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TECTONIC FRAMEWORK OF NORTHEASTERN NEW MEXICO AND ADJACENT PARTS OF COLORADO, OKLAHOMA AND TEXAS

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Abstract—Northeastern New Mexico straddles the join between the craton and the Rocky Mountain foreland province. Principal tectonic features are the Sangre de Cristo uplift, Raton Basin, Sierra Grande arch, Apishapa arch and Dalhart basin; Cenozoic igneous centers are superimposed on these tectonic elements. During the Phanerozoic, two major episodes of strong deformation interrupted long intervals of slow epeirogenic subsidence and uplift.

Late Paleozoic intracratonic block uplifts and basins include the Sierra Grande and Apishapa uplifts and the Dalhart and Rowe-Mora basins that formed during the Ouachita-Marathon orogeny, presumably as a result of collision of North America with South America-Africa. Laramide (latest Cretaceous-early Tertiary) compressional deformation resulted in rise and eastward yielding of the Sangre de Cristo uplift along thrust and reverse faults as the Raton Basin accumulated synorogenic sediments; the Apishapa and Sierra Grande arches were reactivated along with some basement faults of the Texas Panhandle. Laramide deformation was related to subduction along the western margin of North America.

Spanish Peaks alkalic igneous rocks were emplaced during the middle Cenozoic, and upper Cenozoic mafic and intermediate volcanic centers occur across the Raton Basin and Sierra Grande and Apishapa arches. Epeirogenic warping and normal faulting in the late Cenozoic may have been related to development of the Rio Grande rift.

INTRODUCTION

This guidebook covers an area that includes parts of the Rocky Mountain foreland and craton provinces in northeastern New Mexico and adjacent parts of Colorado, Oklahoma and Texas (Fig. 1). This paper provides an overview of Phanerozoic tectonics of the region with an emphasis on the present structural framework.

Details of the Precambrian evolution of the region are poorly understood, partly because of extensive cover by younger deposits; therefore, Precambrian tectonic development is not discussed here. Precambrian igneous, metasedimentary and metaigneous rocks form the structural basement and during Phanerozoic time were deformed by brittle processes. Paleozoic carbonates, arkoses, sandstones and orthoquartzites are more ductile than the basement rocks but are more competent than the thick shale- and mudstone-dominated intervals of the Mesozoic. Thick Cretaceous shales in particular tend to deform plastically. Rocks of Precambrian to Late Cretaceous age are pre-orogenic with respect to Laramide deformation.

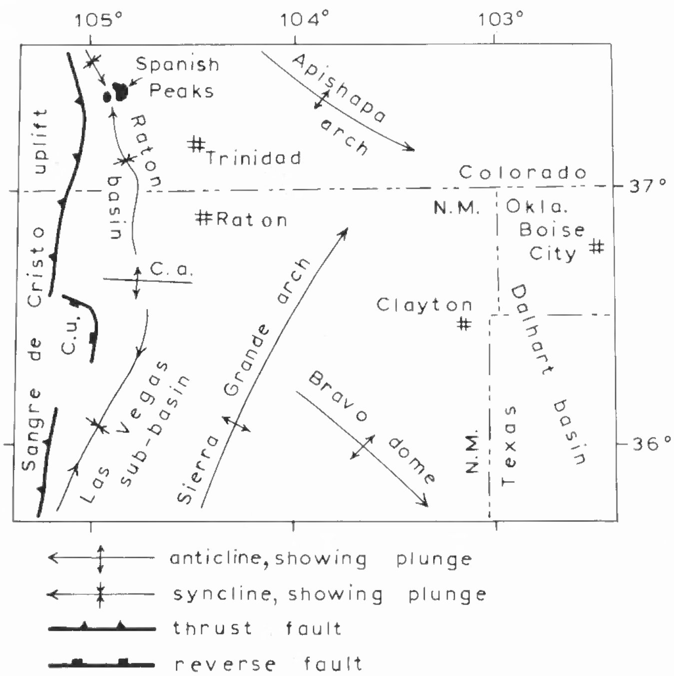

FIGURE 1. Index map showing major tectonic elements of northeastern New Mexico and adjacent parts of Colorado, Oklahoma and Texas. C.u. = Cimarron uplift, C.a. = Cimarron arch.

