial aprons, fans, terraces, and pediment deposits

Tr **Rhyolite (Miocene and Oligocene)**—Felsitic to sparsely porphyritic dikes, dated as 25.0 m.y. (Drewes, 1985)

Tg **Granite (Oligocene)**—Stock, dated as 29.0 m.y. (Erickson, 1968)

TKg **Granite to granodiorite (Paleocene to Upper Cretaceous)**—Stocks, dated as 59.2-64.3 m.y. (Erickson, 1968 and 1981)

TKw **Welded tuff (Paleocene to Upper Cretaceous)**—Upper rhyodacitic ash-flow sheet

TKb **Volcanic breccia (Paleocene to Upper Cretaceous)**—Dacite to rhyolite vent and flow(?) breccias, mostly strongly altered. Includes some intrusive porphyry masses

TKv **Volcanic rocks (Paleocene to Upper Cretaceous)**—Andesitic to dacitic flow and lower rhyodacitic ash-flow sheet

KTRs **Sedimentary rocks (Lower Cretaceous to Triassic)**—Sequence of Triassic or Jurassic Walnut Gap Formation (conglomerate, shale, and siltstone), and Lower Cretaceous Bisbee Group (conglomerate, shale, sandstone, some limestone)

PIPs **Sedimentary rocks (Pennsylvanian)**—Sequence of Permian Concha Limestone, Scherrer Formation (sandstone), Epitaph Dolomite, Colina Limestone, and Earp Formation (marlstone and siltstone), and Pennsylvanian Horquilla Limestone

M€s **Sedimentary rocks (Mississippian to Cambrian)**—Sequence of Mississippian Paradise Formation (shale and limestone), Mississippian Escabrosa Limestone, Devonian Portal Formation (shale and limestone), Ordovician El Paso Dolomite (dolomite, limestone, and siltstone), and Cambrian Coronado Sandstone (sandstone, quartzite, and conglomerate)

Yg **Granitic rocks (Middle Proterozoic)**—Porphyritic and phaneritic granodiorite, quartz monzonite, and granite plutons and smaller bodies of aplite, diorite, and diabase. Dated at 1,375-1,450 m.y. (Erickson, 1968)

Xa **Amphibolitic rock (Early Proterozoic)**—Amphibolite, metadiorite, and metadiabase

Xm **Metamorphic rocks (Early Proterozoic)**—Phyllite, metagraywacke, metaquartzite, conglomerate, and andesitic or dacitic flow breccias and lava flows, all of the Pinal Schist, and some small intrusive bodies

Contact—Dotted where covered

Normal or Strike-slip Fault—Dotted where covered. Ball and bar on downthrown side. Arrow-couple shows relative movement

Thrust Fault—Dotted where covered. Sawteeth on upper plate

Mine Shaft

Adit

X **Prospect**

Table 1. Stratigraphic summary of Dos Cabezas Mountains

Age	Formation	Map symbols: This report	Map symbols: Drewes, 1984, 1985a, 1985b, and others	Description	Thickness[1], in meters, mostly 10%
Quaternary and Tertiary	Sedimentary deposits	QTs	Tg, QTg, QGT, Qg	Gravel, sand, and silt	Unknown
Tertiary and Cretaceous	Unnamed rocks of the Dos Cabezas volcanic pile	TKw	TKw	Rhyodacitic welded tuff	200
		TKb	TKd, TKrb, TKde	Breccias, dacite-rhyolite	Unknown
		TKv	Tkr, TKdl	Rhyodacitic welded tuff and dacite-latite lava flows	300
Late Cretaceous(?)	Unnamed formation	Mzs	Ksv	Sedimentary and volcanic rocks	500
Early Cretaceous	BISBEE GROUP:				
	Cintura Formation	Mzs	Kc	Shale and sandstone	1,700
	Mural Limestone	Mzs	Kmu	Limestone and shale	
	Morita Formation	Mzs	Km	Shale and conglomerate	
	Glance Conglomerate	Mzs	Kg	Conglomerate	
Jurassic or Triassic	Walnut Gap Formation	Mzs	JTR w	Shale, siltstone, and conglomerate	0–50+
Early Permian	NACO GROUP:				
	Concha Limestone	P ℙs	Pcn	Dark gray, cherty	250
	Scherrer Formation	P ℙs	Ps	White sandstone	50
	Epitaph Dolomite	P ℙs	Pe	Dark dolomite	165
	Colina Limestone	P ℙs	Pc	Dark gray, sparse chert	
	Earp Formation	P ℙs	Pea	Marlstone, siltstone	1,200
Early Permian and Pennsylvanian	Horquilla Limestone	P ℙs	P ℙh	Limestone and red siltstone	
Late Mississippian	Paradise Formation	MꞒs	Mp	Shale and limestone	0–40
Mississippian	Escabrosa Limestone	MꞒs	Me	Dark and light, crinoidal	190
Late Devonian	Portal Formation	MꞒs	Dp, Dm, Ds	Shale and limestone	75
Early Ordovician	El Paso Dolomite	MꞒs	Oe	Dolomite and limestone	100
Late Cambrian	Coronado Sandstone	MꞒs	Ꞓcm Ꞓb	Quartzite, sandstone, and basal conglomerate (equivalent to Bolsa Quartzite to west)	150
Early Proterozoic	Pinal Schist	Xm	Xp, Xpv, Xpq	Phyllite, metagraywacke, metaquartzite	Unknown (very thick)

[1]Thickness typically estimated from structure sections of nearby ranges or measured at a few specific localities, not all within study area, such as those by Sabins (1957a), and some which are inadequately supported by detailed mapping.

bedding that are preserved. These include lentils of subgraywacke sandstone and a small amount of coarser clastic material, some of which contains volcanic clasts like those of the associated metavolcanic sheets.

Metavolcanic rocks abundant enough to be separated in mapping (Drewes, 1984, 1986a, 1985b) include flow breccia, some massive flows or intrusives, and volcanic grit and conglomerate beds. Probably these are of an intermediate composition—dacite or andesite—for they are dark colored, contain much altered ferromagnesian minerals, and have little or no quartz.

The Pinal of the Dos Cabezas area is metamorphosed to a low greenschist(?) grade, probably after the propylitic alteration of the volcanic material. This metamorphic grade, however, might reflect a retrograde condition as well as a prograde one, an uncertainty marking one limit of the petrographic study.

The nearly white metaquartzite is interbedded in the phyllitic rocks of the Pinal mainly near Government Peak, located northeast of the Apache Pass fault zone, and north of Dos Cabezas village, situated southwest of the fault zone. At Government Peak the metaquartzite comprises some rock sequences hundreds of meters thick, but at the village the sequences are mostly only a few tens of meters thick, except where secondary flowage may have occurred near fold crests. The quartzite is subtly bedded and in many places graded bedding, crossbedding, and other primary structures are preserved despite the metamorphism. On the more detailed quadrangle maps, top-of-bed controls are shown in order to indicate that overturned beds are rare.

An amphibolitic variety of basement rock forms sills and small pods in the Pinal Schist near Government Peak in the southeastern part of the mountains (unit Xa, fig. 2). These rocks are dark greenish gray, fine to medium grained, and commonly foliated like their host rock. This amphibolitic rock may have been emplaced as a diorite or a diabase protolith, but the metamorphism producing the foliation has obscured this petrograhic distinction. The amphibolite or metadiorite of the central part of the Dos Cabezas is rich in amphibole and also contains biotite, titaniferous magnetite, plagioclase, and in some rocks a small amount of quartz and of sphene replaced by leucoxene.

The Pinal Schist is intruded by large plutons of granitoid rock. Typically, these rocks are brownish-gray, very coarse grained, massive granodiorite or granodiorite porphyry; some are quartz monzonite or granite, and smaller bodies included with the plutons are aplite, diorite, and diabase. Granodiorite of some bodies, such as the Sheep Canyon stock on the northeast flank of the range, underlie a moderately rugged terrane which has some large cliffy areas and rugged canyons. Other granodiorite, such as the mass on the southwest flank, underlies a gentle terrain of grus-veneered slopes and scattered low knobs and ridges.

The petrography of these Precambrian granitoid rocks is typical of the petrography of many other granitoid rocks of this age in southeastern Arizona. Microcline phenocrysts or porphyroblasts may be as much as 1 cm long and make up 5–10 percent of the rock. Typically, the rocks comprise, in percent: plagioclase, 25–45; microcline, 15–35; quartz, 25–45; biotite, 3–12; magnetite, 0.5–1.0; apatite, 0.05–0.4; sphene, trace-0.5; and zircon, trace-0.2. Erickson (1968) describes some of these rocks as rapakivi granite. Mostly, the minerals are assembled in a typical granitic hypidiomorphic granular texture, but near Dos Cabezas village, a felty texture and bimodal grain size, indicative of metamorphism, has been superposed upon the primary texture. These granitoid rocks have been dated as 1,375 and 1,450 m.y. old, using Rb-Sr whole-rock isochrons (Erickson, 1968).

Paleozoic Rocks

Paleozoic sedimentary rocks unconformably overlie the basement rocks. They occur along two northwest-trending belts in the southwest flank of the Dos Cabezas Mountains and in some scattered masses in the central part of the mountains (fig. 2). These rocks are essentially unaltered, except in the northwestern part of the Apache Pass fault zone and in the scattered masses occurring within the dacitic volcanic field. Where the rocks are metamorphosed along the fault zone, the basal contact is also faulted; at least some faulting postdates metamorphism. On figure 2, because of the scale, the Paleozoic rocks are shown only as two map units, essentially upper and lower Paleozoic.

The Upper Cambrian Coronado Sandstone, referred to in some earlier studies on this area as the Bolsa Quartzite, marks the base of the Paleozoic sequence and the top of the sequence is the Lower Permian Concha Limestone. The sequence is about 2,500 m thick, although in the northeastern belt it is commonly reduced to less than half that thickness through compression, flowage, and recrystallization.

The Coronado is mainly a sandstone and quartzitic sandstone; at the base is some lenticular basal pebble and cobble conglomerate, and near the top is some interbedded siltstone. Most clasts of the basal conglomerate are derived from the Pinal metaquartzite. Much of the sandstone is arkosic, and some of it is glauconitic. Sabins (1957a) provides further description of these rocks from local study, and Cooper and Silver (1964) and Gilluly and others (1954) describe the correlative Bolsa Quartzite in the next ranges to the west.

Conformably overlying the clastic rocks are mainly carbonate units. These include, in order of decreasing age, the Ordovician El Paso Dolomite of dolomite, limestone, and some sandstone and siltstone; the disconformably overlying Devonian Portal Formation (Sabins, 1957) of thin-bedded limestone and shale and some dolomitic rock that suggests a lithologic transition with the Devonian Martin Formation of the next ranges to the west. Mississippian Escabrosa Limestone, the next younger unit in the sequence, consists of alternating thick-bedded, light-gray coarse-grained crinoidal, cherty limestone and medium-bedded, medium-gray, fine-grained, in part cherty limestone. To the southeast where the Apache Pass fault zone is broad and the rocks less altered, these light- and dark-gray units are separately mappable, but from place to place their number and order vary, making it impractical to retain the formal subdivision proposed at some localities in ranges to the east (Armstrong and others, 1978).

The Upper Mississippian Paradise Formation, which consists chiefly of fissile shale and shaley limestone, overlies the Escabrosa in the northeastern belt of sedimentary rocks but is absent in the southwestern belt. It thickens and is widespread east of the Dos Cabezas Mountains but is absent to the west. Its disappearance between the two sedimentary belts may be no more than a normal stratigraphic facies change. However, since changes also occur between younger formations of these belts, structural juxtaposition, described in the section on structural geology, may be indicated.

In much of the area, Horquilla Limestone is the youngest Paleozoic unit beneath the Mesozoic sequence, and, indeed, in most places, only the lower or Pennsylvanian part of this unit is recognized. Typically the limestone is light gray, thin to medium bedded, cherty, and fossiliferous. In the few places where some of the Permian part of the formation occurs, such as east of Dos Cabezas village, the limestone has thin interbedded units of reddish-gray shale. The Permian Earp Formation of siltstone and marlstone is known only from a fault slice along the Apache Pass fault zone. Still younger Permian formations, the Colina Limestone, the Epitaph Dolomite, the Sherrer Formation of fine-grained quartzitic sandstone, and the Concha Limestone, occur very locally at Apache Pass (Sabins, 1957b; Drewes, 1984) but are more widespread in other ranges west, south, and southeast of the Dos Cabezas Mountains.

Mesozoic Rocks

The local Mesozoic sedimentary sequence represents only a small part of Mesozoic time; most of that time is represented by unconformities. Also the Mesozoic sequence varies between the two outcrop belts of sedimentary rocks as well as between structural blocks along the northeastern belt. Apparently this variability reflects both changes in initial depositional history and in subsequent deformational history.

At the base of the local Mesozoic sequence is the Triassic or Jurassic Walnut Gap Formation, which is otherwise known only in the next few ranges to the west. In the study area, the Walnut Gap Formation occurs only in the southwestern outcrop belt west of Dos Cabezas village. These rocks comprise a deep-red to purplish-red, poorly indurated shale, siltstone, and some interbedded pebble conglomerate. Exposures are inadequate to determine internal sequence or thickness of this unit; in any case, its base is faulted and its top is either eroded or also is faulted and, thus, our knowledge of the unit is incomplete. Pebbles in the conglomerates are subrounded fragments of limestone and chert, derived from Paleozoic formations, and of purplish-gray hornblende and feldspar porphyry dacite. Potential source rocks for these volcanic clasts are locally unknown. However, early Mesozoic volcanic rocks occur in the Mustang Hills (Hayes and Raup, 1968) and the Santa Rita Mountains (Drewes, 1971), respectively 90 and 115 km to the southwest, and so correlative volcanic rocks may have occurred nearby.

The Bisbee Group of Early Cretaceous age overlies the Walnut Gap Formation, probably disconformably. The Bisbee comprises, in rising order, the Glance Conglomerate, the Morita Formation, the Mural Limestone, and the Cintura Formation. Together, these formations may be 1,700 m thick.

A massive, medium-gray, limestone-cobble conglomerate assigned to the Lower Cretaceous Glance Conglomerate is the basal formation of the Bisbee Group. The basal contact of the conglomerate is inferred from the common regional relations to be a disconformity, but because the contact is covered and overlying bedding obscured, it may prove to be an angular unconformity or even a fault. Along the southwestern belt, the formation is at least 50 m thick, and it may be much thicker in the nearby subsurface beneath a cover of alluvial deposits. Along the northeastern belt, the Glance is mostly absent but is present and thin at Apache Pass. The clasts of the Glance are subrounded to subangular; they were probably derived from erosion of the Paleozoic rocks, particularly the Horquilla Limestone.

The Glance Conglomerate is overlain in sequence by the Morita Formation, the Mural Limestone, and the Cintura Formation. The Morita and Cintura are mainly drab-colored—gray, brown, or olive—siltstone and shale. Both formations contain interbedded sandstone units, and those of the Cintura include some well-indurated light-brownish-gray quartzitic units. Near the stratigraphic level of the Mural Limestone, both the Morita and Cintura also have some thin interbedded, limestone lentils. The Morita of this area contains scattered beds of limestone pebble conglomerate, not only near the bottom of the formation, as is the case in most nearby sections, but throughout the entire formation. The Morita and Cintura are both thick formations, but faulting and shearing probably make thickness measurements of uncertain value until their internal sequences are better known.

The Mural Limestone is a medial zone of clustered limestone beds within the dominantly clastic Lower Cretaceous sequence. Light-gray, fine-grained, locally mollusc-bearing, calcilutite beds and lentils make up only about half of the Mural of this area; siltstone, sandstone, and even some conglomerate are also present. Upper and lower contact of the Mural are gradational. The reefal limestone and massive limestone which is so characteristic of the Mural south of this area are absent in the Dos Cabezas Mountains.

The Bisbee Group is overlain by an unnamed dark-gray or greenish-gray sedimentary and volcanic unit of probable Late Cretaceous age. This unit includes volcaniclastic or subgraywacke sandstone, shale, and conglomerate that is largely made up of angular pebbles of andesitic or dacitic volcanic material. The unit resembles the Fort Crittenden Formation to the west (Drewes, 1971), the formation at Javalina Canyon of Epis (1956) to the south, and the Ringbone Formation to the east (Zeller, 1970).

Mesozoic rocks are more abundant and more varied along the northeastern sedimentary belt than the southwestern belt. Some of this abundance and variability along the northeastern sedimentary belt may be due to the faulting along the Apache Pass fault zone which breaks the rocks into large lozenge-shaped blocks (fig. 2). Of particular interest here are the lithologic variations of some of the Mesozoic rocks from block to block.

In the segment of the Apache Pass fault zone between Wood Canyon and Howard Peak, there are two large structural blocks and several small ones containing various rock sequences. A small block along the northeast strand of the fault zone and near Wood Canyon has the standard Cambrian to Pennsylvanian sequence overlain by thin Morita, Mural, and some Cintura, but Glance is absent, apparently due to nondeposition. At Howard

Peak in another small block along that strand, Cretaceous rhyolite (welded tuff?) is associated with a sliver of Glance. The large block along the center of the fault zone has some of the upper of the Paleozoic formations, thick Glance, thick Morita, and Upper Cretaceous andesite flows. Finally, the large slice along the southwest strand of the fault zone is made up entirely of Upper Cretaceous sedimentary rocks. Clearly these sequences have been tectonically juxtaposed.

Northwest of the Howard Peak, structural blocks are smaller and more elongate. The Mesozoic rocks among the blocks include parts of the Upper Cretaceous volcanic and sedimentary rocks and probably of the Lower Cretaceous Cintura Formation, which is the uppermost part of the Bisbee Group. The absence here of older formations of the Bisbee is probably the result of faulting, but relations along the sub-Bisbee unconformity may be a factor, too.

In general, from the northwestern end of the Chiricahua Mountains, through the central part of the Dos Cabezas, and to the northwestern part of the Dos Cabezas, the sub-Bisbee rocks are progressively older, respectively dropping in stratigraphic level from the Permian to the Pennsylvanian to the Precambrian. The juxtaposition of structural blocks containing various parts of the Mesozoic sequence complicates the inference from stratigraphic relationships that the Bisbee deposits lapped against a highland centered to the northeast.

Mesozoic rocks also occur in the large blocks exposed within the dacitic volcanic pile. However, they are so strongly metamorphosed that even their identity remains tentative. Their tentative identity combined with the uncertainty of their position, before volcanism, discourages speculation on the initial appearance of these Mesozoic masses and on their relationships to adjacent Paleozoic formations.

Latest Cretaceous and Paleocene Rocks

Dacitic to rhyolitic volcanic rocks and granodioritic to granitic plutonic rocks are both widespread in the Dos Cabezas Mountains and probably are genetically closely related to mineralization. These rocks, like their correlative rocks in surrounding ranges, are less deformed than the older rocks so their emplacement was probably separated from the deposition of the older rocks by a period of deformation. Regional studies (Drewes, 1976, 1978, 1981) show that this deformation is part of the widespread Cordilleran orogeny, also referred to locally, with less precision, as the Laramide orogeny. These volcanic and plutonic rocks of the Dos Cabezas, then, are late orogenic or early post-orogenic rocks. Whereas the tectonic effects of this orogeny on the Dos Cabezas rocks are less severe than on rocks of the areas south of the Dos Cabezas, the late orogenic or early post-orogenic magmatic effects are equally strong in the Dos Cabezas and the southern, more deformed terrane. The persistence of magmatic effects may reflect the presence of the major structure of the Apache Pass fault zone, which provided easy egress for both magmas and hydrothermal fluids.

At their present level of exposure, the volcanic rocks of the latest Cretaceous and Paleocene suite are much more abundant than the plutonic rocks. The volcanic rocks comprise a basal and capping rhyodacitic ash-flow tuff and a thick, extensive, composite mass of flow breccia and intrusive breccias of dacitic composition. In the absence of chemical analyses of the unaltered volcanic rocks, which are unavailable, these descriptions of composition are tentative, based on color, abundance of amphibole and quartz, and kind of alteration.

The volcanic pile forms an elongate mass with its southwest side in linear juxtaposition for 13 km along the Apache Pass fault zone and its northeast side curvilinear. The pile is 3 km wide in the central part of the Dos Cabezas Mountains. The oldest rocks of the pile occur to the east in Happy Camp Canyon; the youngest appear to the west near the mouth of Silver Camp Canyon. While these rocks provide a gross bedding characteristic that dips gently west, characteristically the rocks of the volcanic pile are massive.

Thick dacite to latite flows, commonly having an autoclastic breccia structure, overlie Upper Cretaceous sedimentary and volcanic rocks of the upper reaches of Happy Camp Canyon (fig. 2). This unit is a few hundred meters thick near the center of its outcrop area, but it thins rapidly to a few tens of meters along its north-south trace, as if it filled a depression on the subvolcanic surface, or possibly was deposited coevally with faulting. Lentils of conglomerate separate some flows, and the clasts of one lentil include Precambrian granite, suggesting that a source area nearby had already been sufficiently uplifted and eroded to expose the basement beneath Paleozoic and Mesozoic sedimentary cover. A petrographic thin section of a flow breccia fragment shows the rock to contain about 20 percent small phenocrysts of two types of feldspars and some quartz, altered biotite, and magnetite, which are set in a faintly flow-laminated cryptocrystalline matrix and about 10 percent lithic chips, which include sandstone and siltstone, probably derived from the Cretaceous formations.

