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Geology of the Sierra Cuchillo, New Mexico

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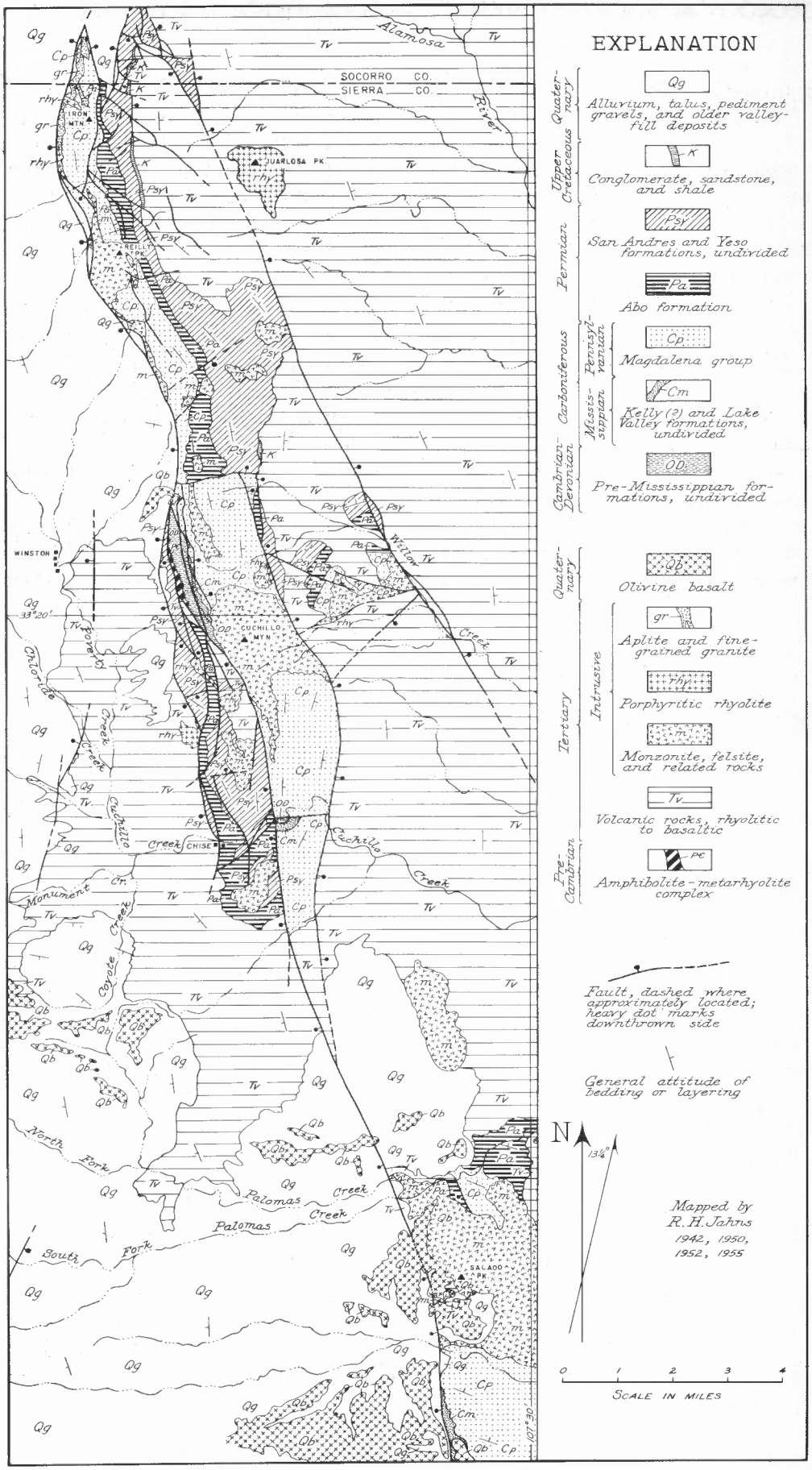


Figure 1. Geology of the Sierra Cuchillo and adjacent areas

GEOLOGY OF THE SIERRA CUCHILLO, NEW MEXICO

By Richard H. Jahns
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Publication approved by the Director, New Mexico Bureau of Mines and Mineral Resources.

GENERAL FEATURES

The Sierra Cuchillo is a narrow, elongate, fault-block mountain range that lies in northwestern Sierra County and extends northward about 2 miles into Socorro County. It is one of several structurally high elements that border the Rio Grande depression west and north of Truth or Consequences (The name Sierra Cuchillo also has been applied in the past to the Mud Springs Mountains, the small range that lies within the Rio Grande depression immediately northwest of Truth or Consequences (e. g., Darton, 1917, p. 38). Fortunately, this dual usage has disappeared during recent years, and the name is now restricted to the larger range discussed in this paper.)

The range is disposed en echelon with respect to the much higher and more extensive San Mateo Mountains to the northeast, and it is separated from the still more extensive Black Range to the west by a well-defined graben valley, about 5 miles in average width, whose surface is very irregular in detail. New Mexico Highway 52, the main route of access, crosses the Sierra Cuchillo at Red Hill Pass, which lies 27 airline miles northwest of Truth or Consequences and 3½ miles northeast of Winston (Fig. 1).

The dominant topographic feature of the range is a rugged spine, about 20 miles long and 1½ miles in average width, that rises 300 feet to nearly 1,200 feet above the flanking country. It trends slightly west of north, and is sharply bounded on the west by a major zone of steeply dipping normal faults (Figs, 1, 3). Its eastern boundary is less simply defined, but is in part marked by normal faults that dip east. At its north and south ends, the spine plunges gently beneath a cover of the same upper Cenozoic volcanic and sedimentary rocks that border the range on both the east and the west.

