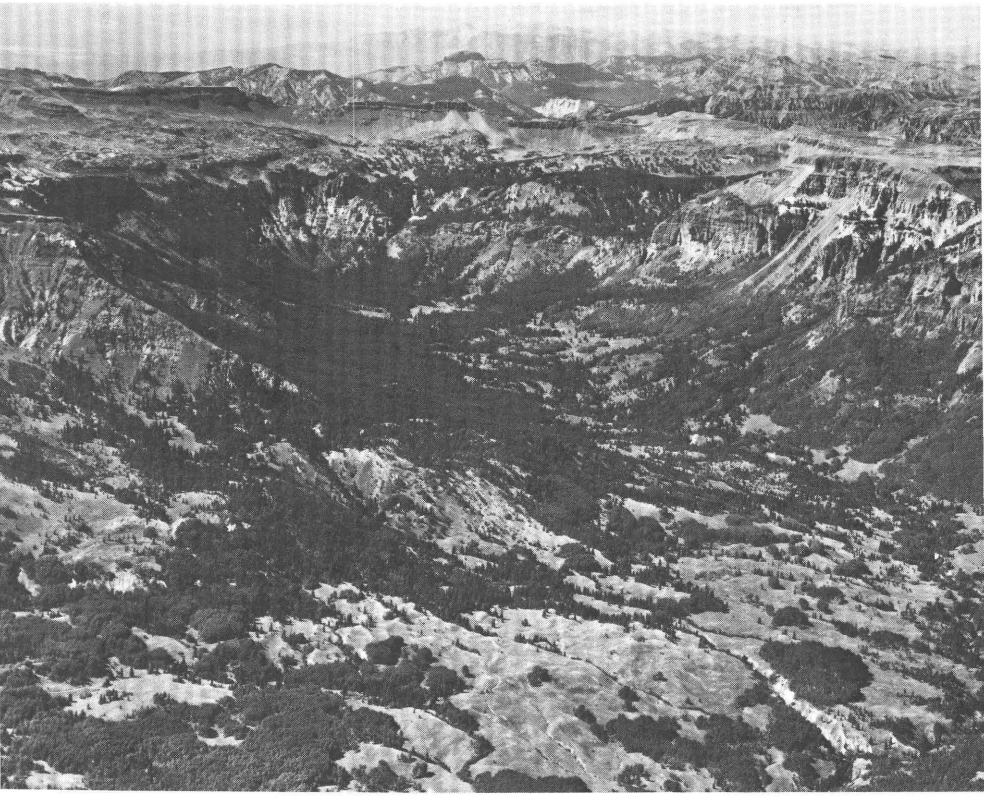
STUDIES RELATED TO WILDERNESS



CHAMA–SOUTHERN SAN JUAN MOUNTAINS, COLORADO

GEOLOGICAL SURVEY BULLETIN 1524

MINERAL RESOURCES OF THE CHAMA-SOUTHERN SAN JUAN MOUNTAINS WILDERNESS STUDY AREA, MINERAL, RIO GRANDE, ARCHULETA, AND CONEJOS COUNTIES, COLORADO



Aerial view looking northwest across the crest of the southern San Juan Mountains. The heavily timbered valley in the middle foreground contains the West Fork Rio Chama, near the southern limit of the study area. The upper half of the prominent cliffs in the foreground is ash-flow tuff; the lower half is a thick sequence of volcanic mudflows and lava flows of the Conejos Formation. Hummocky terrain in foreground is landslide debris. (U.S. Forest Service photograph.)

Mineral Resources of the Chama-Southern San Juan Mountains Wilderness Study Area, Mineral, Rio Grande, Archuleta, and Conejos Counties, Colorado

By U.S. GEOLOGICAL SURVEY and U.S. BUREAU OF MINES

STUDIES RELATED TO WILDERNESS—WILDERNESS AREAS

GEOLOGICAL SURVEY BULLETIN 1524

An evaluation of the mineral potential of the area



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STUDIES RELATED TO WILDERNESS

STUDY AREAS

In accordance with the provisions of the Wilderness Act (Public Law 88-577, September 3, 1964) and the Joint Conference Report on Senate Bill 4, 88th Congress, the U.S. Geological Survey and U.S. Bureau of Mines have been conducting mineral surveys of wilderness and primitive areas. Studies and reports of all primitive areas have been completed. Areas officially designated as "wilderness," "wild," or "canoe" when the Act was passed were incorporated into the National Wilderness Preservation System, and some of them have been studied and others are presently being studied. The Act provided that areas under consideration for wilderness designation should be studied for suitability for incorporation into the Wilderness System. The mineral surveys constitute one aspect of the suitability studies. This report discusses the results of a mineral survey of some national forest lands in the Chama-southern San Juan Mountains wilderness study area, Colorado, that are being considered for wilderness designation.

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METRIC-ENGLISH EQUIVALENTS

Metric unit	English equivalent	
	Length	
millimeter (mm)	= 0.03937	inch (in)
meter (m)	= 3.28	feet (ft)
kilometer (km)	= .62	mile (mi)
	Area	
square meter (m^2)	=10.76	square feet (ft^2)
square kilometer (km^2)	= .386	square mile (mi^2)
hectare (ha)	= 2.47	acres
	Volume	
cubic centimeter (cm^3)	= 0.061	cubic inch (in^3)
liter (L)	=61.03	cubic inches
cubic meter (m^3)	=35.31	cubic feet (ft^3)
liter	= 2.113	pints (pt)
liter	= 1.06	quarts (qt)
liter	= .26	gallon (gal)
cubic meter	= .00026	million gallons (Mgal or 10^6 gal)
cubic meter	= 6.290	barrels (bbl) (1 bbl=42 gal)
	Weight	
gram (g)	= 0.035	ounce, avoirdupois (oz avdp)
gram	= .0022	pound, avoirdupois (lb avdp)
tonne (t)	= 1.1	tons, short (2,000 lb)
tonne	= .98	ton, long (2,240 lb)
	Specific combinations	
gallon/ton=4.172 liters/metric ton		
	Temperature	
degree Celsius (°C)	= 1.8	degree Fahrenheit (°F)
degree Celsius temperature)	= (1.8×°C)+32	degree Fahrenheit

STUDIES RELATED TO
WILDERNESS—WILDERNESS AREAS

MINERAL RESOURCES OF THE CHAMA-SOUTHERN SAN JUAN MOUNTAINS WILDERNESS STUDY AREA, MINERAL, RIO GRANDE, ARCHULETA, AND CONEJOS COUNTIES, COLORADO

By U.S. GEOLOGICAL SURVEY and U.S. BUREAU OF MINES

SUMMARY

A mineral survey was made of the Chama–southern San Juan Mountains wilderness by the U.S. Bureau of Mines and U.S. Geological Survey in 1975. This rugged mountainous tract of 815 km² (square kilometers) lies astride the Continental Divide in the San Juan and Rio Grande National Forests. The western boundary lies about 13 km (kilometers) east of Pagosa Springs and the southernmost limit is 3 km north of New Mexico. The results of the study show that the area contains coal reserves and indicate petroleum, molybdenum, and copper resources.

Folding of Upper Cretaceous and older rocks predates the advent of volcanism that began in middle Tertiary time. The folds are cut by numerous faults, and together these structures account for the entrapment and retention of the oil and gas produced from Cretaceous and older sedimentary rocks in the vicinity of the study area. Faulting continued into the Tertiary, and intersections of northwesterly trending fault zones with an extensive east-west-trending structural sag that extends beneath the northern part of the study area are believed to have served as principal conduits for rising magmas resulting in emplacement of many plutons, some of which breached the surface to become major centers of volcanism. Much of the rock in and near these zones of intersection underwent extensive alteration by hot mineralizing fluids that emanated from the magmas.

Appreciable quantities of lead, zinc, silver, and gold have been produced from adjacent mining districts, but there is no record of production from within the study area. The northernmost part of the area contains extensive hydrothermally altered rock and the few potentially economic veins containing zinc, silver, and lead occur within that 25-km² altered area. No new surface occurrences of metallic resources were found during this study; however, study of the hydrothermally altered area and an associated aeromagnetic anomaly suggests a large buried porphyry deposit of molybdenum or copper or both. To determine its economic significance will require additional geophysical studies and exploratory drilling. Other smaller subsurface deposits may occur in the altered area (fig. 1, area 1).

Investigations by the Bureau of Mines of claims and mining properties within the study area indicate reserves of about 900 t (metric tons) of low-grade ore containing

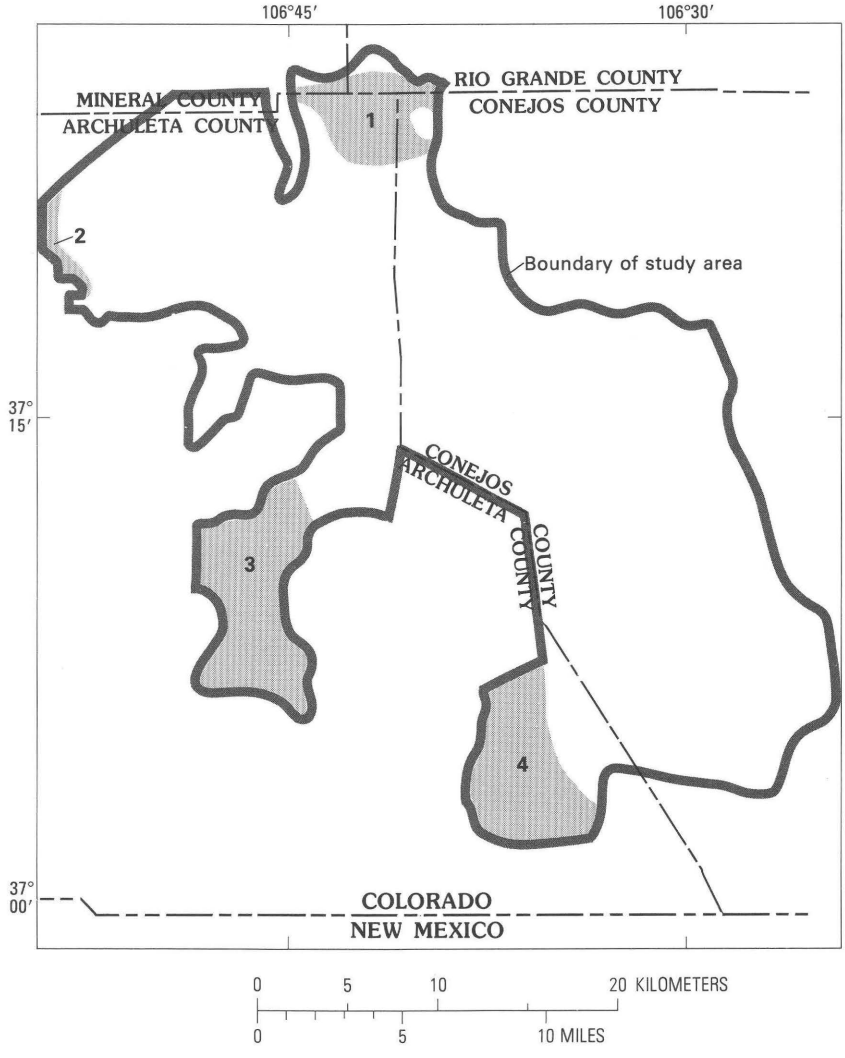


FIGURE 1.—Map showing areas of greatest mineral-resource potential. 1. Area of good potential for large buried porphyry deposit of copper and molybdenum. 2. Area of very good potential for mineable low-sulfur bituminous coal. 3. Area of fair potential for one or more productive oil pools.

lead, zinc, and silver in the Lady Bug mine within the large area of altered rock. Other localities in the altered area are considered to have a small resource potential.

With the exception of the previously mentioned deposits associated with the extensively altered area, the evaluation studies by the Bureau of Mines and Geological Survey failed to reveal the presence of other potential ore deposits within the study area. The many scattered samples containing anomalous values of metals reflect

veins and mineralized zones that are too small and too isolated to be mined profitably either at present or within the predictable future.

Several beds of low-sulfur bituminous coal underlie part of the northwestern corner of the study area (fig. 1, area 2) in the basal 20 m (meters) of the Fruitland Formation. The coal beds crop out near the area boundary and range in thickness from a few centimeters to 3.5 m. They contain reserves estimated at 45 million metric tons to a depth of 900 m, of which about 40 million tons are within the study area. Of this latter figure, 6.5 million tons are an indicated reserve and the remainder is inferred.

Significant quantities of oil may be trapped in buried structures in the southwestern part of the study area, particularly in areas 3 and 4 (fig. 1). Two oil fields are within 6 km of the boundary. Geologic factors suggesting significant oil potential are: (1) proximity of source beds capable of generating oil and gas, (2) some porous sandstone units which permit migration and storage, and (3) presence of favorable structural traps similar to those in the nearby fields. The maximum field size in areas 3 and 4 is estimated to be about 1.3 million m^3 (cubic meters) or about 8 million barrels. The potential for gas production from within these areas is considered poor.

Special attention was given the 25-km^2 area of altered rock in the northernmost part of the study area because of its potential for containing a porphyry copper deposit. Geological, geophysical, and geochemical evidence suggests the occurrence of a large porphyry-type sulfide deposit concealed at a depth of about 1,500 m. The exact depth and nature of the deposit is not determinable from the surface evidence, but the widespread, slightly anomalous values of copper and molybdenum contained in surface samples and associated patterns of alteration indicate that either or both of these metals could occur in greater quantity at depth. A slightly younger episode of mineralization is believed to have superimposed a chimney-type deposit containing copper above the porphyry-type deposit at an estimated depth of a few hundred meters.

An aeromagnetic map completed as a part of this study shows a negative anomaly over the deposit. The anomaly is interpreted to indicate a large intrusive igneous body in which the ferrous iron minerals have been hydrothermally altered to a less magnetic state. This alteration generally involves conversion of iron oxides and iron-bearing silicate minerals to less magnetic iron-bearing minerals such as iron sulfides and hydrous iron oxides. The nature of the magnetic low indicates that the mineralized body is a maximum of a few square kilometers in area and elongate in the east-west direction.

Geology of the Chama–Southern San Juan Mountains Wilderness Study Area, Colorado

By MAURICE R. BROCK and DAVID L. GASKILL
U.S. GEOLOGICAL SURVEY

MINERAL RESOURCES OF THE CHAMA–SOUTHERN SAN JUAN MOUNTAINS WILDERNESS STUDY AREA, MINERAL, RIO GRANDE, ARCHULETA, AND CONEJOS COUNTIES, COLORADO

GEOLOGICAL SURVEY BULLETIN 1524-A

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MINERAL RESOURCES OF THE CHAMA-SOUTHERN SAN JUAN MOUNTAINS WILDERNESS STUDY AREA, MINERAL, RIO GRANDE, ARCHULETA, AND CONEJOS COUNTIES, COLORADO

GEOLOGY OF THE CHAMA-SOUTHERN SAN JUAN MOUNTAINS WILDERNESS STUDY AREA, COLORADO

By MAURICE R. BROCK and DAVID L. GASKILL
U.S. Geological Survey

INTRODUCTION

The Chama–southern San Juan Mountains wilderness study area comprises about 815 km² of rugged mountainous terrain in Mineral, Rio Grande, Archuleta, and Conejos Counties in southwest Colorado (fig. 2).

The area lies astride the Continental Divide within the San Juan and Rio Grande National Forests. Many trails provide access within the area; some are maintained as horse trails. The latter include many kilometers of the popular Continental Divide Trail. The trails connect with several county and U.S. Forest Service roads that approach the boundary. These, in turn, connect to highways U.S. 285, U.S. 160, U.S. 84, Colorado 17, and New Mexico 19 that encircle the area. Newly constructed haulage roads serving lumbering activities and a few four-wheel-drive-vehicle roads penetrate the area a kilometer or so at a few places.

The largest population centers near the study area are Pagosa Springs (population 1,400) to the west and Chama, N. Mex. (population 900) to the south.

Some 130 km² of the study area are above timberline, which ranges between 3,500 m and 3,700 m above sea level. Summit Peak (elevation 4,054 m) is the highest of the many peaks that exceed 3,600 m. The lowest ground within the study area is at its northwesten extremity in the valley of the San Juan River where the elevation is



FIGURE 2.—Index map of southwestern Colorado showing location of Chama–Southern San Juan Mountains wilderness study area.

about 2,390 m. Narrow serrated ridges separate many of the deep canyons that drain the Continental Divide, producing relief that locally exceeds 1,200 m.