Pale-yellowish-gray to brownish-gray, crystal-lithic, welded, ash-flow tuff overlies the basal lava flows, and another similar ash-flow tuff caps the volcanic pile. The lower sheet is several hundred meters thick, apparently reflecting proximity to source or indicating topographic impoundment. While most of the tuff is massive near the tops it has thin interbedded gray volcaniclastic sandstone and sedimentary breccia, which show that the tuff is a composite of several ash flows. In composition the tuff is probably a rhyodacite. It contains about 20 percent phenocrysts, mainly of quartz, feldspar, biotite(?), and amphibole, and also trace amounts of smaller crystals of magnetite, apatite, and zircon. Their matrix is devitrified glass that contains relict shard structures and flattened pumice fragments. Lithic fragments resemble the underlying dacitic or latitic rocks and also the sandstone or siltstone. In outcrop appearance, the capping ash-flow sheet resembles the lower one, except the sandstone or siltstone lithic fragments are absent, but petrographically the capping sheet differs from the lower one in that albite and potassium feldspars are present and amphibole is absent.

The main part of the volcanic suite of latest Cretaceous and Paleocene age comprises extrusive and intrusive dacitic breccias. Breccias commonly are purplish gray, bluish gray, or greenish gray, and they contain fragments 1-10 cm across, surrounded by finely pulverized dacitic material, all of which is indurated and altered. In thin section, dacitic fragments are seen to contain plagioclase and amphibole phenocrysts and some smaller crystals of biotite, apatite, and zircon. The groundmass probably contains much plagioclase and amphibole; however, alteration is so strong that petrographic study, chemical analysis, and radiometric dating would lead to results of uncertain value.

We obtained dates of the dacitic breccias on zircon by the fission-track method; several different dates of 20.5 and 27.0 m.y. (C. W. Naeser, written commun., 1981) are neither in agreement with each other nor with the age relations to intruding granitic rock in the Simmons Peak quadrangle (Drewes, 1986a; Erickson, 1968). The young dates obtained from the dacitic breccias apparently indicate effects of another thermal event postdating initial emplacement, an event perhaps related to the emplacement of the mid-Tertiary Ninemile stock and to the assorted veins and dikes.

Irregular pipe-like and vertical sheet-like masses of a latitic, rhyodacitic, or rhyolitic breccia appear to intrude the dacitic breccias. Where field relations do not show crosscutting relations between the breccias, these rocks intermingle as if they were cogenetic. Rhyolitic breccia masses near Dos Cabezas and Cooper Peaks suggest possible sites of individual volcanic centers. The rhyolitic rocks are nearly white to very pale orange, and the size of fragments is commonly smaller than those of the dacitic breccias. Where quartz is present as small phenocrysts, the color change of the rhyolitic breccia masses probably reflects primary compositional variation. In other rocks of light color that do not contain quartz, the color may simply reflect differences in kind or intensity of alteration. However, more detailed study could reveal that the observed presence of blocky quartz is not everywhere a diagnostic feature of primary composition of the breccia, for several sources of quartz and generations of quartz may be expected in rocks whose alteration and brecciation is intense. In thin section, the rhyolitic rocks are seen to have not only quartz phenocrysts, but also one or two kinds of feldspar plus biotite and small crystals of magnetite, apatite, and zircon.

Mixed dacitic and rhyolitic breccia forms a pipe-like body 1 km in diameter southwest of the Elma mine. The mixing is on an outcrop-to-outcrop scale, with masses of each kind a few meters to tens of meters across alternating irregularly throughout the pipe, and yet rarely showing a sharp contact with each other.

Some breccia pipes are mapped as exotic-block breccia, because they contain sedimentary fragments among the predominant dacitic clasts. Typically, these sedimentary clasts are of limestone, dolomite, quartzite, or sandstone, derived from Paleozoic or Mesozoic formations. Such indications of the rock types that may underlie the volcanic pile could have important implications for projecting mineralized ground. Most of the exotic fragments are the same size as the volcanic fragments of a given outcrop, but in a few places near Cooper and Dos Cabezas Peaks, quartzite and limestone fragments a meter to a few tens of meters across are scattered among the volcanic fragments that are typically 5-10 cm in size. A few of the largest blocks are shown by way of example on the Dos Cabezas quadrangle map (Drewes, 1985).

Hypabyssal intrusive rocks occur as plugs, as thick masses resembling segments of a ring dike, or as thin tabular dikes, which differ only subtly in appearance from the dacitic volcanic rocks which they intrude because they, too, are intensely altered. Northwest of Cooper Peak a large irregular-shaped plug of pale-brownish-gray, moderately coarse, and abundantly porphyritic biotite rhyolite (or rhyodacite?) intrudes dacitic breccia (Drewes, 1985). Its phenocrysts include chloritized biotite, amphibole, plagioclase, possible potassium feldspar, and quartz. The rock is friable in outcrop and therefore remains poorly exposed even on moderately steep slopes. The strong clay-mineral and sericite alteration along most margins of the body has given the rock a gradational appearance. Age relations between the plug and the mixed dacitic and rhyolitic breccia mass north of the plug remain uncertain. The phenocryst content and outcrop appearance of the plug and its relationship to the dacitic breccia are characteristics found in the granitic stocks of the Mascot and Silver Camp Canyon; presumably these rocks are genetically related.

Tabular masses of porphyritic rhyolite as much as 0.5 km thick form a discontinuous ring dike along the northeastern side of the volcanic pile. The masses have a vertical flow foliation that strikes northwest, parallel to the elongation of the masses and to the orientation of the volcanic pile as a whole. The rhyolite is pale yellowish gray to pale brownish gray and underlies moderately rugged slopes that generally contrast with the gentler slopes underlain by the nearby dacitic breccias and

Precambrian granodiorite. Phenocrysts in the rhyolite include quartz, one or two feldspars, and hydromica altered from biotite. Their groundmass is fine grained and commonly obscured by a clay-mineral and sericite alteration as intense as that of the rhyolite breccia masses northeast of Cooper Peak. In places, the rhyolite may even grade into a rhyolite breccia, by way of a rock type whose breccia texture is of microscopic size.

A few, thin (1-3 m), tabular dikes of andesitic or dacitic composition trend mostly northeast across the pile at the suspected volcanic centers near the Elma mine and Silver Peak (Drewes, 1985, 1986a). Other, shorter, less conspicuous dikes probably remain unrecognized. Thin tabular rhyolitic dikes in and near the Mascot stock are also believed to be closely related to the latest Cretaceous and Paleocene volcanic event, and distinct from the mid-Tertiary rhyolite dikes.

These hypabyssal bodies are probably transitional in position between the volcanic edifice at the surface and the stocks barely exposed in the highest cupolas that reached the basal volcanic level. The suspected ring dike masses were probably emplaced when the older volcanic rocks collapsed, somewhat in caldera-fashion, because of the loss of support above the main part of the magma chamber. The collapsed mass may have been controlled by splay faults of the Apache Pass fault zone during periods of reactivation. It is likely that the same changes in structural integrity and strength of the initial volcanic cap over the chamber led to the development of some of the breccia types, as well as to the upward movement of granodioritic magma into the two cupolas now exposed at the surface.

The volcanic pile is intruded by two small stocks of granodiorite to granite composition, the Mascot and Silver Camp Canyon stocks. Typically, the rocks are light gray and fine grained; they weather pale brownish gray and underlie gentle to moderately steep grus-covered slopes and moderately rugged small and bouldery outcrops. Fresh rocks are light gray and fine grained. Under the microscope, the rocks are seen to have a hypidiomorphic granular texture. Common minerals include, in percent: quartz, 14–17; plagioclase (An 30–35), 47–53; orthoclase, 16–22; biotite, 3–8; hornblende, 6–9; and pyroxene, 0–0.6. Accessory minerals are titaniferous magnetite, 1.5–2.0; apatite, 0.05–0.3; sphene, trace–0.05; and zircon, 0–0.1. The rocks commonly are moderately altered to clay minerals and sericite.

Granodiorite from the Silver Camp Canyon stock yielded a K-Ar date of 64.3±1.9 m.y. (Erickson, 1968 and 1981). Another stock, just north of the study area of the central part of the Dos Cabezas Mountains, was dated by Erickson at 59.2±1.7 m.y. The emplacement of these stocks, then, took place at the close of the Cretaceous or (and?) in early Paleocene time.

Many of the mines and mineralized areas are near the stocks, and others occur along quartz veins or fracture zones within a few kilometers of the stocks. Some of these deposits occur in tactite bodies formed where stocks cut the Paleozoic or Mesozoic sedimentary rocks. Other deposits are vein-type deposits, either formed within the stocks or near them, particularly along fracture zones in Mascot Canyon north of Dos Cabezas village. Still other deposits lie near suspected blind stocks whose presence is suggested by geophysical evidence described in the section on geophysics in this report. The physical association of these Upper Cretaceous and Paleocene igneous rocks with the mineralized rocks indicates a common genesis, and accordingly, the mineralization is believed to be a late orogenic feature of the Cordilleran event.

Mid-Tertiary Intrusive Rocks

The Ninemile granite stock of late Oligocene age intrudes the basement rocks east of the dacitic volcanic pile, and many rhyolite dikes of Oligocene to early Miocene age cut all the rocks types of the Dos Cabezas Mountains. The stock is barren and most of the dikes are barren also, but a few dikes in the central and northwestern part of the mountains are associated with mineralization.

The Ninemile stock is a subcircular granite body in the central part of the Dos Cabezas Mountains that extends northeast an unknown distance beneath the gravel deposits of San Simon Valley. It is cut by a swarm of Oligocene to Miocene rhyolite dikes and thus is Oligocene or older. Much of the granite contact with its host rocks dips gently outward to suggest that the top of the stock is exposed. The granite is light pinkish gray, moderately coarse grained, and moderately to strongly resistant to weathering. It typically underlies extensive outcrop surfaces, some subdued domical knolls, bald slabs, and some knobby- to bouldery-weathering terrain.

The granite is texturally and mineralogically similar to other mid-Tertiary stocks of the region. It has a hypidiomorphic granular texture and contains quartz (24-29 percent), plagioclase with An25–30 (38–51 percent), potassium feldspar (18–34 percent), biotite (4-9 percent), magnetite (0.5–0.9 percent), and trace amounts of apatite, zircon, sphene, and allanite. Most potassium feldspar is orthoclase, but a few grains have faint microcline twinning. Perthitic intergrowths are strongly developed; micrographophyre is sparse.

The granite yielded a K-Ar date on biotite of 29.0±1.7 m.y. (Erickson, 1968). Correlative stocks occur along or near the Apache Pass fault zone along the entire 40 km exposed length (Sabins, 1957a; Cooper, 1960; Drewes, 1982a, 1982b, 1984).

Many dikes and a few sills and plugs of rhyolite or felsite intrude all of the rocks types of the Dos Cabezas

Mountains as young as the granite of the Ninemile stock. These dikes typically cut northeast across the structural grain of the mountains, but along the two belts of sedimentary rocks and at a few other widely scattered sites dikes trend northwest. Most dikes are resistant to weathering and therefore form rock ribs or outcrop trains; some weaker dikes are friable enough to underlie depressed belts. The rhyolite is nearly white to very pale yellowish brown and weathers to small blocks or chips where not friable. It is either aphanitic or sparsely (1-5 percent) porphyritic, and its groundmass is very fine grained and strongly altered to clay minerals. Phenocrysts include quartz, biotite, sanidine(?), plagioclase, and magnetite.

One rhyolite dike from the pediment southwest of the mouth of Wood Canyon, southeast of the main part of the range, is dated at 25.0±1.3 m.y. by the fission-track method on zircon (Drewes, 1985). Another dike, of hornblende andesite porphyry, from northwest beyond the area of this study, is dated at 34.8 m.y. (Erickson and Drewes, 1984; originally reported as 33.1 m.y. by Erickson, 1968, based on old constants). Most of these dikes, then, are early Miocene, and a few may be late Oligocene.

In several places dike clusters may reflect concealed structural features. Eight kilometers southeast of Dos Cabezas village, one such dike cluster fans outward from a site having anomalously high aeromagnetic values (fig. 3, site 5). A second dike cluster, 2-3 km southeast of the village, changes trend from north-northeast to east-northeast near a similar magnetic anomaly. Genetic implications of these relationships are explored in the section on geophysics. A third cluster of dikes intrudes the volcanic pile and some adjacent metasedimentary rocks, following a straight pattern near the Elma mine and an arcuate one near the Ivanhoe mine. Where the swarm is straight, it trends southwest and lies along an enigmatic magnetic trough; where it is arcuate, it follows the curvature of rocks and faults splaying off the Apache Pass fault zone.

Young Surficial Deposits

Gravel, sand, and silt, of late Tertiary to Holocene age, fill the valleys next to the Dos Cabezas Mountains and lap onto their flanks. These deposits are typically unindurated to weakly indurated, and an immature soil is developed on some of the older ones. Clast types in these deposits closely reflect the rocks in the local drainages, and clast size reflects the variations of local relief. Pediments are not obviously present around much of the range, but southeast of Dos Cabezas village a veneer of gravel covers extensive areas of bedrock, and another pediment occurs at the northwestern end of the range, outside this study area. Regional gravity data, to be discussed in the section on geophysics, bear on the extent of pediment surrounding the range.

The surficial deposits locally contain placer gold in those canyons draining from areas of known auriferous veins and mineralized dikes. Production appears to have been small and relied on dry placer operations much of the time. The areas where surficial deposits conceal pediments provide few signs favorable of mineralization of the rocks beneath the gravel.

Structural Geology

The rocks of the central Dos Cabezas Mountains fall into two large structural terranes separated by a third terrane consisting of the Apache Pass fault zone. The two large terranes have only slightly different characteristics from each other; the third terrane has markedly different structural features. This three-fold structural division extends along the full 40-km length of the exposed segment of the Apache Pass fault zone (fig. 2; Drewes, 1982a and 1982b), but to the southeast the contrast between the three terranes is less pronounced, and a major thrust-fault system crosses the terranes oblique to the trend of the Apache Pass fault zone. Thus, in the central Dos Cabezas, the Apache Pass fault zone is the major feature critical to the structural development of the area and probably to the movement of magmas and hydrothermal fluids. Some smaller structural features also deserve attention because of their genetic ties to major structures of the northern part of the Chiricahua Mountains or to major structural events of nearby areas, but they are mostly too small to show on figure 2 and must be seen on the quadrangle maps (Drewes, 1984, 1985, and 1986a).

Southwestern Terrane

The structural terrane southwest of the Apache Pass fault zone is a southwest-dipping block made up of a crystalline basement exposed along its northeast side and southwest-dipping sedimentary rocks unconformably overlying the basement along its southwest side (fig. 3). Some of the crystalline rocks are tightly folded and faulted, and the sedimentary cover rocks are cut by a few low-angle faults and several sets of high-angle faults. While these folds and faults appear to be only local or minor features, they probably are responses to regional stresses of important structural events (Drewes, 1976, 1978, 1981).

Tight folds and steep faults deform the metaquartzite unit of the Pinal Schist 1-2 km north of Dos Cabezas village (fig. 3, point 1; Drewes, 1985). The folds have amplitudes of several hundred meters, axial planes nearly upright, and axes that strike northwest and are subhorizontal to southeastward plunging. Some folds have the attenuated limbs and thickened crests of similar folds; others are sheared by faults that seem to merge with

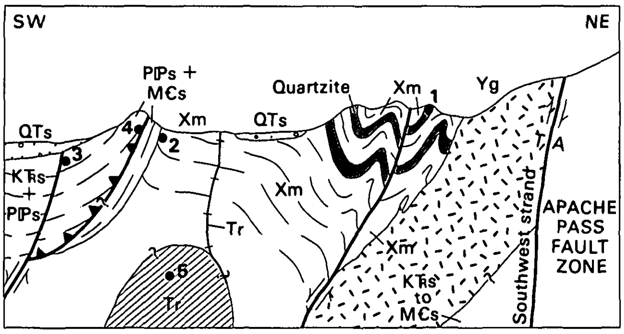


Figure 3. Diagrammatic section through the southwestern structural block near Dos Cabezas village. Points reviewed in text: 1, folded Proterozoic quartzite; 2, profound unconformity beneath Mississippian to Cambrian rocks; 3, normal fault along range front; 4, minor(?) bedding-plane thrust fault; and 5, blind Tertiary plug inferred from geophysical data. See figure 2 for explanation of rock units and symbols; arrows show relative movement on faults; T, movement toward viewer; A, movement away from viewer.

the structures of the Apache Pass fault zone. The southernmost of these folds are cut by the Precambrian granodiorite pluton.

While the origin of these folds remains uncertain, they appear to be of ancient age and were probably formed in a deep structural environment unlike any subsequently affecting the area. The plastic style of deformation suggests that the rocks were fairly hot during deformation, and thus folding may have occurred during metamorphism of the Pinal, presumably under deep cover and possibly during an ancient orogenic period. Activation of the Apache Pass fault zone late during this period is plausible, for the faults cutting these folds also seem to end near the Precambrian pluton which was emplaced during late or post orogenic times of this ancient event.

The profound angular unconformity between the basement rocks and capping sedimentary sequences reflects a regional uplift not recorded directly by local structural features (fig. 3, site 2). The peneplane conditions, following a period of deep erosion of the basement rocks, is widely recognized, but some local relief was preserved around ancient quartzite terranes, as recognized by Sabins (1957a). Some relief may also be indicated by the lenticularity of the basal conglomerate, rich in Precambrian quartzite clasts, of the Upper Cambrian Coronado Sandstone.

The sedimentary rocks overlying the unconformity dip moderately southwest and are cut by many northeast-trending short high-angle cross faults, a few northwest-trending long high-angle faults, and a few moderately dipping bedding-plane faults. The northeast-trending faults are concealed but have small offsets that may have formed through normal, strike-slip, or oblique-slip movement. If they are normal faults, they may have been formed through adjustment to local tensional stress during Basin-and-Range block faulting and tilting of the block. If they are strike-slip faults, they may be related to regional compressional stress predating the Basin and Range block faulting.

The few steeply dipping northwest-trending faults are possibly of several kinds, but they are so poorly exposed that interpretation relies largely on certain geophysical features and on regional structural considerations. These faults occur west of Dos Cabezas village and at the southeastern end of the belt of Paleozoic rocks (Drewes, 1985, 1986a) West and south of the village (fig. 3, point 3), younger Paleozoic and Mesozoic rocks are faulted down to the southwest against older Paleozoic rocks. Where this fault underlies gravel deposits its presence is shown by a steep gravity gradient. This partly concealed fault is inferred to be a range-front fault. This interpretation is adequate to the northwest, where the adjacent lower Paleozoic rocks dip only moderately and the steep fault cuts across the bedding of these rocks. However, to the southeast, where the lower Paleozoic rocks and faults both seem to be vertical and parallel, this interpretation is inadequate; perhaps there the structure is a steep thrust or reverse fault. This alternative view gains strength upon considering that only 10 km farther to the southeast, near Bowie Mountain, thrust faults are common features that trend northwest toward this segment of possible steep thrust or reverse fault. Indeed, the steep thrust or reverse fault may be part of the thrust fault system at Bowie Mountain and may be continuous with them beneath the alluvium. Accordingly, faulting at the southern end of the belt of Paleozoic rocks probably resulted from compressive stress, and if not as the main thrust fault, then as sympathetic minor reverse faults near a main thrust fault. The range-front fault likely cuts these thrust faults, inasmuch as they usually are the younger structures. Such a reverse fault response to compressive stress may help explain some features of the Apache Pass fault zone, too.

Bedding-plane faults that place younger rocks upon older ones occur in the Paleozoic rocks west of Dos Cabezas village (fig. 3, point 4), where they change in trend from west-northwest to north-northwest and approach the Apache Pass fault zone. The offset along cross faults here is larger than to the southeast of the village where there are no small bedding-plane faults, and a few small northwest-trending folds occur near the stratigraphic levels of the bedding-plane faults west of the village. Some cross faults abut one of the bedding-plane faults, showing they were formed simultaneously.

The origin of these structures is not clear from local relations alone. Such features typically occur with thrust faults of southeastern Arizona and southwestern New Mexico. Yet, in the Dos Cabezas they occur close to the

Apache Pass fault zone, whose dominant movement is believed to have been left lateral strike slip. Thrust-faulted terrane lies to the south (Drewes, 1980), both to the southeast in the Chiricahua Mountains (Drewes, 1982a, 1982b) and to the southwest in the Dragoon Mountains (Gilluly, 1956; Drewes, 1986b). The northern edge of the allochthonous terrane is believed to contain many strike-slip and oblique-slip faults, and the pre-frontal zone in south-central New Mexico has reverse faults that are believed to mark the outermost responses to compressive deformation (Drewes and others, 1982). Perhaps then, the deformation near the Dos Cabezas segment of the northern edge of the allochthon was oblique slip, and available older structures, such as the Apache Pass fault zone, just beyond the allochthon were locally reactivated as an oblique-slip and reverse-fault combination.

Northeastern Terrane

The structural block northeast of the Apache Pass fault zone contains remnants of the ancient folded terrane massively intruded by Precambrian granitic plutons, evidence of large recurrent uplift, and an extensive Late Cretaceous or Paleocene volcanic and plutonic center (fig. 4). Some of these structural features also occur in the southwestern block; others occur only in some nearby ranges, and none are unique to the region.