Drainage from the northern part of the range is eastward to the Alamosa River, a southeast-flowing tributary of the Rio Grande, and westward to Poverty Creek, which traverses a longitudinal valley whose lower end lies at Winston. Drainage from the southern part of the range is eastward via tributaries of Cuchillo Creek and westward to the canyon of Poverty Creek-Cuchillo Creek. Cuchillo Creek crosses the range in a tortuous canyon east of the village of Chise (Fig. 1), and thence flows eastward to the Rio Grande.

The Sierra Cuchillo is geologically divisible by a major cross fault into two distinct parts, herein referred to as the Northern Cuchillo and the Southern Cuchillo. The crest line of the Northern Cuchillo, which reaches altitudes of 7,600 to 8,200 feet, is dominated by Iron Mountain and Reilly Peak (Fig. 2). Cuchillo Mountain, a somewhat lower but very prominent peak east-southeast of Winston, marks the crest of the Southern Cuchillo.

The Northern Cuchillo is fundamentally an east-dipping section of Pennsylvanian and Permian sedimentary rocks. These are cut by numerous hypabyssal igneous intrusives of Tertiary age, and in many places they have been considerably affected by contact metamorphism. They are overlain to the east by remnants of an Upper Cretaceous sedimentary section and by a considerable thickness of Tertiary volcanic rocks. The volcanic section is transected by at least one major normal fault that in part defines the uplift on the east (Fig. 1).

The Southern Cuchillo, also known as the Cuchillo Negro Range, is a fault-bounded block composed mainly of east-dipping Pennsylvanian strata and several intrusive masses of Tertiary monzonite (Fig. 4). The largest of these masses, which has an outcrop area of nearly 3 square miles, is responsible for the narrow, serrate range crest that originally prompted the designation Cuchillo (knife, knife blade). The western flank of the Southern Cuchillo is distinguished by fault slices of Precambrian, lower Paleozoic, and Permian rocks, and this narrow, structurally complex area provides the only complete section of pre-Pennsylvanian rocks in the entire range. Farther south, where the range is gashed by the canyon of Cuchillo Creek, strata as old as Ordovician are exposed in a small block that has been raised by transverse faulting (Fig. 1).

The eastern flank of the Southern Cuchillo is bounded by a zone of normal faults, beyond which is a lowland area underlain by volcanic and intrusive rocks of Tertiary age. The volcanic rocks form a

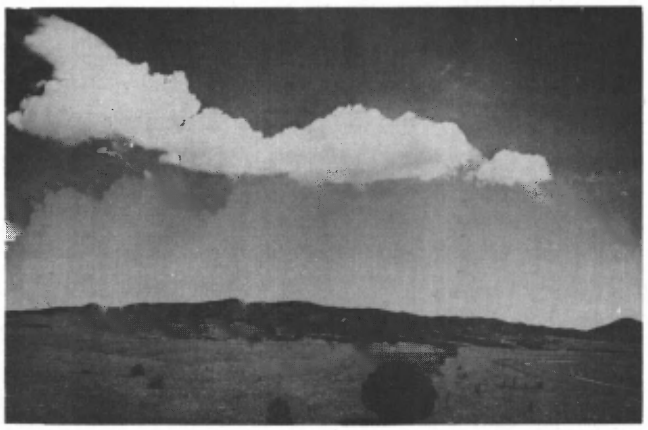


Figure 2. East-southeastward view of the Northern Cuchillo. Iron Mountain is in center distance, and Reilly Peak is at far right. The faceted spurs mark a major zone of faulting along the western edge of the range.

blanket over strata of Pennsylvanian and Permian age, which are exposed in several erosional windows in the area traversed by State Highway 52 between Cuchillo Mountain and Willow Creek (Figs. 1, 3, 5).

The Salado Mountains, which rise island-like above a sea of Upper Cenozoic sedimentary and volcanic rocks, lie immediately south of Palomas Creek and about 6 miles south of Cuchillo Creek. They occupy an area of about 18 square miles, and consist of a north-northeast-dipping section of Paleozoic strata cut by monzonite of Tertiary age. Most of the sedimentary section ranges in age from Mississippian to Permian. These mountains lie at the north end of the Animas uplift (Kelley, 1952), and geologically are a south-southeastward extension of the Sierra Cuchillo. The zone of normal faults that bounds the Sierra Cuchillo on the west also bounds the Salado Mountains on the west (Fig. 1), and definitely does not swing east-southeastward to join the fault near the base of the Mud Springs Mountains, as suggested by some investigators.

The published record contains little information on the general geology of the Sierra Cuchillo, mainly because no attempt has been made to study the area systematically until recent years. Scattered notes on the stratigraphy and structure of the range were included by Gordon in his early account of the geology of Sierra and central Socorro Counties (Lindgren, Graton, and Gordon, 1910, p. 213-285). A geologic sketch map included with this report exaggerates somewhat the extent of Paleozoic rocks in the Sierra Cuchillo and adjacent areas, and provides an interesting contrast with later maps (Darton, 1928b; Harley, 1934), in which the extent of Tertiary volcanic rocks is considerably exaggerated instead. The iron deposits at Iron Mountain have been described briefly by Smythe (1921), Lasky (1932, p. 138-139), Harley (1934, p. 118), Jahns (1944b, p. 54-55, 60-61), and Kelley (1950, p. 198-202), and the beryllium and tungsten deposits in the same area have been mapped and discussed by Jahns (1944a, 1944b). The iron and base-metal deposits of the Southern Caballo have been described by Harley (1934, p. 118-125) and by Kelley (1950, p. 202-203). The geology of the southern part of the range long ago was outlined briefly by Darton (1928a, p. 326-329), who included a sketch section from Winston toward Cuchillo, and later was summarized by Harley (1934, p. 113-116).