Precipitation varies with altitude. Annual precipitation ranges from 1.25 m on the Continental Divide near the northern boundary of the study area to 0.6 m near the lowest part of the area. About 65 percent of the precipitation falls as snow. The abundant moisture supports heavy vegetation on most mountain slopes and valley floors.

The frontispiece is an oblique aerial view of a part of the wilderness study area taken from near the southern boundary to show topography, vegetation, and geology that is fairly typical of much of the area.

PREVIOUS GEOLOGIC INVESTIGATIONS

Most previous investigations involving the geology within the study area were part of reconnaissance studies of much larger areas; however, geologic mapping of the Durango 2° Quadrangle in the late

1960's and early 1970's covered most of the study area at scales of 1:62,500 and 1:125,000.

One of the comprehensive contributions to the geologic knowledge of the region is a study of the volcanic rocks of the San Juan Mountains by Larsen and Cross (1956) that includes information on several localities within the study area. That study established the regional distribution of the principal units of volcanic rocks that blanket most of the San Juan region. Gardner (1909) briefly described the geologic setting of the coal deposits that crop out near the northeast corner of the study area and included some observations on the character of the coal beds exposed in the mines of that area. Patton (1917) described the geology of the ore depoists in the nearby Summitville and Platoro mining districts, and Steven and Ratte (1960) in their detailed study of the Summitville ore bodies determined the structural and stratigraphic controls on the deposition of the ores. Steven, Luedke, and Lipman (1974) discussed the mineralization and its relation to calderas in the San Juan volcanic field. The igneous events that brought about the alteration and accompanying mineralization are now better understood as the result of recent studies by Lipman (1974, 1975a, b). Lipman's work revealed the presence of a volcanic center including two previously unrecognized calderas that were the source of the quartz latite ash-flow tuffs and andesitic lavas that are well exposed in the study area. The geologic setting of the southern San Juan Mountains is best depicted on the geologic map of the Durango Quadrangle (scale 1:250,000) by Steven and others (1974). Steven (1975) summarized the evolution of the San Juan volcanic field in terms of the recent studies by many different investigators and related the volcanism to recently developed ideas on the sequence of tectonic events that formed the southern Rocky Mountains. In their most recent published work on the volcanics of the San Juan Mountains, Steven and Lipman (1976) described the events that produced the 18 known and inferred calderas by incorporating many recently available age determinations and studies of volcanic stratigraphy. Recent mapping by Lipman (1974, 1975b) and Lipman and Hail (1975) furnished most of the geologic information shown on plate 1 of this report. The geology shown in the area west of Quartz Creek in the northern part of the map area incorporates mapping by Dunn (1964) and Sinclair (1963).

PRESENT INVESTIGATIONS

Mineral-resource investigations of the wilderness study area were made in the summer of 1975 by the Bureau of Mines and the Geological Survey.

The investigating team of the Bureau of Mines included A. E. Lindquist, F. E. Williams, and G. L. Krum. They searched public records for mining-claim locations. The region's mining history was reviewed, and Bureau of Mines and state records were checked for recorded mineral production. Field work included visits to all known mine workings, dumps, prospect pits, veins, and many alteration zones; 181 samples were collected. A helicopter was used for access to areas of interest. Results of the Bureau of Mines investigations are reported in Chapter E of this report.

The Geological Survey's efforts involved three separate studies: (1) a geological and geochemical reconnaissance of the entire area including a detailed geochemical study of the Crater Creek area that offered promise for discovery of porphyry copper-molybdenum deposits; (2) an evaluation of the oil and gas potential; and (3) an analysis of several types of geophysical data.

The Geological Survey's field teams consisted of M. R. Brock and D. L. Gaskill, assisted by D. P. Jones and W. T. Schuiling; G. T. Neuerburg studied in detail the character of the altered rock within a 25-km^2 area in the vicinity of Crater Creek to evaluate its potential for concealed base-metal deposits. Theodore Botinelly assisted Neuerburg in laboratory study of the alteration mineralogy. Analysis of the oil and gas potential was made by R. T. Ryder using well-log and geophysical data. All of the above investigators relied on interpretations of the subsurface geology by J. C. Wynn based on the aeromagnetic and gravity data. Samples collected by the field team were analyzed under the supervision of C. L. Whittington and H. N. Barton. Results of the Geological Survey investigations are presented in Chapters A, B, C, and D of this report.

ACKNOWLEDGMENTS

We are grateful for the cooperation given the Geological Survey by the U.S. Forest Service in providing valuable information and facilities during the course of the field studies; in particular, we wish to thank Dan Peters, Bob Lynn, and Terry Brock. We thank W. E. Hughes and C. L. Hughes of the Banded Peak Ranches for granting access to company maps and oil-well data that provided much valuable information pertaining to subsurface geology in the vicinity of the Gramps oil field. We thank Dalton Morrow for permitting use of U.S. Bureau of Reclamation facilities during the fieldwork. Thanks are also extended to AMAX Exploration, Inc. for making available information concerning mineralized ground near the northern part of the area.

GEOLOGIC SETTING

The southern San Juan Mountains contain a thick sequence of volcanic rocks that are the southeastern part of a very large volcanic field covering many thousands of square kilometers of the San Juan Mountains region. The earliest volcanic rocks were deposited on an uplifted erosion surface underlain by 900–1,500 m of sedimentary rocks that range in age from Jurassic to early Tertiary. The sedimentary rocks rest unconformably upon a Precambrian basement complex consisting of granitic plutons, gneiss, schist, and metaquartzite.

Volcanism began in Oligocene time with eruption from many centers throughout the San Juan volcanic field (Lipman, 1975a). In the southern San Juan Mountains the eruptive rocks are predominantly of intermediate composition and include alkali andesite and rhyodacite. Rhyolite and basalt are sparse and for the most part represent the latest stages of volcanism. The basal volcanic-rock unit is a thick sequence of predominantly volcaniclastic sedimentary rocks interlayered with flow breccia and lava, and a few layers of ash-flow tuff, all of intermediate composition. The maximum exposed thickness of this basal unit is in excess of 1,100 m. Collapse of calderas at several of the volcanic centers followed outpouring of extensive sheets of slightly more silicic ash-flow tuff. The nearest of these, the Platoro caldera, is partly encircled by the northeast boundary of the study area and consists of a complex of intrusive and extrusive rocks that range in composition from andesite to rhyolite. Extensive alteration and mineralization took place along zones within and adjacent to the caldera during the waning stages of volcanism in this area. The nearby Summitville and Jasper mining districts are within such zones. At about this time the region was subjected to rifting and gentle tilting related to the development of the Rio Grande Trench (Lipman and Mehnert, 1969) that lies beneath the San Luis Valley about 30 km east of the study area. Attendant with the tilting and faulting was another period of volcanism that resulted in the outpouring of extensive basaltic lava flows that are interlayered with thick accumulations of gravel.

Glaciers have modified the surface morphology of the volcanic field. Widespread piedmont glaciers originated in the higher elevations of the volcanic field and flowed southeast and south across the relatively flat highlands. Later, alpine glaciers originated above 3,300 m elevation at the head of the principal valleys. After the the glaciers melted, the oversteepened valley walls were subject to landsliding that broadened many of the valleys. In some areas landslides altered valley configuration to a very significant extent and

resulted in slide-debris aprons, the largest of which covers approximately 130 km^2 as mapped by Steven and others (1974) and surrounds the Chalk Mountains between the Rio Blanco and Navajo River basins.

PRECAMBRIAN ROCKS

The Precambrian basement underlying the southern San Juan Mountains study area contains crystalline granitic gneisses, micaceous schists, and metaquartzite as determined from the few deep drill holes which have bottomed in basement rocks, from two small outcrops exposed outside of the east boundary in the floor of the Conejos River valley, and from the presence of xenoliths of gneiss in the Bear Creek stock at the northeast edge of Crater Lake (G. L. Neuerburg, oral commun., 1976).

SEDIMENTARY ROCKS

Although only the uppermost Cretaceous and younger sedimentary rocks are exposed in the study area (pl. 1), all sedimentary formations which are known at depth are described briefly because of their importance in the search for oil and gas. Much of the information on rocks of the subsurface was derived from published and unpublished descriptions by others working west and south of the study area. More detailed information on these rocks is in Chapter D of this report.

The thick sequence of sedimentary rock that lies between the Precambrian basement and the blanketing Tertiary volcanic rocks ranges in age from Jurassic to Oligocene. The basal member of the sedimentary sequence represents an invasion of dune sand across nearly level flanks of the eroded San Luis highland in Late Jurassic time. Further leveling and subsidence of the landmass resulted in burial of the sands by carbonate sediments deposited on the floor of an inland saline sea. These carbonate rocks were in turn covered by flood-plain sediments of regional extent that marked the end of the Jurassic deposition in this area. Following a period of erosion that lasted from Late Jurassic to Late Cretaceous, a series of invading seas deposited a thick sequence of mudstone, siltstone, and sandstone. The sandstone beds in the uppermost Cretaceous formations reflect minor orogenic events believed to be the precursors of the Laramide orogeny. About 1,100 m of sediments represent basin accumulations in the Jurassic and in the Cretaceous prior to the Laramide orogeny. The pre-Laramide rocks within the study area were folded and beveled by erosion prior to deposition of a thick se-

quence of conglomerate, arkose, and siltstone that represents Laramide deposition on the flanks of the highland from which they were derived. The maximum preserved thickness of rocks of this younger series is approximately 180 m in and near the study area.

The stratigraphic nomenclature used for the Cretaceous units in this report generally follows that used by Landis and Dane (1967) in the Tierra Amarilla Quadrangle, N. Mex., centered approximately 40 km south of the study area.

ENTRADA SANDSTONE

Crossbedded Middle Jurassic Entrada Sandstone lies on the Precambrian crystalline basement in the southwestern part of the study area where it is about 50 m thick as determined by nearby drilling. The formation thins northeastward and may pinch out locally beneath the northeastern sector. The rock is fine-grained, well-sorted quartz sand cemented by carbonate and locally by quartz. Limonite and hematite impart a pale orange to brownish red color to the rock. The Entrada Sandstone represents an invasion of sand, largely or entirely by eolian processes, upon the broad west flank of the ancient San Luis highland, which existed north of the study area.

TODILTO LIMESTONE

The Todilto Limestone of Middle Jurassic age conformably overlies the Entrada Sandstone and consists of approximately 30 m of laminated brown limestone rich in organic material. It was deposited from a saline inland sea that remained stagnant during much of its existence. The limetone is conformably overlain by sandy beds at the base of the Morrison Formation.

MORRISON FORMATION

Drill holes in the Gramps oil field penetrated about 215 m of Morrison Formation of Late Jurassic age composed of interstratified, varigated mudstone, sandy and silty shale, siltstone, and sandstone, all of continental origin. The closest outcrops are in the Chama Quadrangle. They were described in general terms by Muehlberger (1967), who stated that the most complete exposure was found in the Wolf Creek drainage on the state line a few kilometers south of the study area. Ryder (Chapter D of this report) stated that the three members of the Morrison Formation are probably present—the Brushy Basin, Westwater Canyon, and Recapture—although not specifically identified on the well logs of the area. The Morrison is an oil-producing formation in the Gramps oil field. Because of a lack of

outcrop and of detailed description of subsurface rocks, the detailed character of the Morrison is unknown in the general vicinity of the study area.

DAKOTA SANDSTONE

The Dakota Sandstone of Late Cretaceous age consists of resistant quartz sandstone that is locally conglomeratic plus thin-bedded, gray siltstone and gray to black carbonaceous shale. The sandstone layers are brown to tan on weathered surfaces and are parallel bedded and commonly cross laminated. Though the thick resistant sandstone beds are dominantly quartzose, they are locally arkosic and contain as much as 15 percent feldspar (Dunn, 1964). The sandstone is light gray to white on fresh surfaces and commonly displays flaky black carbonaceous debris. The Dakota does not crop out in the study area, but in nearby outcrops and oil wells it is 65–80 m thick. The lower part of the formation is of continental origin and lies disconformably upon the Morrison Formation; the upper part is of marine origin. Muehlberger (1967) reported that the upper contact is gradational with the overlying marine shale of the Graneros Member of the Mancos Shale in the Chama Quadrangle.

Physical properties of the Dakota that relate to oil and gas resources are given in Chapter D of this report. The Dakota Sandstone does not contain commercial coal beds in the northern and northeastern flanks of the San Juan Basin (Gardner, 1909; Muehlberger, 1967).

MANCOS SHALE

The Mancos Shale is of Late Cretaceous age and consists of a thick sequence of dark-gray shale with variable sand and silt content; calcareous layers and thin limestone beds are found in all but the basal members. A few hundred meters of Mancos was mapped in the southern part of the study area, but exposures are rare and no attempt was made to subdivide the shale in outcrop.

In this region, the Mancos Shale has been divided by Ryder (Chapter D) into five units that, beginning with the basal member, include the Graneros Member, Greenhorn Limestone Member, Carlile Shale equivalent, Niobrara Formation equivalent, and upper shale unit. The Graneros is approximately 60 m thick, containing basal sandstone layers intertonguing with the underlying Dakota. Conformably above the Graneros the Greenhorn Limestone Member contains about 11 m of thin-bedded alternating layers of limestone and calcareous shale. Conformably above the Greenhorn is about 115 m of olive-gray to dark-gray shale that is equal in age to the Carlile Shale

of eastern Colorado. For this report, the shaly unit is designated the Carlile Shale equivalent. The basal 60 m of shale is equivalent to the lower shale as described by Landis and Dane (1967) from outcrops in the Tierra Amarilla Quadrangle centered about 40 km south of the study area. This shale does not crop out in the area but was identified in drilling logs. Conformably above this shale is a sandy zone 30–40 m thick designated the Juana Lopez Member of the Mancos Shale by Dane, Cobban, and Kaufman (1966) in their studies to the south. As described by them, the member contains abundant fossils in dark-gray shale with interlayered hard, very fine grained calcarenite beds of mostly bioclastic material plus some layers of silty, sandy shale. The closest described outcrop of the Juana Lopez is approximately 15 km south of the study area in Willow Creek (Muehlberger, 1967). There the unit is about 15 m thick and contains in its upper part a marker zone easily recognized in outcrop by the presence of three resistant beds separated by shale. Muehlberger describes the lowest of these beds as a cross-bedded, commonly ripple-marked, sandy limestone several centimeters thick that contains fragments of fish scales and carbonized wood. The middle bed is cross-bedded calcarenite several centimeters thick containing abundant fossil oysters. The upper bed is 4.5 m thick, parallel-bedded, resistant calcarenite that generally caps the low hills in the area. Dunn (1964) mentioned the presence of this unit in the low hills immediately to the west and southwest of the study area but gives neither a specific locality nor a detailed description. His estimate of the thickness of the member agrees with that of Muehlberger's Willow Creek occurrence. Dunn assigned the Juana Lopez and the overlying 15 m of shale to the upper member of the Carlile Formation. The shale throughout his upper member weathers yellowish-brown in contrast to the distinct gray of his lower member, and the bluish-gray to light-gray weathered shale of the overlying unit is equivalent in age to the Niobrara Formation of eastern Colorado. The thickness and stratigraphic position of Dunn's upper member has the same general character as the Juana Lopez Member as defined by Landis and Dane (1967) in the Tierra Amarilla Quadrangle except that the uppermost thin calcarenite beds are apparently missing in the area mapped by Dunn. The Juana Lopez Member of the Mancos Shale as used in this report is restricted to the 15-m interval containing the calcarenite beds. The overlying 15 m of shale, which has many of the characteristics of the shale within the Juana Lopez, remains an unnamed upper unit equivalent in age to the uppermost Carlile Shale.

The contact between the Carlile and the overlying shale member of the Mancos, which is equivalent in age to the Niobrara Formation, appears to be conformable in the vicinity of the study area as determined by Ryder (Chapter D of this report) and Dunn (1964). The

Niobrara equivalent is a dark-gray, calcareous, fissile, marine shale that on weathered surfaces is whitish to bluish gray. This member is 150 m thick, and Dunn reported the occurrence of several thin limestone beds within a 10-m interval a few kilometers west of the study area.

Above and gradational with the Niobrara-equivalent member is 320 m of shale and sandy shale herein referred to as the upper shale unit of the Mancos Shale. The shale is light to medium gray and becomes increasingly silty in the upper 100–130 m; sandy layers are common in the upper 50 m of the unit, some of which are identical in composition to the basal sandstone layers of the overlying Mesaverde Group.