At widely scattered locations, the Pinal Schist in the northeastern terrane is folded. About 3 km north of Apache Pass, bedding and foliation are systematically flexed as if in a northwest-trending fold, or as if dragged along the fault zone that cuts the fold. A large north-trending syncline occurs in the Pinal Schist 6 km east of Apache Pass (Drewes, 1984). The east limb of this fold is concordant with a nearby Precambrian granitic pluton, and the west limb is cut by (or dragged along?) the Apache Pass fault zone. A foliation that parallels bedding is also folded. By way of contrast, the metaquartzite near Government Peak, resembling that near Dos Cabezas village in the southwestern block, is unfolded.

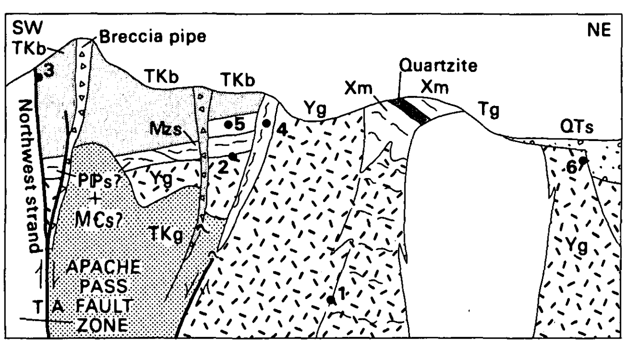


Figure 4. Diagrammatic section of the northeastern structural block near the Elma mine. Points reviewed in text: 1, Proterozoic late orogenic and post-orogenic plutons; 2, profound composite unconformity beneath Cretaceous to Triassic sedimentary rocks; 3, faulted southwestern margin of the volcanic field; 4, faulted and intruded (ring-dike segment) northeastern margin of the volcanic field; 5, basal ash-flow sheet of volcanic pile; and 6, normal fault along northeast front of the range. See figure 2 for explanation of rock units and symbols; arrows show relative movement on faults; T, movement toward viewer; A, movement away from viewer.

Several granitic plutons were emplaced in the Pinal largely after they were foliated (fig. 4, point 1). Both the irregular-shaped amphibolitic bodies near Government Peak and the elliptical granitic mass of the Sheep Canyon stock were emplaced during the waning phase of development of foliation. However, the stock cutting the fold 6 km east of Apache Pass and the one or several bodies north of Dos Cabezas Peaks are younger post-foliation (and possibly post-orogenic) granites.

The profound unconformity beneath the Paleozoic rocks of all three terranes is modified in the northeastern terrane by additional erosion (fig. 4, point 2). Paleozoic rocks are not seen to lie depositionally upon the basement rocks northwest of Apache Pass, but they are mostly faulted. In a few places they are rafted or faulted into rocks of the dacitic volcanic pile. For instance, the blind body of Paleozoic limestone that was host for some mineral deposits in the Elma mine is possibly an exotic block, or it may be in place at the base of the volcanic pile. This general absence of exposed Paleozoic rocks is illustrated at Camels Back Mountain, just northwest of the volcanic pile and the area of figure 2, where rocks from the middle of the Lower Cretaceous Bisbee Group lie depositionally directly upon the Pinal Schist. The sub-Bisbee unconformity here is a composite of the widespread sub-Paleozoic unconformity plus a post-Permian to pre-Lower Cretaceous unconformity. In other words, the effects of at least two periods of uplift and consequent erosion have reinforced each other. The area of pre-Bisbee uplift lies to the northeast, for Paleozoic rocks are still commonly present in the other directions but are absent in the area of the Burro arch of southwestern New Mexico (Thompson, 1982, fig. 3), a recurrently positive zone during at least Mesozoic time.

Structural features of the dacitic volcanic pile that are of potential interest to the distribution of mineralized rocks are mostly related to vent sites and marginal faults. However, the overall extent of the pile and its buried base are also of concern, although inferences about these features are particularly speculative. In plan view, the volcanic pile forms a segment of a circle of 12 km radius, whose chord is part of the northeast strand of the Apache Pass fault zone (fig. 3; Drewes and others, 1985). The volcanic mass thus stretches along the fault zone for 13 km but is only 3 km wide across the highest part of the Dos Cabezas Mountains. In structure section, across the width of the volcanic rocks, the pile is viewed as forming a downward-tapering, lopsided, conical frustum (fig. 4). These rocks possibly were deposited in a caldera that was strongly controlled by older faults and subsequently was cut by renewed movement on the Apache Pass fault zone. The southwest or fault-zone side of the pile is vertical (fig. 4, point 3), the northeast side dips moderately to steeply southwest, and the base of the pile is presumed to lie upon a gently southwest-dipping surface that has been broken by normal faults and intrusive masses (fig. 4, point 4). In a northwest-trending structure section, the central half of the pile probably overlies a base that is much deeper than the other parts of the pile. Indeed, the base is exposed east of the high part of the mountains, in Happy Camp Canyon, where the lowest volcanic unit may overlie the possible sedimentary and volcanic rocks of Late Cretaceous age (fig. 4, point 5; Drewes, 1985). In Silver Camp Canyon basal volcanic rocks overlie Precambrian crystalline rocks, and at Camels Back Mountain they overlie the Bisbee Group. Elsewhere, the contact is faulted or intruded by elongate rhyolite intrusive bodies that may be a segmented ring dike (fig. 4, point 4).

The ring dikes are tabular bodies that dip steeply southwest and are as much as 3 km long and 0.5 km wide. They are strongly laminated rhyolitic rock. Their contact outward against the crystalline basement rocks is sharp and typically intrusive, but their contact inward with the breccia pile is, in places, gradational, with a gradual diminution of flow layering and an increase in brecciation. As rugged and inaccessible as the area of these dikes is, much remains to be learned about them.

The southwest side of the volcanic pile is faulted against Paleozoic and Mesozoic rocks of the Apache Pass fault zone. At the surface, this strand of the fault is vertical or inclined steeply to the southwest. In the subsurface, as suggested by geophysical evidence, the rocks of this zone and perhaps some strands of the fault zone may flatten downward, but the main fault zone, perhaps its narrower configuration, probably remains a steep structure. Although much of the earlier movement along the fault on the southwest side of the volcanic pile was left lateral, the volcanics themselves had a downward component of movement relative to the rocks within the fault zone. The curvature of an inferred fault branching from the Apache Pass fault zone in the upper reaches of Mascot Canyon (fig. 2) suggests that even this late volcanic or post-volcanic faulting had a left-lateral component of movement. The actual movement, then, may have been left-olique slip, with a wedge of El Paso(?) Dolomite, Pinal Schist, and rhyolite resembling the rocks of the ring dikes next to the branch fault detached from the terrane of the fault zone and dragged into the breccia pile of the northeastern terrane. The extent to which this drag may have been produced by volcanic action or by tectonic action is unknown; possibly the two were concurrent events. This structural complication to the downfaulted central mass of the volcanic pile is a feature not typical of classic calderas; nevertheless, the general aspect of the pile is that of a caldera formed alongside a major fault.

North of the Elma mine, another wedge of rock like the one at Mascot Canyon, except that it is of Precambrian granitic rock, extends into the breccia pile. A fault does not appear to border this wedge, as in the Mascot Canyon case. Several small masses of granite also occur within the breccia pile near the wedge (Drewes, 1985). The granite wedge appears to have been incompletely torn from the wall rock of the pile by volcanic action. Perhaps the included masses of granite were formed similarly, with the process having progressed further than in the case of the granite wedge.

The several large blocks of Paleozoic and Mesozoic rocks that are included in the dacitic volcanic pile north and west of Dos Cabezas Peaks may have been formed by volcanic processes as rock flaps torn off the adjacent or underlying wall or floor rocks. One of these exotic blocks is 1.4 km long and 0.3 km wide, and another is about 1 km long and 0.4 km wide. The sedimentary rocks of these blocks are altered to tactite and recrystallized to marble and metaquartzite. In several places they are also mineralized.

The volcanic pile is probably a stratovolcano that had several adventive volcanic centers on its flanks. Its location and northwest-elongated distribution were controlled by the northeast strand of the Apache Pass fault zone. Some caldera-like collapse of the central part of the volcanic mass occurred, probably concurrently with the early and late explosive volcanism that led to deposition of the two ash-flow deposits. The main dacitic period of volcanism produced voluminous flow breccia and throat breccia deposits from a center not precisely identified, but suspected to lie amid the area of most of the breccia pipes. With the general collapse of the main part of the breccia pile along the Apache Pass fault zone and the northeastern wall, some rhyolitic magma intruded the dacitic breccia mass as ring dikes and as breccia pipes or tabular bodies. Adventive centers of these late magmatic types developed near Silver Peak, Dos Cabezas Peaks, Cooper Peak, and the Elma mine. A few of the youngest breccia pipes contain exotic clasts of Paleozoic rocks, suggesting their presence in the subvolcanic floor, as generalized on figure 4. The thick basal ash-flow sheet and lava flows in Happy Camp Canyon suggest the northeastward spread of these deposits from the Apache Pass fault zone.

Ultimately, under more passive conditions, magmas moved up into the lower levels of the volcanic pile to form biotite rhyolite or rhyodacite and granite to granodiorite stocks, as well as some andesitic dikes. Perhaps these stocks are the sites of early volcanic centers. A period of intense alteration changed the appearance of many rocks, and at certain sites the alteration process was accompanied or followed by mineralization.

During late Oligocene-early Miocene time the northeastern terrane received additional magmas. These led to emplacement of a granite stock and then a swarm of rhyolite dikes.

Finally, a normal fault along the northwestern part of the northeastern range front cuts rocks as young as some of the gravel deposits (fig. 4, point 6). With its displacement down to the northeast, the fault is undoubtedly a Basin-and-Range type of fault that led to the physiographic separation of the Dos Cabezas and Pinaleno Mountains.

Apache Pass Fault Zone

A narrow terrane of faulted Paleozoic and Mesozoic sedimentary rocks is referred to as the Apache Pass fault zone. At the surface, this fault zone flares out from a width of 0.2 km near the mouth of Silver Camp Canyon in the northwest to 1.5 km near Apache Pass in the southeast. The flaring out continues southeastward into the Cochise Head area (Drewes, 1982a). In the subsurface, these features apparently change; some features dip gradually more gently to the southwest and others remain steep (fig. 5*B*).

The trace of the fault zone in the southeastern part of the Dos Cabezas Mountains is slightly arcuate, concave to the southwest. Such a curvature also occurs in the Cochise Head area. Similar fault zones of southeastern Arizona are seen to be slightly sinuous (Drewes, 1980, 1981).

In the Dos Cabezas Mountains, the fault zone is generally bordered on the northeast and southwest by faults of great length and stratigraphic offset that are referred to as the northeast (fig. 5, point 1) and southwest (point 2) strands. Between the strands, the rocks are variously cut by smaller subparallel faults, some northeast-trending cross faults, and in a few places also by low-angle faults. The proportion of these three kinds of faults within the Apache Pass fault zone changes southeast beyond the Dos Cabezas, where they are of several ages and origins. Presumably, these genetic differences apply also in the Dos Cabezas Mountains; some faults are strike-slip faults with single or recurrent movement, some are thrust or reverse faults, and others are local adjustment features related to thrust faulting or to subsequent block faulting and tilting.

The main fault strands and smaller subparallel faults are about vertical at the northwest end of the fault zone. Southeast of the arcuate bend of the trace of the fault zone, these faults dip moderately to the southwest. Dips change gradually around the arcuate trace. Typically, the dip of the rocks is like that of the nearby faults of this set. The main strands and smaller faults break the rocks into large and small lozenge-shaped blocks or slivers

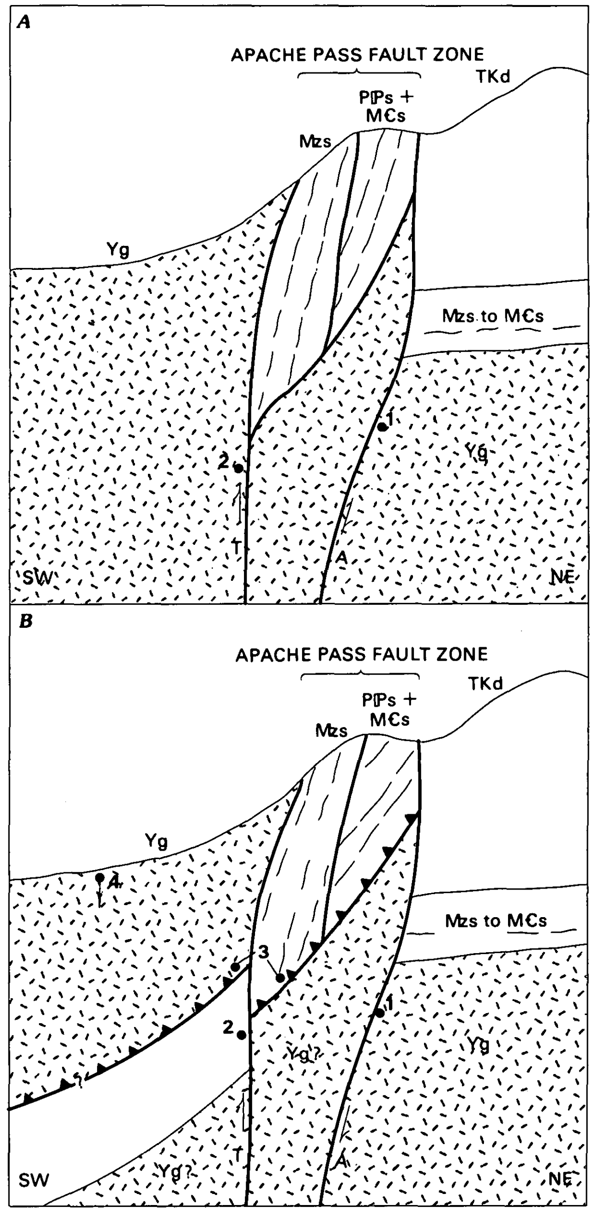


Figure 5. Diagrammatic sections of the Apache Pass fault zone, showing optional interpretations: *A*, from geologic map data; *B*, from geologic map plus magnetic data. Points reviewed in text: 1, northeast strand of the Apache Pass fault zone; 2, southwest strand of the Apache Pass fault zone; 3, inferred blind thrust fault; and 4, axis of magnetic trough. See figure 2 for explanation of rock units; arrows show relative movement on fault; T, movement toward viewer; A, movement away from viewer.

along the fault zone. Many of these blocks and slivers are made up of incomplete stratigraphic units that are not in their usual stratigraphic position. For example, at Howard Peak a sliver of Glance Conglomerate and other Bisbee rocks lies between the uppermost Cretaceous or Paleocene dacitic breccia pile and an Upper Cretaceous(?) rhyolite slice. Northwest along the fault zone, this slivering is accompanied by a stretched appearance of the slices and the rocks themselves, presumably signs of more intense shearing and somewhat plastic deformation, which could imply a greater cover of overlying rocks at the time of the last major movement.

Where the fault zone is about 1 km wide, near Howard Peak (fig. 2), the larger fault blocks contain sequences of rock representing several formations, and the sequences vary from block to block. Moreover, a thick-Glance facies occurs in several blocks, whereas away from the blocks at Howard Peak, Glance is typically thin. Moreoever, from southeast to northwest, the stratigraphic position of the conglomerate shifts up section within the Bisbee Group, and its base laps upon progressively older subjacent rocks. That the erratic thickness of Glance is found only in these fault blocks may be fortuitous, but it may imply that the blocks were tectonically transported into their present position from outside of the plane of exposure.

Locally near Apache Pass, and also extensively farther southeast beyond the area of figure 2, the rocks of the Apache Pass fault zone are folded and thrust faulted, as recognized by Sabins (1957b), compiled by Cooper (1960) and Drewes (1980), and remapped in greater detail by Drewes (1982a, 1982b). At Apache Pass, Permian rocks are thrust upon Cretaceous rocks, and the older Permian Colina Limestone is thrust upon the younger Permian Scherrer Formation. Thrust plates dip gently westward and are truncated by the southwest strand of the Apache Pass fault zone. In one of these thrust plates a small moderately tight syncline is vergent to the northeast.

East of Apache Pass, the rocks at the base of the Paleozoic sequence are also thrust faulted. Locally, Precambrian rocks are intercalated into the Cambrian formation, and a thrust fault dips 20 southwest. Also locally, still smaller folds overlie a thrust fault that branches off the main fault. Between the area of Apache Pass and the curved segment of the fault zone near Wood Canyon, the fault strand must be inferred from conditions along strike or, perhaps, although it is less likely, the entire movement has shifted to the single plane of the southwestern strand.

Small cross faults systematically offset the rocks of the Apache Pass fault zone, especially where the zone curves. Typically, stratigraphic offset is measured in a range of meters to a few hundred meters. Some cross faults offset only a formation or two; others offset the entire zone. Rhyolite dikes of the Miocene dike swarm intrude some cross faults or follow fractures having no recognizable offset that abut the cross faults. The slight concentration of cross faults along the margins of the fault zone and the paucity in the center of the zone suggest that the central rocks may have adjusted plastically to the stresses producing cross faults. Indeed, west of Howard Peak where shearing and plastic flow are a pronounced feature of the zone, cross faults are absent.

Movement along the Apache Pass fault zone probably began in the Precambrian, was recurrent during the Cordilleran orogeny, and probably was resumed locally during the mid-Tertiary (Drewes, 1981). A history of recurrent movement is based on evidence of various amounts of offset of diverse rocks throughout the length of the fault zone. The Precambrian movement was probably large and left lateral, as is suggested by the large amount and the likely direction of offset of Precambrian quartzite between Bowie Mountain of the southwestern terrane (Drewes, 1982a and 1982b) and Government Peak of the northeastern terrane, compared to the lesser offset of Paleozoic and younger rocks. During the peak phase of the Cordilleran orogeny, perhaps during late Late Cretaceous time, thrust faults crossed the fault zone obliquely near Apache Pass and to the southeast. They were deflected within parts of the fault zone as steeply inclined reverse faults extending along the Apache Pass fault, probably to the vicinity of Howard Peak, and possibly across the entire Dos Cabezas Mountains. This movement may explain the juxtaposition of diverse Glance facies in the fault blocks near Howard Peak, and it may also account for the bedding-plane faults in the southwestern terrane where the southwestern sedimentary belt approaches the Apache Pass fault zone.

Late during the Cordilleran orogeny, magmas rose along the fault zone forming a large stratovolcano. These volcanic rocks were offset through another reactivation of the Apache Pass fault, possibly with minor left-lateral movement, as documented along Emigrant Canyon 9 km southeast of Apache Pass (Sabins, 1957a; Drewes, 1982a). The central part of the volcano probably also was downdropped as a fault-controlled caldera. The two faults branching off the Apache Pass fault zone between Government and Howard Peaks, marking approximately the northeastern edge of the volcanic field, may be similar to, but smaller than, the Emigrant Canyon fault. Away from the Apache Pass fault zone, these branch faults more likely are oblique-slip faults. The cross faults that cut rocks of the Apache Pass fault zone may be related to a period of Basin-and-Range uplift and tilting of the Dos Cabezas Mountains that occurred during or after Oligocene time. Probably segments of the Apache Pass fault zone were also reactivated as normal faults during this event.

Mineral Deposits

Base- and precious-metals deposits occur at many localities in the central part of the Dos Cabezas Mountains, in the Dos Cabezas and Teviston mining districts (fig. 6). Although mining began in 1878, most of the production was from 1910 to 1955, and the last activity appears to have been in 1970 (Keith, 1973; Richter and Lawrence, 1983). Production records are incomplete and cover mainly activities of a few mines during the last few decades of mining. They show the following combined production: copper, 2,000 tons (1,814 metric tons); lead, 700 tons (635 metric tons); silver, 430 oz (12 kg); gold, 10,000 oz (283 kg); tungsten, less than 50 tons (45 metric tons); and beryllium, in an unknown but probably small amount.

These mineral deposits were from irregular plug-like masses, veins, replacement bodies, and disseminated ore chiefly in Paleozoic limestones, in Upper Cretaceous or Paleocene volcanic rocks and, less commonly, in Precambrian schist, Cretaceous shale, Paleocene granitic rock, and mid-Tertiary rhyolite dikes. Some of the larger veins are in shear zones and some replacement bodies are along contact zones of intrusive bodies in metamorphosed rocks.

The Elma, Mascot, and Dives mines were the largest producers of base metals with chalcopyrite, bornite, and galena the main ore minerals. The Elma mine was in a pyrometasomatic pipe-like body along a shear zone cutting the Upper Cretaceous or Paleocene volcanic rocks and in a Paleozoic limestone (Richter and Lawrence, 1983). The limestone body apparently is blind, or has been completely replaced by pyrite at the surface level. It is probably an exotic block within a breccia pipe, but may be the top of the subvolcanic basement. The Mascot mine is also in a sheared block of Paleozoic limestone and in the dacitic breccia at a site near the Paleocene Mascot granitic stock. Ore was obtained from veins, replacement bodies, and disseminated bodies. A little gold, tungsten, and beryllium minerals were also produced here (Elsing and Heineman, 1936; Richter and Lawrence, 1983). The Dives mine was on a quartz vein separating Cretaceous shale from Precambrian granitic rock along the southwest strand of the Apache Pass fault zone.