Much of the Northern Cuchillo was mapped in detail by Jahns (1944b) during World War II, and this work has been continued southward in the range since 1950 under the auspices of the New Mexico Bureau of Mines and Mineral Resources. Inasmuch as these investigations are still in progress, some of the generalizations set forth in this paper may require future modification in the light of more complete data. Further, the geologic features shown in Figure 1 are based in part upon reconnaissance observations, especially in the area south of Cuchillo Creek, and hence this map should be regarded as a preliminary compilation.

THE GEOLOGIC SECTION

An excellent section of pre-Tertiary rocks is exposed in the Sierra Cuchillo (Table 1), thanks to its topographic and structural height above the surrounding country. Indeed, a surprisingly broad sampling of older rocks in a region otherwise dominated by sedimentary and volcanic rocks of Cenozoic age is provided by this and nearby uplifts, among them the Caballo and Mud Springs Mountains (Kelley and Silver, 1952, p. 30-130) to the southeast; the Hermosa area (Jahns, 1955), Kingston area (Kuellmer, 1954, p. 6-85), and Lake Valley and Cooks Peak areas (Jicha, 1954, p. 6-53) to the south; the Santa Rita-Silver City region (Spencer and Paige, 1935, p. 12-41 Lasky, 1936, p. 15-47; Entwistle, 1944, p. 13-29) to the southwest; and the Magdalena district (Loughlin and Koschmann, 1942, p. 7-47) to the north-northeast. The geologic sections in these areas differ from one another in some respects, including a few features of major significance, but in general they are remarkably similar and bespeak geologic histories with numerous elements in common.

Paleozoic Sedimentary Rocks

A brief summary of the sedimentary rocks ex-

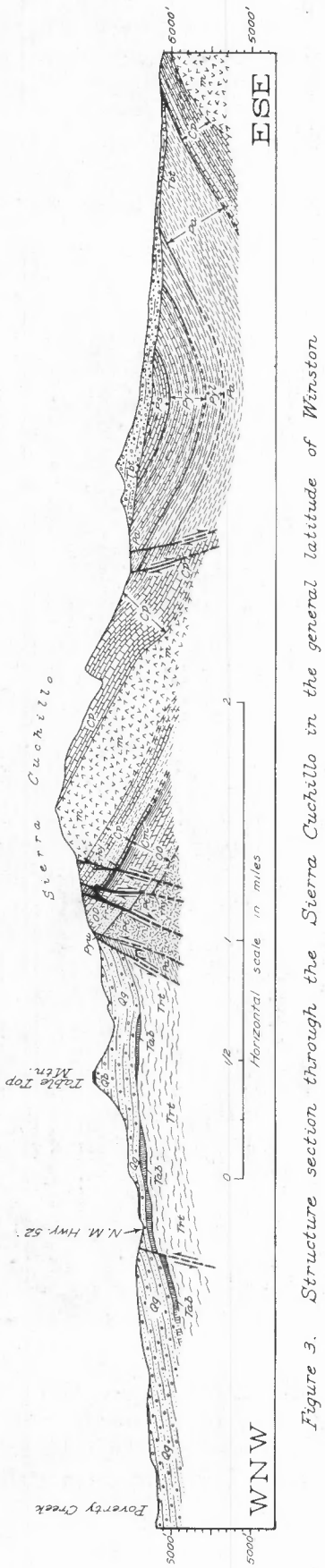


Figure 3. Structure section through the Sierra Cuchillo in the general latitude of Winston

posed within and adjacent to the Sierra Cuchillo is presented in Table 1. The Paleozoic section is approximately 5,000 feet in maximum known thickness, and about three-fifths of this comprises limestones and redbeds of Permian age. The Pennsylvanian section, mainly limestone and subordinate clastic strata, is about 1,400 feet thick, and the older Paleozoic rocks, among which dolomite is dominant, have a maximum aggregate thickness of little more than 600 feet. All of these rocks are essentially compatible in their lithology, sequence, and other features of occurrence with corresponding parts of the Paleozoic section elsewhere in the southern and southwestern New Mexico region (Flower, 1953).

The Cambro-Ordovician Bliss formation and Lower Ordovician El Paso group, though somewhat thinner than they have been reported from areas to the southeast, south, and southwest, nevertheless maintain the same broad variations in lithology. The Sierrite limestone and Bat Cave formation of the El Paso group in the Caballo Mountains (Kelley and Silver, 1952, p. 40-52), for example, are readily identifiable in the Southern Cuchillo. Equally well defined are the Cable Canyon sandstone, Upham dolomite, and Aleman formation of the Montoya group, which have been recognized in many other areas (Kelley and Silver, 1952, p. 56-62). The lithologically distinctive Cutter (Valmont) formation, thought by some investigators to have been overlapped northward by Devonian strata in the Sierra Cuchillo (Kelley and Silver, 1952, p. 65), actually is present in the range wherever rocks of Ordovician age are exposed. It is not here regarded as a unit in the Montoya group, because it evidently corresponds

Figure 3. Structure section across the Sierra Cuchillo and adjacent areas in the general latitude of Winston. Qg-alluvium, talus, and older valley-fill deposits; Qb-mesa-capping olivine basalt; Tab-andesite and olivine-poor basalt; Trt-rhyolitic tuff and associated volcanic and sedimentary rocks; Tbt-andesitic and latitic pyroclastic rocks; fr- intrusive felsite and porphyritic rhyolite; rhy- intrusive porphyritic rhyolite and rhyolite prophyry; mon-monzonite; Ps- San Andres formation; Pyu-Yeso formation, upper member Pyl-Yeso formation, lower member; Pa-Abo formation; Cp-Magdalena group; Cm-Lake Valley formation and Kelly (?) limestone; OD-Bliss formation, El Paso group, Montoya group, Cutter formation, Onate formation, and Percha shale; P€- amphibolite and metarhyolite.