Synorogenic sedimentary rocks (Raton, Poison Canyon, Cuchara and Huerfano formations) are latest Cretaceous to early Tertiary in age. Intrusive rocks of the Spanish Peaks area appear to mostly postdate Laramide deformation in the Raton Basin, but one radiometric date of 39.5 m.y. (late Eocene) was reported by Armstrong (1969).

Neogene volcanic and sedimentary rocks are post-orogenic. Although not intensely deformed, the volcanic rocks are brittle and tend to fracture. Sedimentary rocks also are brittle where well lithified.

PALEOTECTONICS

This area was on the south flank of the transcontinental arch during early Paleozoic time. Cambrian rocks were not deposited here (Lochman-Balk, 1972), and Ordovician strata are absent except in the northeasternmost corner of New Mexico and adjacent states to the north and east (Foster, 1972). Silurian strata are absent here (Gibbs, 1972), and Devonian rocks are present only in the northeasternmost corner of New Mexico and locally in southeastern Colorado and western Oklahoma (Baars, 1972).

During the Mississippian a thin sequence of shelf carbonates accumulated in northern New Mexico (Armstrong and Mamet, 1979), but high-angle faulting and epeirogenic uplift resulted in removal of most of the Mississippian prior to deposition of Pennsylvanian strata. Mississippian rocks occur east of a wedge-edge near the northeastern corner of New Mexico, attaining a thickness of about 160 m in western Oklahoma (Craig, 1972).

In the late Paleozoic, structurally and topographically high, partly fault-bounded uplifts of the ancestral Rocky Mountains were formed. The Sierra Grande uplift of northeastern New Mexico (Read and Wood, 1947) and the Apishapa uplift of southeastern Colorado (De Voto, 1980) shed arkosic sediments into the Rowe-Mora basin located in the western part of the present Raton Basin and southern part of the present Sangre de Cristo uplift (Baltz, 1965) as well as into the Dalhart basin to the east (Petroleum Information Corp., 1986). The Cimarron arch (Fig. 1) rose at this time to separate the Rowe-Mora basin into two parts. Mallory

(1972) inferred that the north-trending Pecos-Picuris fault in the present Sangre de Cristo uplift was active during Pennsylvanian deposition, and the Uncompahgre uplift to the west shed considerable arkose into the Rowe-Mora basin. These uplifts were high during Pennsylvanian time and locally persisted as mild positive areas into the Permian (Rascoe and Baars, 1972).

Triassic and Jurassic strata were deposited as relatively uniform layers across the region. Epeirogenic uplift and tilting resulted in regional, low-angle unconformities between Permian and Triassic, and between Triassic and Jurassic strata, with large parts of the Triassic and Jurassic Systems being absent. Another major regional disconformity separates Jurassic from Cretaceous strata. The lower part of the Cretaceous is also blanket-like, but in the latest Cretaceous this pattern was interrupted by rise of the Sangre de Cristo uplift and strong subsidence of the Raton Basin.

STRUCTURE

The principal tectonic elements in this region (Fig. 2) are the Sangre de Cristo uplift which includes the smaller Cimarron uplift, the Raton Basin and its southern extension (Las Vegas sub-basin), the Sierra Grande arch with a southeastern prong (Bravo dome), the Apishapa arch and the Dalhart basin. The Sangre de Cristo uplift and the Raton Basin are parts of the Rocky Mountain foreland, and the area to the east is within the craton. The present day Sierra Grande and Apishapa arches are characterized mainly by flexed strata, whereas uplifts of the same names were late Paleozoic features at least partly fault bounded. Superimposed on major tectonic elements are the Spanish Peaks igneous center and several volcanic centers.

Sangre de Cristo and Cimarron uplifts

The Sangre de Cristo uplift, one of the largest positive elements of the Rocky Mountain foreland, is about 320 km long and as much as 30 km wide. The western margin of the uplift is bounded by the late Cenozoic Rio Grande rift. The eastern margin of the uplift is characterized by Laramide reverse and thrust faults that yielded eastward over the Raton Basin (Northrop et al., 1946). There are at least 4,700 m of structural relief between the uplift and the trough of the Raton Basin.

The eastern extension of the Sangre de Cristo uplift, the Cimarron uplift, is bounded on the north and east by the high-angle Fowler Pass reverse fault (Goodknight, 1973). Cenozoic igneous rocks are injected along much of the fault, thereby obscuring its trace and dip. Minimum stratigraphic separation along the fault is 1,500 m (Robinson et al., 1964), but structural relief between the uplift and the Las Vegas sub-basin is at least 4,200 m (Woodward and Snyder, 1976).