MESAVERDE GROUP

The Mesaverde Group of Late Cretaceous age crops out a few kilometers west and south of the study area. It consists of two formations in this part of the San Juan basin: the Point Lookout and Cliff House Sandstone. The Point Lookout Sandstone rests conformably upon the Mancos Shale and is conformably overlain by the Cliff House Sandstone. The Menefee Formation, a shale unit that separates these two sandstone units farther west and south, is absent in the northeastern part of the basin. Dunn (1964) and Muehlberger (1967) mapped the two sandstones as a single unit because of the difficulty of recognizing a contact between them.

The two sandstones are of marine origin and contain both nearshore and offshore facies of well-rounded and well-sorted quartz grains in sand that increases in silt content seaward (northeastward). Bedding thickness varies laterally, the maximum thickness near 12 m in the upper sandstone layers to nearly 5 cm in the basal unit as determined by Muehlberger in the Chama Quadrangle. Dunn described a rapid change over a distance of 6.5 km from a measured section containing 5 percent sand to an outcrop of massive sandstone which he concluded was an offshore bar. The combined thickness of the two sandstone formations that compose the Mesaverde is 95 m near the southeastern margin of the area and 137 m near the northeast margin as determined from subsurface information (Ryder, Chapter D, this report).

LEWIS SHALE

The Lewis Shale of Late Cretaceous age crops out in the northern part of the area along lower Quartz Creek and East Fork San Juan River near its junction with Quartz Creek. It also crops out along

Coal Creek at the west edge of the area. In these small outcrops the unit consists of dark-gray, fissle shale that is believed to represent only the upper 100–150 m of the formation, which has a total thickness of about 750 m. The Lewis is typically dark-gray marine shale resembling the Mancos; it is sandy at its base and top. Dunn (1964) and Muehlberger (1967) both described the unstable nature of the shale and its tendency towards mass movement. The slopes underlain by Lewis Shale above Quartz Creek and East Fork San Juan River are largely mantled by landslide debris.

Neither the lower nor the upper contacts of the Lewis Shale were observed in the study area. The lower contact is buried and the upper contact is mantled by landslides and other kinds of slope debris. The contact with the overlying Animas Formation in and near the Quartz Creek drainage is marked by a subtle topographic bench along much of its extent. Below the bench the decomposed shale contains mostly clay with minor silt. The upper contact may be located by a change from clayey soils formed from the Lewis to silty and sandy soils formed from the Animas Formation. The Pictured Cliffs Sandstone and Fruitland Formation are absent above the Lewis Shale in the Quartz Creek area, and an angular unconformity separates the moderately folded Lewis Shale from the overlying, slightly tilted Animas Formation.

PICTURED CLIFFS SANDSTONE

The Pictured Cliffs Sandstone is the uppermost marine unit and marks the final regression of the Cretaceous sea in late Campanian time. The formation consists of beach and nearshore deposits of brackish- and freshwater mud, silt, and sand that grade upward into the coal-bearing beds of the Fruitland Formation.

Twenty-three meters of Pictured Cliffs Sandstone is exposed in the Coal Creek drainage within and adjacent to the west edge of the study area. At that locality, Dunn (1964) described the formation as containing 7 m of fine-grained friable quartz sandstone in beds 1–2 m thick separated by thin shale partings. Above this sandstone is 1.7 m of brown carbonaceous shale, and the shale is overlain by 15 m of light-buff fine-grained feldspathic sandstone. This unit, in turn, is overlain by 3 m of interbedded brown sandstone and carbonaceous shale.

FRUITLAND FORMATION

The uppermost Cretaceous sedimentary rocks exposed in and adjacent to the study area are the lower 18 m of the Fruitland Formation. The beds include interbedded sandstone, shale, and coal that

were preserved from erosion along a part of the northwestern boundary of the area by a thick mantle of Tertiary rocks. Erosion of the upper part of the Fruitland Formation and overlying Kirtland Shale occurred in early Tertiary time. The overlying Animas Formation was deposited upon a surface that has several meters of local relief.

Prior to 1967, the coal-bearing beds in the Fruitland had been assigned to other formations. They were first described and assigned to the Laramie Formation by Gardner (1909), and later they were placed in the Animas Formation by Barnes (1954) and Dunn (1964). More recently this coal sequence has been identified as the slightly older Fruitland Formation by C. S. V. Barclay (oral commun., 1975) and by W. J. Hail, Jr. (oral commun., 1975) of the U.S. Geological Survey. Physical characteristics of the Fruitland which affect its qualities as a reservoir for oil and gas are given in Chapter D of this report.

The uneroded part of the Fruitland contains several beds of bituminous coal that can be seen in outcrops in the proximity of the northwest part of the area. A stratigraphic section of this interval was measured and described by C. S. V. Barclay (written commun., 1968) and is shown in table 1.

TABLE 1.—*Measured section of Fruitland Formation near the Himes-Kleckner coal mine shown in plate 1*

[Sec. 36, T. 36 N., R. 1 W. Measured by C. S. V. Barclay, USGS]

Unit	Lithology	Thickness (m)
Animas Formation	Pebble conglomerate and arkose	Not measured
Fruitland Formation	Coal	0.9
	Red clinker zone	1.5
	Thin coal seams in shale	1.5
	Sandstone	1.6
	--do	1.5
	--do	.8
	--do	.7
	Impure coal in shale	.9
	Claystone	1.4
	Sandstone	.6
	Coaly silt	.5
	Sandstone	.5
	Coal	2.0
	Carbonaceous shale	1.7
	Coal	1.2
Pictured Cliffs Sandstone	Light-gray sandstone	Not measured

ANIMAS FORMATION

The Animas Formation is a sequence of orogenic sediments of Late Cretaceous and Paleocene age that was deposited in response to major Laramide uplift and volcanism. This once-thick formation, which mantled the southern and southwestern flanks of a Laramide highland that rose at the site of the Paleozoic San Luis highland (Tweto, 1975), is missing from all but the western part of the study area, where it rests on eroded upturned beds of the Fruitland Formation and Lewis Shale. The basal beds of the Animas Formation consist of pebble conglomerate and coarse gritty sandstone. These grade upward into thick interlayered beds of arkosic and graywacke sandstone, siltstone, conglomerate, and mudstone, all of which contain detritus of pre-Tertiary rocks including Precambrian crystalline rocks, Paleozoic and Mesozoic sedimentary rocks, and andesite of probable late Mesozoic age. The rocks are mostly greenish gray to gray and weather light gray to buff. Bedding is mostly poorly defined and lenticular; some individual beds are a few kilometers in extent (Simpson, 1960).

The Animas Formation is poorly exposed in the study area and was not mapped separately from the overlying Blanco Basin Formation along the west side of the study area. Exposures in and near the Quartz Creek drainage and north of Harris Lake in the Rio Blanco drainage, however, contain only Animas Formation.

The maximum thickness of the Animas Formation within the study area is not known. Dunn (1964), whose mapping extended into the northwestern sector of the wilderness study area, described 122 m of Animas exposed in Klutter Mountain which is centered about 13 km west of the area. There the top of the formation has been removed by erosion. He described a pronounced discordance between the Animas and overlying beds of the Blanco Basin Formation at three nearby localities to the east of the study area.

BLANCO BASIN FORMATION

The Blanco Basin Formation of Eocene age consists of varicolored conglomerate, sandstone, and sandy siltstone which, like rocks of the Animas Formation, record a period of uplift of the highland to the northeast. The coarser sandstone and conglomerate contain abundant fragments of Precambrian rocks and sparse andesite fragments among the more abundant quartz and chert debris.

The Blanco Basin crops out at several places along the west, southwest, and south borders of the study area. The best outcrops are on the south flank of Blackhead Peak overlooking Blanco Basin.

Here 60 m of orange, purple, gray, and reddish-brown siltstone and sandstone overlie a large laccolith of porphyritic granodiorite. The Blanco Basin and overlying ash flows were raised several hundred meters during emplacement of the laccolith. Beds of the Blanco Basin in this vicinity are unconformably overlain by a basal unit of sandstone and siltstone of the Conejos Formation that contains much reworked volcanic material. At the southern tip of the area, a conspicuous ledge of Blanco Basin is exposed on the northern side of Archuleta Creek. Here a resistant cap about 7 m thick of thick-bedded to massive brown feldspathic sandstone overlies several meters of reddish siltstone and silty fine-grained sandstone. The Animas and Blanco Basin Formations are poorly exposed along the western boundary of the study area between East Fork San Juan River and Blanco Basin because of a cover of colluvial and landslide debris; consequently they are combined on pl. 1.

Muehlberger (1967, p. 99) measured 118 m of the Blanco Basin Formation exposed in the Chama Quadrangle to the south of the study area and estimated that another 6 m are not exposed.

The Blanco Basin Formation is equivalent in age and composition to the San Jose Formation found throughout much of the San Juan basin (Baltz, 1967), and both are considered to be of early Eocene age.

CONEJOS FORMATION

The Conejos Formation includes a thick series of layered volcaniclastic mudflows and lava flows, most of which are rhyodacite and andesite, that were drived from several volcanic centers within the San Juan volcanic field that mantled most of the region now occupied by the San Juan Mountains between 35 and 30 m.y. (million years) ago in Oligocene time. Lipman (1975a) divided the formation into a vent facies, consisting largely of lava flows, flow breccia, and explosion breccia, and a volcaniclastic facies consisting of mudflow breccia, conglomerate, and other volcanic sedimentary deposits. The vent facies represents the primary products of eruption, and the volcaniclastic facies represents reworked volcanic rock. Two local subdivisions of the vent facies include cone breccia and the upper lava unit.

Individual beds range in thickness from a few millimeters in silty units to 100 m and more in some massive mudflows and flow breccia. The bedding is generally crudely developed within the coarser debris and is most evident when viewed from a distance. Although the rocks of the Conejos Formation are most commonly light to medium gray, at many places throughout the study area the Conejos rocks have been altered to pale green by hot meteoric and magmatic water.

Mudflow breccia accounts for three-quarters or more of the volume of the formation and is typically a heterogeneous mixture of angular to rounded rock fragments of various compositions, color, and size. Most mudflows show little or no evidence of sorting, and the fragment size ranges from more than a meter down to silt-size debris. The greatest bulk of most mudflows consists of fragments within the range of 1–10 cm. The degree of induration varies greatly among the layers. Some of the finer grained alluvial beds have remained essentially uncemented and, where a few meters or more thick, form soil-covered low-angle slopes. Canyons cut into the Conejos Formation tend to be steep with nearly vertical cliffs.

ASH-FLOW TUFF AND LAVA

A sequence of tuffaceous ash flows and lava flows, which attains a maximum thickness of about 420 m on Summit Peak, overlies the Conejos Formation and at one time blanketed the entire southern San Juan Mountains. These rocks, deposited between 29 and 4 m.y. ago, now occupy an estimated one-quarter of the area, remaining on the higher peaks and ridges, particularly the plateaus in the southeastern part of the area. The following general descriptions have been summarized from more detailed descriptions by Lipman (1975a). Each of the volcanic units discussed is shown on plate 1.

The lower part of the sequence contains three sheets of quartz latite ash-flow tuff designated the Treasure Mountain Tuff by Lipman. The three members, in ascending order, are the La Jara Canyon, Ojito Creek, and Ra Jadero. Less widespread ash-flow tuff of the Treasure Mountain Tuff occurs below, between, and above the three formal members. Lipman designated these less extensive flows as the lower, middle, and upper tuffs. The middle tuff includes all subordinate flows between the La Jara and Ra Jadero Members. The three principal members each contain a resistant central zone of reddish-brown welded tuff. The upper and lower less welded zones weather readily and are pink to gray. Thin black glassy chilled zones are visible in many cliffs at the base of one or more of the ash flows. The Ojito Creek and part of the middle tuff have normal magnetic polarity; all other Treasure Mountain flows have reverse polarity as determined by Lipman. The formation attains a maximum thickness of 300 m near Summit Peak in the northern part of the area. The Treasure Mountain flows originated in the Platoro caldera complex that lies a short distance to the northeast of the study area.

The Masonic Park Tuff of Oligocene age (28.2 m.y.; Lipman and others, 1970) overlies the Treasure Mountain Tuff in the Summit

Peak–Montezuma Peak area and is about 120 m thick at that location. Other areas of outcrop include Chalk Mountain, high ridges overlooking the headwaters of Rio Chama, and the southeasternmost extremity of the area. The Masonic Park Tuff appears to be a single ash flow, similar in composition to the Treasure Mountain Tuff, and it consists of a completely welded black glassy base, a less densely welded central zone, and a nonwelded gray-to-pink capping zone. The remnant magnetic polarity of the Masonic Park Tuff is reverse. The Masonic Park Tuff probably originated in the Mount Hope caldera centered about 20 km north of the study area.

A series of andesite lava flows and related breccia flows which originated from the Platoro caldera and which are equivalent in age to the upper part of the Treasure Mountain Tuff were designated Summitville Andesite and divided into three members by Lipman. Only two of the members—the lower member and the upper member—occur in the study area. The lower member contains a series of dark-gray aphanitic flows containing sparse phenocrysts of plagioclase and pyroxene and attains a maximum thickness in the study area of 80 m; flows breccias of similar composition are among the lava flows. The lava flows and breccia flows of the upper member are petrographically similar to those in the lower member, but flows containing only sparse phenocrysts are interlayered with porphyritic flows that contain 5–25 percent phenocrysts. The upper member attains a maximum thickness of 300 m. Lipman reported the lavas of the Summitville Andesite have normal remnant magnetism. The age is approximately 29 m.y.

Isolated remnants of andesitic and rhyodacitic flows and breccias that occur on top of Summit Peak and nearby promontories are informally called andesite of Summit Peak. The unit overlies Masonic Park Tuff and is about 220 m thick on Summit Peak. The flows and breccias probably were derived from the Platoro caldera, and they are considered to be very close in age to the youngest flow of Summitville Andesite.

Basalt flows of the Hinsdale Formation were deposited from many widely dispersed eruptive centers near the close of the long period of episodic volcanism (Lipman, 1975a). Two large and several small patches of the basalt are preserved on high plateaus in the southeastern part of the wilderness study area and are remnants of an extensive veneer of alkalic basalt flows that covered most of the southeastern flank of the San Juan Mountains in late Pliocene time. Hindsdale lavas intertongue with gravels and volcaniclastic rocks of the Los Pinos Formation in the area. The basalt sequence has a maximum thickness of about 200 m near No Name Lake in the eastern part of the area. Hinsdale lavas in the southern San Juan Mountains range in age from 4.7 to 23.4 m.y.

INTRUSIVE ROCKS

Many small stocks, laccoliths, plugs, dikes, and sills have intruded the Conejos Formation and older rocks, mostly in the northern part of the wilderness study area. They range in composition from granodiorite to basalt and are part of a cluster of small intrusions that were emplaced within and peripheral to the Platoro caldera that adjoins the study area on the northeast.

The Bear Creek stock, the largest in the area, is about 2.5 km long and 1 km wide and crops out in the basin of Bear Creek near the northern boundary. It consists of monzonite (Lipman, 1975a), and ranges from coarse grained equigranular through medium-grained to a very fine grained porphyritic facies. The rock is mostly plagioclase (An_{40}) with lesser amounts of quartz and orthoclase and some hornblende, biotite, and augite. Two smaller stocks exposed nearby in Elwood Creek and Crater Creek are of similar appearance and texture and are probably comagmatic. All show variable degrees of hydrothermal alteration and mineralization; large areas of the intruded host rocks are altered also. Another small stock of similar composition, the Cataract Creek stock, is 1.5 km east of Montezuma Peak. It is also extensively altered and mineralized and may be satellitic to the Bear Creek stock. The mapping by Lipman (1974) shows that the Bear Creek stock cuts the La Jara Canyon Member of the Treasure Mountain Tuff, and that the emplacement of the Bear Creek and related stocks was, in part, controlled by the Elwood Creek fault system.

Two monzonite laccoliths, each several square kilometers in extent, are exposed along the western edge of the study area. The southernmost, the V Mountain laccolith (Larsen and Cross, 1956), was emplaced along or near the base of the volcanic section. The rock is a medium-fine-grained seriate-textured olive-brown monzonite with relict augite. Much of the top of the laccolith is exposed by erosion, but isolated patches of siltstone and mudstone remain along the west edge to attest to its generally conformable nature. This overlying sedimentary rock most closely resembles thin-bedded siltstone of the Animas Formation. It is metamorphosed to hornfels through an interval ranging in thickness from a few centimeters to 1 m above the contact. The greatest exposed thickness of the V Mountain laccolith is about 250 m at its southern limit where the basal contact is not exposed.