Figure 4. Vertical air view of a part of the Southern Cuchillo. Pennsylvanian limestones (Cp) form the prominently cliff-ribbed slopes, and overlie a laccolithic mass of monzonite (m) to the north. The main uplifted block of the range is flanked on the east by Tertiary volcanic rocks (Tv) and on the west by redbeds and limestones of Permian age (P). Mississippian limestones (Cm) and older Paleozoic rocks (OD) crop out in one area along Cuchillo Creek. For more geologic details see Figure 1.

to beds that lie above the type Montoya in the Franklin Mountains north of El Paso (Pray, 1953, p. 1907).

The Silurian Fusselman formation and Devonian Onate formation and Percha shale, like the older Paleozoic formations, are exposed only in the Southern Cuchillo, where they are much thinner than in areas farther south. They are separated from one another and from the formations above and below them by pronounced unconformities. The overlying Mississippian Lake Valley formation is readily divisible into the Andrecito, Alamogordo, Nunn, and Tierra Blanca members described from other areas by Laudon and Bowsher (1949), although these units are not noted separately in Table 1. Also of Mississippian age is an overlying sequence of thick- to massive-bedded, coarsely crinoidal limestone that is tentatively correlated with the Kelly limestone of the Magdalena district (Loughlin and Koschman, 1942, p. 14-16: Laudon and Bowsher, 1949, p. 71-73).

All of the pre-Pennsylvanian sedimentary formations in the Sierra Cuchillo seem to reflect a general northward thinning, as suggested by comparison with the sections exposed in areas to the south and southeast. This thinning appears to be ascribable as much to successive periods of erosion during development of the section as to original tapering of the units during their deposition. Thinning within the length of the range is difficult to demonstrate, owing to the restricted outcrop areas of these rocks and to their extreme deformation in some places, but the Fusselman formation and perhaps one or two members of the Lake Valley formation appear to pinch out entirely between the canyon of Cuchillo Creek and the latitude of Winston.



Figure 5. View southeastward from the Sierra Cuchillo in the vicinity of Red Hill Pass. Limestones and redbeds of the Yeso formation (Py) form the hills at left and Tertiary volcanic rocks (Tv) underlie the hills and ridges in middle distance. Redbeds of the Abo formation (Pa) crop out in foreground. The Mud Springs Mountains (M) and Caballo Mountains (C) are in the far distance.

The Pennsylvanian Magdalena group is divisible into the Sandia formation and the Madera limestone, as in the Magdalena district (Loughlin and Koschmann, 1942, p. 16-18). The Sandia formation, which is mainly orthoquartzite, shale, conglomerate, and limestone, overlies the Mississippian section with a pronounced unconformity that involves an erosional surface with several tens of feet of relief. In contrast, the Madera limestone is overlain by redbeds of the Abo formation without conspicuous unconformity. A limestone-redbeds transition zone, 60 to 110 feet thick, marks the top of the Magdalena section. It has yielded fossils of Virgilian age.

The Abo formation contains a few thin, lenticular beds of pebble conglomerate and silty limestone near the base, but otherwise is an unusually fine-grained and uniform assemblage of thin-bedded sandstone, siltstone, and mudstone. The conformably overlying Yeso formation is divisible into a lower member of variegated fine-grained clastic strata and a somewhat thicker upper member in which limestone forms about one-third of the section. Gypsum is present also, but only in sparing amounts. The San Andres formation is mainly limestone; clastic strata, including some redbeds, appear in all parts of the section, and amount to about one-fourth of its total thickness. The Glorieta sandstone does not seem to be present in recognizable form, and the Yeso-San Andres contact has been placed arbitrarily at the base of a 120-foot sequence of limestone.

Younger Sedimentary Rocks

Erosional remnants of Upper Cretaceous marine strata, chiefly pebble to cobble conglomerates and finer-grained clastic rocks, are preserved beneath a cover of Tertiary volcanic rocks along the east side of the Northern Cuchillo. They rest with moderate angular discordance upon strata of the Yeso and San Andres formations, and appear to have been deposited on a surface with as much as several hundred feet of local relief.

Much younger nonmarine strata overlie the Tertiary volcanic section and are in part interlayered with it. They comprise fine- to coarse-grained clastic rocks, some of them markedly tuffaceous, and represent the thick basin-fill deposits that are so extensive in this part of the state. These rocks are widely exposed on both sides of the range (Fig. 1), and contain a preponderance of fragments that are lithologically