Precambrian crystalline rocks in the Sangre de Cristo uplift are in fault contact with sedimentary strata along much of the central and southern parts of the eastern edge of the uplift (Schowalter, 1968). Cordell and Keller (1984) suggested, on the basis of gravity data, that the central part of the uplift has been thrust eastward for long distances over the Raton Basin and Las Vegas sub-basin. This interpretation is supported by the presence of a flat-lying thrust north of Eagle Nest and the Moreno Valley (Clark and Read, 1972; Reed et al., 1983; J. S. Walker, unpubl. data, 1986), but the steeply dipping Fowler Pass fault is difficult to reconcile with this concept for the Las Vegas sub-basin. Perhaps the Fowler Pass fault is listric and flattens with depth in a manner similar to range-marginal thrusts to the south, as shown in cross sections by Baltz (1972).

Lindsey et al. (1983, 1984) noted the presence of large, arcuate, intersecting thrusts with at least 14 km of shortening along the northeastern margin of the uplift. These thrusts are high- to intermediate-angle reverse faults at the leading edges of the thrust plates, but flatten to about 30° of dip at depth. Thrust plates were folded internally, and the stacked plates containing Precambrian and Paleozoic rocks have been concordantly folded after thrusting.

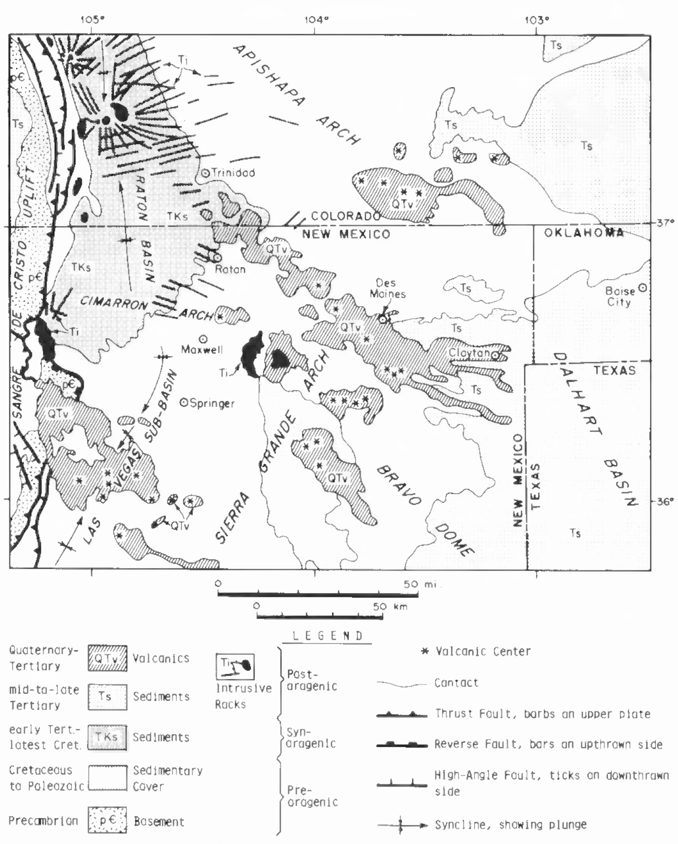

FIGURE 2. Generalized tectonic map of northeastern New Mexico and adjacent parts of Colorado, Oklahoma and Texas. Compiled from Bachman (1953), Wood et al. (1953), Baldwin and Muehlberger (1959), Cohee (1961), Scott (1968), Johnson (1969) and Woodward and Snyder (1976).

Raton Basin

The Raton Basin, as defined here to include the Las Vegas sub-basin, is about 300 km long and as much as 100 km wide. It is strongly asymmetric with steeply dipping to overturned beds on the west limb near the Sangre de Cristo uplift and a gently dipping eastern limb that merges with the Sierra Grande and Apishapa arches. South of Las Vegas, New Mexico, the axis of the basin dies out in gently dipping Permian and Triassic beds. Near its north end (north of Fig. 2) the basin axis bifurcates with the main La Veta syncline trending northwesterly and the Del Carbon syncline trending toward the northeast. The basin contains several thousand meters of upper Paleozoic to Tertiary strata, including synorogenic deposits of Laramide age (Baltz, 1965; Johnson and Wood, 1956).