The intrusive bodies in the east and west walls overlooking Blanco Basin are probably parts of a single large laccolith termed the Squaretop laccolith by Larsen and Cross (1956). The chemical and mineralogical composition are much the same as the V Mountain laccolith. The texture differs in that some parts of the Squaretop lac-

colith contain a quartz monzonite variant having conspicuous, glassy, colorless plagioclase phenocrysts as much as 5 cm long in a fine- to medium-grained equigranular groundmass containing potassium feldspar, hornblende, biotite, and quartz. The laccolith was intruded along or near the base of the Blanco Basin Formation, which caps most of the body. The overlying Conejos Formation and Treasure Mountain Tuff, including the uppermost tuff layer, are domed by the intrusion and show the time of intrusion to be younger than the 29-m.y.-old Treasure Mountain Tuff. The laccolith probably is of the same general age as the Alamosa River stock (pl. 1 inset maps) within the Platoro caldera, which has been dated at 29.1 m.y. (Lipman 1975a, p. 78). The stock and the laccolith have similar mineralogy, equigranular texture, and monzonite to porphyritic quartz monzonite composition.

A concealed quartz diorite intrusive body was intersected at about 300-m depth in the three holes drilled in a search for oil along the crest of an anticline in the valley of Quartz Creek near the northern boundary of the study area (Sinclair, 1963). The rock is porphyritic and medium to coarse grained and is believed to be a small laccolith or stock. A sample from the Benson-Montin-Greer No. 1 Quartz Creek drill hole gave a fission-track age of 23.6 ± 2.5 m.y. from contained zircon as determined by C. W. Naeser, U.S. Geological Survey (written commun., 1976).

The many northeast- and east-trending dikes in the central and northern parts of the study area have the same compositional range as the stocks and laccoliths. The dikes, for the most part, are considered to be of the same general age as the stocks because they are most numerous within and near the stocks. Most were designated in the field as andesite and andesite porphyry on the basis of their megascopic properties. Many dikes extend west from the vicinity of the Platoro caldera and separate into two broad zones; one zone parallels the northwest-trending zone of faulting, the other curves southward to join the southerly trending dike swarm that extends at least 40 km into New Mexico. The southwest- and south-trending dikes are nearly all of andesitic composition. The west- and northwest-trending dikes include rhyodacite and quartz latite as well as andesite. The quartz latite dikes locally attain thicknesses in excess of 120 m.

LOS PINOS FORMATION

A thick wedge of alluvial material along the eastern and southeastern front of the San Juan Mountains was named the Los Pinos Formation by Larsen and Cross (1956). It accumulated in

Oligocene to Pliocene time through erosion of mostly volcanic rock. At the type locality near the southern limit of the area the Los Pinos contains mostly semiconsolidated conglomerate, sandstone, and mudflow breccia that underlie and intertongue with basaltic flows of the Hinsdale Formation.

The coarse detritus in the Los Pinos is almost entirely brownish, unweathered, porphyritic rhyodacite and andesite but locally includes sparse cobbles of medium- to coarse-grained granitic rocks of Precambrian and probable Tertiary age. This coarse debris within the conglomerate varies from well-rounded, polished pebbles and cobbles that are obviously derived from distant sources to angular fragments derived from neaby sources. Some mudflow layers are inferred to have been derived locally from volcano slopes because they contain only angular fragments derived from nearby sources. Some mudflow layers are inferred to have been derived locally from volcano slopes because they contain only angular fragments of a single rock type.

SURFICIAL DEPOSITS

Surficial deposits include unconsolidated and slightly consolidated materials deposited by alluvial, glacial, and gravity processes in Pleistocene and Holocene time.

ALLUVIUM

Alluvial sand and gravel cover the valley floors of the larger streams and rivers in the southern San Juan Mountains to a depth as much as a few tens of meters. They consist almost entirely of reworked igneous-rock debris derived from the surrounding volcanic and intrusive units. The gradients of most stream beds within the study area are too steep to permit deposition of other than isolated pockets of alluvium, most of which are too small to map, but a few of the larger streams contain sizable bodies of alluvial gravel within the area, and the largest of them are in Elk Creek. Also, the upper extremities of large alluviated basins in Rio Blanco, Rio Chama, and Quartz Creek extend into the area.

LANDSLIDE DEPOSITS

Thick landslide deposits mantle approximately 10 percent of the study area. Small patches of landslide debris occur in many places throughout the area but the larger, more extensive deposits lie below steep slopes and cliffs along much of the western margin of the study

area. The high ridge between the Rio Blanco and Navajo River is surrounded by a continuous apron of landslide debris covering 130 km^2. Landslide deposits contain mostly volcanic debris derived from the Conejos Formation and overlying flows. Typically the slide debris is a mixture of fine to coarse fragments that locally include rock slabs as much as a few meters thick. However, some slides contain much larger slabs that were transported almost intact downslope for more than a kilometer. Geologic conditions along the western margin of the area are ideal for generation of landslides. A thick accumulation of rather porous volcanic rock rests on dissected water-saturated Cretaceous shale, which provides an unstable environment. The shale, because of the heavy burden, becomes a somewhat plastic media that migrates first laterally and then upon breaking away from the wall, slides downslope. The descent can occur in seconds in the form of an avalanche, or more commonly, as a slower slump process that may continue to move over periods of many hundreds of years.

COLLUVIUM

Colluvial deposits include slope wash and alluvial-fan debris that mantle the bedrock at the base of slopes and on valley floors where it commonly intertongues with alluvium.

Colluvium is the most extensive of the surficial deposits but only the larger thicker deposits were mapped.

TALUS AND ROCK GLACIERS

Talus deposits consist of aprons and cones of coarse blocky debris that accumulates at the base of rock cliffs and on steep slopes. The bulk of the fragments range in size between several centimeters and a few meters. The deposits rarely exceed a thickness of 20 m.

Some of the thicker talus deposits at the higher elevations in the northern part of the study area retain a perennial ice matrix that permits the rock mass to move in much the same manner and configuration as an ice glacier. These are mapped as rock glaciers. The largest rock glaciers are in the glacial cirques above Carter Lake in the northern part of the area where they serve as natural storage for water.

GLACIAL DEPOSITS

Till, composed of heterogeneous mixtures of coarse and fine rock fragments, occurs within many valleys and covers parts of the high plateau between Elk Creek and South Fork Conejos River. The till,

which is shown with the symbol Qm on plate 1, represents two distinct types of glaciation: the older ice-cap glaciation that blanketed much of the San Juan Mountains in late Pleistocene time (Atwood and Mather, 1932), and the younger more restricted valley glaciation. Both types were much more extensive than is indicated by present distribution of the till (pl. 1), for much has been removed by erosion or buried by landslides.

The ice-cap deposits are tentatively assigned to an early stage of the Pinedale Glaciation.

STRUCTURE

The study area contains parts of several major structural elements (fig. 14, chapter D), the oldest of which evolved in Late Cretaceous time. At that time, the floor of a sedimentary basin that was regional in extent was differentially uplifted to form several large anticlines and large intervening basins. Prior to uplift, the old sedimentary basin extended eastward far beyond the area now occupied by the southern San Juan Mountains. The largest of these structural basins—the San Juan Basin—lies to the west of the study area. The uplift forming the northeast flank of the San Juan Basin is the Archuleta Anticlinorium, a northwest-trending structural high that isolated the Chama Basin on the east from the San Juan Basin to the west. The floor of the Chama Basin was elevated appreciably higher than the floor of the San Juan Basin. The Chama basin is flanked on the east by another of the large northwest-trending anticlinal structures—the Brazos Uplift.

The importance of vertical forces in the development of the regional structures described above has been stressed by Muehlberger (1967) and Woodward (1974). Baltz (1967) offered evidence suggesting that the Archuleta Anticlinorium originated from vertical forces resulting from isostasy. In late Laramide time the uplift was further subjected to northeast-oriented compression that generated secondary structural discontinuities including northwest-trending faults and asymmetric folds. These younger structures are combined with older north-trending symmetrical folds to form the structural pattern shown on plate 3.

Vertical displacement of large blocks of Precambrian basement during Laramide time is believed to have generated a series of large horsts and grabens on the basement surface, which are expressed as large anticlinal highs and synclinal basins in the overlying sedimentary rocks. The Brazos Uplift is cored by Precambrian crystalline basement rock as revealed in outcrops to the south of the study area. Muehlberger (1967) found the subordinate folds in overlying sedimentary rocks in the Brazos Uplift in the Chama, N. Mex., region to have

formed by deformation of those rocks over displaced basement blocks. There the anticlines overlie the horsts and the synclines reflect the grabens. The large north-plunging salient feature expressed in the gravity contours in the southeastern part of the gravity map (fig. 3, chapter B) probably reflects the northern terminus of the Brazos Uplift (discussion of the gravity survey, chapter B). The similar broad north-trending gravity high in the southwest quarter of the map reflects the trend of the Archuleta Anticlinorium. Presumably the Archuleta Anticlinorium is also cored by uplifted blocks of crystalline basement. The gravity low in figure 3 separating these two highs occupies the approximate position of the northern limit of the Chama Basin as proposed by Kelley (1955). Baltz (1967) modified Kelley's province map by extending the Chama Basin northward to where it joins the broader San Juan Sag in the northeastern part of the study area. This proposed continuity of the basin is in agreement with the Bouguer gravity data shown in figure 3 of this report and in the regional Bouguer gravity-anomaly map of the San Juan Mountains and vicinity (Plouff and Pakiser, 1972, fig. 3).

A postulated major basement structure having an east-northeast trend is in the northern part of the study area. From the vicinity of Pagosa Springs this structure in the form of a narrow trough extends eastward 50–60 km from a structural saddle that transects the Archuleta Anticlinorium near Pagosa Springs. Several geologic factors indicate that the trend reflects a zone of tensional stress that formed between two major areas of vertical uplift in Laramide time. As disussed earlier, vertical tectonic forces prevailed over horizontal forces during the early part of Laramide time. It is proposed here that elevation by vertical forces of the San Juan Uplift to the north and the Archuleta Anticlinorium and Brazos Uplift to the south created deep-seated easterly trending fractures within a zone of tensional stress in the intervening structural trough. Many northeast-trending dikes are contained within the postulated sag zone that contains the many intrusive and extrusive centers which, in turn, became important centers of mineralization. The Summitville and five other lesser mining districts including the Crater Creek district, which lie within the study area, are localized along the postulated structural zone at intersections with major northwest-trending fault zones. This zone is reflected in the contoured surface of a north-sloping regional gravity gradient (fig. 3, chapter B) as a narrow, east-trending bench having local depressions. The trough merges eastward with the San Juan Sag.

All of the above structural features were formed in Late Cretaceous and earliest Tertiary time.

The many faults mapped within the study area trend mostly north to northwest, are nearly vertical, and, where determined, have vertical displacements of as much as 180 m. Some are thought to have much greater displacements. Many in the northern part of the area are extensively mineralized. Faults also were important in the entrapment of oil in the nearby producing fields and their presence in the study area enhances the chances for entrapment of significant quantities of oil beneath parts of the study area (pl. 3).

Regional eastward tilting of between 5° and 10° is recorded in the layered volcanic rocks along the lower eastern flank of the San Juan Mountains including rocks throughout the study area. The tilting began in late Miocene time in response to the development of the Rio Grande Trench—a major structural trough that extends from central Colorado southward through New Mexico to the Mexico border.

COAL AND MINERAL DEPOSITS

Coal and metalliferous sulfide deposits occur within the study area; however, the recorded production of these commodities is only from mines outside the area.

COAL

Beds of low-sulfur bituminous coal in the basal 20 m of the Fruitland Formation of Late Cretaceous age have been mined near the northwest boundary of the study area where they dip eastward 5°–20°. Because of the scarcity of outcrops and inaccessibility of underground mine workings, most of the information concerning the coal in this area was obtained from brief descriptions by Gardner (1909) of the Himes–Kleckner and Dowell coal mines (pl. 1), and from C. S. V. Barclay (U.S. Geological Survey, unpub. data, 1968) and other occurrence and production data in Geological Survey and U.S. Bureau of Mines files in Denver, Colo. A well-exposed 20-m-thick coal-bearing interval in the cliff near the Himes-Kleckner mine is described in table 1. Thicknesses of individual coal beds within the 20-m interval range from a few centimeters to 3.3 m. Production was mostly from a bed that ranged in thickness from 1.7 to 2.2 m, but a thicker and possibly different discontinuous coal layer as much as 3.3 m was mined in the Dowell mine. According to Gardner (1909), mining was hampered to some extent by 'discontinuity' and 'displacement' of coal beds.

Gardner did not explain the nature of the 'discontinuity,' but presumably the mined bed was a discontinuous layer and the discontinuity is either a result of localized deposition or the coal bed has

been eroded locally. A discontinuity in the coal bed exposed near the portal of the Cox mine (pl. 1) may represent the type referred to by Gardner. There an erosion channel filled with conglomerate and coarse arkose of the overlying Animas Formation has cut through the principal coal bed. That channel is part of a nearly horizontal erosion suface that formed in Late Cretaceous time throughout the southern San Juan Mountains. The unconformity transected the folded sedimentary rocks in the vicinity of the coal mines and almost certainly extends through the upper mine levels.

The above-mentioned unconformity marks the base of the Animas Formation in the study area. Erosion during that time removed the entire Fruitland Formation and underlying Pictured Cliffs Sandstone several kilometers to the east in the valley of Quartz Creek. There the Animas Formation lies unconformably on the Lewis Shale. The Fruitland Formation is completely covered by a thick sequence of Animas and younger rocks in the area between the coal mines and the Quartz Creek drainage basin, thereby obscuring the eastward terminus of the coal beds. The Fruitland coals have also been removed by erosion to the west of the outcrop belt but reappear many kilometers further west along the flank of the San Juan Basin where mines produce from as many as three beds within the Fruitland. Too little is known of the thickness of Fruitland coal beds at depth beneath the study area to evaluate the potential for production from other than the one mined bed there. However, because of the eastward dip of the Fruitland in outcrops along the margin of the study area, it is possible that a complete interval of the formation is preserved downdip from the unconformity. It is also possible that the interval of coal beds preserved downdip is thicker than at the exposed, partially eroded level. Minable quantities of coal have not been identified in other formations in the vicinity of the southern San Juan Mountains.

More information on the composition of the coal and on coal production and reserves is contained in chapter E of this report.

MINERALS

A large area of altered and iron-stained rock, which is centered in the Crater Creek drainage in the northernmost part of the study area (fig. 1, area 1; pl. 1), has been explored for base and precious metals periodically since 1882. Other much smaller altered zones and veins surround the larger area. The extensively altered area is the western part of a much larger zone of hydrothermally altered rock that extends eastward from the Crater Creek area nearly continuously for approximately 25 km and contains the Crater Creek, Elwood, Stun-

ner, Gilmore, Summitville, and Jasper mining districts. Mineralization in all six districts is related to the emplacement of middle Tertiary plutons in the proximity of the Platoro and Summitville calderas (Lipman, 1975a; Lipman and others, 1976). Two other nearby mining districts, Platoro and Cat Creek (about 25 km northeast of Platoro) lie outside the zone of alteration, but Lipman and others (1976) have shown that the ores of these districts are also related to this period of igneous activity. Veins in the several nearby districts have yielded ores of silver, gold, copper, lead, and zinc valued at several million dollars.

Several lines of evidence indicate that a buried mineralized stock underlies the Crater Creek altered area. They include: (1) presence of several small mineralized plutons within the area of alteration, (2) prevalence of fractures throughout much of the area, (3) zonal alteration patterns, and (4) coincident gravity and aeromagnetic anomalies. A cluster of small monzonite stocks have intruded the volcanic country rocks in the Crater Lake area. These plutons and the rocks that enclose them are hydrothermally altered and pyritic. Conspicuous iron oxide staining occupies broad, ill-defined, easterly trending zones of fracturing. Narrower and generally more intensely altered northwesterly trending fault zones transect the broader zones. Most of the rock within the Crater Creek area is fractured, altered, and mineralized to some extent. Key minerals contained in each of the altered zones are: quartz and sericite in a phyllitic zone; albite, calcite, chlorite, and epidote in a propylitic zone; and chlorite, calcite, montmorillonitic clays, and epidote in a chloritic zone.