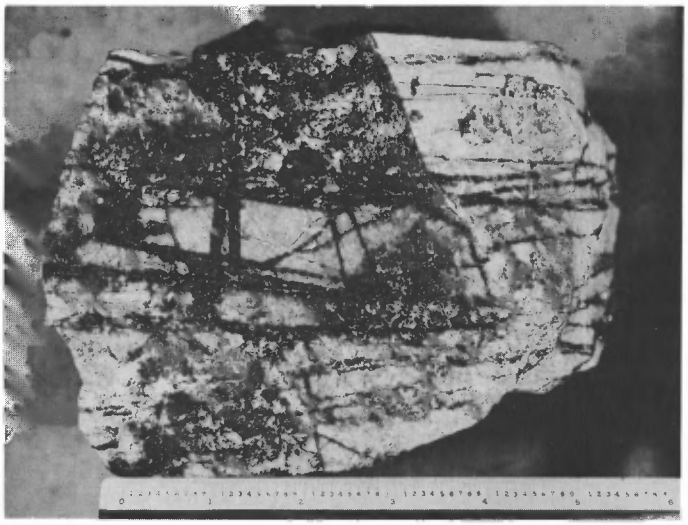


Figure 6. Typical light-colored, fine-grained granulite, veined by dark-colored, iron-rich tactite, Iron Mountain. This rock was formed by contact metamorphism of shaly limestone.

like the older rocks now exposed in the adjacent highland areas. They have been variously termed Palomas gravel, Rio Grande gravel, Gila conglomerate, and Santa Fe formation, and probably correspond to the upper part of the Tertiary-Quaternary section of the nearby Rio Grande valley (c.f. Kottlowski, 1953). Vertebrate and invertebrate fossils of early Pleistocene age have been obtained from these beds at three localities adjacent to the Sierra Cuchillo, two of them in the Valley of Poverty Creek north of Winston.

Lying unconformably on the basin-fill section are remnants of pediment gravels that once capped broad surfaces of erosion on both sides of the range. The pediments have since been dissected, and the gravels are now preserved on the tops of ridges and mesas; in places they are protected by overlying flows of olivine basalt. Terrace gravels, talus, and alluvium of Recent age are present on some slopes and in all of the major valleys.

Igneous Rocks

Metamorphosed igneous rocks of Precambrian age are exposed in a large, structurally high fault slice along the west edge of the range opposite Winston (Fig. 1). A sequence of basic volcanic rocks is represented by dark-colored amphibolite, and a younger group of shallow-seated intrusive rocks by lighter-colored, distinctly flow-layered metarhyolite. Both of these rock types resemble parts of the Precambrian assemblage in the Magdalena district, as well as in the Fra Cristobal and Caballo Ranges to the east and southeast and the Hillsboro-Kingston area to the south.

Volcanic rocks of Miocene and/or Pliocene age occupy large areas on both sides of the range (Fig. 1) where they have an aggregate thickness of several thousands of feet. They are readily divisible into a lower unit of andesitic and latitic tuff breccias, tuffs, and other pyroclastic and flow rocks; an unconformably overlying middle unit of rhyolitic flows, tuffs (including welded tuffs), tuff breccias, and tuffaceous sandstone and conglomerate; and an upper unit of fine-grained, dense to scoriaceous andesite and olivine-poor basalt. This section has been summarized briefly by Callaghan (1953), and is described in greater detail elsewhere in this guidebook.

Widespread volcanic activity in Quaternary time is attested by numerous flows and broad, low domes of olivine basalt. These postdate the main period of pediment formation in this region, and now appear as dark-colored mesa cappings in the area south of Coyote Creek and southwest of Chise, as well as in a broader area that fringes the Salado Mountains on the north, west, and southwest (Fig. 1). An isolated remnant of the same rock type caps Table Top Mountain 2 miles northeast of Winston (Figs. 1, 3).

At least seventeen types of readily distinguishable hypabyssal intrusive rocks, all of middle Tertiary to Quaternary age, are exposed in the area shown in Figure 1. The general features of the most common types are summarized in Table 2. They range in composition, with progressively decreasing age, from andesitic through dacitic, latitic, quartz latitic, and rhyolitic to basaltic, and many of them plainly are related in a genetic way to various parts of the volcanic succession noted above.

Fine- to medium-grained monzonite, by far the most abundant of the intrusive rocks, forms large plugs and laccoliths through almost the entire length of the uplift (Fig. 1). Porphyritic rhyolite and rhyolite porphyry form many smaller but very prominent masses in the part of the range that lies north of Cuchillo Creek, and a host of other silicic types, including aplite and fine-grained granite, is restricted in outcrop to the Northern Cuchillo. Juarlosa Peak, a high topographic outlier east of the Northern Cuchillo, marks an exceptionally large mass of porphyritic rhyolite (Fig. 1).

STRUCTURE

The structural pattern of the Precambrian terrane in the Sierra Cuchillo area is not decipherable, owing to the very small outcrop area of these rocks, and the oldest pattern that can be recognized is the result of folding that affected the Paleozoic rocks and antedated the principal episodes of Tertiary

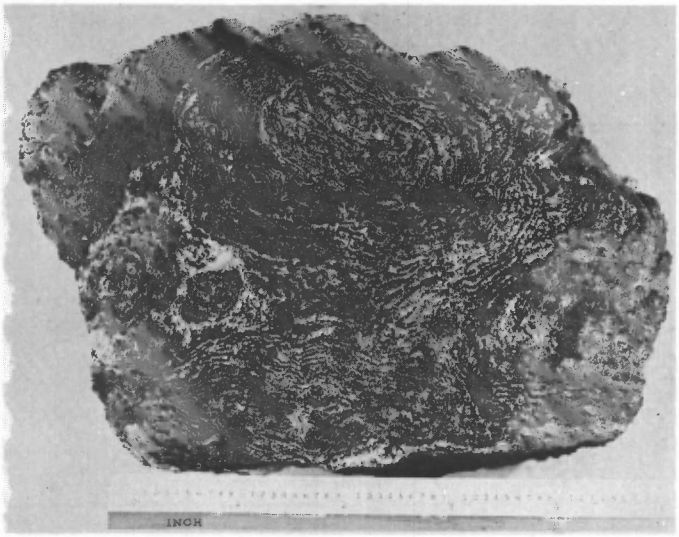


Figure 7. Typical "ribbon rock" variety of tactite, Iron Mountain. The dark-colored layers are mostly magnetite, and the light-colored layers are crystalline aggregates of fluorite, helvite, chlorite, and quartz.

volcanism. The folds evidently were broad and open, and appear to have trended in a northerly direction. Most prominent among them is a shallow syncline or elongate basin that is at least 5 miles wide. The Paleozoic rocks that form the main spine of the range outline the western flank of this fold, and the rocks of its eastern flank are exposed here and there in the lower country east of the range (Figs. 1, 3).