Maximum structural relief between the deepest part of the basin, in Colorado, and the Sangre de Cristo uplift is not known because of lack of subsurface data, but there are at least 4,700 m of structural relief between the basin and the uplift in New Mexico. There are 1,200 to 2,100 m of structural relief between the basin and the Sierra Grande arch in New Mexico and probably at least that amount in the northern part of the basin where it adjoins the Apishapa arch.

Within the basin the major structure is the Cimarron arch which separates the main Raton Basin from the Las Vegas sub-basin in the subsurface; there is no surface expression of the arch (Woodward, 1983). There are also at least 20 anticlines, ranging from small domes to elongate folds up to 20 km long. Some of the domes are caused by intrusion of igneous rocks; among the largest are the Turkey Mountains in the Las Vegas sub-basin (Hayes, 1957) and the anticlinal axis north of Vermejo Park. Other folds appear to have formed by compression along the western margin of the basin, by uparching of Precambrian basement blocks, and by draping of strata over basement faults.

Sierra Grande arch

The low, broad Sierra Grande arch trends north-northeasterly through northeastern New Mexico (Foster and Stipp, 1961) and merges through gently dipping beds with the Raton Basin on the west and the Dalhart basin to the east (Roberts et al., 1976). This arch is about 250 km long, and its width ranges from 40 to 110 km, depending on how the arbitrary boundaries with the adjacent basins are chosen. Extending southeast from the Sierra Grande arch is the Bravo dome, a low, broad, southeast-plunging anticline that is approximately 100 km long (Sulieman and Keller, 1985). Mesozoic strata and post-orogenic upper Cenozoic sediments and volcanic rocks are present at the surface along much of the arch.

Minimum structural relief between the arch and the Dalhart basin is 2,900 m (Petroleum Information Corp., 1986), and structural relief is 1,200 to 2,100 m between the arch and the Raton Basin. To the south of the arch and the Bravo dome lies the Tucumcari basin, most of which is outside the area of this guidebook; structural relief between the arch and the Tucumcari basin is at least 2,900 m (Foster et al., 1972).

It is likely that many of the smaller domes on the Sierra Grande arch are laccolithic because of the abundance of Tertiary igneous rocks and the circular map outlines of the domes. Several folds occur on the east side of the arch and include the Guy monocline and the Clapham anticline (Baldwin and Muehlberger, 1959), which have about 100 to 150 m of structural relief. There are three domes along the Clapham anticline that Bates (1942) called the Clapham, Leon and Tate anticlines.

Foster et al. (1972) inferred that several northwest- and northeast-trending faults offset the Precambrian rocks along the southern part of the arch; these faults are not seen at the surface and presumably are mainly of late Paleozoic age. Baldwin and Muehlberger (1959) reported that normal faults having about 5 to 10 m of separation are common along the northeast end of the arch.

Apishapa arch

The Apishapa arch extends southeasterly from the Wet Mountains uplift in Colorado for about 150 km, terminating near the southeastern corner of Colorado. This southeastern end has sometimes been called the Animas arch (Petroleum Information Corp., 1986). Both limbs of the arch dip gently, merging with the Denver basin to the northeast and the Raton Basin to the southwest. There is a low sag near the Colorado-New Mexico border separating the Apishapa and Sierra Grande arches. Mesozoic strata are exposed along most of the Apishapa arch.

Several small domes occur along the crest of the arch, together with high-angle faults that mostly have a few tens of meters of separation (Johnson, 1969). Arcuate to northerly- and northeasterly-trending cross folds occur along the central part of the arch (Scott, 1968; Johnson, 1969). Anticlines, synclines and monoclines are present along the northeastern limb and near the southeastern end of the arch.

Although the Apishapa uplift was strongly elevated in the late Paleozoic (Mallory, 1972), the present form of the arch is due largely to Laramide deformation (Oborne, 1956).

Dalhart basin

The north-trending Dalhart basin, located in the northwestern corner of the Texas Panhandle, is about 100 km long and 75 km wide. The basin is bounded on the west by the Sierra Grande arch and on the southwest by the Bravo Dome, with at least 2,900 m of structural relief. To the north the basin merges with the southeastern end of the Apishapa arch. To the east the basin is bounded by the Amarillo uplift and the Cimarron arch (different than the feature of the same name in the Raton Basin). Toward the south the Dalhart basin is separated from the Whittenberg trough by a structurally low saddle.