Pyrite occurs as thin films commonly less than 1 mm (millimeter) thick on surfaces of small fractures and as disseminated grains throughout all altered zones exposed in the Crater Creek area. In general, pyrite is less than 1 percent of the rock, but locally it constitutes as much as a few percent. Oxidation of the pyrite on weathered surfaces accounts for the extensive yellow, orange, and red that typify much of the altered rock. Pyrrhotite is fairly common in parts of the area and has much the same habit as pyrite. Other sulfide minerals disseminated in the altered rock include chalcopyrite and molybdenite; however, these minerals are much more restricted in distribution and quantity than pyrite. The mineralized host rocks along some of the shear zones and closely spaced joint sets have been converted to soft punky material that in some zones has been enriched in quartz and in others is impoverished in quartz. In some places such zones are bleached white owing to removal of iron. Locally the rock in the propylitic and chloritic alteration zones contains myriad veinlets of either calcite or opaline quartz and little or no sulfide minerals. Sparse zeolite occurs in fractures through much of the altered area.

Veins more than 0.3 m thick are relatively sparse both within and beyond the Crater Creek area. No more than a couple of dozen were seen during the course of the study and most are in the vicinity of Crater Creek. For the most part their surface exposures contain only quartz and pyrite, but some also contain calcite. The more common ore-forming sulfide minerals such as galena, sphalerite, and chalcopyrite are visible in only a few of the veins and fracture zones. One of the more extensive vein systems is exposed in the Lady Bug mine in lower Crater Creek basin. There a few hundred meters of mine workings follow a system of narrow veins containing sphalerite, galena, and chalcopyrite in a gangue of quartz, calcite, and pyrite. The Lady Bug vein system is described in more detail in chapter E. Analyses of the many samples collected from veins and altered zones from throughout the study area are discussed in chapters C and E.

The altered and mineralized rock and the results of geophysical studies strongly suggest the existence of a buried mineralized stock—a geologic setting typical of most large porphyry-type copper deposits. A large positive gravity anomaly that surrounds the Crater Creek basin and parts of adjacent drainages is also very likely an expression of a large concealed stock. The several small monzonitic plutons in this area are believed to be the exposed uppermost surface of the stock. Coincident with this positive gravity anomaly is a negative aeromagnetic anomaly believed to reflect a mass of mineralized ground that occupies the upper part of the siliceous stock. Geologic models prepared from studies of many of the world's better known porphyry-copper deposits (Lowell and Guilbert, 1970) indicate that many of the physical and chemical features found in the Crater Creek area are entities of a porphyry-type sulfide deposit. Those models generally contain a large calc-alkalic porphyry stock having a large body of fractured and mineralized rock within its uppermost part that extends into adjacent roof rock. The fracturing, mineralization, and alteration formed during the cooling of the solidifying stock. Hot magmatic fluids were forced upwards from its crystallizing interior to permeate a stockwork of large and small fractures and pervaded the rock in the vicinity of the fractures. The fluids changed the composition of the invaded rocks by altering their contained minerals and locally enriched them in metals transported from the cooling magma.

The intrusive quartz diorite body concealed beneath Quartz Creek, which was intersected by the three oil wells in that valley at about 300-m depth, is propylitized in its upper part. One of the wells (No. 1, pl. 2) penetrated an additional 300 m into the quartz diorite,and a sample from the bottom of this hole contains a trace of molybdenum and is only slightly chloritic (sample courtesy of Benson-Montin-

Greer Drilling, Farmington, N.Mex.). Sparse molybdenite coats fractures in phyllitic altered volcaniclastic rocks of the Conejos Formation and sandstone of the Animas Formation in a small stockwork deposit exposed on the east side of the Quartz Creek valley. The deposit is centered on a small plug of andesite porphyry that is bordered by intrusive breccia and intruded by rhyodacite dikes. The age of the two molybdenite occurrences in the vicinity of Quartz Creek is not certain, but their association with quartz diorite and andesite implies a separate period of mineralization from the copper-molybdenum mineralization associated with monzonite in the Crater Creek area.

The previously described veins occur mostly within and proximate to the Crater Creek altered area, and most are believed related to that episode of alteration.

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Geophysical Investigation of the Chama-Southern San Juan Mountains Wilderness Study Area, Colorado

By JEFFREY C. WYNN, U.S. GEOLOGICAL SURVEY

MINERAL RESOURCES OF THE CHAMA–SOUTHERN SAN JUAN MOUNTAINS WILDERNESS STUDY AREA, MINERAL, RIO GRANDE, ARCHULETA, AND CONEJOS COUNTIES, COLORADO

GEOLOGICAL SURVEY BULLETIN 1524–B

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MINERAL RESOURCES OF THE CHAMA–SOUTHERN SAN JUAN MOUNTAINS WILDERNESS STUDY AREA, MINERAL, RIO GRANDE, ARCHULETA, AND CONEJOS COUNTIES, COLORADO

GEOPHYSICAL INVESTIGATION OF THE CHAMA–SOUTHERN SAN JUAN MOUNTAINS WILDERNESS STUDY AREA, COLORADO

By JEFFREY C. WYNN, U.S. Geological Survey

INTRODUCTION

Regional gravity, aeromagnetic, and AMT (audio-frequency magnetotelluric) measurements were made in the Chama–southern San Juan Mountains wilderness study area to augment geological and geochemical studies and to aid in the analysis of the mineral resources of the area. Gravity anomalies reflect basement relief, thicknesses of volcanic rocks and sediments, large intrusive bodies, and zones of extensive alteration. Magnetic anomalies are produced by the volcanic rocks, topography, and alteration zones. The single application of AMT in this study was to investigate the basement structure in an area where gravity and magnetic information were inconclusive.

AEROMAGNETIC SURVEY

An aeromagnetic survey was flown by Aerial Surveys in November 1974 to supplement a previous survey made in 1967 by the U.S. Geological Survey. Together, these surveys covered most of the proposed wilderness area (pl. 1). The older survey, covering the area north of lat 37°15', was flown at a constant barometric elevation of 4,400 m, and the southern part was flown at an elevation of 3,800 m. The data from the southern survey was processed (upward continued) to an equivalent elevation of 4,400 m.

A major difficulty in interpreting the magnetic data is the effect of surface topography. In the southern half of the study area, the surface elevation ranged from 1,400 m below to nearly 100 m above the

stated flight elevations, with the rocks at the higher elevations consisting mainly of highly magnetic volcanics. As a result, the magnetic data over most of the southern half of the area reflects the topography very strongly. The data from the northern half is less obviously affected by topography, owing partly to the fact that much of the surface rock is less magnetic. The topography is nevertheless a major contributor to the magnetic map at the higher elevations. To minimize the effect of topography, a terraine-effect reduction technique developed by Bhattacharyya and Chan (1977) was utilized. The technique allows one to calculate an equivalent dipole distribution on the original observational surface, then it continues the field to a new pseudo-observational surface that has everywhere a constant vertical separation from the ground surface. The net effect is to simulate a perfect drape flight and a consequent reduction of the topographic effect in the data.

The dominant features of the aeromagnetic map are the magnetic highs over Summit Peak and Klondike Mountain in the north and over the Chalk Mountains and Chama and Banded Peaks in the south. In the northeastern part of the map, the axes of the magnetic lows coincide with the western and southern margins of the Platoro caldera. In the southern part of the map, the shapes of the lows closely coincide with the shapes of the valleys, with one notable exception that will be discussed later.

The following analysis proceeds roughly across the study area from the northwest to the southeast. In the northwest corner, south and west of the valley of Quartz Creek, there are two prominent magnetic anomalies (1 and 2 on pl. 1). Both of these magnetic anomalies are highs and are underlain by thin layers of volcanic rocks that are topographically higher than the surrounding volcaniclastic rocks of the Conejos Formation. Magnetic-high 1 (pl. 1) is centered near the uppermost limits of Mill Creek. This location suggests that the high is not a second-order terrain effect, but rather it may be caused by a pluton, although there is no visible surface expression of an intrusive mass or of basement relief in this area. Magnetic-high 2 (pl. 1) is centered over Quartz Ridge, which is capped by about 150 m of quartz latite flows including the La Jara Canyon Member of the Treasure Mountain Tuff. The magnetic polarity of the La Jara Canyon flows is negative, according to Lipman (1974). If so, this occurrence—as well as others in the study area that are beneath magnetic highs—implies that the remanence is too weak or the layers too thin to counter the effect of positive polarity of surrounding rocks in topographic highs. Gravity data discussed in the following section, however, do lend some support to the probable existence of a large buried pluton.

Magnetic-low 3 (pl. 1) over the Quartz Creek area is due mainly to

the lack of volcanic rocks caused by the canyon. In the original aeromagnetic data, the Quartz Creek magnetic low extended farther to the south and east. The data, corrected for topographic effect by parallel-surface continuation methods, defines the underlying Tertiary and Cretaceous sediments exposed in the bottom and flanks of the canyon.

East of the canyon of Quartz Creek a broad magnetic low (4 on pl. 1) has a V-shaped southern boundary. In the original aeromagnetic data, this magnetic low had very little relief within it, and it extended southward to Horse Thief Park, northwest of Platoro Reservoir. Most of the rocks underlying this low are hydrothermally altered. The axis of the low, when combined with the axis of the magnetic low to the south (9 on pl. 1), closely follows the boundary of the Platoro caldera; this point is discussed later. Magnetic-high 5 (pl. 1) remaining within the caldera is centered nearly over Klondike Mountain, and may be caused by an unaltered extension of the quartz monzonite intrusive that crops out to the north.

The north-northwest-trending magnetic-highs 6 and 7 (pl. 1) extend from south of Summit Peak, through Montezuma Peak and Crater Lake, northward to the area just west of Bonito Pass. Monzonite plutons crop out at several places along this feature and probably represent cupolas of a larger buried mass that appears responsible for the high magnetic response. The magnetic data are consistent with the existence of a batholith extending from south of Summit Peak to Bonito Pass where several cupolas crop out at the higher elevations. The batholith itself probably extends westward to Quartz Creek, where as much as 300 m of quartz diorite has been intersected in three drill holes, beginning at depths of about 300 m. This batholith may be related to a much larger batholith several kilometers to the north postulated by Plouff and Pakiser (1972) on the basis of a large closed low in Bouguer anomaly values in the northern and central San Juan Mountains.

A magnetic saddle (8 on pl. 1) in the Summit Peak high occurs just north of Crater Lake and correlates with a zone of hydrothermal alteration and an unusually dense concentration of fractures at the surface. The flight-line spacing partly brackets this feature, and a reliable dimensional estimate is therefore not possible. The flight elevation in this area was nearly 1,200 m above the surface, indicating that the alteration observed at the surface could be both intense and deep. This magnetic low is important, for it raises the possibility that significant sulfide mineralization exists in association with this extensive alteration. The aeromagnetic data strongly suggest that the ferromagnesian minerals have been altered. Alteration patterns and indicator elements tend to support this hypothesis,

as described in Chapter C in a study of mineral resources in the Crater Creek area.

A strong magnetic low (9 on pl. 1) about 6 km southeast of Platoro Reservoir on the study area boundary is potentially important because it coincides with the edge of the Platoro caldera. Another magnetic low (4 on pl. 1) also lies on the caldera boundary, and together they suggest a source of extensive hydrothermal alteration. Anomaly 9 is also underlain by less magnetic volcanic rocks than those in the surrounding areas, and this fact may partly account for the magnetic low.

South of lat 37°15', most magnetic features are related to surface rocks in high topographic relief. Virtually the entire magnetic response obtained in the valley of the Navajo River near its junction with Iron Creek and Fall Creek (10 on pl 1), appears to be produced by thin layers of highly magnetic ash flows and lava flows overlying a thick sequence of strata having weak magnetic susceptibility. A possible magnetic expression of a major linear feature (which trends N. 15° W. in the LANDSAT imagery of the area) is difficult to discern because of the magnetic effect of these rocks. This linear feature, which extends far southward from the study area, coincides with the east side of the broad basin in the Navajo River drainage, and with the fault that extends into and through Blanco Basin (11 on pl. 1) to the northwest. A possible buried intrusive body in the floor of the Navajo River valley is suggested by extensive alteration of canyon walls, by the AMT measurements, and by the LANDSAT-observed lineament, but not by the aeromagnetic measurements, which are dominated by the surrounding volcanics.

A north-northeast-trending magnetic high (12 on pl. 1) begins over Neff Mountain northeast of Cumbres Pass in the southeast part of the study area, and additional highs (13 and 14 on pl. 1) occur above the western edge of the high plateau bounded on the east by the Conejos River valley. All these highs are apparently caused by basaltic flows of the Hinsdale Formation. The nearby magnetic lows partly reflect less magnetic units but generally correlate closely with canyons and other areas of low elevation.

An exception is the magnetic low (15 on pl. 1) over Hourglass Lake which may have economic importance. In the original aeromagnetic data, this low was isolated, but after parallel surface continuation, it combined with another magnetic low to the northwest. Neither the main body of the the magnetic low, centered over Hourglass Lake, nor its northwestern extension can be explained by reversely polarized rocks exposed at the surface. After topographic effects were compensated for, the northwest extension of the Hourglass Lake anomaly was shifted nearly 2 km to the east to its present location (pl. 1). Its northern edge now alines more closely with two small zones of altera-

tion in volcaniclastic rocks of the Conejos Formation, and possibly concealed deep-seated alteration may be responsible for this magnetic low. The gradients observed on the flanks of the main body indicate that the top of the source is about 300 m below the ground surface. However, the canyon of Elk Creek is more than 300 m deep across the southern margin of the anomaly, and no evidence of alteration or of an intrusive mass has been observed anywhere in the walls of the canyon.

GRAVITY SURVEY

Gravity measurements made at 22 stations in and adjacent to the study area (fig. 3) augmented previous measurements made along roads surrounding the area. Stations in the interior of the study area were established to achieve a density of slightly less than one station per 25 km^2. The gravity stations were tied to a base established in Pagosa Springs by the U.S. Geological Survey; this base has been tied to the observed gravity datum of Behrendt and Wollard (1961). Elevation control was from spot elevations shown on topographic sheets. The gravity data were reduced to the complete Bouguer anomaly using an assumed average rock density of 2.67 g/cm^3 (grams per cubic centimeter).

One of the dominant features of the map is a gradient in the Bouguer anomaly that decreases from -240 mgal (milligals) on the south edge to -300 mgal on the north edge of the study area. A major part of this decrease is caused by isostatic compensation for the higher regional topography to the north. The regional gradient is interrupted in the north by a major disruption of the -280-mgal contour over an area covering most of the northern part of the study area. The gravity high thus outlined lies over the same area as magnetic-highs 1, 2, and 6 (pl. 1). The gravity and magnetic data taken together suggest that the pluton penetrated by the drill holes in Quartz Creek may extend several kilometers west of Quartz Creek, although there is no surface evidence of the pluton.

At Crater Lake, the -280-mgal contour defines (by means of only a single station, however) an anomaly of nearly 15 mgals. This anomaly is believed to be caused by an intrusive body, mineralized cupolas of which crop out northwest, west, and south of Crater Lake. Although the anomaly is supporting evidence of the stock, no relevant quantitative information can be derived from the gravity data concerning the mineralization.