The main gold production came from the Gold Prince mine, which lies along quartz reefs in Cretaceous shale along the Apache Pass fault zone ("reef": a broad diffuse zone in the miner's sense of the word of rather than the sedimentologist's). Other gold production was from the Mascot, the Mineral Park, the Leroy, and possibly the Cottonwood mine. Some of these deposits are on quartz veins in a variety of host rocks, and others are along shear zones or in contact or replacement bodies (Richter and Lawrence, 1983). A little gold was obtained from dry placers in alluvium on the north and southwest flanks of the Dos Cabezas. Non-placer gold was mostly obtained from pyrite, from galena, and as native gold.

Tungsten production was small and came largely from the Teviston district. Scheelite-bearing quartz veins in Paleozoic and Mesozoic rock along the Apache Pass fault zone were the main sources of ore. Typically, they occurred near intrusive bodies, such as the Mascot stock and smaller rhyolite bodies, but only in a few cases is skarn associated with scheelite (Dale and others, 1960).

Other deposits have had little production and few records. Their distribution and association is best shown by Keith (1973) and Richter and Lawrence (1983). They are scattered mainly along the Apache Pass fault zone and the area of the dacitic breccia volcanic pile. Supplemental observations on minerals found on dumps and on a few outcrops away from mines and prospects are shown on the geologic maps (Drewes, 1985, 1986b).

In summary, most mineral deposits are genetically related to the magmatic activity of Late Cretaceous or Paleocene age, and some are related to dikes or quartz veins that possibly are as young as the Miocene. Aside from a spatial relationship to intrusive bodies of Paleocene age, and less commonly of mid-Tertiary age, faults have been a strong control of the distribution of ore deposits. The Apache Pass fault zone, particularly near the intrusive rocks, has produced the most favored sites. Smaller faults branching from this fault zone, such as the one in Mascot Canyon have also acted as channelways along which the ore fluids were dispersed.

Replacement bodies and skarn deposits occur preferentially in sedimentary formations of mixed lithologic components. Favored host rocks are the El Paso Dolomite, the Horquilla Limestone, and the Bisbee Group. A few deposits also occur in the dacitic breccia or in the Pinal Schist.

Lastly, quartz vein deposits are scattered throughout in nearly all of the Paleocene and older formations. While these vein deposits are almost all undated, many are probably also associated with late Cordilleran orogenic igneous activity.

GEOCHEMISTRY

A geochemical reconnaissance study of the central part of the Dos Cabezas Mountains shows that base and noble metals are widely, but not entirely erratically, dispersed. They occur mainly in certain sedimentary rocks and in the dacite breccia pile, particularly where these rocks occur near Paleocene granitic stocks, breccia pipes, or the Apache Pass fault zone.

This geochemical study combines scattered observations on the mineralization at prospects, mine portals, and mine dumps, with analyses of a suite of samples taken from the dumps (fig. 6). The map scale selected for this study, 1:24,000, limits the effective spacing of the samples to about 300 m; where prospects or mines are closer together, the larger one was generally sampled. In a few instances, where several adits lay close together along a single vein, the observations and samples were combined.

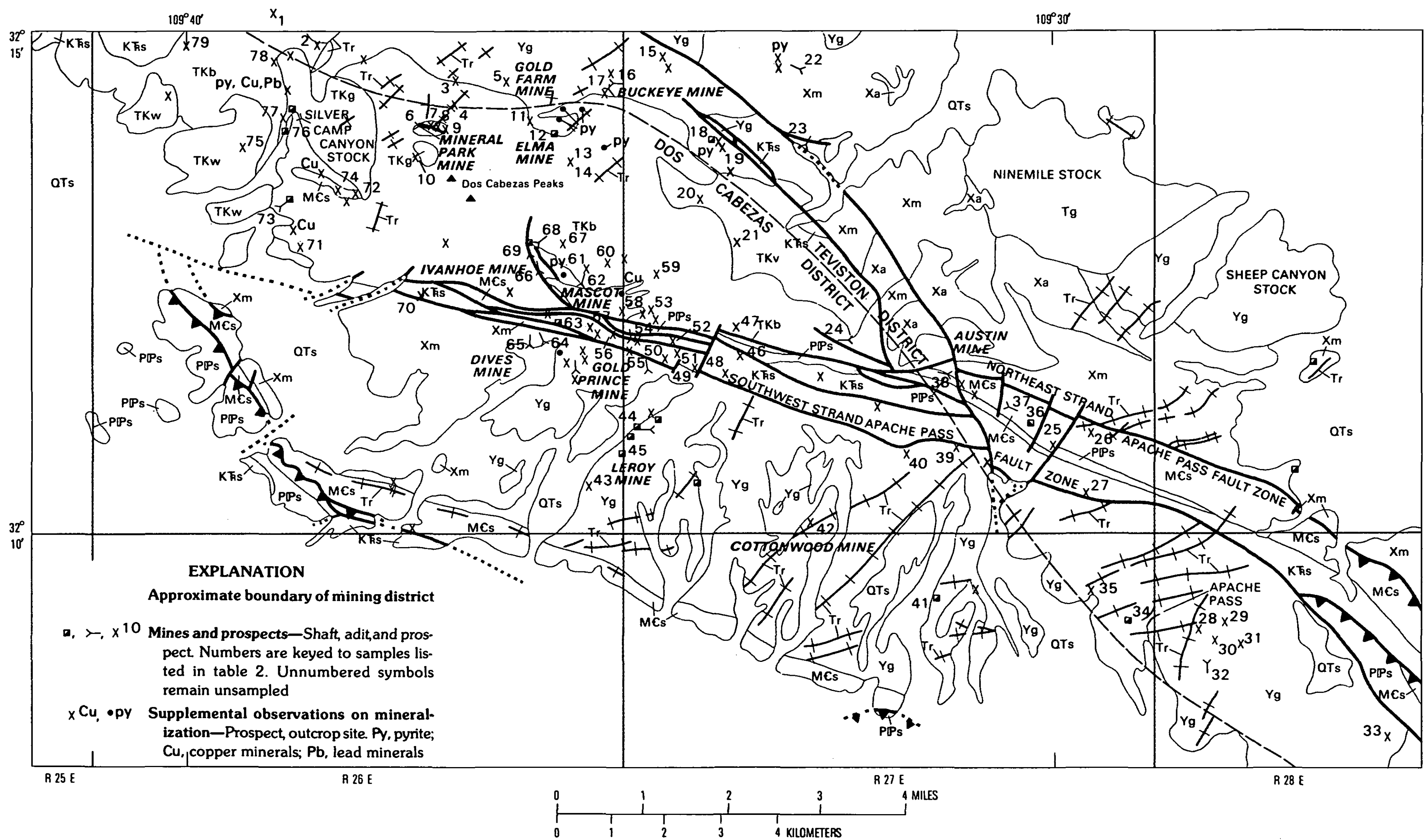


Figure 6. Map of the mining districts, mines and prospects, and geochemical sample localities of the Dos Cabezas Mountains. Supplemental observations on mineralization given at unsampled prospects, x, and at sites without prospects, (•); py, pyrite; Cu, copper minerals; and Pb, lead minerals. Minerals found at sampled sites listed in table 2. See figure 2 for explanation of rock units and their symbols.

Table 2. Semiquantitative spectrographic and atomic absorption analyses of rock samples from the Dos Cabezas Mountains

[All results in parts per million; *, indicates samples tested by atomic absorption method; parenthetic numbers beneath element symbols indicate lower limit of detection; N, not detected; L, detected but not measurable; G, greater than the value following. Abbreviations given under remarks of minerals and oxides seen at collection sites: act, actinolite or tremolite; az, azurite; bo, bornite; ca, calcite; ce, cerrusite; co, covellite; cpy, chalcopyrite; csm, calcsilicate minerals; ep, epidote; fl, fluorite; ga, galena; gr, garnet; he, hematite; ma, malachite; py, pyrite; qt, quartz; sh, sheelite; CuO, copper oxides; FeO, iron oxides; MnO, manganese oxides; ZnO, zinc oxides. APFZ, Apache Pass fault zone]

Sample no.	Field no.	Ag (.5)	As* (10)	Au* (.05)	B (10)	Bo (20)	Be (1)	Bi (10)	Cd (20)	Cu (5)	Mn (10)	Mo (5)	Pb (10)	Sb* (1)	W (50)	Zn* (5)	Remarks: minerals, oxides, geologic setting
1	79D284	0.5	N	N	10	70	7	30	N	70	1000	N	70	N	200	200	ep, hem, qt; on Yg-TKb contact.
2	79D283	N	N	N	10	700	2	N	N	70	G5000	30	70	N	N	300	he, qt; FeO; near Yg-TKb contact.
3	79D312	7	N	N	L	1000	1	N	N	1500	1000	7	150	N	N	N	az, bo, cpy, ma; on Tr dike.
4	79D311a	.5	N	N	L	500	L	N	N	70	700	N	150	N	N	N	qt; vein near Tr dike.
5	79D311b	500	N	70	L	100	1	50	N	1000	700	7	7000	N	N	N	ga, py, qt, sp; CuO, ZnO; vein.
6	79D285	70	N	N	50	700	N	50	N	7000	2000	N	200	N	N	300	csm, qt; in Pzl.
7	79D286	N	N	N	50	N	N	100	N	70	5000	N	150	N	N	200	ep, he, qt; in Pzl.
8	79D287a	7	700	N	10	150	1	N	20	3000	5000	N	30	N	N	10000	act, asbestos?, ep, he, qt; in Pzl.
9	79D287b	20	700	N	10	70	N	200	N	100	700	N	70	N	N	L	csm; in Pzl.
10	79D288	70	N	N	10	200	2	10	100	2000	2000	30	G20000	N	N	200	ga, py; CuO, FeO; vein in TKb.
11	79D317a	50	700	N	30	200	3	10	N	3000	1000	N	70	N	N	N	ma; CuO; ring dike in TKb.
12	79D278	30	N	N	20	100	2	20	50	5000	3000	N	500	N	200	5000	cpy, py; CuO; replacement of Pzl.
13	79D277	3	N	N	10	1000	2	N	N	2000	500	30	70	N	N	N	cpy, ma; in TKb breccia pipe.
14	79D306	.5	N	N	L	1500	L	N	N	50	200	50	150	N	N	N	ep, py; FeO; in TKb breccia pipe.
15	79D303	200	N	N	L	300	5	150	N	200	500	30	7000	N	50	N	ga, py, qt; vein in Yg.
16	79D309	15	N	N	L	500	3	N	N	70	700	5	200	N	N	N	ga, he, py, qt; vein in Yg near TKb.
17	79D308	200	N	2	L	100	1	100	N	3000	150	20	10000	N	N	N	ga, he, py, qt; vein in Yg near TKb.
18	79D234	200	N	10	L	200	2	20	N	70	150	50	1500	N	N	N	ga?, py; vein, shear zone in Yg.
19	79D233	2	N	N	L	500	5	N	N	30	300	N	150	N	N	N	ga, py; vein near ring dike.
20	79D228	200	N	N	L	N	N	200	N	5000	200	N	20000	N	N	N	az, bo?, ga, ma, py, qt; CuO, MnO; vein.
21	79D227	N	N	N	L	500	1	N	N	5	150	N	20	N	N	N	qt; vein in lower welded tuff.
22	79D235	150	N	N	L	N	1	100	N	1500	30	150	2000	N	N	200	cpy, ga?, py, qt; vein in Xm.
23	79D231	20	N	N	L	500	5	30	20	500	300	150	2000	N	N	500	ga, py, qt; FeO, MnO; vein by fault.
24	79D247a	30	700	N	L	300	2	N	N	3000	700	N	50	N	N	N	CuO?, FeO; vein near base of TKb.
25	79D195	1.5	N	N	N	100	N	N	N	50	1000	7	300	N	N	200	py, qt, talc?; FeO; in Portal Fm.
26	79D196	50	N	N	10	L	5	N	150	1000	300	7	20000	N	N	5000	act, cpy, py, qt; CuO, FeO.
27	79D194	7	700	N	20	50	1.5	N	N	200	20	20	1500	N	N	300	py, qt; FeO; on Tr dike.
28	79D181	7	N	N	10	700	5	N	N	700	1000	5	1500	N	N	2000	ep?, py, qt; near Tr dike.
29	79D182	1	N	N	L	300	2	N	N	50	500	N	150	N	N	700	py, qt; vein and fracture in Yg.
30	79D180	15	N	N	10	200	2	10	500	1000	300	7	1000	N	N	10000	he, py, qt; FeO; vein in Yg.

Sample no.	Field no.	Ag (.5)	As* (10)	Au* (.05)	B (10)	Bo (20)	Be (1)	Bi (10)	Cd (20)	Cu (5)	Mn (10)	Mo (5)	Pb (10)	Sb* (1)	W (50)	Zn* (5)	Remarks: minerals, oxides, geologic setting
31	79D183	N	N	N	L	500	5	N	N	15	700	N	30	N	N	N	he, py, qt; FeO; vein in Yg.
32	79D185	20	N	N	15	150	L	10	N	700	70	100	1500	N	N	200	py, qt; fracture and vein.
33	79D177	N	N	N	L	500	2	N	N	15	700	N	30	N	N	N	py, qt; FeO; vein in Yg.
34	79D242	5	N	N	L	100	5	N	N	500	700	50	500	N	N	300	qt; vein.
35	79D243	150	N	N	15	200	5	20	30	1500	200	300	G20000	N	N	1000	ga, py, qt; vein and dike in Yg.
36	79D240	500	N	15	L	500	10	10	N	500	300	30	10000	N	70	200	ga, qt; CuO, FeO; vein in sandstone.
37	79D239	150	N	N	L	300	10	N	200	2000	500	20	20000	N	1000	1000	ga, py, qt; CuO, FeO; vein.
38	79D246	30	N	N	L	150	1	N	500	3000	300	10	20000	N	2000	10000	cpy?, ga, py, sp; CuO; vein in Pzl.
39	79D245	2	N	N	L	500	1	L	N	1000	500	N	1000	N	N	N	qt; CuO, FeO, MnO; SW strand APFZ.
40	79D248a	15	700	N	L	150	3	N	N	70	150	N	2000	N	N	L	ga; MnO; near SW strand APFZ.
41	79D342	1	N	N	10	200	2	N	N	700	700	N	1500	N	N	700	ce, he, py, siderite; FeO; vein.
42	79D249	1	N	N	10	1000	1	1	N	70	300	7	500	N	50	200	py, qt; vein near Tr dike.
43	79D339	3	N	N	L	300	2	N	N	50	500	N	500	N	N	500	py, qt; FeO; on andesite dike, Yg.
44	79D338	100	N	15	20	200	1	N	G500	3000	3000	N	20000	N	N	G10000	ga, py; vein in Yg.
45	79D337	70	200	10	20	N	1	N	500	2000	2000	N	10000	N	N	G10000	ca, cpy, ga, he, py, qt; FeO; vein, Yg.
46	79D259	15	N	N	10	700	1	N	20	500	700	N	2000	N	N	700	qt; pod in Mz shale by Tr, in APFZ.
47	79D257	7	N	N	L	700	1	N	N	100	500	10	1000	N	N	N	ga, py, qt; vein in TKb near APFZ.
48	79D255	N	N	N	L	300	N	N	N	20	200	N	50	N	N	N	ce?, qt; FeO; vein near APFZ.
49	79D256	.5	N	N	10	500	1	N	N	15	300	N	50	N	N	N	py?, qt; vein near SW strand APFZ.
50	79D260	N	N	N	10	500	1	N	N	15	700	N	100	N	N	N	qt; FeO; vein near SW strand APFZ.
51	79D261	N	N	N	30	300	1	N	N	200	2000	15	150	N	N	300	qt; FeO; vein in APFZ.
52	79D262	3	N	N	20	700	2	N	N	100	2000	N	200	N	N	300	qt, sh; FeO; vein in APFZ.
53	79D264	7	N	N	10	1000	1	N	N	7000	700	N	70	N	N	N	cpy, py, qt; FeO; vein in TKb.
54	79D263	7	N	N	20	700	2	N	N	100	100	N	700	N	50	500	py, qt; FeO; vein in APFZ.
55	79D270	3	N	N	20	500	1	N	N	70	700	N	500	N	N	700	py, qt; FeO; silica reef in APFZ.
56	79D269	7	500	N	20	200	1	N	N	20	100	N	1000	N	N	300	py, qt; FeO; vein in APFZ.
57	79D268	3	N	N	20	700	1	N	N	300	2000	N	300	N	N	300	py, qt; FeO; vein? in APFZ.
58	79D267	7	N	N	20	1000	1	N	N	1000	700	50	1000	N	N	N	py, qt; FeO; fractures in TKg stock.
59	79D295	30	N	N	L	500	2	N	N	3000	700	N	50	N	N	N	ep, he; at rhyolite contact in TKd.
60	79D273	15	N	N	100	100	2	N	N	20000	500	50	50	N	N	300	he, ma, qt; CuO; breccia pipe in TKd.

Table 2. Continued.

[All results in parts per million; *, indicates samples tested by atomic absorption method; parenthetic numbers beneath element symbols indicate lower limit of detection; N, not detected; L, detected but not measurable; G, greater than the value following. Abbreviations given under remarks of minerals and oxides seen at collection sites: act, actinolite or tremolite; az, azurite; bo, bornite; ca, calcite; ce, cerrusite; co, covellite; cpy, chalcopyrite; csm, calcsilicate minerals; ep, epidote; fl, fluorite; ga, galena; gr, garnet; he, hematite; ma, malachite; py, pyrite; qt, quartz; sh, sheelite; CuO, copper oxides; FeO, iron oxides; MnO, manganese oxides; ZnO, zinc oxides. APFZ, Apache Pass fault zone]

Sample no.	Field no.	Ag (.5)	As* (10)	Au* (.05)	B (10)	Bo (20)	Be (1)	Bi (10)	Cd (20)	Cu (5)	Mn (10)	Mo (5)	Pb (10)	Sb* (1)	W (50)	Zn* (5)	Remarks: minerals, oxides, geologic setting
61	79D327	30	N	N	L	300	1	300	N	G20000	200	500	50	N	N	N	py; CuO, FeO; rhyolite breccia, TKd.
62	79D330	15	700	N	10	150	1	30	300	2000	1000	N	1000	N	1000	10000	CuO; Pinal Schist near TKg stock.
63	79D328	30	200	N	L	300	5	L	150	1500	150	10	10000	N	N	2000	ga, py, qt; CuO, FeO; reef in APFZ.
64	79L334	N	N	N	L	500	1	1	N	50	700	N	70	N	N	200	qt; at diabase? pod in Yg.
65	79L333	7	N	N	20	300	1	N	N	100	300	N	150	N	N	200	qt; vein in Yg.
66	79D324	7	N	N	L	N	2	N	N	5000	3000	N	50	N	N	N	act?, ca, co, cpy, ep, fl, gr, he, ma, py.
67	79D279	10	N	N	50	200	N	N	N	G20000	1000	30	N	N	N	200	he, py, qt; CuO, FeO; skarn in TKb.
68	79D325	7	N	N	L	100	2	70	N	20000	3000	N	200	N	N	N	az, he, py, qt; FeO; in Pzl.
69	79D323	15	N	N	L	100	1	30	N	20000	500	100	50	N	N	N	act?, az, ca, cpy, ep, he, ma; FeO; Pzl.
70	79D329	30	N	N	L	200	1	L	N	2000	20	N	2000	N	N	500	qt; CuO; vein along SW strand APFZ.
71	79L350	30	700	N	L	500	1	L	N	10000	150	N	300	N	N	N	ma, qt; vein in TKb.
72	79D320	7	700	N	10	30	1	20	50	3000	1000	30	500	N	N	10000	he, py, qt; CuO, FeO; replacement Pzl.
73	80D100	50	N	N	2000	500	1	15	N	5000	G5000	N	1500	N	N	300	ca, he, qt; CuO; on fractures in TKd.
74	80D102	10	N	N	70	200	1	10	N	10000	2000	50	1000	N	L	1000	cpy, ep, he, qt; CuO, FeO; replacement.
75	80D91	300	N	N	50	100	1.5	G1000	200	20000	G5000	50	15000	5000	N	1000	ep, he, qt; FeO; vein, upper tuff.
76	80D104	15	N	N	30	L	L	N	N	G20000	2000	N	N	N	N	1000	az, ca, cpy, ma, qt; in TKd by stock.
77	79D345	50	700	N	20	G5000	2	N	N	1500	2000	30	1000	150	N	N	he, py, qt; CuO, FeO; vein fractures.
78	79D344	30	700	N	L	150	1	20	N	7000	50	5	10000	N	N	N	az, ga, ma, py, qt; FeO; vein by stock.
79	79D347	7	700	N	10	5000	3	N	N	20000	200	15	30	N	N	N	py; CuO, FeO; vein, volcanic center.

A few observations and samples are from mineralized outcrops devoid of prospects.

Each sample was a composite of 8 to 12 rock chips of about walnut size that was selected to represent the variety of altered and mineralized rocks at each site. Chip selection emphasized variety rather than the proportion of altered rock types. Inasmuch as these chips were obtained from the surface of dumps, they probably were obtained disproportionately from the deeper parts of the mine workings. Also, parts of some of the dumps, such as the typical high-grade piles, have been sorted on the basis of tenor. Regardless of these possible local biases, all parts of a dump were examined and included in the composite sample, which consequently included chips of ore, vein material fracture walls, gossan, and discolored rock in whatever combination was present at a site. These samples then show chiefly what elements were mobile and where they occur in the range; they add little new to an understanding of the quantitative aspects of mineral distribution. On the basis of the observations made at each site, certain elements detected analytically can be associated with readily visible minerals and others with less conspicuous minerals, which could serve as field guides to these elements.