Growth faults active during Late Mississippian to Middle Pennsylvanian time are inferred to bound partly the Dalhart basin in the subsurface (Petroleum Information Corp., 1986), with large amounts of coarse clastic sediment being derived from the bounding uplifts. The eastern margin of the basin is a large fault whereas the western limb, although cut by a north-trending fault, merges more gradually with the Sierra Grande arch.

Minor, episodic basin subsidence continued until the Laramide when some of the older faults were reactivated; recent seismic activity indicates that movement along some of the faults is still occurring. Bedrock units in the Dalhart basin range from Cambrian to Cretaceous in age, with the Silurian and Devonian being absent (McCasland, 1980).

Spanish Peaks igneous center

Rising to an elevation of 4,152 m, the Spanish Peaks dominate the physiography of the northern Raton Basin. Two main stocks, centered at the East Peak and West Peak, are surrounded by at least 500 radial dikes and numerous other dikes and sills (Knopf, 1936). The following discussion is taken principally from reports by Knopf (1936) and Johnson (1968).

The Spanish Peaks igneous center is superimposed on the structure of the Raton Basin, with intrusions cutting strata as young as early Eocene. East Spanish Peak is formed on a granite and granodiorite porphyry stock 8 km long and 4 km wide. West Spanish Peak is underlain by a syenodiorite stock of irregular outline that is 4 km long and as much as 2.5 km wide. There is a contact metamorphic aureole about 275 m wide around the West Peak stock, but metamorphism is negligible adjacent to the East Peak stock.

Dikes radiate mainly from the West Peak stock, forming a steeply dipping swarm that is elliptical in map view (Johnson, 1961). There is also a large system of sub-parallel, steeply dipping dikes that strike about perpendicular to the axis of the Raton Basin. Dikes are as much as 22 km long and range from 0.3 to 30 m wide; some tend to be more resistant to erosion than the sedimentary host rocks and stand as vertical walls up to 30 m high. Compositions of the dikes range from highly silicic to mafic, including granite and diorite porphyries, microsyenodiorite, teschenite, shonkinite, biotite lamprophyres, augite syenodiorite and basalt or gabbro.

Intrusions cut the early Eocene Huerfano Formation and were inferred to be late Eocene and Oligocene (Johnson, 1969). However, radiometric age determinations give conflicting dates; three K-Ar dates by Stormer (1972a) for dikes and sills range from 23.4 ± 1.0 to 25.7 ± 0.8 m.y. Armstrong (1969) reported a K-Ar age of 39.5 m.y. (late Eocene) for the East Peak stock, but a K-Ar date by Stormer (1972a) for the same intrusion is 21.7 ± 1.0 m.y.

Volcanic centers

Volcanic rocks and associated shallow intrusions are widespread in northeastern New Mexico and southeastern Colorado. Extrusive rocks are unconformable on deformed strata of the Sangre de Cristo uplift, Raton Basin, Las Vegas sub-basin and Sierra Grande and Apishapa arches and were erupted from at least 100 volcanic centers. The dominant rock type is sodium-rich alkali olivine basalt, some of which contains nepheline and hauynite, but quartz-normative basalt and basaltic andesite as well as andesite and dacite comprise a significant volume of the volcanic rocks (Stormer, 1972b). Volcanic forms range from cinder cones, such as Capulin Mountain, to a shield volcano at Sierra Grande (Kudo, 1976). The Raton, Mesa de Maya, Clayton and Mora volcanic fields are olivine basalt, whereas Red Mountain consists of dacite and andesite occurring as plugs, domes and remnants of flows. Andesite also forms a large volcano overlying Clayton basalt.

These volcanics range in age from about 8 m.y. to Holocene (Stormer, 1972a) and constitute the northeastern end of the diffuse Jemez lineament (Aldrich et al., 1986; Chapin et al., 1978) or magmatic zone (Lipman et al., 1986). Volcanic centers of the Sierra Grande arch are aligned along a northeastern trend parallel to the axis of the arch and an en echelon northwesterly trend parallel to the Clapham anticline according to Kudo (1976).