In the southern part of the map area, a large gravity low of nearly 20 mgal exists near Banded Peak. Part of this anomaly might be explained by the fact that 2.67 g/cm^3 may be a high estimate for the

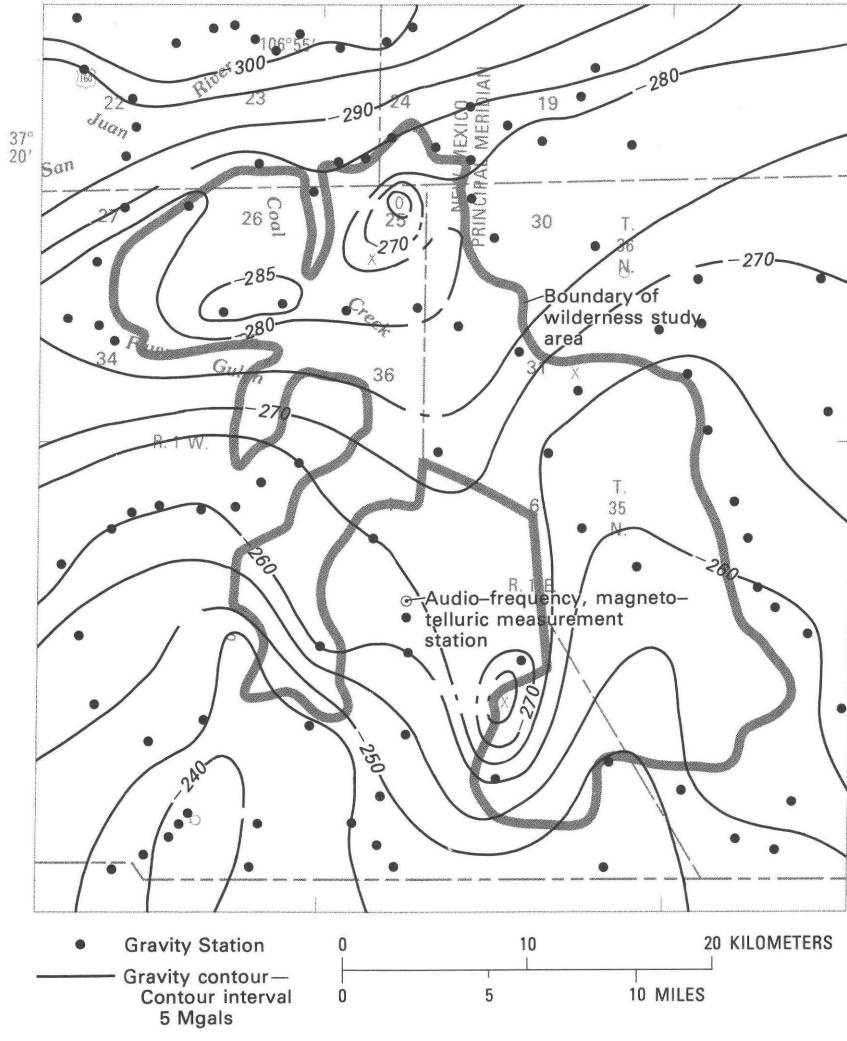


FIGURE 3.—Complete Bouguer gravity anomaly map of the Chama-southern San Juan Mountains wilderness study area and vicinity. Dots show gravity-measurement stations. Contour interval 5 mgals.

local average rock density. However, in the northern part of the map area, the density of most of the exposed rock types is about 2.70 g/cm^3. No geologic evidence is available that suggests a volcanic vent at this location, which would contain lighter rocks. The west edge of the anomaly does, however, coincide in part with the LANDSAT lineament discussed in the previous section, and it also correlates

roughly with the northern extension of the Chama Basin discussed in Chapter A.

A northeast-trending spur of the gravity high over the Chromo oil field souhwest of the study area extends up the Navajo River through the Gramps oil field where it abuts the Banded Peak low. The high at Chromo and the Navajo River basin and a related high in the Rio Chama drainage (east of Banded Peak) agree with the inferred raised basement discussed in the chapter on oil and gas potential. The Chromo gravity high probably reflects the east flank of the Archuleta Anticlinorium; the Rio Chama gravity high probably represents the northern extension of the Brazos Uplift (Muehlburger, 1960, p. 108).

AUDIO-FREQUENCY MAGNETOTELLURIC SURVEY

An AMT sounding made in the upper part of the Navajo River basin suggests the presence of an intrusive stock beneath the alluvium-mantled floor; this stock is roughly coincident with the LANDSAT lineament discussed in the section on 'Aeromagnetic Survey.' The steep canyon walls surrounding the Navajo River basin at the southwest edge of the study area precluded use of the aeromagnetic and gravity data to further interpret the geology concealed beneath its floor.

The AMT technique utilizes audio-frequency electrical noise generated by the magnetosphere of the earth as a source. By measuring the ratio of horizontal electrical field E to horizontal and orthogonal magnetic field H, the attenuation of the energy (that is, its penetration) can be measured as a function of frequency and be converted to the form of resistivity-as-a-function-of-depth. This technique samples a large volume beneath the measuring station, in effect averaging lateral discontinuities into the final results. The technique also has limitations; it cannot resolve thin layers and it cannot penetrate deeply in conductive earth environments.

An AMT station was set up at the north end of Navajo Basin, approximately on the LANDSAT lineament feature. The results indicate a 9-m-thick resistive layer at the surface. Beneath this 9-m-thick layer lie about 50 m of conductive material believed to be water-saturated alluvium or sedimentary rock. Beginning almost 60 m below the surface is a third, highly resistive unit (2,000–5,000 ohm meters) that is roughly 500 m thick. Beneath this thick resistive layer is probably a very good conductor of unknown nature or thickness. The possible apparent conductor at depth could be caused by conductive sediments in unconformable contact with resistive rock.

The 500-m-thick resistive unit is possibly a part of the Mancos Shale; however, other control soundings made at different levels in the exposed Mancos to the south did not indicate high resistivity. The strong possibility, therefore, exists that the resistive unit is indeed an intrusive body, possibly a stock, and that its emplacement was facilitated by a major fracture visible today as the LANDSAT lineament.

SUMMARY OF CONCLUSIONS

A major magnetic high over the Summit Peak-Bonito Pass area appears to be caused by major intrusive bodies of monzonitic composition that are only partly exposed. A gravity high supports this conclusion and indicates that the intrusives may extend 12–15 km to the west of Summit Peak beneath the volcanics. The intrusives outcropping in the Summit Peak area may in fact be cupolas of a batholith more than 15 km wide and as much as 20 km long. A magnetic low interrupting the Summit Peak feature north of Crater Lake could be caused by a large mass of intensely altered rock that extends to considerable depth. This zone is discussed in more detail in Chapters A and C of this report.

The gravity data appear to delineate a structural high in the basement that underlies the Gramps and Chromo oil fields. Magnetic effects of this basement high are obscured by nearby magnetic volcanic rocks to the northeast and northwest. This structural high is a northeast-trending fold on the east flank of the Archuleta Anticlinorium of northern New Mexico.

An AMT sounding in the north end of the Navajo River basin indicated a significant resistive body of rock that could be a buried intrusive body. This anomalous station lies on a major LANDSAT lineament that passes through Blanco Basin and the north edge and eastern side of Navajo Basin.

A strong gravity low of nearly 20 mgal delimits the east side of the LANDSAT lineament and is centered on Banded Peak. The cause of this gravity low is unknown, but may be due to a postulated graben concealed in the crystalline basement.

Two aeromagnetic lows on the east and northeast edges of the study area may have economic significance. One low lies 6 km southeast of Platoro Reservoir on the southern boundary of the Platoro caldera and may be caused by extensive alteration beneath the surface. The other low lies over Hourglass Lake and may also be caused by altered rocks beneath the volcanic rocks. This latter low, however, lies fairly close to the surface, and no evidence of alteration or of a buried intrusive is apparent from geological mapping or from geochemical sampling.

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Geochemical Evaluation of Mineral Resources in the Chama-Southern San Juan Mountains Wilderness Study Area, Colorado

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MINERAL RESOURCES OF THE CHAMA–SOUTHERN SAN JUAN MOUNTAINS WILDERNESS STUDY AREA, MINERAL, RIO GRANDE, ARCHULETA, AND CONEJOS COUNTIES, COLORADO

GEOLOGICAL SURVEY BULLETIN 1524-C

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MINERAL RESOURCES OF THE CHAMA-SOUTHERN SAN JUAN MOUNTAINS WILDERNESS STUDY AREA, MINERAL, RIO GRANDE, ARCHULETA, AND CONEJOS COUNTIES, COLORADO

GEOCHEMICAL EVALUATION OF MINERAL RESOURCES IN THE CHAMA-SOUTHERN SAN JUAN MOUNTAINS WILDERNESS STUDY AREA, COLORADO

By MAURICE R. BROCK, GEORGE J. NEUERBERG, and THEODORE BOTINELLY, U.S.Geological Survey

INTRODUCTION

A total of 1,335 samples of rocks and stream sediments were collected and analyzed to evaluate known mineralized ground and to search for and evaluate previously undetected mineralized areas. In addition, special attention was directed at identifying zonal mineral patterns within the extensive area of hydrothermally altered rock in the Crater Creek basin and vicinity in an effort to evaluate the altered area as the surface expression of a concealed porphyry-copper deposit.

GEOCHEMICAL EVALUATION OF NEAR-SURFACE RESOURCES

Results of the geochemical search for near-surface deposits support the geologic observation that the Crater Creek area was a principal center of hydrothermal activity and that there is a significant decrease in both the number and extent of mineralized localities away from that center. The Crater Creek area contains the greatest concentration of anomalous values of base and precious metals; however, the geochemical studies revealed no significant near-surface ore deposits either within the Crater Creek area or elsewhere in the study

area, nor did they reveal alteration halos indicative of concealed porphyry-copper deposits.

METHODS OF EVALUATION

This geochemical evaluation includes analyses of 640 samples of rock and 695 samples of stream sediments from throughout the area. Previous geologic mapping (Lipman, 1974, 1975; Lipman and Hail, 1975) greatly increased the efficiency of the sampling by identifying and delineating rock units and by depicting some of the larger altered areas.

The rocks were categorized at the collection site as unaltered and altered. Unaltered rocks were collected and analyzed to determine background values for various elements in the principal types of rock. Care was taken to select fresh representative samples. Two hundred and thirty-nine samples, each containing about half a kilogram of rock fragments, were collected to determine background values. They are of fresh rock from the four main rock types including Conejos Formation, Treasure Mountain Tuff, Hinsdale Formation, and intrusive rock. The first three types constitute about 90 percent of the exposed bedrock in the study area, and the Conejos Formation covers about three-quarters of the total area.

Nearly all of the analytical values above background are from the altered rocks and are considered to be a measure of the amount of metal added during hydrothermal alteration and mineralization. Veins, mineralized shear zones, and zones of pervasively altered and mineralized rock were sought out and sampled. Veins were sampled by chipping rock from across the most intensely altered and mineralized part of the outcrop. The width of the sampled interval generally was a meter or two. The same procedure was followed in sampling altered zones that lacked a well-defined vein, but the width sampled was generally greater.

Analyses of stream-sediment samples from all major drainage basins in the study area provided a reconnaissance technique that aided the evaluation using relatively few samples from each basin. The sediments represent a composite of material derived from the chemical and mechanical weathering of the rocks within the area drained. The finest grained material in the sediment tends to reflect the concentration of metals present in the rocks upstream. About half a kilogram of the finest grained sediment available was collected from the bed of the stream at each site. All tributary streams of about 1.5 km or more in length were sampled near their junction with larger streams, and additional samples were collected along the larger streams and rivers at intervals of 1 to 2 km.

Six elements are significant in evaluating the ore potential of the

study area. Selection of the six elements (copper, molybdenum, lead, zinc, silver, and gold) was based on three factors: (1) metals mined in nearby districts, (2) extrapolation of the kinds of ores likely to occur in the geologic environment, and (3) results of sample analyses. Gold is the principal metal produced from nearby mining districts in terms of total value, but significant quantities of silver, copper, lead, and zinc were also produced. Because the same extensive belt of altered pyritized rock that encloses the nearby districts extends into the Crater Creek altered area, it was assumed that anomalous quantities of these metals, and perhaps additional ones, would occur within the study area. Results of sample analyses indicate these five metals plus molybdenum are the elements of most interest in this geochemical evaluation.

Threshold value, which is defined as the upper limit of background, was determined for the six selected elements. Anomalous values include all determined values above threshold. For the purpose of determining thresholds, the samples were grouped into five categories: stream sediments, three mapped volcanic formations, and intrusive rock. The threshold values mostly were determined by plotting cumulative-percent frequency curves for each element on log-probability graph paper as described by Sinclair (1974). The results are listed in table 2. Molydenum values were below the detectable limits in most samples and did not permit computation of a statistically valid threshold; therefore, the minimum anomalous value for that element was chosen arbitrarily as 5 ppm. Detectable gold and silver in any sample is considered anomalous. Table 3 lists the analyses for copper, molybdenum, lead, and zinc in samples of unaltered dikes and plutonic rocks.

ANALYTICAL METHODS

Most samples were analyzed in mobile laboratories of the Geological Survey during the field study. The remainder were analyzed later in the Survey's Denver laboratories by the same analysts. All samples were scanned for 30 elements by a six-step semiquantitative method using emission spectroscopy (Grimes and Marranzino, 1968). Because of the relatively high detection limits of zinc and gold by the semiquantitative method, all samples were analyzed for these metals by atomic-absorption spectrometry, using procedures slightly modified from those described by Ward, Nakagawa, Harms, and Van Sickle (1969, p. 9–10, 10–22, 35–37). Lower limits of detection for gold and zinc using atomic-absorption spectrometry are 0.05 ppm and 5 ppm, respectively.

Elements analyzed by the spectrographic method and their detection limits in parts per million are: silver, 0.5; arsenic, 200; gold, 10;

TABLE 2.—*Threshold values for three elements in stream sediments and principal rock types exposed in the study area*

[Analyses are spectrographic. All values in parts per million]

Material sampled	No. of samples analyzed	Copper	Lead	Zinc
Stream sediments	695	50	30	70
Unaltered rocks:				
Conejos Formation	99	70	30	50
Treasure Mountain Tuff	42	50	50	30
Hinsdale Formation	24	50	20	100
Instrusive rocks	54	100	30	70

TABLE 3.—*Copper, molybdenum, lead, and zinc contents in unaltered intrusive igneous rocks*

[Values are in parts per million. Analyses are spectrographic except for Zn, which was atomic absorption, partial digestion. N, looked for but not detected at indicated detection limit; <, less than]

Sample No.	Cu	Mo	Pb	Zn	Sample No.	Cu	Mo	Pb	Zn
Dikes					Plutonic rocks				
180	30	5 N	10	45	050	100	5 N	20	40
182	70	5	30	55	152	50	5 N	10	45
307	10	5 N	20	15	262	50	5 N	20	50
326	70	5 N	20	40	354	10	5 N	20	20
337	100	5 N	30	40	356	20	5 N	30	10
342	70	5 N	50	20	499	70	5 N	20	45
355	100	5 N	30	25	677	200	5 N	10	20
390	20	5	15	30	678	150	5 N	15	50
415	50	5 N	30	15	723	100	5 N	30	30
449	50	5 N	10	40	1129	100	<5	15	30
462	<5	5 N	<10	50	1130	70	5 N	10	35
628	70	5 N	20	65	1420	70	5 N	30	45
641	100	5 N	30	45	1422A	10	5 N	15	35
642	200	5 N	30	80	1448	100	5 N	10	80
661	10	5 N	20	10	1450	100	5 N	<10	40
673	20	5 N	20	20	1474A	50	5 N	20	60
1406	70	5 N	20	45	1474B	150	5 N	15	45
1407	70	5 N	20	50	1475	150	5 N	20	40
1412B	200	5 N	10	70	1484B	20	5 N	100	50
1447	30	5 N	<10	45	1485B	200	5 N	20	50
1449	70	5 N	<10	50	1486	70	5 N	10	95
1452	50	5 N	15	85	1489	100	5 N	<10	65
1456	100	5 N	15	45	1510	100	5 N	20	45
1470A	30	5 N	10	45	1511	70	5 N	20	20
1477	100	5 N	20	80	1515A	150	5 N	20	65
1525	70	5 N	30	40	1516	100	5 N	20	35
1529	30	5 N	50	40	1527	30	5 N	50	35

boron, 10; barium, 20; beryllium, 1; bismuth, 10; calcium, 500; cadmium, 20; cobalt, 5; chromium, 10; copper, 5; iron, 500; lanthanum, 20; magnesium, 200; manganese, 10; molybdenum, 5; nickel, 5; niobium, 10; lead, 10; antimony, 100; strontium, 100; tin, 10; scandium, 5; titanium, 20; vanadium, 10; tungsten, 50; yttrium, 10; zinc, 200; and zirconium, 20.

Samples were prepared for analysis in the laboratory. Stream sediments were air dried and some were dried further in an electric oven at 105° C., sieved to minus-80 mesh, split, and a 10-mg (milligram) split was analyzed. Rock samples were crushed in a small jaw crusher, and a split of 100–150 g (grams) was ground in a pulverizer and submitted for analysis.

GEOCHEMICAL RESULTS

The mineral-resource potential of the wilderness study area is to, a large degree, interpreted from the results of the geochemical studies. The analytical results of copper, silver, molybdenum, lead, and zinc for samples that contain anomalous amounts of one or more of these elements are listed in tables 4 and 5. Samples having detectable amounts of gold are listed in table 6.

All sample localities are shown on plate 2 by sample number and type. The distribution of samples having anomalous amounts of one or more of the elements copper, silver, molybdenum, lead, and zinc are given in figures 4 through 11. The stream-sediment samples contained no anomalous values of molybdenum. The spectrographic threshold value of an element in rock varies with rock type (table 2).