The samples were analyzed in the U.S. Geological Survey laboratories for 31 elements by the semiquantitative, six-step, spectrographic method similar to that described by Grimes and Maranzino (1968). Those elements having the greatest potential for locating new deposits of possible economic interest and those which may offer some help in understanding the mineralization are listed in table 2. The full analytical reports, which also give values of the major elements iron, magnesium, calcium, and titanium, and the minor elements chromium, niobium, nickel, vanadium, and zirconium are available through the U.S. Geological Survey data bank. The analyses for arsenic, gold, antimony, and zinc were done by the atomic absorption method described by Ward and others (1969). This method is generally more accurate for these elements in the low quantities in which they typically occur.

The distribution and generalized abundance of three groups of four elements are shown with a simplified geologic base on figures 7, 8, and 9. Each element is represented by a quadrant of a circle, and the blackened amount of a quadrant indicates the abundance of that element in approximate orders of magnitude. The lowest level of abundance of an element reported present through a blackened quadrant is roughly twice background value. Gold, with its limited range of abundance in these analyses, is shown in approximate half-orders of magnitude. This method of presenting data serves to show the extent of areas within which geochemical anomalies occur, as well as to present the relationship between several elements. With a sampling net focused heavily on mine dumps, we recognize that the combined distribution of elements is likely to highlight the existing mining camps, but using this technique we may indicate some elements that have discernible patterns of distribution.

The significance of the relationship between elements has been evaluated by comparing the presence or absence of elements within individual samples and to the sample population as a whole. Comparisons were made entirely on a quantitative basis despite the weakness inherent in the sampling method. If two or more elements occurred together consistently in a significant proportion of the samples, then some association was recognized, regardless of the origin. Elements which are associated in this manner may not show any strong quantitative correspondence, but the absolute analytical values for the samples are not as important as are the general geochemical associations and the patterns of distribution.

Precious Metals

Silver and gold have both been of commercial interest in the Dos Cabezas Mountains; silver production has been more important than gold production.

The geochemical data suggest that both lead and copper are associated with silver in many parts of the Dos Cabezas Mountains, although they may not both be present everywhere. The association of silver with lead is a well established one, for much silver production is known to have been from argentiferous galena. The reason for the silver-copper association where lead is absent is uncertain. That reason is not likely to center on multiple times of mineral emplacement because no indications of such an involved history of mineralization have been reported or observed during this study. In any case, field observation of the easily recognized and usually oxidized minerals of lead and copper may be viewed as favorable indicators of anomalous concentration of silver as well.

The highest silver values lie in the north-central part of the area and along the southeast strand of the Apache Pass fault zone (fig. 7). Values as much as 500 ppm (about 14.6 oz per ton) were found in mineralized quartz-vein samples collected from the Gold Farm mine, and anomalously high values were also found to the east at the Howell (fig. 7, site 23,) and the Buckeye mines, and from quartz veins on Rough Mountain (site 22) and Virginia Hill (site 15). High silver concentrations also occur at other localities (sites 35 and 37) as well as at the Silver Strike mine (site 36) along the Apache Pass fault zone where values are up to 500 ppm. Historical records from this mine show the main ore mineral was argentiferous galena contained in fissure veins and associated quartz masses (Richter and Lawrence, 1983).

Gold is found in several samples of the Dos Cabezas area (fig. 8). The highest concentration, 70 ppm (about

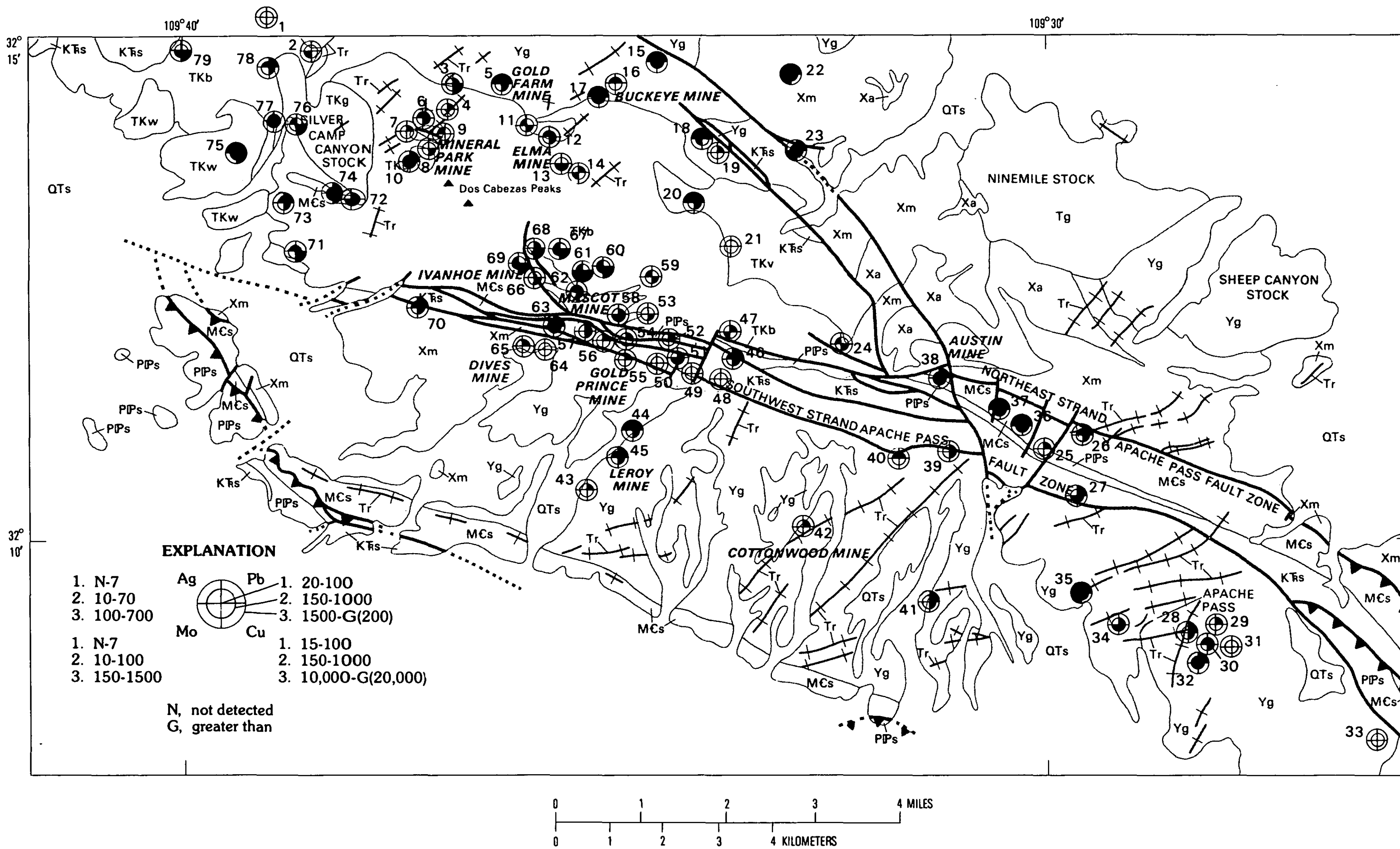


Figure 7. Map showing distribution and degree of concentration in ppm (parts per million) of silver (Ag), lead (Pb), molybdenum (Mo), and copper (Cu) in the Dos Cabezas Mountains. See figure 2 for explanation of map units and their symbols.

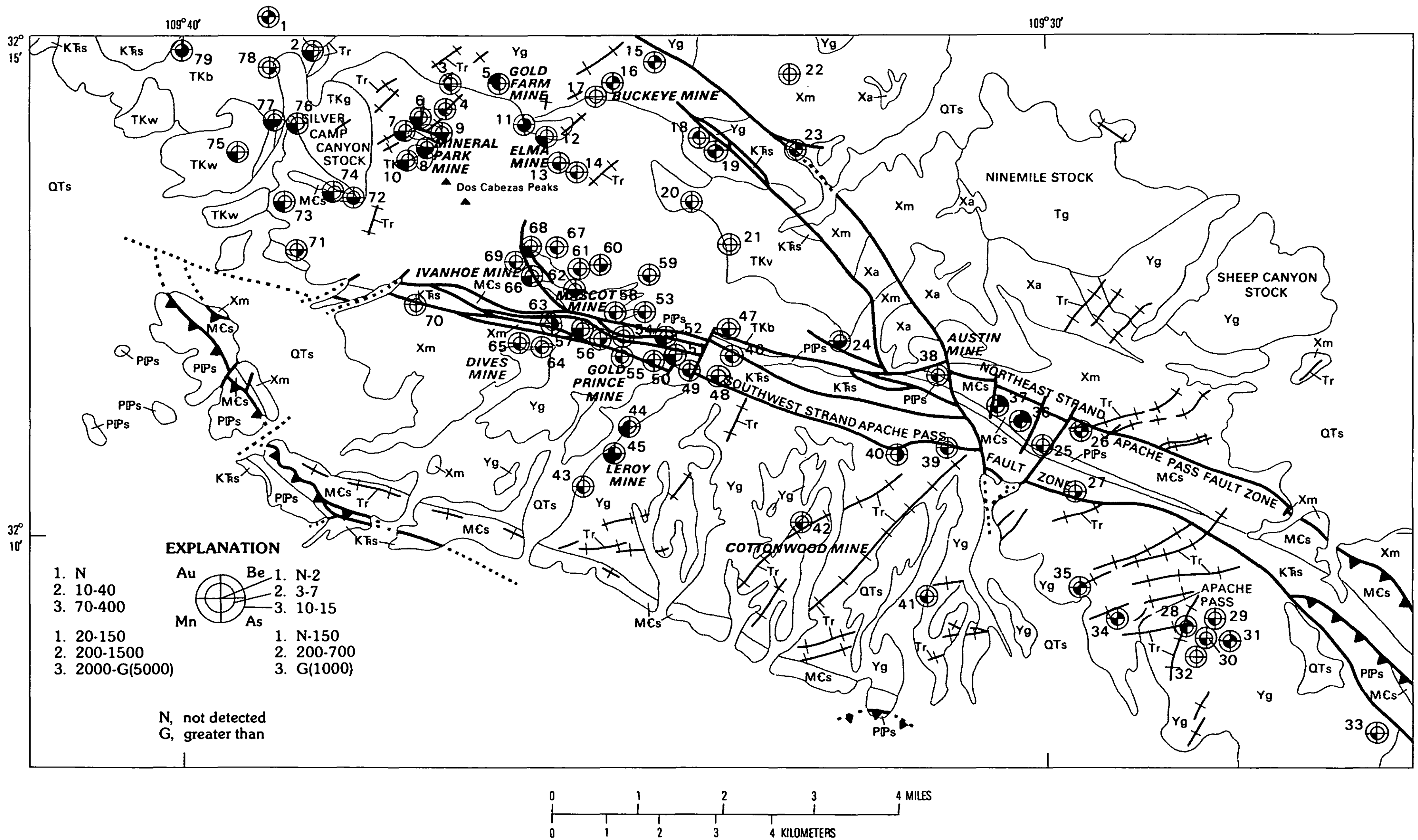


Figure 8. Map showing distribution and degree of concentration in ppm (parts per million) of gold (Au), beryllium (Be), manganese (Mn), and arsenic (As) in the Dos Cabezas Mountains. See figure 2 for explanation of map units and their symbols.

2 oz per ton), is from a sample collected at the Gold Farm mine (the same sample having 500 ppm silver). The shallow workings at the Gold Farm are on quartz veins carrying auriferous pyrite and argentiferous galena. A sample from the Howell mine (fig. 8, site 23) had 10 ppm gold along with silver, and this gold also was from auriferous pyrite in quartz veins. The Dives mine, the largest gold producer of the area, had gold concentrations of 10 and 15 ppm. Gold was not detected from samples collected at other producers of gold, such as the Gold Prince mine, suggesting possible inadequacies in the sampling procedure.

Common Base Metals

Copper, lead, and zinc are the most widespread metals occurring in the Dos Cabezas Mountains (figs. 7 and 9). The analytic values of these three base metals is high in many samples, particularly those collected at mines having had a known production of base metals. While copper, lead, and zinc minerals are common on the dumps of these mines, and so high values are to be expected, they are also common at other sites from which there was little or no production. Particularly at the sites with little or no production, the quantitative aspect of the analyses must be used with care, because the sampling procedure was designed to show distribution more than degree of concentration.

Copper occurrence is nearly coextensive with the volcanic pile, extending along faults, dikes, and veins a short distance beyond the edge of the pile (fig. 7). Copper enrichment extends farthest from the pile along the Apache Pass fault zone, yet it is absent at many sites along the fault zone near the Mascot stock. Additionally, copper occurs along Tertiary dikes or quartz veins of unknown age in the Precambrian terrane at Apache Pass, east of Dos Cabezas village, and elsewhere.

Lead is slightly less widespread than copper (fig. 7). It occurs at most sample sites in the northwestern and northeastern parts of the volcanic pile, along the Apache Pass fault zone, and with the dikes and veins in the basement rocks, but is found only sporadically around the Mascot area. Both lead and copper occur in abundance (two orders of magnitude above background) at many, but widespread, sites.

Zinc is as widely dispersed as is copper, but within the area its occurrence is more erratic than that of the other base metals (fig. 9). Furthermore, there are fewer large concentrations of zinc than of the other metals. Apparently zinc was a highly mobile but subordinate partner to the strong copper and lead mineralization. The distribution of zinc is coextensive with that of cadmium, which is commonly present in sphalerite, the zinc sulfide.

The geographic affinity of the sites of enrichment of the common base metals with the Late Cretaceous or early Tertiary volcano-plutonic system suggests at least their preference for a much brecciated dacitic host rock, if not their genetic association. In some of those areas where base-metal mineralization occurs away from the igneous system, the presence of strong faults or fractures followed by long dikes or veins indicates a ready means for dispersion. However, where such faults are not available or where fractures utilized by short dikes or veins apparently are local, wide dispersion of base-metal mineralization cannot readily be explained, and consequently these mineralized sites may reflect a genesis unrelated to the igneous system.

The distribution of copper, lead, and zinc gives some insight in the dominant direction of movement of hydrothermal fluids that could be a useful factor in searching for blind ore deposits. The common occurrence of these metals and their great geochemical mobility make them truly key base metals in this region. In the Dos Cabezas Mountains copper, lead, and zinc occurrences are seen to be dispersed mainly along vertical structural features, such as beds, faults, and intrusive bodies, near the volcano-plutonic center. Consequently, hydrothermal fluids are believed to have moved mainly upward, with perhaps two exceptions. The Apache Pass fault zone shows scattered mineralization even far from the volcano-plutonic center; therefore, lateral movement of fluids is a significant consideration along the fault zone. Lateral movement may also have taken place along gently inclined structures, such as beds or unconformities beneath the volcanic pile, but lateral movement of hydrothermal fluids would have been confined largely to the extent of the pile itself, for the structures have been eroded from the adjacent terrane.

Some sites of base-metal mineralization favored Paleozoic host rocks, and in some of these sites replacement deposits are found along with, or instead of, the vein deposits. These favorable host rocks appear along the Apache Pass fault zone and in large inliers and flaps in the dacitic breccia pile near the Mineral Park area southeast of Silver Camp Canyon and at the Mascot mine (fig. 2; Drewes, 1985). Possibly smaller inclusions of these host rocks have been replaced at the Elma mine. Some replacement deposits are associated with skarn mineralization, particularly near intrusive bodies of the Mascot area and the Silver Camp Canyon-Mineral Park areas.

Other Metals

The less common base metals and other elements of interest in a mineral assessment of the Dos Cabezas Mountains that are summarized on figures 8 and 9 include molybdenum, bismuth, arsenic, tungsten, barium, beryllium, and manganese. Some of these may occur in sufficient concentration to have byproduct potential in a mining venture, whereas others may simply serve as indicators to the type or locus of other products of economic interest. Their occurrence is more sporadic than that of the common base metals. Almost certainly, this reconnaissance geochemical sampling must be augmented to properly utilize the hints of mineralization offered.

Molybdenum occurs mostly in a low range of anomalous concentration (one to two orders of magnitude above background or 10–100 ppm) across much of the volcanic terrane of Late Cretaceous or early Tertiary age (fig. 7). It generally occurs with the common base metals, usually in the presence of high concentrations of both copper and lead, although least commonly in association with lead alone. Samples that have higher concentrations of molybdenum (two to three orders larger than background, or 150–1,500 ppm) occur in only a few places, and most of these are outside the area of the volcano-plutonic system and away from known faults. Thus, the samples may have a genesis unrelated to Late Cretaceous-early Tertiary mineralization in the core of the Dos Cabezas Mountains. In essence, most molybdenum enrichment is expected to be associated with that of copper. Moreover it may be of lower value and more sporadic distribution than that of copper.

Arsenic also has a sporadic occurrence in the Dos Cabezas Mountains (fig. 8). It appears in anomalous amounts in three samples from near the volcanic center northwest of Silver Camp Canyon and in one or two samples in each of the other mining areas, except those along the Apache Pass fault zone southeast of the volcanic pile. As was the case for bismuth, arsenic forms no apparent association with base or precious metals, and so it probably has an independent mineralogy and may be of little use as an indicator metal.

Bismuth is infrequently present in anomalous quantities (fig. 9). It does occur at a few sample sites in veins northeast of the volcanic pile, at the Mascot mine, at Mineral Park, and at one prospect west of Silver Camp Canyon, where it is present at a concentration greater than 1,000 ppm. While some of these anomalous concentrations of bismuth occur with lead, as is the case in many other mining districts, here many sites with bismuth have little lead. Apparently bismuth has an independent history of formation, which, together with its sparse occurrence, give it little value as an indicator.

Tungsten is concentrated in noteworthy amounts at the Austin, Silver Bell (fig. 9, site 37), and Silver Strike (Devonian group of mines, site 36) mines in the Teviston district, and it appears sporadically near the Mascot and Elma mines and in the northwest part of the volcanic pile (figs. 2 and 8). The anomalous samples from the Teviston district indicate a known occurrence of scheelite mineralization in quartz veins present in the area. These veins are also reported to contain base-metal sulfides, uranium minerals, and fluorite (Richter and Lawrence, 1983), indicating a genesis in common. Apparently, however, tungsten was much less widely dispersed than the base metals. According to Richter, such an association is suggestive of mid-Tertiary mineralization in the Silver City region. Some of the scheelite deposits at the Silver Strike mine (site 36) occur along foliation in the Early Proterozoic Pinal Schist, suggesting that these deposits may have originated during a different event than the vein deposits.

Barium is found throughout the Dos Cabezas in moderate concentrations, with some apparent enrichment in the northwest part of the area (fig. 9). It does not show any obvious association with other elements of interest.

Beryllium is present throughout the Dos Cabezas Mountains, but in such small concentrations to be economically insignificant. The only known occurrences of beryllium minerals are at the Beryl Hill prospect (probably the shaft 6 km east-southeast of Government Peak) and at the Mascot group. Traces of beryllium were detected in samples in concentrations up to 10 ppm, but most analyses were half this or less (fig. 8). The highest analyses were from samples collected from the Silver Strike mines, which also contained anomalous amounts of tungsten.

Manganese is distributed throughout the Dos Cabezas Mountains in varying concentrations with several locations showing some enrichment. In the northwest quarter of the area, near the head of Silver Camp Canyon, Mineral Park, and the Mascot and Elma mines, manganese values are highest near contacts between volcanic rocks, stocks, Proterozoic rocks, and particularly in replacement bodies of Paleozoic rocks. Some of the anomalous manganese values were obtained from vein deposits, such as along the western half of the Apache Pass fault zone and near the Leroy mine area. The samples from the Leroy area and some of the replacement bodies also contained anomalous amounts of base and precious metals, suggesting that over much of the study area, manganese displays geochemical tendencies similar to these metals.

GEOPHYSICS

Aeromagnetic and gravity data constitute the geophysical input for this study. Although the data were acquired to view regional features, they provide an independent perspective of the local geological features of the central Dos Cabezas Mountains. These data complement geological mapping by providing a window into features extending laterally and vertically beyond those apparent in the exposed bedrock.