The simplicity of the early folds has been largely destroyed by widespread faulting of Laramide and younger ages. The faults define numerous slices and blocks that have been juggled about in a dominantly vertical sense. Most of the breaks are steep, with normal movement, and nearly all of those with large displacement can be classed as transverse or longitudinal with respect to the elongation of the range.

The transverse faults trend almost directly across the range, and are relatively old in the sense that they are cut by the longitudinal faults. They affect rocks as young as Upper Cretaceous, but few of them have been active since the period of monzonite intrusion (Table 2). One of these breaks, which has a stratigraphic throw of nearly 1,000 feet, lies east-northeast of Winston and separates the rocks of the Northern Cuchillo from those of the Southern Cuchillo. Another large one is responsible for the exposures of lower Paleozoic rocks in the canyon of Cuchillo Creek east-northeast of Chise (Fig. 1).

The longitudinal faults trend north to north-northwest, and are breaks along which movements have been recurrent from Laramide time to as late as mid-Pleistocene time. The youngest of these, which lie along the borders of the range, cut strata of early Pleistocene age but are covered in many places by unbroken sheets of younger pediment gravels and pediment-capping olivine basalt. Numerous subparallel faults along the western margin of the Southern Cuchillo define a zone, slightly less than a mile wide, that contains some of the structurally highest blocks in the region. These appear as slices of Precambrian and lower Paleozoic rocks that lie between slices of Permian rocks on the west and the main mountain-forming block of Pennsylvanian rocks on the east (Figs. 1, 3). The mechanics of elevation of these relatively thin blocks poses an interesting and provocative problem.

Two other well-defined sets of steep joints and faults trend northwest and north-northwest within the range and the country to the east. Like the transverse faults already noted, many of these breaks are occupied by igneous dikes.

Smale-scale warping, folding, and local crumpling and rupturing of the Paleozoic rocks attended the intrusion of monzonite and other igneous rocks during Tertiary time. The "cross-fracturing" and "tear faults" emphasized by Harley (1934, p. 115) in the Cuchillo Negro Range may have been formed in this way, but most of the features he describes appear to belong in the category of the early transverse faults.

The upper Cenozoic volcanic and sedimentary rocks that flank the range dip gently to moderately away from it on both sides. It has not yet been determined whether this relationship represents on initial off-dip from an ancestral (Tertiary) Sierra Cuchillo or the opposed tilting of a section whose dip originally was uniform. These rocks have participated in much of the longitudinal faulting and have been strongly deformed along these faults, but otherwise their structure appears to be simple.

METAMORPHISM

Metamorphism associated with the Tertiary intrusive rocks is a prominent feature of the Sierra Cuchillo. Its intensity increases rapidly from east to west in the range, as well as progressively northward from the vicinity of Cuchillo Mountain to a maximum at Iron Mountain, where the altered rocks appear to form a relatively thin and discontinuous cover over a complex assemblage of igneous intrusives. The metamorphism is related mainly to masses of rhyolite, aplite, granite, and other silicic rocks, and has affected sedimentary rocks of Cambrian to Permian age. The largest and most abundant masses of metamorphic rocks have been derived from lime-

TABLE 1. LAYERED ROCKS OF THE SIERRA CUCHILLO AND IMMEDIATELY ADJACENT AREAS

Name or type of rock unit	Age	Thickness (feet)	Simplified description
Surficial deposits	Recent and Pleistocene	0-200+	Stream alluvium, terrace and pediment gravels, talus, and landslide debris
U			
Mesa-forming basalt		0-55	Olivine basalt, dark gray, commonly vesicular
U			
Palomas gravel and Santa Fe formation	Pleistocene and Pliocene	0-1,200+	Interbedded sandstone, conglomerate, siltstone, and tuff, generally very tuffaceous near base; poorly indurated in some areas
Andesite and basalt	Pliocene	0-150+	Flows and tuffs of medium-gray andesite and olivine-poor basalt, generally fine-grained and vesicular
Early gravels and tuffs	Pliocene	0-200+	Interbedded rhyolitic tuff, tuff-breccia, conglomerate, sandstone, and local siltstone
U			
Rhyolitic volcanic sequence	Pliocene and/or Miocene	2,500+	Rhyolite tuff, tuff-breccia, welded tuff, and local flows, light gray, pinkish and tan
U			
Andesitic-latitic volcanic sequence		3,000±*	Tuff breccia, purplish to greenish gray, with subordinate interlayered tuff, agglomerate, volcanic conglomerate, and local flows and shallow sills; andesitic to quartz latitic in composition
U			