The distribution of anomalous samples (figs. 4–11) clearly depicts the widespread mineralization in the Crater Creek drainage and reflects the scarcity of significant concentrations of metals in most of the remainder of the area. Although the mineralization in the Crater Creek area was widespread, the symbols indicating the higher values represent very localized concentrations of metals.

Figure 4 shows that the values of copper in rock samples are generally higher and anomalies most numerous in the Crater Creek area. The coincidence of the cluster of anomalies with a large area of intense alteration, an aeromagnetic low, and a gravity high are the principal reasons for postulating a porphyry-copper deposit concealed beneath the Crater Creek area. The concentration of molybdenum anomalies in this same area (fig. 6) suggests significant quantities of that metal could occur at depth in association with copper. The remaining anomalies of copper and molybdenum in rocks are widely distributed in the study area and reflect the many small veins and

TABLE 4.—*Analysis of stream-sediment samples containing one or more anomalous values for copper, silver, molybdenum, lead, and zinc*

[All values in parts per million. s, analyses by six-step semiquantitative spectrography and determinations reported to nearest number in series 1, 0.7, 0.5, 0.3, 0.2, 0.15, and 0.1, which represents the approximate midpoints of group data on a geometric scale; aa, atomic-absorption analysis; analysis of zinc utilized partial digestion of sample; <, less than; N, not detected]

Sample	X coordinate	Y coordinate	Ag-ppm s	Cu-ppm s	Mo-ppm s	Pb-ppm s	Zn-ppm aa
016	358,590	410,168	N	100	N	20	50
018	359,060	410,109	N	70	N	10	45
033	348,050	411,954	N	100	N	15	60
051	343,850	412,535	N	100	N	15	90
053	339,870	413,446	N	100	N	20	80
054	340,090	413,449	N	70	N	20	100
055	340,550	413,595	N	70	N	20	85
056	340,570	413,608	N	70	N	30	85
057	339,610	413,540	N	70	N	15	95
058	339,500	413,512	N	70	N	20	75
060	339,180	413,578	N	70	N	20	65
061	338,970	413,642	N	70	N	15	120
064	337,820	413,750	N	100	N	20	60
075	333,050	413,100	N	70	N	20	55
076	363,220	410,375	N	70	N	30	55
077	363,120	410,395	N	70	N	20	55
096	347,230	413,585	N	100	N	20	110
109	349,740	412,999	N	100	N	20	55
111	349,600	413,008	N	70	N	10	45
115	348,500	412,919	N	70	N	10	60
119	338,820	414,112	N	70	N	30	50
120	345,140	414,030	N	10	N	70	45
129	343,910	411,867	N	70	N	20	55
144	355,820	412,186	N	70	N	30	45
160	352,480	414,158	N	70	N	30	65
163	348,810	414,182	N	150	N	100	140
164	331,590	413,248	N	70	N	30	80
169	374,640	410,355	N	70	N	30	45
174	353,550	413,881	N	50	N	70	70
178	353,010	413,680	N	50	N	50	75
189	356,810	413,251	N	5	N	70	35
193	351,280	412,658	N	70	N	50	45
199	352,640	412,551	N	70	N	100	55
203	357,330	410,443	N	150	N	15	80
213	357,310	410,086	N	70	N	20	45
216	342,590	411,440	N	100	N	50	70
218	342,780	411,533	N	70	N	100	45
222	345,180	413,081	N	70	N	50	50
224	344,790	412,911	N	70	N	30	70
225	344,790	412,881	N	70	N	20	55
226	345,340	412,798	N	70	N	70	70
227	345,600	412,669	N	70	N	30	65
229	343,520	413,660	N	100	N	150	70
230	344,150	413,642	N	30	N	100	65
231	344,260	413,691	N	50	N	70	85

TABLE 4.—*Analysis of stream-sediment samples containing one or more anomalous values for copper, silver, molybdenum, lead, and zinc*—Continued

Sample	X coordinate	Y coordinate	Ag-ppm s	Cu-ppm s	Mo-ppm s	Pb-ppm s	Zn-ppm aa
239	336,110	413,251	N	70	N	30	55
253	341,780	412,930	N	70	N	10	40
261	345,340	412,575	N	70	N	10	50
269	367,060	410,447	N	70	N	30	50
272	368,000	410,359	N	70	N	30	35
276	369,200	410,236	.5	7	N	15	35
286	335,220	413,597	N	70	N	50	80
287	334,000	413,538	N	70	N	20	90
299	349,430	413,059	N	70	N	15	40
300	349,380	413,056	N	150	N	20	45
311	349,660	412,820	N	100	N	30	40
312	349,310	412,860	N	70	N	20	40
313	349,370	412,863	N	70	N	20	35
319	348,000	413,810	N	10	N	15	100
320	347,850	413,858	N	20	N	10	100
324	346,570	414,084	N	10	N	10	110
340	352,440	412,976	N	100	N	30	55
341	352,520	412,969	N	150	N	50	50
343	352,910	413,102	N	150	N	50	60
345	352,960	413,086	N	30	N	70	60
346	353,030	413,082	N	100	N	30	50
347	353,430	413,132	N	70	N	30	45
350	354,130	413,165	N	100	N	30	55
351	354,650	413,216	N	70	N	20	50
360	359,450	412,880	N	70	N	30	45
361	359,020	412,971	N	70	N	20	45
366	355,990	413,115	<.5	10	N	N	65
369	356,710	413,074	N	70	N	20	75
374	365,960	412,649	N	70	N	20	30
381	368,640	412,310	N	70	N	30	40
401	349,500	412,513	N	70	N	20	55
402	349,430	412,507	N	70	N	15	60
403	349,480	412,522	N	100	N	20	35
404	349,050	412,540	N	100	N	30	45
405	348,710	412,520	N	100	N	30	50
407	347,540	412,522	N	100	N	30	65
408	347,100	412,495	N	100	N	30	45
409	347,360	412,483	N	100	N	30	60
410	346,880	412,420	N	100	N	30	60
412	346,720	412,324	N	100	N	20	50
413	346,760	412,291	N	150	N	20	70
416	342,650	413,474	N	15	N	10	100
417	341,970	413,496	N	70	N	20	70
422	340,190	413,376	N	70	N	20	80
426	340,020	413,442	N	70	N	20	75

TABLE 4.—*Analysis of stream-sediment samples containing one or more anomalous values for copper, silver, molybdenum, lead, and zinc*—Continued

Sample	X coordinate	Y coordinate	Ag-ppm s	Cu-ppm s	Mo-ppm s	Pb-ppm s	Zn-ppm aa
427	337,580	413,087	N	70	N	30	70
445	342,800	412,307	N	50	N	20	120
454	345,150	413,501	N	20	N	10	100
457	332,010	413,638	N	20	N	15	100
464	342,690	410,912	N	100	N	30	90
465	343,030	410,840	N	70	N	50	85
475	346,840	412,845	N	100	N	15	60
479	351,060	414,007	N	70	N	10	260
482	350,600	414,015	N	10	N	<10	250
488	350,420	413,253	N	70	N	10	55
489	351,120	413,239	N	100	N	20	55
490	351,260	413,259	N	70	N	20	60
492	352,470	413,251	N	70	N	20	65
508	357,910	412,722	N	70	N	<10	70
509	357,530	412,827	N	70	N	30	45
513	367,600	412,781	N	100	N	10	80
518	368,590	412,640	N	<5	N	<10	130
565	369,830	410,661	N	15	N	15	100
600	358,820	410,759	N	70	N	10	55
601	358,790	410,741	N	70	N	15	50
609	362,020	410,639	N	70	N	15	35
611	362,390	410,581	N	100	N	15	55
612	362,160	410,603	N	100	N	10	55
613	362,010	410,547	N	70	N	20	90
615	361,400	410,550	N	50	N	10	110
616	361,260	410,454	N	70	N	15	120
630	344,610	413,301	N	70	N	10	100
656	346,740	413,178	N	150	N	20	60
660	346,120	413,099	N	70	N	20	45
663	346,170	413,069	N	70	N	20	45
666	346,060	413,000	N	100	N	10	35
679	347,120	412,080	N	70	N	20	40
693	353,880	412,020	N	100	N	30	25
698	352,630	412,013	N	70	N	20	25
701	349,790	414,008	N	70	N	30	110
702	349,800	414,018	N	100	N	50	85
703	349,480	414,081	N	150	N	150	110
707	348,800	414,075	N	100	N	100	95
714	347,480	414,159	N	300	N	300	140
715	349,330	414,018	N	70	N	20	60
716	349,280	414,088	N	150	N	30	90
717	349,810	414,102	N	100	N	100	110
718	348,600	414,141	N	100	N	70	110
719	347,620	414,160	N	70	N	150	85
734	356,890	413,074	N	70	N	20	75

TABLE 4.—*Analysis of stream-sediment samples containing one or more anomalous values for copper, silver, molybdenum, lead, and zinc*—Continued

Sample	X coordinate	Y coordinate	Ag-ppm s	Cu-ppm s	Mo-ppm s	Pb-ppm s	Zn-ppm aa
739	351,890	412,829	5.0	50	N	50	70
741	352,460	412,911	N	70	N	50	70
747	353,400	412,845	N	70	N	20	60
749	353,770	412,822	N	100	N	30	65
750	354,000	412,802	N	10	N	20	120
755	355,750	412,659	N	20	N	10	110
756	356,030	412,645	N	100	N	10	80
759	366,120	411,846	N	70	N	50	90
766	361,120	411,501	N	50	N	100	75
772	368,080	411,705	N	70	N	30	50
802	353,350	412,503	N	100	N	30	85
803	353,300	412,519	N	100	N	20	50
814	363,420	412,854	N	70	N	20	45
815	364,080	412,843	N	70	N	20	40
826	364,630	412,147	N	70	N	30	45
828	365,510	412,122	N	70	N	30	30
912	372,610	410,786	N	15	N	150	40
923	345,730	412,635	N	20	N	200	80
1131B	333,050	413,191	<.5	5	N	15	60

mineralized fractures that appear to diminish in both size and quantity with distance from the Crater Creek area. Most of the higher values of copper in stream-sediment samples (fig. 5) are concentrated in the Crater Creek drainage basin and are believed to reflect the same center of mineralization suggested by copper in rock samples. Many low-value copper anomalies seemingly reflect a broad zone of mineralization extending northwestward from the vicinity of Conejos Peak. The anomalies are probably not an expression of extensive hydrothermal mineralization. No obvious geologic reason accounts for the many anomalies, but perhaps copper-bearing accessory minerals weathering from the locally derived vent-facies flows exposed among the thick sequence of volcanic rocks are sufficiently concentrated in the stream sediments to contribute to the anomalous results. The relatively low copper content in both rock and stream-sediment samples indicates no large concentrations of copper in near-surface deposits within the study area. The maximum copper value is 1,500 ppm (parts per million)(0.15 percent) and is from mineralized rock in the Crater Creek area. The maximum molybdenum content in mineralized rock is 150 ppm.

Lead, zinc, and silver anomalies in rock are largely confined to the Crater Creek altered area (figs. 7, 9, 11). The patterns of distribution

TABLE 5.—*Analyses of rock samples containing one or more anomalous values for copper, silver, molybdenum, lead, and zinc*

Sample	X coordinate	Y coordinate	Ag-ppm s	Cu-ppm s	Mo-ppm s	Pb-ppm s	Zn-ppm aa
001	364,850	410,568	N	300	N	15	45
004	365,640	410,307	N	20	N	70	15
006	366,040	410,141	N	20	N	70	15
011	358,770	410,444	N	100	N	30	15
038	342,750	412,819	N	100	N	15	35
040	342,240	412,760	N	100	N	150	15
047	342,390	412,675	N	<5	N	100	15
050	343,190	412,540	N	100	N	20	40
069	335,570	413,500	N	100	N	30	30
084	348,270	413,200	N	20	<5	70	20
086	348,780	413,280	N	100	<5	30	15
094	347,570	413,555	N	100	<5	30	30
097	347,320	413,587	N	100	30	50	10
117	348,220	412,924	.7	70	100	50	15
121	345,300	414,023	N	100	50	200	20
140	355,000	412,035	N	100	N	20	10
148	351,600	412,439	N	100	N	30	15
156	351,640	414,228	N	50	30	20	10
182	353,060	413,391	N	70	5	30	55
186	356,500	413,318	N	<5	5	50	10
188	356,750	413,265	.7	<5	5	<10	5
200	355,490	410,750	N	100	N	20	20
223	345,140	412,948	N	100	N	70	65
279	346,520	413,297	N	50	5	50	20
288	349,390	413,246	N	100	10	50	20
289	349,310	413,246	N	100	5	30	40
290	350,340	413,192	N	20	5	10	35
301	349,360	413,050	N	70	50	50	25
304	345,070	411,096	N	100	N	10	15
305	345,480	411,053	N	70	150	10	20
306	345,540	410,975	N	100	N	10	40
309	340,510	412,652	N	100	N	20	25
328	349,340	413,722	N	100	N	50	30
329	349,110	413,763	N	5	N	30	70
331	348,870	413,828	N	300	N	20	100
334	348,410	413,919	N	150	N	100	40
335	348,370	413,955	N	200	N	15	70
337	347,760	413,990	N	100	N	30	40
338	347,510	414,014	N	500	N	50	55
352	360,760	412,785	N	150	N	30	15
355	359,460	412,704	N	100	N	30	25
370	356,050	413,126	N	50	70	<10	25
372	365,060	412,651	N	150	N	50	10
373	365,340	412,690	N	150	N	20	15
390	349,450	413,444	N	20	5	15	30

TABLE 5.—*Analyses of rock samples containing one or more anomalous values for copper, silver, molybdenum, lead, and zinc*—Continued

Sample	X coordinate	Y coordinate	Ag-ppm s	Cu-ppm s	Mo-ppm s	Pb-ppm s	Zn-ppm aa
392	350,270	413,484	N	5	70	10	10
393	350,850	413,507	N	10	5	10	25
400	349,980	412,425	N	150	N	20	25
410	347,280	412,476	N	150	N	20	30
448	345,820	413,210	N	70	N	100	55
452	346,380	413,460	N	500	N	50	60
460	342,720	411,088	N	150	N	20	40
467	350,690	412,780	N	100	5	20	15
477	352,140	414,011	N	20	N	1,000	10
480	350,680	413,984	2.0	200	N	50	85
483	350,600	414,007	.5	70	5	50	20
540	359,900	411,680	N	5	5	10	10
545	360,670	411,765	N	15	10	10	10
550	362,550	411,689	N	15	5	10	45
552	353,050	414,124	N	15	5	15	40
553	352,960	414,092	N	15	5	20	20
556	351,660	413,933	N	10	7	15	45
557	351,260	413,874	N	20	10	20	20
588	370,020	411,378	N	30	N	<10	70
590	371,590	410,664	N	30	5	10	55
594	363,640	410,955	N	30	5	15	30
595	371,480	411,240	N	30	<5	10	25
597	371,620	411,810	N	5	5	20	45
598	372,220	411,150	N	30	7	10	20
625	344,290	413,219	N	5	30	<10	35
641	342,120	413,686	N	100	N	30	45
642	342,120	413,686	N	200	N	30	80
645	342,590	413,921	N	30	N	100	90
647	343,370	414,031	.5	20	N	70	30
648	342,750	414,098	1.0	30	N	30	70
650	342,350	414,095	N	100	N	70	100
654	346,890	413,209	N	100	N	50	55
665	346,230	413,029	N	100	N	30	60
670	346,330	412,912	N	100	N	10	85
674	344,660	411,188	N	200	N	30	35
677	340,730	411,009	N	200	N	10	20
678	341,550	411,469	N	150	N	15	50
680	346,630	412,089	N	100	5	30	65
681	346,340	412,127	N	100	N	20	45
710	350,710	413,745	N	15	N	30	70
711	350,650	413,728	N	20	N	30	85
723	353,540	412,990	N	100	N	30	30
724	353,750	413,039	N	100	N	N	30
725	354,110	413,064	N	15	N	20	15
743	352,700	412,843	N	5	5	N	40

TABLE 5.—*Analyses of rock samples containing one or more anomalous values for copper, silver, molybdenum, lead, and zinc*—Continued