The aeromagnetic data provide a more detailed and aerially consistent coverage than the gravity data. The

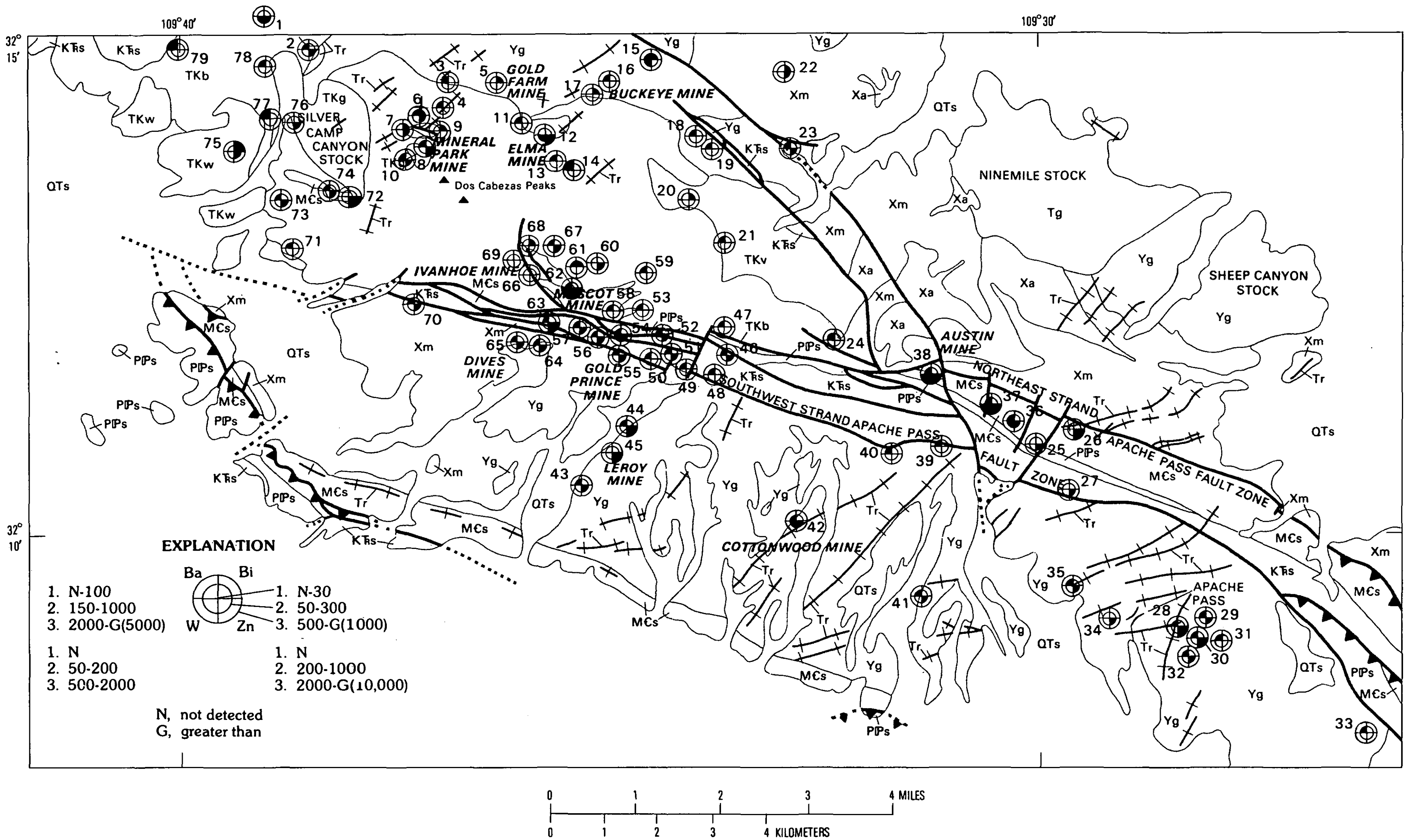


Figure 9. Map showing distribution and degree of concentration in ppm (parts per million) of barium (Ba), bismuth (Bi), tungsten (W), and zinc (Zn) in the Dos Cabezas Mountains. See figure 2 for explanation of map units and their symbols.

aeromagnetic data were acquired in two surveys whose north-south borders overlap along a line crossing the central part of the Dos Cabezas Mountains at about longitude 109°35′ W. (fig. 10). Data west of this line were acquired at 457 m (1,500 ft) above ground along north-south lines spaced at 1.6 km (1.0 mi) (U.S. Geological Survey, 1979). Data east of the line were acquired at 152 m (500 ft) above ground along east-west lines spaced at 1 km (0.62 mi) (U.S. Geological Survey, 1980). Plate 1 provides a mosaiked aeromagnetic map with generalized geology for the study area and its surroundings.

For the purpose of providing a regional map on a consistent datum, the original aeromagnetic data were upward-continued to an elevation of 3.5 km above sea level (fig. 10) (U.S. Geological Survey, 1986). The upward-continuation is based on a surface of equivalent magnetization. The effect of upward-continuation is to smooth the variations in the magnetic field. This diminishes the amplitude and gradients of individual anomalies (as can be seen by comparing figure 10 to the original data of pl. 1 or the simplified data on fig. 14) and deemphasizes anomalies whose source has lateral dimension smaller than the separation distance between the source and the upward-continued datum of measurement.

Gravity measurements (Wynn, 1981) are relatively sparse over the mountainous areas (fig. 11). Nevertheless, these data can provide some insight on the geological features surrounding the range, such as flanking faults and geological trends in the bedrock across areas that are covered by alluvium.

The gravity data (fig. 11) and the upward-continued aeromagnetic data (fig. 10) are used to describe the regional geophysical features of the Dos Cabezas Mountains and the surrounding basins. A closer investigation of features within the central Dos Cabezas Mountains (figs. 10 and 11) will rely largely on the original, low-level aeromagnetic data.

Regional Aspects

The fundamental geologic feature extending through the study area and beyond it to the southeast and the northwest is the Apache Pass fault zone, a left-lateral shear zone whose recurrent movement from Precambrian through at least early Tertiary time has had a strong effect on the geologic evolution of the Dos Cabezas Mountains. Other major geologic features are the volcano-plutonic area of the central Dos Cabezas Mountains, the branch faults of the Apache Pass fault zone west of Government Peak and at Emigrant Canyon, and the southwestern sedimentary belt. These features are either closely related to the Apache Pass fault and its tectonic evolution or, in the case of the southwestern sedimentary belt and the separate sedimentary belt crossing Wood Canyon, the result of northeast-southwest compressional features that interacted with the Apache Pass fault zone (Drewes, 1980, 1981).

A significant overall aspect of the regional aeromagnetic map (fig. 10) is the distribution of large anomalies not reflected in either topography or outcrop pattern and only weakly expressed in the gravity patterns. Many of the magnetic anomalies trend transverse to the gravity contours (fig. 11). For example, closely spaced aeromagnetic contours extend northeast from Emigrant Canyon between a high over Wood Canyon and a low northeast of Apache Pass, whereas the gravity gradient is gentle and trends northwest in this area. Also, southeast of Willcox Playa on the north flank of a strong magnetic high, closely spaced aeromagnetic contours trend east, whereas the gravity contours are widely spaced and generally trend northwest. Finally, about 12 km south-southwest of Orange Butte, closely spaced aeromagnetic contours trend northwest, whereas the gravity field is nearly flat.

Major gravity anomalies (fig. 11) show a more straightforward relationship to topography and outcrop pattern. Density values within crystalline bedrock generally have a smaller range than the difference between values for crystalline bedrock and alluvium (Sumner and Schnepfe, 1966; Aiken, 1978; Klein and Wynn, 1984); thus the gravity minimums (values less than about -160 to -170 mGal) provide a generalized picture of the distribution of deep fault-controlled basins.

The subsurface bedrock relief, like that of the conspicuously linear ranges and basins of this part of the Basin-and-Range province, is generally related to mid-Tertiary faulting. The northwest-trending gravity high of the Dos Cabezas Mountains, somewhat more westward-oriented than the north-northwest-trending lows over Sulfur Springs and San Simon Valleys, suggests the outline of the structurally high crystalline basement terrane associated with the study area. Aeromagnetic anomalies that lie within such structurally high areas indicated by gravity are inferred to represent plutonic bodies or bodies of varying composition that are juxtaposed by faulting.

Three gravity profiles across the Dos Cabezas Mountains were modeled to illustrate typical relationships that might exist between the depth of bedrock and the Bouguer gravity anomalies (figs. 11 and 12). The subsurface rock distributions were obtained by a trial-and-error fitting of the calculated field to the observed field for various body shapes and density of differences. Calculations allow multicornered, finite-length prisms that strike normal to the profile (Cady, 1980; Campbell, 1983). The regional gravity correction was a straight line that brought the end-point values calculated for each profile into agreement with the contoured Bouguer values shown on

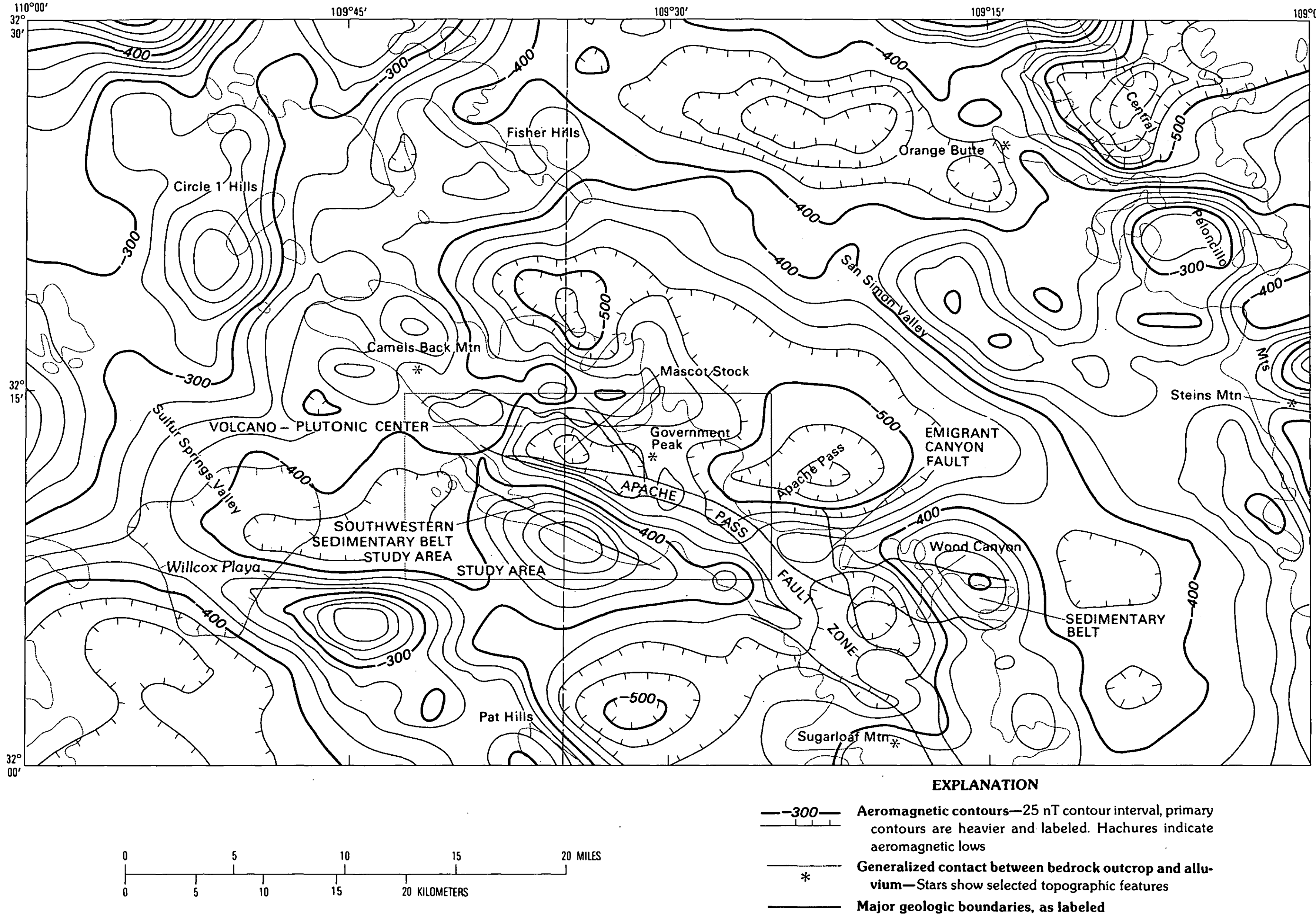


Figure 10. Upward-continued aeromagnetic map of the Dos Cabezas Mountains area. Upward-continuation to 3.5 km above sea level was based on a surface of equivalent magnetization as described in U.S. Geological Survey, 1986. Contour interval is 25 nanoTesla (nT, 1 nT is 1 gamma). The study area is within the rectangular box. The north-south dashed line separates the two surveys from which this map was taken (U.S. Geological Survey, 1979, 1980). Features discussed in the text include the Apache Pass fault zone, the southwestern terrane including the southwestern sedimentary belt, and the northeastern terrane including the volcano-plutonic center.

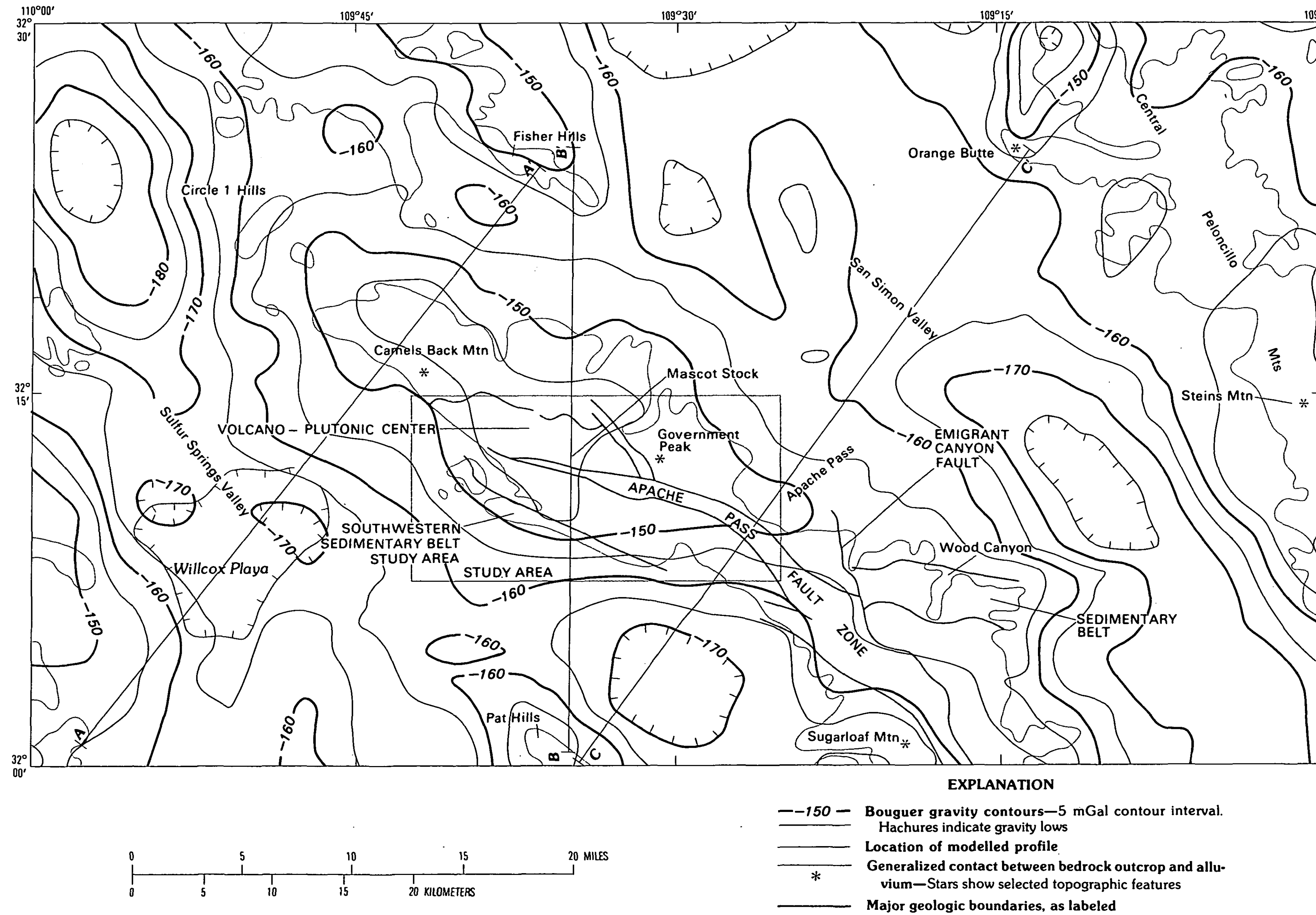


Figure 11. Bouguer gravity map of the Dos Cabezas Mountains area. The Bouguer and terrain corrections are based on a reduction density of 2.67 gm/cm^3 (Wynn, 1981). Contour interval is 5 mgal. The study area is within the rectangular box. Features discussed in the text include three profiles A-A', B-B', and C-C' and the following geologic terranes: the Apache Pass fault zone, the southwestern terrane, including the southwestern sedimentary belt, and the northeastern terrane including the volcano-plutonic center.

figure 11. Although gravity data cannot provide an unambiguous solution to the rock distribution, it does provide constraints on the lateral position of buried density differences. Density changes along the surface were constrained by elevation, mapped contacts between Precambrian rock and younger rocks, and mapped contacts between bedrock and basin fill. Rock densities used for the models are chosen from within known ranges for certain rock types (Sumner and Schnepfe, 1966; Aiken, 1978; Klein and Wynn, 1984). Changes in modeled density have a first-order effect on the depth of the bodies that will fit the data, but only a second-order effect on the horizontal locations of changes in density. Thus, the major features of the models that may be taken with a reasonable amount of confidence are the relative thicknesses of basin fill and the existence of an anomalously dense subsurface mass associated with the Precambrian rocks of the Dos Cabezas Mountains. The former are associated with bodies having a modeled density of 2.37 gm/cc, the latter with the bodies having a modeled density of 2.77 gm/cc. All other regions are assumed to be represented by a density of 2.67 gm/cc, which was used in the Bouguer and terrain corrections. Laterally uniform increases in density with depth will have no effect on the shape of gravity anomalies. Alternative gravity profile interpretations have been provided by Aiken (1978). The location of Aiken's profile 2 (1978, p. 302 and 309) is close to the southern part of the location of profile A–A′ (fig. 11) of this report, and his locations on profiles 3 and 6 impinge on the northern Chiricahua Mountains.

The crystalline basement platform of the Dos Cabezas Mountains is indicated from gravity to be at relatively shallow depth (about 500 m or less) and extensive to the north, northeast, and southwest of the range. Particular note might be taken of the gentle gravity gradients extending across alluvium southwest of Camels Back Mountain and east of Apache Pass. These areas contrast with the steep gravity gradient south of Government Peak (profiles B–B′ and C–C′, fig. 11), which suggests a west-trending flanking fault that is relatively close to the exposed outcrop. Similarly steep gradients closely bound the east and west sides of the Chiricahua Mountains, but are complicated by an incursion of a gravity low into the Sugarloaf Mountain area and an excursion of a gravity high outward to the east of Wood Canyon.

Various aeromagnetic anomalies in the western and the northwestern parts of the southwestern flank of the Dos Cabezas Mountains and the northeastern flank of the Dos Cabezas Mountains extend well over the inferred shallow bedrock platform beneath these areas (fig. 10). The aeromagnetic high anomalies on the northeastern flank of the mountains most likely reflect the general extent of plutons, including Precambrian, Late Cretaceous to Paleocene, and possibly Tertiary plutons that intrude the Proterozoic Pinal Schist. Aeromagnetic anomalies over the relatively shallow bedrock southwest of Camels Back Mountain suggest the possible westward extension of the Apache Pass fault zone.

Upward-continued aeromagnetic data (fig. 10) indicates the large-scale aspects of the Apache Pass fault zone and of the core of the volcano-plutonic center more clearly than the lower level data which is complicated by the effects of smaller geologic bodies. The Apache Pass fault zone northwest of Apache Pass is clearly paralleled by aeromagnetic contours that form a distinct high centered over the southwestern terrane and an associated low located west of the branch faults near Government Peak. The parallel contours along the fault zone form a steep gradient that reflects contrasts across the fault zone. The maximum gradient lies about 2–3 km southwest of the fault zone, suggesting a substantial flattening at depth compared to the mapped dips, discussed in the section of this report on structural geology. Southwest of the fault zone, the high corresponds with a Precambrian pluton; the minimum of the low to the northwest corresponds with the eastern half of the volcano-plutonic center. The aeromagnetic low is in part a polarization low, but also may represent the center of the volcanic vent and caldera area discussed in the section on geology. That part of the volcano-plutonic center to the west, distinguished on the aeromagnetic data as a high, generally corresponds to the Silver Camp Canyon stock of Late Cretaceous-Paleocene age.

Central Dos Cabezas Area

Low-level aeromagnetic data of the central Dos Cabezas Mountains present a considerably more complex pattern of anomalies than the high-level data considered. An overview of the main low-level aeromagnetic and geological features is shown on figure 13. The aeromagnetic contours on figure 13 are identical to those in the more fully annotated figure 14 (also pl. 1), but on figure 13, the major amplitude variations are emphasized through shading of those areas where aeromagnetic values exceed 49,700 nanotesla (nT, 1 nT is 1 gamma). The detail retained in contours based on the low-level data (152 m to 457 m above the ground) resolves magnetic anomalies of geophysical features having extent, both laterally and vertically, as small as 1 km or less. A primary limitation in the resolution is the 1-km flight line spacing.