	Cretaceous sedimentary sequence	Upper Cretaceous	200 ±	Interbedded orthoquartzite, shale, limestone, and conglomerate with rounded pebbles and cobbles of limestone, chert, and sandstone; locally underlain by brown calcareous shale and overlain by reddish brown shale
	U			
Manzano group	San Andres formation	Permian (Leonardian and Wolfcampian)	1,360*	Limestone, fine-grained, medium to dark gray, even-bedded, with subordinate interbedded silty limestone and reddish siltstone and sandstone
Manzano group	Yeso formation	Permian (Leonardian and Wolfcampian)	750	Sandstone and siltstone, variegated (chiefly greenish, yellowish, and reddish brown), thin- to medium-bedded, with abundant even-bedded, medium- to dark-gray limestone and dolomite in upper half; rare thin gypsiferous beds
Manzano group	Abo formation	Permian (Leonardian and Wolfcampian)	920	Siltstone, mudstone, and sandstone, red to reddish brown, thin- to medium-bedded, in part calcareous; thin, lenticular beds of greenish gray limestone and reddish brown limestone-pebble conglomerate near base
	U ?			
Magdalena group	Madera limestone	Pennsylvanian (Virgilian through Derry?)	1,250*	Limestone, fine- to medium-grained, medium to light gray, thin- to very thick-bedded, commonly cherty; local lenses of limestone-pebble conglomerate and reddish-brown to greenish-gray sandstone near top
Magdalena group	Sandia formation	Pennsylvanian (Virgilian through Derry?)	120-150	Interbedded limestone, fine-grained, medium to light gray, medium- to thick-bedded, commonly cherty; shale and fine-grained sandstone, greenish gray to reddish brown, thin-bedded; and orthoquartzite, light gray to brown, thick-bedded; chert-pebble conglomerate at base

U			
Kelly (?) limestone	Mississippian (Osagian)	35*	Limestone, coarse-grained, light gray, crinoidal, thick-bedded to massive, locally very cherty; forms cliffs
Lake Valley formation		45*	Limestone; lower part fine-grained, medium to dark gray, thick-bedded, and cherty; forms cliffs; upper part coarser-grained, light gray, thinner-bedded, crinoidal, and locally chert-rich
U			
Percha shale	Devonian (Upper)	40*	Shale and siltstone, dark gray, homogeneous, in part calcareous; weathers to thin, greenish gray chips
U			
Onate formation	Devonian (Middle)	25*	Siltstone, medium to dark gray, calcareous, with interbedded medium-gray, nodular to flaggy dolomite and limestone; weathers light brownish gray
U			
Fusselman formation	Silurian (Niagaran)	0-15*	Dolomite, fine- to medium-grained, medium to dark gray, medium- to thick-bedded, locally cherty; forms cliffs
U			
Cutter (Valmont) formation		10-35*	Dolomite, light gray to greenish gray, finely crystalline to sublithographic, in part cherty; local silty layers; thin- to thick-bedded, with some very irregular beds

	U?			
Montoya group	Aleman formation	Ordovician (Cincinnatian)	60*	Dolomite, fine-grained, medium gray, thin-bedded, with abundant layers of chert; local thin beds of sandstone at base
	Upham dolomite	Ordovician (Mohawkian?)	70*	Dolomite, fine- to medium-grained, light to medium gray, in part very thick-bedded and locally cherty; forms cliffs
	Cable Canyon sandstone		25±	Sandstone, coarse-grained, medium gray, with local lenses of pebble conglomerate; clasts mainly quartz and cement mainly dolomite
	U			
El Paso group	Bat Cave formation	Ordovician (Canadian)	90*	Dolomite and limestone, fine-grained, medium gray, thinly and irregularly bedded, locally cherty; local sandy and silty beds; forms some low cliffs
	Sierrite limestone		75*	Dolomite and limestone, fine-grained, light to medium gray, thin- to medium-bedded with abundant thin, irregular laminations of light gray chert; glauconitic near base
Bliss formation		Ordovician (Lower) and Cambrian (Upper)	95±	Interbedded orthoquartzite, feldspathic sandstone, and oolitic hematite beds in lower part, which is light gray to dark greenish gray and reddish; upper part interbedded reddish to greenish gray sandstone, siltstone, and dolomite, with many glauconite-rich layers; basal part of section forms dark-colored cliffs

U			
Metamorphic sequence	Precambrian	500+	Amphibolite, medium- to coarse-grained, distinctly foliated, medium to dark greenish gray, and meta-rhyolite, fine-grained and porphyritic, pinkish to creamy gray

U -- Distinct, well-established unconformity

U? -- Minor or doubtfully-established unconformity

* -- Thickness based on composite preliminary section, and hence subject to later revision

TABLE 2. PRINCIPAL INTRUSIVE ROCKS OF THE SIERRA CUCHILLO AND IMMEDIATELY ADJACENT AREAS

(Listed in order of increasing age*)

Rock type	Texture	Principal occurrences	Youngest rocks known to be transected (see Table 1)
Olivine basalt	Dense and aphanitic to medium-grained porphyritic aphanitic	Many dikes and several small plugs, mainly in Palomas gravel, Santa Fe formation, and Tertiary volcanic rocks	Palomas gravel, Santa Fe formation, and oldest pediment gravels
Andesite and basalt	Aphanitic, dense to highly vesicular	Dikes and volcanic necks in older gravels and volcanic rocks	Early gravels and tuffs that lie upon the rhyolitic volcanic sequence
Red felsite (rhyolite)	Dense and aphanitic; locally in part glassy	Thin dikes, stringers, and breccia cement in older rocks, especially Pennsylvanian limestones	Intrusive porphyritic rhyolite, aplite, and granite (see below)
Aplite and granite	Fine-grained and even-grained; local large pods of quartz	Small to moderately large sills, dikes, and plugs; on Iron Mountain only	Intrusive porphyritic rhyolite (see below)
Porphyritic rhyolite	Medium to very coarsely porphyritic, with dense, aphanitic groundmass	Dikes and irregular, small to very large plugs in all older rocks	Andesitic-latitic volcanic sequence and lower part of rhyolitic volcanic sequence; also intrusive white felsite (see below)
White felsite (leucolatite) and monzonite	Dense and aphanitic to fine-grained and phaneritic	Dikes, sills, plugs, and large, partly concordant stocks, especially in upper Paleozoic rocks; almost wholly in the Northern Cuchillo	Gray monzonite (see below) and andesitic-latitic volcanic sequence