TECTONIC EVOLUTION

Northeastern New Mexico was located along the southern flank of the northeast-trending transcontinental arch which was a mildly positive feature during much of the early Paleozoic. This time of relative tectonic quiescence ended with development of the ancestral Rocky Mountains during the late Paleozoic. The Sierra Grande and Apishapa intracratonic block uplifts were deeply eroded and clastic sediments were shed into the adjacent Dalhart and Rowe-Mora basins.

Kluth and Coney (1981) suggested that the deformation resulted from the collision of North America with South America-Africa during the Ouachita-Marathon orogeny. Geometry of the uplifts and basins indicates that deformation was concentrated along zones extending from parts of the Ouachita foldbelt undergoing the strongest compression (Woodward and Ingersoll, 1979). The tectonic setting of northeastern New Mexico at this time was similar to that of modern central Asia north of Tibet where collision-related deformation is occurring hundreds of kilometers from the suture belt (Molnar and Tapponnier, 1975, 1978).

Although a broad area of southern Colorado and northern New Mexico encompassing some of the ancestral Rocky Mountains remained high during much of the Triassic (MacLachlan, 1972), a thin blanket of Upper Triassic sediments accumulated during mild epeirogenic subsidence of the rest of the region. Upper Jurassic strata covered the entire region. Following complex early Mesozoic deformation in the Cordilleran region (Dickinson, 1976), an Andean-type arc-trench system formed and was the major tectonic control of orogeny and basin formation into the Cenozoic. A foredeep east of the foldbelt in Cretaceous time was filled mainly with marine clastic sediments that wedged out to the east of New Mexico. Thus, tectonic activity at this time was mainly mild subsidence in northeastern New Mexico, presumably due to subduction-related deformation to the west.

With the onset of Laramide (latest Cretaceous to early Tertiary) deformation, the Sangre de Cristo uplift was thrust eastward and shed synorogenic sediments into the rapidly subsiding Raton Basin. Johnson and Wood (1956) noted seven orogenic pulses defined by angular unconformities and lithologies characteristic of synorogenic strata. The Sierra Grande and Apishapa arches probably rose during the Laramide, and the Sierra Grande arch may have been tilted eastward as basement faults were reactivated to the east (Petroleum Information Corp., 1986).

Intrusive rocks of the Spanish Peaks area were emplaced after most of the Laramide deformation in the Raton Basin and may range in age from late Eocene to early Miocene. The east-trending sub-parallel dikes were emplaced along extensional fractures formed during Laramide compression. The radial dike pattern was attributed by Odé (1957) to radial fissuring during intrusion of the West Peak stocks while undergoing approximately east-west compressional stress; Johnson (1961), however, suggested that the radial dikes were emplaced along conjugate shears and extensional fractures that formed during compression and that the radial pattern is fortuitously associated with the stocks.

Late Cenozoic regional epeirogenic rise may have been contemporaneous with development of the Rio Grande rift during crustal extension of much of the western U.S. The present Sangre de Cristo Range is a remnant of the east flank of the Laramide uplift and was elevated as a horst in the Neogene (Tweto, 1980). Broad warping of the Ogallala Formation (Baldwin and Muehlberger, 1959; Frye et al., 1978) indicates late Cenozoic epeirogenic deformation.

Volcanic centers postdate orogenic deformation and mark the eastern limit of late Cenozoic volcanism in the western U.S. Stormer (1972b) proposed that the Raton-Clayton basalts formed by partial melting in the mantle, the Sierra Grande andesites and the feldspathoidal basalts may have formed by wet melting in the mantle and the dacites were generated by fractional wet melting of lower crustal amphibolites. Magma generation occurred during extensional stress in the Rio Grande rift (Aldrich et al., 1986), and extrusion of some of the volcanic rocks took place along zones of weakness in the basement rocks.

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Valley of Ute Creek about 29 km east of Mosquero. View is N30°W up valley. Ute Creek (dark line in middle distance) flows in a wide sandy channel bordered by a low scarp underlain by Quaternary alluvium and Triassic shale. Salt cedar is abundant in places along the channel. Camera station is on bench underlain by crossbedded Triassic sandstone; man is standing at edge of bench. Partially stabilized eolian sand covers Triassic sandstone at left and right edge of photograph. Hills in distance are made up of Triassic and Jurassic sedimentary rocks capped by remnants of an upper Tertiary basalt flow. Camera station is in NW1/4 sec. 15, T18N, R31E. Altitude about 1,356 m. W. Lambert photograph No. 86L95. 27 December 1986, 4:08 p.m., MST.