Major amplitude variations in the low-level aeromagnetic data (fig. 13) are generally consistent with the upward continued data (fig. 10), but the steeper gradients and shorter wavelengths apparent in the low-level data are more readily correlated to near-surface geologic features. Note, for example, the relatively narrow and elongate low that follows the transition between the

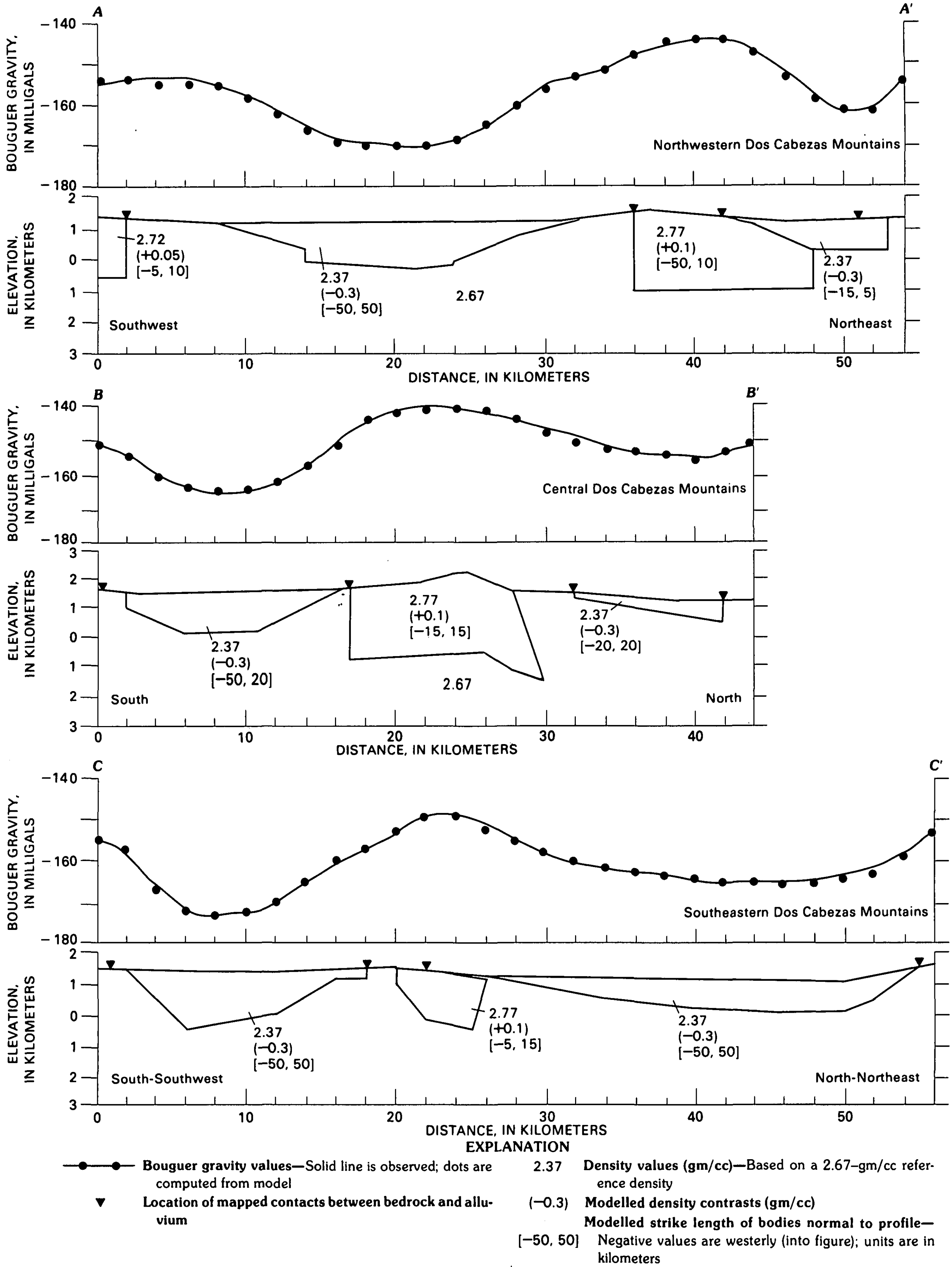
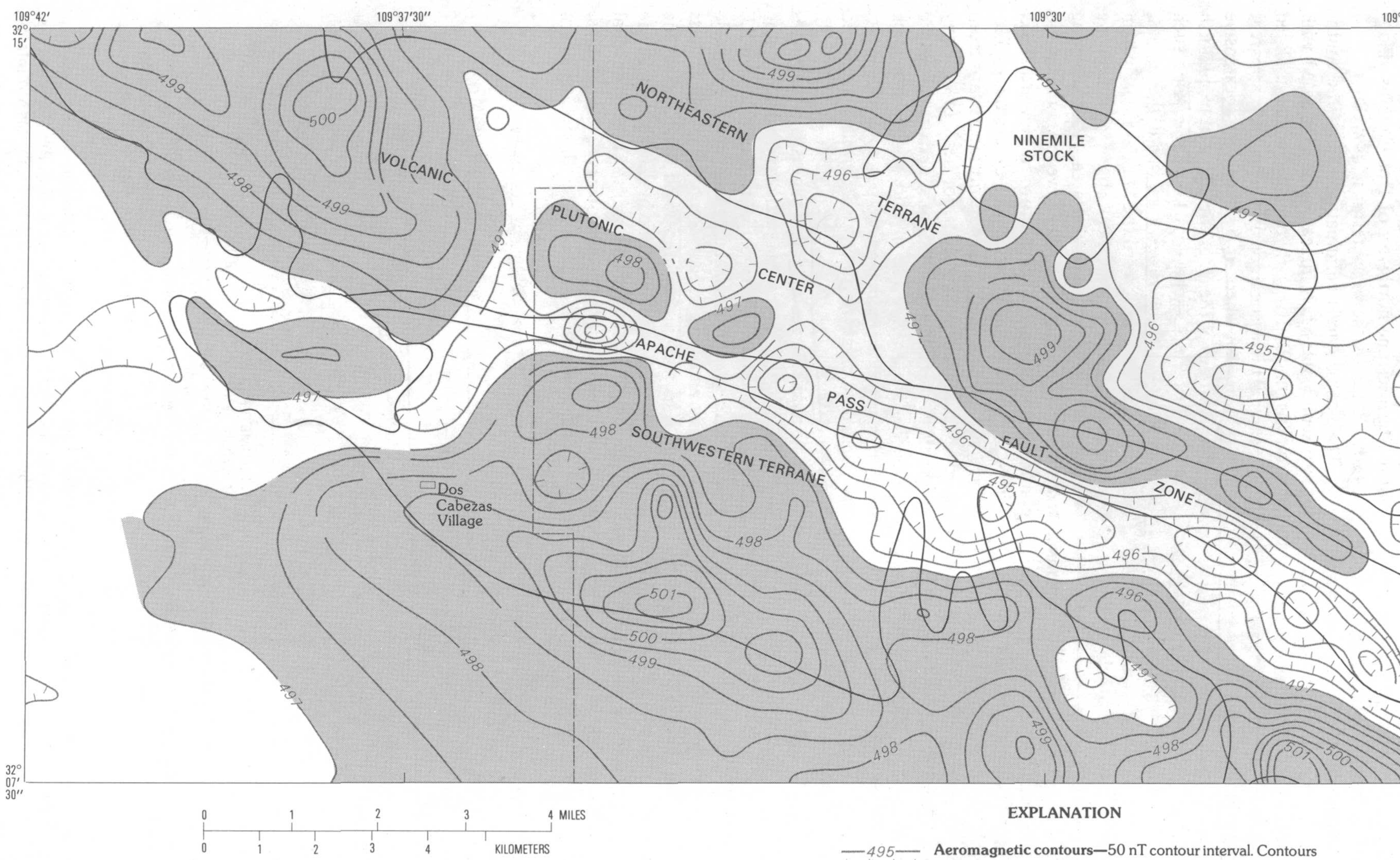


Figure 12. Gravity profiles and models of bedrock density distributions across the Dos Cabezas Mountains. Profile locations are shown on figure 11. Features discussed in the text include the area south of the northwestern part of the Dos Cabezas Mountains on profile A-A′ and the extensive areas of relatively shallow bedrock north of the central Dos Cabezas Mountains on profiles B-B′ and C-C′′



EXPLANATION

—495— **Aeromagnetic contours**—50 nT contour interval. Contours labeled in units of 100 nT. Aeromagnetic highs exceeding 49,700 are stippled. Hachures indicate aeromagnetic lows

—— **Generalized borders between different geologic terranes, contacts of major stocks, and edge of alluvial cover**

Figure 13. Generalized aeromagnetic map of the central Dos Cabezas Mountains extracted from figure 14 (also pl. 1). Darkened areas show where aeromagnetic values exceed 49,700 nT (1 nT is 1 gamma). Major aeromagnetic features discussed in the text include the following: the aeromagnetic trough that parallels the Apache Pass fault zone, the aeromagnetic high over the Proterozoic granite of the southwestern terrain, the transition from low aeromagnetic values of the eastern part of the volcano-plutonic center to high values of the western part.

southwestern terrane and the northwestern terrane. Each of the three main terranes, southwestern, northeastern, and the Apache Pass fault zone that lies between the other two terranes (fig. 13), contain distinctive aeromagnetic features.

Magnetic susceptibility data for rocks of the central Dos Cabezas Mountains are fairly limited (table 3). However, these data, in conjunction with observed relationships between aeromagnetic anomalies and outcrop patterns, provide tentative insight into magnetic contrasts between rock units and thus suggest the geologic composition of units responsible for aeromagnetic anomalies where projections from outcrops are inconclusive. Each measurement is the result of a linear average of several readings taken with a hand-held susceptibility meter used on hand specimens or at an outcrop site. One may note the relatively large magnetic susceptibility associated with the Upper Cretaceous-early Tertiary granitic rock as compared to its volcanic counterparts. Other rocks having relatively high susceptibility include the Precambrian granite and some of the rocks of the Pinal Schist. Measured susceptibilities on rhyolite dikes, both of Late Cretaceous-early Tertiary and mid-Tertiary affinities, were uniformly low.

Southwestern Terrane

A broad aeromagnetic high occurs over the southwestern terrane (fig. 13) centered over the southwestern sedimentary belt that overlies the dominant Precambrian granitic basement rocks (fig. 14). Along the axis of this sedimentary belt, the aeromagnetic high has several culminations. Particularly noteworthy is a strongly developed northeast-trending low that crosses the southwestern terrane northwest of Dos Cabezas village and extends across the other terranes as well.

The aeromagnetic culminations along the southwestern sedimentary belt appear to be associated with areas having mid-Tertiary rhyolite dikes and undated quartz veins. This association is particularly apparent northeast of the belt where dike swarms are coextensive with several prongs of the magnetic high that trend north to east toward the Apache Pass fault zone. One such prong extends north-northwestward from the highest culmination and points toward the Mascot stock, which lies just southwest of Cooper Peak (fig. 14). This prong is interrupted near the Leroy mine area. Another prong trends north-northeastward from a lower culmination and gradually swings northwestward toward Howard Peak, a site of suspected plutonic activity of Cretaceous or Tertiary age. A third prong trends east-northeastward from the lower culmination, but does not head toward any known or suspected site of plutonic activity along the Apache Pass fault zone. The rhyolite dikes, with which these aeromagnetic anomalies are partially coincident, have negligible magnetic susceptibility where measured (table 3).

The available geologic data suggest several possible explanations for the magnetic anomalies of the southwestern terrane. Foremost is the liklihood that the Precambrian granite constitutes the primary magnetic source body and the configuration of the high reflects unknown and presumably unexposed variations in the magnetic material in this rock and in the geometry of the body with respect to adjoining rocks. Three additional possibilities may contribute to the observed relationships. First, the broad high that peaks over the southwestern

Table 3. Magnetic susceptibility of rocks in the central Dos Cabezas Mountains based on measurements at outcrops or on hand specimens

Rock unit	Susceptibility, emu-cgs × 10^5 (no. of measurements)	Comment
Tg	250 (1)	
Tr	0 (2)	
TKg	1050 (1)	
TKv	30 (2)	From dacite (unit TKd) and rhyolite breccia (unit TKrb; Drewes, 1985).
TKb	100 (1)	
TK_{ri}	50 (1)	Ring dike intrusive breccia, not differentiated on map.
Mzs (Ka)	0 (1)	See Drewes (1985b) for andesite and Cintura Formation (units Ka and Kc).
(Kc)	500 (1)	
CMs	0 (2)	
Yg	670 (5)	Range 300-1050.
Xa	170 (3)	Range 50-1050.
Xm (Xpq)	550 (4)	See Drewes (1985b) for Pinal Schist, quartzite member (unit Xpq); range 150-1600.

sedimentary belt partly, or wholly, reflects the contact between the Precambrian plutonic rock and the weakly magnetic sedimentary rock and alluvium to the southwest. The effect of this contact may be complicated by flanking faults along the southwest margin of the range. Second, inasmuch as the relatively sharp aeromagnetic peaks of this high are precisely over the sedimentary rock belt, there is the option that the basal clastic unit, the Coronado Sandstone which overlies a peneplaned surface, may locally contain unusual concentrations of magnetite or ilmenite winnowed from the detritus derived from the basement during a period of extensive erosion. This option could only be a secondary contributing factor, but it lends itself to field checking and, if borne out, may have an implication of potential economic significance in that other heavy minerals may also be found with magnetic ones. Third, the culminations and prongs of high magnetic value may be underlain by blind plutonic bodies from which the rhyolite dikes are derived. The third option is not readily checked, but it could also have potential economic implications, if the bodies intruded sedimentary rocks and thus formed a geologic environment favorable for mineralization. In both the second and third cases, the proposed features would be superposed on the general effect of the widespread Precambrian granitic rock.

Resolution of these options requires further work. Aside from the obvious testing of the magnetic property of the Coronado Sandstone, a detailed geochemical and petrographic study could provide clues bearing on blind plutonic masses.

Northeastern Terrane

The northeastern terrane is characterized by two kinds of aeromagnetic patterns that generally reflect the rock types exposed in this terrane. To the northwest of Dos Cabezas Peak and the east of Wood Canyon are areas having magnetic anomalies determined by large wavelength and amplitude. These areas are separated by a central area having anomalies of smaller wavelength and amplitude (fig. 13). The eastern and northwestern areas are underlain mainly by Precambrian and Upper Cretaceous-Paleocene plutonic rocks and locally by their metasedimentary host rocks or a thin(?) cover of Upper Cretaceous-Paleocene volcanic rocks. The central area, on the other hand, is underlain by the thick mass of rhyolitic to dacitic volcanic rocks.

Specific magnetic anomalies within these three parts of the northeastern terrane reflect structural features or rock types that may be inferred from study of the surface geology, and some of these geological-geophysical associations may have potential economic interest.

In the eastern area (fig. 14), the broad low saddle along the southeastern part of Happy Camp Canyon partly coincides with the mid-Tertiary Ninemile stock, which is more alkalic and less rich in magnetic minerals than most older stocks. A southeastern extension of this low saddle covers the area of the Precambrian Sheep Canyon stock, which is unusual also in that it is foliated and the oldest of the Precambrian bodies, possibly also unusually poor in magnetic minerals. The southwestern extension of this low, along Happy Camp Canyon, is an area of Precambrian metasedimentary rocks and a few amphibolite masses.

The broad magnetic high west of Dos Cabezas Peaks is coextensive with the Upper Cretaceous-Paleocene stock at Silver Camp Canyon. The contrast in magnetic signature of stocks of this age with those of mid-Tertiary age is noteworthy because the older stocks are associated with mineralization, whereas the mid-Tertiary rocks are generally barren. One of the two maxima of the broad high in the western area is clearly coincident with the Silver Camp Canyon stock. The other maximum, only partly shown in the northwest corner of figure 14, is over volcanic rock of Cretaceous-early Tertiary age, but it may be indicating a second blind intrusion.

The central part of the northeastern terrane, between Dos Cabezas and Howard Peaks, is marked by a magnetic pattern of shorter wavelengths and by many areas of low magnetic intensity. This area is roughly coextensive with the volcanic pile of the core of the Dos Cabezas Mountains, and is mineralized at many localities. A strongly developed magnetic trough marks the west side of the central area, a curvilinear belt of magnetic lows occurs on the northeast side of the area, and two magnetic highs lie to the south, essentially next to the Apache Pass fault zone.

The strongly developed magnetic trough on the west continues southwest across the Apache Pass fault zone and into the southwestern terrane. To the northeast, it merges with the belt of magnetic lows that follows the northeast margin of the volcanic pile. Near the junction of these elongate magnetic lows is the Elma mine, where the dacitic breccia pile is cut by dikes and a breccia pipe and is the site of considerable mineralization.

The two small magnetic highs next to the Apache Pass fault zone near Cooper and Howard Peaks (fig. 14), along with other features composed of similarly short wavelengths, largely vanish in the upward-continued data shown on figure 10, which indicates shallow vertical extent as well as small horizontal extent of the source bodies. The high at Cooper Peak is the area where the Upper Cretaceous-Paleocene Mascot stock is exposed (fig. 14). On the more detailed map (Drewes, 1985), some breccia pipes and rhyolitic intrusive bodies are also shown. The high near Howard Peak is centered in an area where several small intrusive bodies are shown on

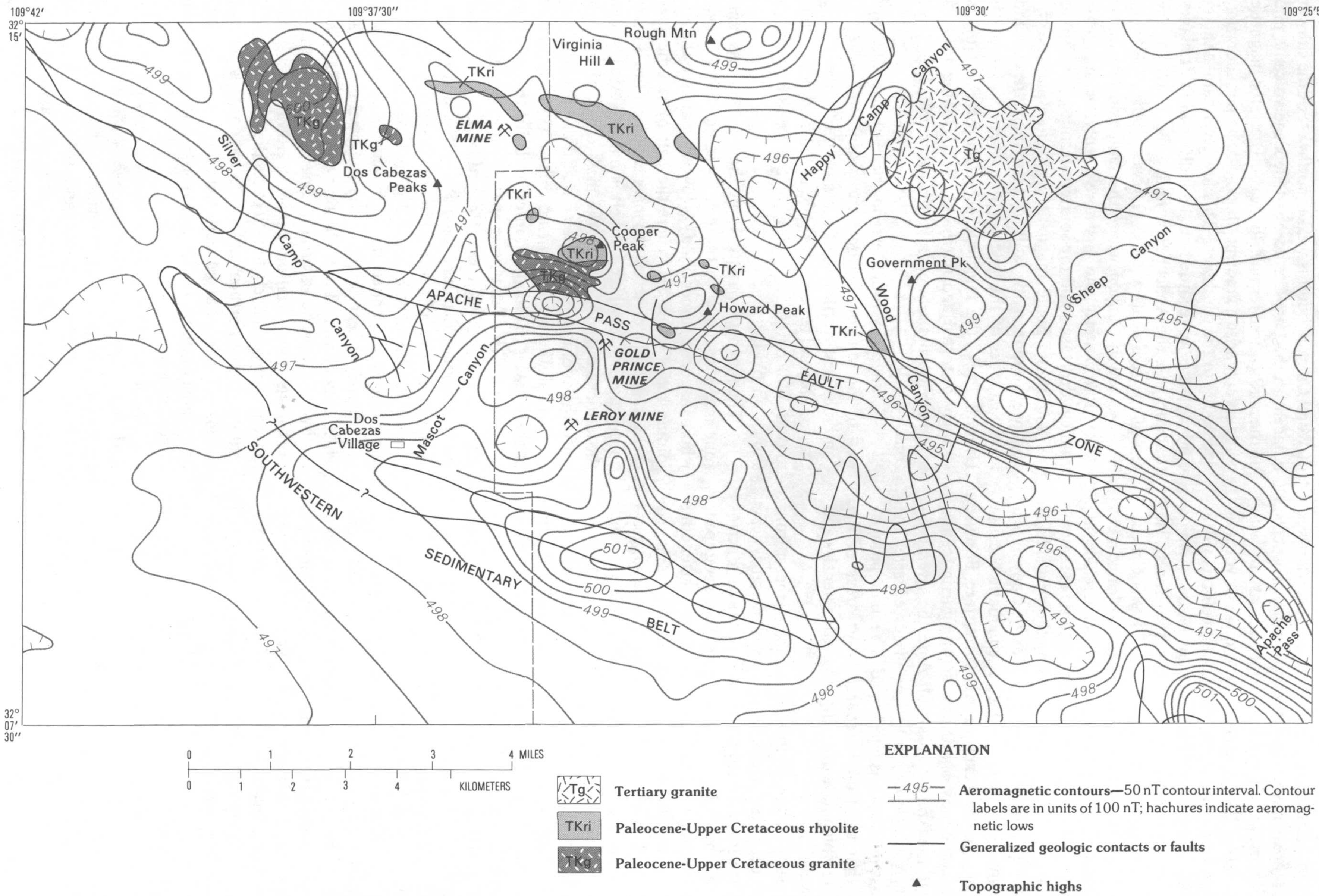


Figure 14. Aeromagnetic map of the central Dos Cabezas Mountains simplified from original contour maps based on low-level (150 and 450 m) data (U.S. Geological Survey, 1979, 1980; pl. 1). The dashed north-trending border at about longitude 109°35′ W. shows the locus of hand-interpolated contours between the areas of the two different aeromagnetic surveys.

figure 14 and more breccia pipes are mapped (Drewes, 1985). Both areas have mines and numerous prospects.

The short wavelength aeromagnetic pattern with overall low values is characteristic of a mass of volcanic rocks having silicic to intermediate compositions. Such a terrane may readily have local shallow bodies giving a variety of short wavelength magnetic signatures. The relative prominence of this pattern east of Dos Cabezas Peak (figs. 13 and 14) supports the idea that volcanic rocks forms a thin cap over parts of the Upper Cretaceous-Paleocene stocks and the Precambrian granitic basement.

The strong magnetic trough along the west side of the central area running parallel to Mascot Canyon is a major aeromagnetic feature, which is enigmatic because of its lack of geological expression at the surface. Because this trough is the most significant aeromagnetic feature transverse to the Apache Pass fault zone, the several options of its geologic origin will be discussed after the Apache Pass fault zone is considered. The main point at present is that the trough separates two areas of the volcanic pile which have differing magnetic intensity and anomaly wavelengths.