Gray monzonite	Fine- to medium-grained and even-grained; locally porphyritic	Dikes, sills, plugs, and large, partly discordant laccoliths, especially in upper Paleozoic rocks; most common in the Southern Cuchillo	Andesitic-latitic volcanic sequence
Andesite-latite tuff breccia	Medium- to extremely coarse-grained non-vesicular	Small to very large plug- and sheet-like masses, especially in upper Paleozoic rocks	Cretaceous sedimentary rocks and, locally, basal part of andesitic-latitic volcanic sequence
Metarhyolite	Fine-grained and dense, with small phenocrysts of quartz; groundmass recrystallized	Exposed in Southern Cuchillo only; form of intrusive body or bodies is not known	Amphibolite of Precambrian age

*All of the types listed, with the exception of the Precambrian metarhyolite, are Cenozoic in age.

stones of the Magdalena group.

Recrystallization has formed coarse-grained marble from the relatively pure limestones, marble with scattered masses of tremolite, garnet, and epidote from the less pure limestones, coarse-grained quartzite from the relatively pure sandstones, and dense, platy hornfels from the shaly rocks. All of these metamorphic rocks form rather smooth, featureless slopes typically developed on unmetamorphosed parts of the section (Figs. 2 and 4).

Where metasomatism has accompanied the recrystallization, the products include both iron-poor and iron-rich silicate rocks. Bed-by-bed silication of the sandy and shaly limestones, as well as some of the calcareous redbeds in the Permian section, has formed dense, very fine-grained, light-colored granulites that contain quartz, diopside, clinozoisite, epidote, grossularite, lime-soda feldspars, wollastonite, and other minerals in various proportions. The purer limestones, in contrast, have been converted to iron-rich rocks, or tactites, in which magnetite, hematite, andradite, diopside, and hedenbergite are the most abundant constituents. Dark-colored aggregates of these minerals also occur as fracture fillings and replacement masses in granulite and other iron-poor silicate rocks (Fig. 6).

At least one ancient episode of middle-rank "regional" metamorphism is attested by the pervasive recrystallization and reconstitution of the Precambrian rocks. Superimposed upon the effects of this metamorphism, which plainly antedated the deposition of the Paleozoic rocks, are fracture-controlled aggregates of epidote, diopside, and other minerals formed during the Tertiary episode of contact metamorphism.

MINERAL DEPOSITS

A wide variety of mineral deposits in and near the Sierra Cuchillo has prompted more interest than production over a long period of years. A modest output of lead-zinc-copper ore, mostly of shipping grade, has come from the Cuchillo Negro district, in the northern part of the Southern Cuchillo. The largest deposits are hydrothermal replacements in Pennsylvanian limestone along the margins of two large laccolithic masses of monzonite, and several others occur in Permian limestone along contacts with intrusive monzonite and porphyritic rhyolite on the western face of the range. Somewhat similar deposits, also associated with monzonite. are scattered through the Northern Cuchillo.

Concentrations of copper and uranium occur in some redbeds of the Abo formation throughout the length of the range, where they are spatially associated with sills of monzonite and dikes of porphyritic rhyolite. All of the copper deposits are low in grade, whereas most of the uranium deposits are of moderate to high grade but are extremely small in size. The richest concentrations of uranium minerals appear to be replacements of wood and other carbonaceous material in the sedimentary rocks.

Large pyrometasomatic deposits of iron ore, chiefly admixed magnetite and hematite, occur in Pennsylvanian limestone in the Iron Mountain district, as well as in Pennsylvanian and older limestones on the west side of the Southern Cuchillo in the general latitude of Winston. They have not been worked commercially. A small production of tungsten has been obtained from deposits of scheelite and powellite in the Iron Mountain district. The tungsten-bearing minerals occur as disseminations and closely spaced, subparallel fracture fillings in magnetite- and garnet-rich tactite, and many of the concentrations are small but rich.

Beryllium, chiefly in the mineral helvite, also is present in the Iron Mountain district, where it is a product of hydrothermal activity associated with the contact metamorphism. The helvite is essentially restricted to an unusual, rhythmically-layered variety of magnetite-fluorite tactite known as "ribbon rock" (Jahns, 1944a). In color, texture, structure, and composition this rock (Fig. 7) differs considerably from the Pennsylvanian limestone from which it was formed! Some of it also contains quartz, chlorite, idocrase, and grossularite. In a few places, fluorite is sufficiently abundant in the "ribbon rock" and other kinds of tactite to form ore bodies, one of which has been mined on a small scale.

Scattered deposits of cassiterite occur in the rhyolite that is exposed between Willow Creek and the Alamosa River along the east edge of the area shown in Figure 1. The cassiterite is associated with specular hematite in fracture- and vug-filling aggregates, and the occurrences resemble the larger deposits described from the Black Range to the west (Hill, 1921; Fries, 1940).

Prospects for the discovery of petroleum in commercial quantities, either within the Sierra Cuchillo or in immediately adjacent areas, cannot be regarded as better than poor.

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