The belt of magnetic lows extending northeast from the Howard Peak area is another significant aeromagnetic feature indicating a buried structural feature or a petrological variation within the volcanic pile. Well developed, northwest-trending, aeromagnetic contours extending northwest of the study area (pl. 1) appear to be a related continuation of this belt of lows. This feature suggests a fault that may be expressed as a volcanic-filled trough within the volcanic pile.

The aeromagnetic high areas at Cooper Peak and near Howard Peak are indicative of small cupolas of granitic or granodioritic rocks. The Mascot stock near Cooper Peak is part of one of these cupolas; the rhyolite intrusive west of the peak (Drewes, 1985) may reflect another part. Smaller intrusive bodies also intrude the breccias near Howard Peak, suggesting a larger concealed parent body. The breccia pipes at both peaks are additional signs of more magmatic activity at depth. Such concealed cupolas may also have been loci for movement of hydrothermal fluids. Where these fluids may have had access to favorable host rocks, such as particular Paleozoic and Mesozoic sedimentary rocks, mineralization may have occurred. Thus, potentially favorable terrane for mineral exploration is expected in the adjacent part of the northeastern sedimentary belt and at depth below the volcanic pile.

Apache Pass Fault Zone

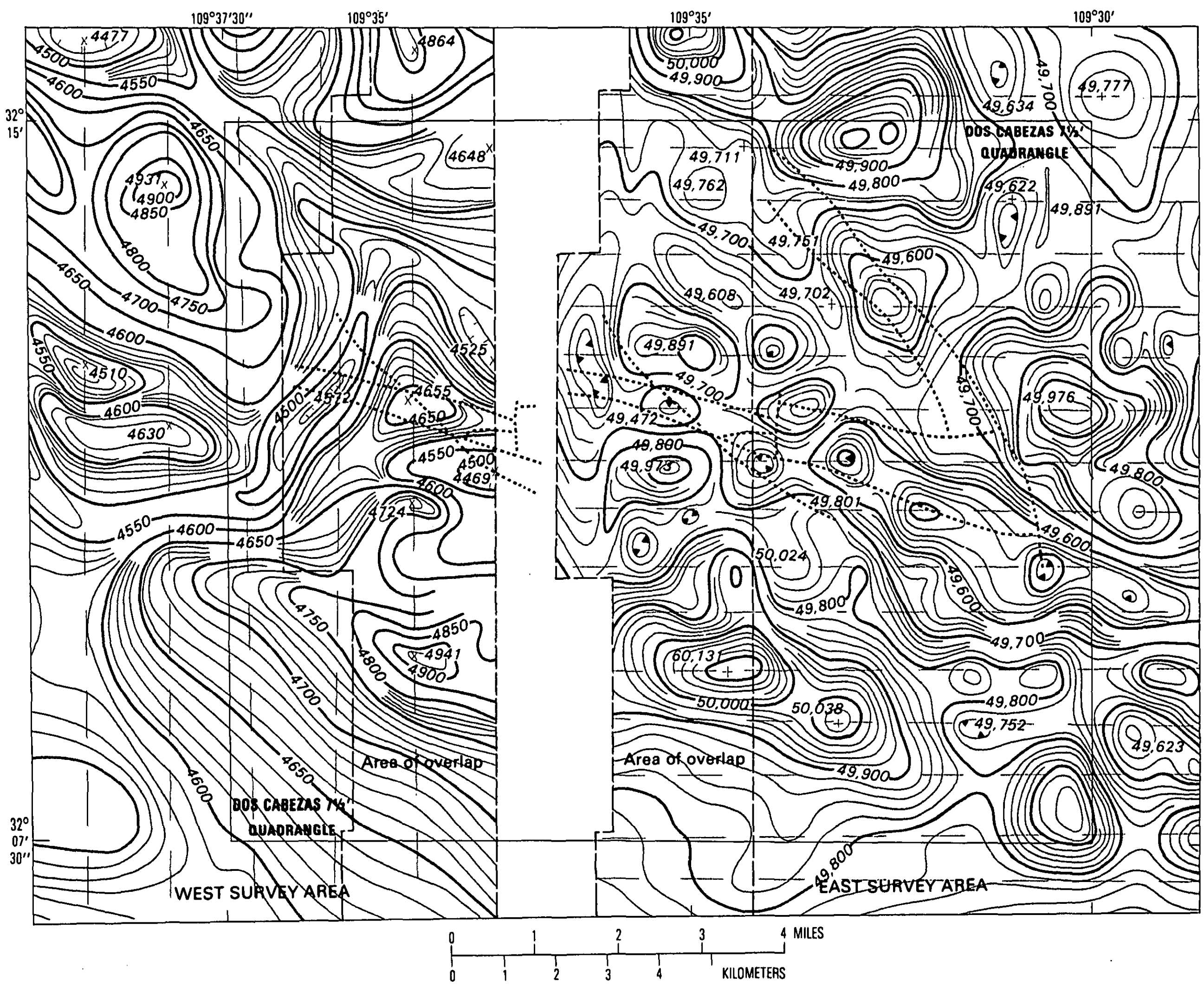
The typical aeromagnetic signature of the Apache Pass fault zone is a distinct linear gradient, with a magnetic trough to the southwest of the zone (fig. 14). This magnetic signature is strongly developed southeast of Wood Canyon, but it is weaker northwest of the canyon adjacent to the Late Cretaceous-Paleocene volcanic pile on the northeastern terrane. To the southeast, the magnetic contours comprise a gradient of 300–400 nT per kilometer, decreasing to the southwest. This low-level data is in accord with the dip recorded on the individual fault planes that compose the Apache Pass fault zone, as well as the dip of the sedimentary rocks (Drewes, 1985a, 1985b).

At Wood Canyon where the fault zone begins to strike more westerly and dip more steeply, the magnetic gradient decreases, and the southwestern low is offset to the southwest. Some magnetic contours splay north-northwestward from the fault zone and mark the east and northeast sides of the volcanic pile. Near, and west of, Howard Peak, the magnetic signature of the fault is strongly distorted and narrowed. Near Cooper Peak, a magnetic low lies athwart a vertical segment of the fault zone.

A magnetic trough extends beneath the alluvium west of the Mascot Canyon transverse feature, where it continues west-northwest of the mouth of Silver Camp Canyon, beyond the area of figure 14 for many kilometers toward Willcox (U.S. Geological Survey, 1979; partly shown on pl. 1).

The magnetic pattern along the Apache Pass fault zone is the response to the belt of sedimentary rocks, whose magnetic susceptibility is low compared to the adjoining rocks (table 2). Where the belt of sedimentary rocks is wide, the effect on the magnetic signature is more conspicuous than where the belt is narrow. Also, where those rocks dip moderately, the mass effect of the belt shifts the anomaly in the direction of dip; where the dips are vertical, there is little or no offset. The coincidence of these places of change in inferred dip of the sedimentary rock of the fault zone with places of transverse magnetic features, such as at Howard Peak, suggests that the transverse structures shown on figure 2 may be more than just minor faults formed in response to stress variations across the fault zone during the time the sedimentary rocks were upended. The transverse features may, in part, represent tear faults in the southwestern terrane, which may be viewed as the upthrown block of a reverse fault of the Apache Pass fault zone. The concentration of known mineralization between Howard Peak and Mascot Canyon is likely to reflect conditions in the adjacent part of the northeastern block, but perhaps areas of similar complications beneath the alluvium to the west of the area of figure 14 may also be potential exploration targets.

A prominent magnetic trough across the Apache Pass fault zone in the upper reaches of Mascot Canyon extends far into the adjacent terranes. Its close proximity to certain geologic features and to areas of strong mineralization make it important in any assessment of economic potential. The magnetic trough is prominent



EXPLANATION

x 4931 —4550— Aeromagnetic contours—20 nT contour interval, 100 nT between primary contours indicated by heavier lines. Hachures or teeth indicate lows, extrema indicated by X or +. West survey flown 457 m (500 ft) above ground. Flight lines are shown by light dashes.

.... Generalized location of Apache Pass Fault Zone and major branch faults

— — — Extent of overlap of two surveys

Figure 15. Original aeromagnetic maps that cover parts of the Dos Cabezas and Simmons Peak 7 1/2-minute quadrangles (U.S. Geological Survey, 1979, 1980). The feature discussed in the text is the north or north-northeast-trending low near the east-central border of the quadrangle.

because it is deep and narrow as well as long, and because it offsets the magnetic-low associated with the Apache Pass fault zone. It extends southward from the Elma mine area, where it merges with a belt of lows along the northeastern side of the volcanic pile, continues past the end of the flap of sedimentary rock near the Ivanhoe mine, crosses the Apache Pass fault zone near the Dives mine, and trends about S. 35 W. near the contact of Precambrian metasedimentary rock with Precambrian granitic rock in the southwestern terrane.

The original aeromagnetic data of both surveys (fig. 15) help to show the configuration of this magnetic trough as well as to indicate the limitations in the available data. The magnetic low is constrained by four north-south lines in the western survey and by five east-west lines in the eastern survey. The axis and orientation of the contoured minimum appear offset at the zone of overlap between these surveys, but the existence of the trough and its general position and configuration are ascertained.

This magnetic trough may be explained in various ways, several of which have potentially favorable economic implications. For one, a septum of concealed sedimentary rock may extend north from the exposed flap near the Ivanhoe mine to the mass reported in the subsurface at the Elma mine. In the southwestern terrane, the edge of the Precambrian granite mass may fortuitously be aligned with this belt of sedimentary rock. The offset in the Apache Pass fault zone may reflect a short cross fault. Alternatively, a larger cross fault may be present in the subsurface, and various kinds of rock having low magnetic susceptibility may be aligned on this structure. In the northeastern terrane, this blind fault may mark the western edge of a thicker pile of volcanic rocks, or perhaps the margin of a major vent. In the southwestern terrane, this fault may be a tear fault in the raised block of a major reverse fault segment of the Apache Pass fault zone. A mapped tear fault that offsets the southwestern belt is mostly concealed beneath alluvium near Dos Cabezas village and is the site of slivers of Paleozoic sedimentary rocks in the subsurface (Drewes, 1985a). Another alternative may be that the magnetic trough is the signature of a blind septum-like mass of silicic igneous rock, such as an elongate cupola of mid-Tertiary granite or a rhyolite dike swarm.

Both the cross fault explanation and the sedimentary rock septum ideas imply the presence of sites promising for mineralization, particularly between the Ivanhoe and Elma mines. It is thus desirable to augment the magnetic study with additional flights along northwest-trending traverses at 0.5-km intervals. Electromagnetic and gravity traverses would also provide important additional constraints to the structural interpretation.

SUMMARY

The combined results of geological, geochemical, and geophysical studies of the central Dos Cabezas Mountains indicate the presence of a setting favorable for undiscovered base- and precious-metal deposits. The focus of economic potential is a dacitic volcanic center of Late Cretaceous-early Tertiary age along the crest of the mountains northeast of the village of Dos Cabezas, roughly between Howard Peak and Silver Peak. This area has a history of significant mining activity, mainly associated with vein and replacement deposits. However, production in the Dos Cabezas Mountains has not equalled that from nearby ranges, such as the Pyramid Mountains to the east that host the Lordsburg and Animas districts and the Little Dragoon Mountains to the west that host Johnson Camp. The central Dos Cabezas Mountains, although exposing larger outcrops of Precambrian rock than most nearby ranges, bear sufficient geologic similarities to more mineral-productive ranges to suggest the possibility of significant unexploited mineral resources that may include additional base- and precious-metal vein and replacement deposits as well as disseminated mineralization.

Geologic groundwork over the Dos Cabezas Mountains, including related regional studies, has established the structural and plutonic framework of the area. Geochemistry has delineated some aspects of the metallization anomalies and their geologic controls, and geophysical studies have provided some insight into the subsurface regime.

The central Dos Cabezas is inferred to straddle an ancient northwest-trending shear structure, the Apache Pass fault zone and its branch faults. The Apache Pass fault zone has responded to a succession of orogenic events to form a swath of deformed and metamorphosed Paleozoic and Mesozoic sedimentary rock that provides a deeply penetrating path for magmas and hydrothermal fluids. One of the larger of the magmatic events along the zone was effusion of the Late Cretaceous-early Tertiary dacitic breccia pile and emplacement of related granodioritic stocks and rhyolitic dikes and tabular masses. This volcano-plutonic complex is interpreted to represent a mid-level remanant of a stratovolcano, at least part of which is believed to have collapsed, caldera-fashion, to form bordering structures and to reveal vent structures, both of which appear to be the centers of exposed mineralized rock.

Additional control of intrusion along the Apache fault zone by transecting northeast-trending features is indicated by geophysical patterns. An area of inferred collapse in the core of the volcanic pile may be bounded by a fault marked by northeast-trending geophysical features and a segment of the Apache Pass fault zone. Relatively small northeast-trending faults have been mapped, mainly near the Apache Pass fault zone, and in many places Tertiary rhyolitic dikes trend northeast. Whereas many of these features are interpreted as secondary features that resulted from an adjustment response to the primary tilting of the rocks along the two sedimentary belts, some may be tear faults connected with reverse fault movements along a segment of the Apache Pass fault zone.

Several features delineated within the central volcano-plutonic complex bear on future mineral exploration in the area; these include the following: (1) The extent of buried granodiorite plutons within the breccia pile which may be the source or host of disseminated deposits; (2) the location of leakage of magmatic fluids along and across the Apache Pass fault zone which may result in vein or replacement deposits; (3) the possible existence of Paleozoic rock in place beneath the volcanic pile which may be a locus of massive replacement deposits; (4) the location of vent sites and marginal faults which control the passage of hydrothermal fluids; and (5) the controlling structures around the inferred collapse area, which may contain a major concentration of passages for hydrothermal fluids and metallization.

An aeromagnetic anomaly near Howard Peak suggests one stock of a dimension slightly smaller than the Mascot stock 2 km to the west. Scattered outcrops of Late Cretaceous-early Tertiary rhyolite surround this anomaly and suggest that the inferred stock may be of the same age and composition as the Mascot stock. The Mascot stock itself only borders an aeromagnetic anomaly, which suggests that it is the cupola of a larger body at depth that is centered upon the anomaly.

The area west of Dos Cabezas Peaks is marked by an extensive aeromagnetic high that includes two distinct maxima. The higher maximum corresponds to the mapped Late Cretaceous-early Tertiary Silver Camp Canyon stock, the other may be a second stock of related age and composition. The higher aeromagnetic values west of Dos Cabezas Peaks suggest that the major portion of volcano-tectonic collapse occurred to the east. A northeast-trending low that separates these two geophysically distinct parts of the volcano-plutonic center remains unsatisfactorily explained, but provides one of the more

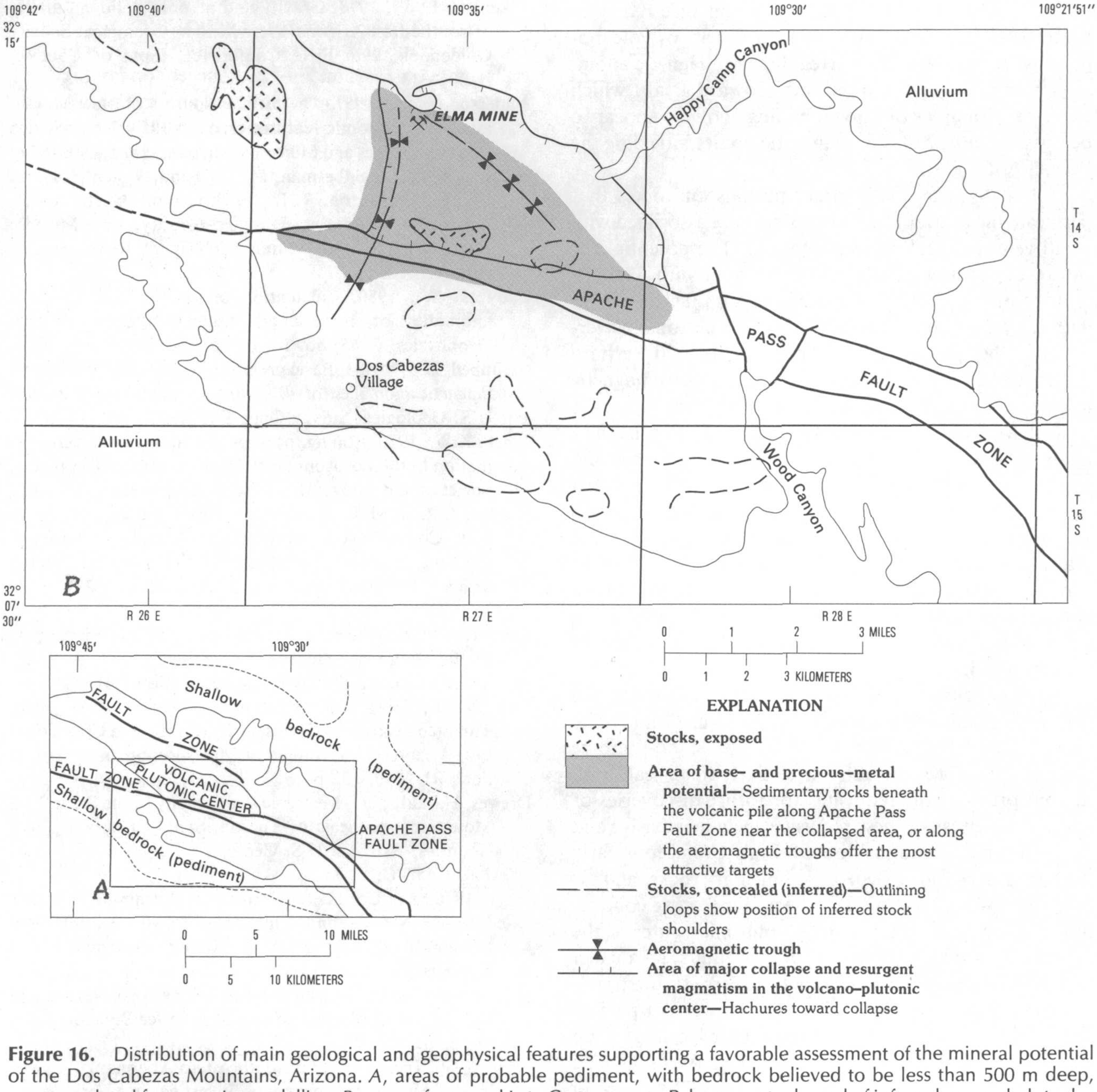


Figure 16. Distribution of main geological and geophysical features supporting a favorable assessment of the mineral potential of the Dos Cabezas Mountains, Arizona. *A*, areas of probable pediment, with bedrock believed to be less than 500 m deep, as extrapolated from gravity modelling. *B*, areas of exposed Late Cretaceous to Paleocene stocks and of inferred concealed stocks, shoulders of stocks, and the volcano-plutonic center.

intriguing targets for future investigation as it leads into the Elma mine area.

A curvilinear aeromagnetic trough marks the central-northeast part of the volcano-plutonic complex. This may simply reflect a major thickness of buried sedimentary rocks, a nonmagmatic blind intrusive body, or a blind structure at depth.

Numerous mapped faults associated with the Apache Pass fault zone are the main candidates for the lateral migration of metallizing fluids. This seems borne out by geochemical studies. This fault system would work in concert with the less extensive northeast-trending fault paths as well as with the extensive and inferred deep brecciation associated with the eastern part of volcano-plutonic center. Numerous irregular aeromagnetic anomalies south of Mascot stock and Howard Peak, which coincide with areas of known mining activity, appear to be possible indications of magmatic bodies intruding the Precambrian granite.

Locally, the mid-Tertiary plutons and dikes that permeate the central Dos Cabezas area are associated with small vein and replacement deposits. The potential for future discoveries of deposits associated with Tertiary plutons has weaker historical basis than that associated with the Late Cretaceous-early Tertiary plutons. Nevertheless, the potentials associated with mid-Tertiary magmatic activity should not be neglected. Aeromagnetic anomalies along the southwest edge of the outcrop of the central Dos Cabezas Mountains are intriguing in their relationship to a Paleozoic-Mesozoic sedimentary belt and several groups of rhyolitic dikes and dike swarms that fan out from these anomalies. However, the relationships are ambiguous inasmuch as several explanations are plausible, each of which will require further study to verify. Geophysical evidence points to large areas of accessible pediment bordering much of the northeastern flank of the range and the northwestern half of the southwestern flank.

In conclusion, the present study points out the following relationships, illustrated on figure 16. (1) The central Dos Cabezas is marked by a volcano-plutonic center that has been an area for relatively small-scale mining but provides the requisites for future discoveries of additional deposits. These requisites include intensive and deep faulting, juxtaposition of Late Cretaceous-early Tertiary stocks with Paleozoic sedimentary rocks, and extensive known alteration. (2) The major feature controlling the location of the volcano-plutonic center is the Apache Pass fault zone and its branch faults, an ancient and probably deeply penetrating transverse suture trending northwest along the range. (3) The western part of the volcano-plutonic center is marked by a large Late Cretaceous-early Tertiary granite stock. Aeromagnetic data suggest this stock may be accompanied by a second similar stock and appear to confirm the existence of two smaller stocks to the east. (4) The volcano-plutonic complex is interpreted to be the remnants of a stratovolcano, part of which collapsed to form a brecciated and permeable mass that is known to have acquired moderate concentrations of metals and is interpreted to be a potential target for more extensive metallization at depth. Aeromagnetic data suggest that the main area of collapse may be east of Dos Cabezas Peaks.

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