Sample	X coordinate	Y coordinate	Ag-ppm s	Cu-ppm s	Mo-ppm s	Pb-ppm s	Zn-ppm aa
765	359,350	410,913	N	100	N	30	35
770	369,040	411,519	N	100	N	N	45
773	367,780	411,724	N	100	N	30	35
774	369,500	411,740	N	100	N	50	35
777	352,100	413,729	N	20	7	15	60
778	352,050	413,737	N	5	5	20	25
779	352,210	413,753	N	15	5	15	60
780	351,900	413,758	N	5	5	15	40
783	351,790	413,722	3.0	50	5	70	25
784	351,850	413,727	.7	15	<5	20	40
785	351,910	413,734	1.0	10	5	30	40
786	351,970	413,732	.7	10	<5	20	30
787	352,030	413,732	1.0	20	<5	30	60
790	361,240	411,055	N	5	5	30	25
805	355,550	412,580	N	10	30	10	10
818	361,540	412,768	N	5	N	70	20
944	334,490	413,000	N	30	<5	20	70
947	348,720	412,066	N	5	7	10	30
951	341,250	412,637	N	10	N	15	70
1013	365,540	411,018	N	10	5	30	30
1014	363,280	410,956	N	30	10	20	40
1018	358,510	411,879	N	50	5	15	20
1030	373,880	411,113	N	100	5	20	30
1100	373,640	411,003	N	<5	5	20	15
1109	368,100	412,088	N	20	5	15	30
1121	350,950	414,255	N	5	5	30	25
1126	340,390	411,710	N	100	N	15	45
1129	340,130	410,942	N	100	<5	15	30
1137	332,790	413,446	<.5	30	N	15	40
1381	348,400	414,180	N	100	N	20	120
1382	348,400	414,185	N	5	N	15	90
1384	348,650	414,185	N	150	N	30	130
1385	348,670	414,180	N	100	N	15	70
1386	348,650	414,175	N	150	N	50	180
1387	348,500	414,172	N	100	N	15	35
1392	347,140	414,175	N	10	N	30	95
1394	346,700	414,200	N	100	N	10	60
1395	345,800	414,285	N	150	N	10	75
1396	345,730	414,285	N	100	N	20	100
1397B	345,710	414,285	N	30	N	30	90
1397C	345,710	414,285	N	30	N	50	70
1398	345,810	414,220	N	<5	20	30	55
1400	347,700	414,118	N	10	N	<10	150
1401B	347,700	414,100	N	150	N	30	110
1402	347,680	414,088	1.0	100	N	10	60

TABLE 5.—*Analyses of rock samples containing one or more anomalous values for copper, silver, molybdenum, lead, and zinc*—Continued

Sample	X coordinate	Y coordinate	Ag-ppm s	Cu-ppm s	Mo-ppm s	Pb-ppm s	Zn-ppm aa
1403	347,600	414,085	N	200	N	15	70
1404	347,500	414,075	N	100	10	15	60
1405	347,500	414,075	2.0	70	N	300	20
1408	347,300	414,167	N	30	N	15	100
1410B	347,950	414,182	N	150	N	15	20
1411	348,450	414,207	N	70	N	20	75
1412A	348,610	414,222	N	700	N	N	130
1412B	348,610	414,222	N	200	N	10	70
1415	349,020	414,275	./	300	30	1,500	5
1416	349,060	414,282	N	300	N	20	65
1417	349,250	414,310	N	300	N	20	55
1418	347,830	414,115	N	70	N	30	80
1421	348,200	414,118	N	150	N	15	55
1423	348,480	414,085	N	100	N	20	60
1424	348,630	414,087	N	100	N	30	30
1425	348,400	414,135	1.0	100	N	200	95
1426B	346,200	414,077	N	70	N	20	90
1428	346,100	414,097	N	15	N	300	130
1432A	346,020	414,065	N	150	N	20	50
1432B	346,020	414,065	N	150	N	300	70
1433	345,970	414,055	N	150	N	700	5
1434	345,820	414,055	1.0	200	N	700	40
1435	345,750	414,052	N	150	N	500	170
1441B	351,700	413,840	N	30	N	20	70
1445A	350,020	413,889	N	150	N	10	25
1445B	350,020	413,889	N	150	N	15	50
1448	349,800	413,951	N	100	N	10	80
1450	349,900	414,005	N	100	N	<10	40
1451	350,000	414,005	N	100	N	10	30
1452	349,880	414,020	N	50	N	15	85
1453	349,820	414,030	N	30	N	15	80
1455	349,700	414,086	N	70	N	30	75
1456	349,800	414,102	N	100	N	15	45
1459A	349,120	414,087	N	70	N	100	10
1461A	349,060	414,102	2.0	100	N	1,000	150
1461B	349,060	414,102	N	500	N	30	90
1462A	349,010	414,117	.5	5	10	500	5
1462B	349,010	414,117	.5	300	N	10	5
1463	349,130	414,118	N	100	N	20	65
1464	349,230	414,138	.7	10	15	200	50
1465	349,100	414,129	3.0	10	N	500	5
1466A	349,040	414,134	.5	5	N	1,000	<5
1466B	349,040	414,134	N	150	N	20	90
1467A	349,010	414,143	1.0	50	N	200	20
1467B	349,010	414,143	1.0	10	10	1,000	10

TABLE 5.—*Analyses of rock samples containing one or more anomalous values for copper, silver, molybdenum, lead, and zinc*—Continued

Sample	X coordinate	Y coordinate	Ag-ppm s	Cu-ppm s	Mo-ppm s	Pb-ppm s	Zn-ppm aa
1468	348,960	414,040	N	5	15	500	5
1472A	350,630	413,797	N	100	N	20	15
1472B	350,630	413,797	N	150	N	30	65
1472C	350,630	413,797	N	20	N	30	75
1473	350,530	413,811	N	200	N	20	75
1474B	349,960	413,855	N	150	N	15	45
1475	350,000	413,835	N	150	N	20	40
1476A	349,870	413,899	50.0	70	N	15	50
1476B	349,870	413,899	N	1,500	5	50	110
1477	351,960	413,730	N	100	N	20	80
1478	351,990	413,728	N	100	N	30	75
1479	351,890	413,720	N	100	N	30	20
1481	351,700	413,742	N	50	5	30	75
1484A	349,370	413,820	N	70	N	20	110
1484B	349,370	413,820	N	20	N	100	50
1485B	349,120	413,835	N	200	N	20	50
1486	349,130	413,865	N	70	N	10	95
1489	349,150	413,955	N	100	N	<10	65
1490	349,230	414,000	N	15	10	50	30
1491	349,450	414,032	N	100	N	<10	45
1492A	345,530	414,047	.5	150	N	100	100
1492B	345,530	414,047	.7	150	N	100	95
1492C	345,530	414,047	1.5	200	50	3,000	95
1494	350,150	414,200	N	150	N	20	35
1495A	350,010	414,152	1.0	70	N	3,000	<5
1495B	350,010	414,152	1.5	20	5	3,000	<5
1496	349,860	414,155	N	<5	N	100	60
1497	349,710	414,140	.5	100	N	700	<5
1498	349,510	414,117	N	200	N	50	55
1499	349,430	414,122	N	150	N	70	75
1501	352,070	414,018	1.0	20	N	500	<5
1502	351,650	414,014	1.0	20	N	1,000	5
1503	351,220	413,987	N	300	N	50	35
1504	350,920	413,988	N	5	N	100	35
1506	350,320	413,993	N	300	N	30	70
1507	350,180	413,991	N	300	N	30	120
1508	350,180	413,967	N	20	20	<10	20
1510	350,260	413,835	N	100	N	20	45
1512	349,800	413,935	N	70	N	<10	130
1513	349,700	413,935	N	100	N	50	85
1514A	349,570	413,947	N	30	N	20	95
1514B	349,570	413,947	N	70	N	10	100
1515A	349,830	413,940	N	150	N	20	65
1516	349,750	413,980	N	100	N	20	35
1517	349,400	414,020	N	200	N	20	70

TABLE 5.—*Analyses of rock samples containing one or more anomalous values for copper, silver, molybdenum, lead, and zinc*—Continued

Sample	X coordinate	Y coordinate	Ag-ppm s	Cu-ppm s	Mo-ppm s	Pb-ppm s	Zn-ppm aa
1518	349,250	414,056	N	100	N	30	120
1519	345,420	414,047	N	100	N	50	5
1520	346,780	414,207	N	200	N	10	35
1521	348,650	414,150	.7	50	5	1,500	20
1522A	348,670	414,182	N	70	5	30	110
1523	348,610	414,165	2.0	100	N	1,000	420
1523PEG	348,610	414,165	30.0	100	30	15,000	9,000
1524A	348,750	414,250	.5	100	N	300	65
1524B	348,750	414,250	N	100	N	30	60
1526B	349,050	414,300	2.0	70	N	300	480
1528	354,270	414,038	N	150	N	30	320
1530V	354,630	413,948	2.0	<5	70	50	<5
1531A	354,890	413,932	N	150	5	50	60
1531B	354,890	413,932	N	5	5	30	40
1531C	354,890	413,932	N	30	5	100	40
1532A	355,000	413,932	N	70	15	100	45
1533A	354,880	413,912	N	100	N	20	90
1533B	354,880	413,912	N	150	N	50	10

TABLE 6.—*Analyses of rock and stream-sediment samples containing anomalous gold*

[Values are in parts per million. <, less than]

Sample No.	Gold	Location
121----------	<0.05	Quartz Creek area.
602----------	.05	West Fork Rio Chama.
607----------	<0.05	Rio Chama near Dipping Lakes.
402----------	.05	North Fork Fish Creek.
59----------	<0.05	Sand Creek.
514----------	<0.05	South Fork Conejos River.
750----------	<0.05	North Fork Conejos River.
868----------	.05	Lower Elk Creek.
1405----------	<0.05	Crater Creek area.
1434----------	<0.05	Quartz Creek area.
1435----------	<0.05	Do.
1462-B----------	<0.05	Crater Creek area.
1476-B----------	<0.05	Do.
1487----------	.05	Do.
1492-A----------	<0.05	Quartz Creek area.
1492-C----------	<0.05	Do.
1508----------	.05	Crater Creek area.
1519----------	<0.05	Quartz Creek area.

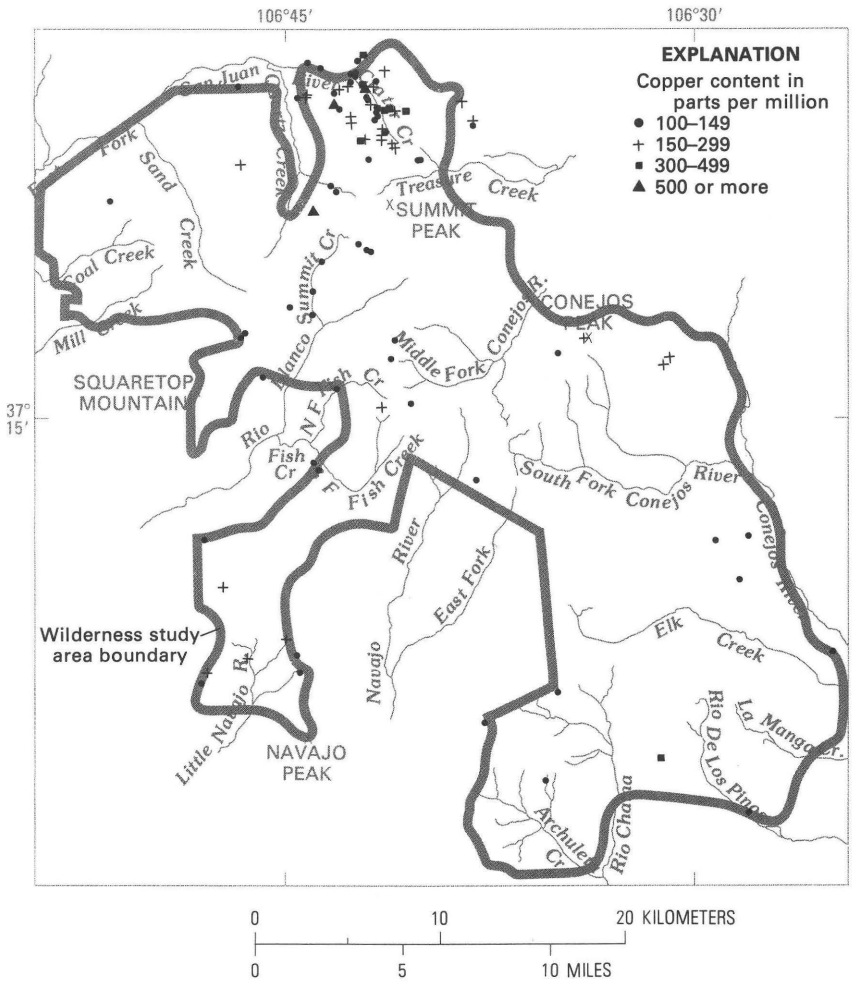


FIGURE 4.—Locations of rock samples containing 100 ppm or more copper.

of lead and silver anomalies in that area indicate an affinitive association of the two metals, and, although it is not verified mineralogically, the association probably reflects silver-bearing galena proximate to a magmatic source. None of the lead-bearing samples from beyond the vicinity of the postulated source of mineralization contain anomalous silver. The maximum lead value obtained in the geochemical study is 15,000 ppm (1.5 percent) in a sample collected from a narrow quartz-bearing shear zone. The highest silver value (50 ppm) is in a sample from the altered wall of a small vein, but the vein material did not contain silver in detectable quantity. Although zinc values in rock are highest in the vicinity of Crater Creek, their pattern of distribution

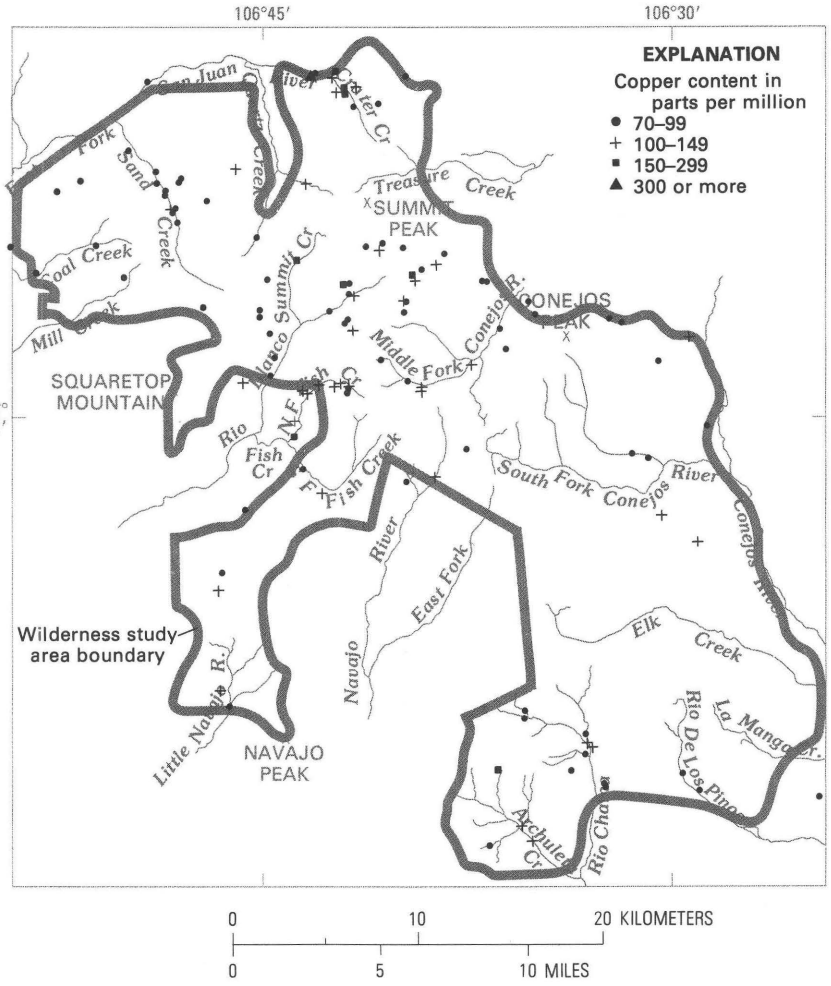


FIGURE 5.—Locations of stream-sediment samples containing 70 ppm or more copper.

within the area differs from that of lead and silver. Zinc is believed derived from the same magmatic source as the other metals studied. Zinc values in rock are generally less than 150 ppm and a maximum of 9,000 ppm (0.9 percent). Stream-sediment samples containing anomalous amounts of lead, zinc, and silver also are mostly from the Crater Creek area and diminish in numbers away from that postulated center of mineralization. Outlying anomalies are derived from sparsely distributed small veins and mineralized fracture zones in other parts of the study area. Geochemical studies suggest only a small potential for production of the three metals from near-surface deposits anywhere in the area.

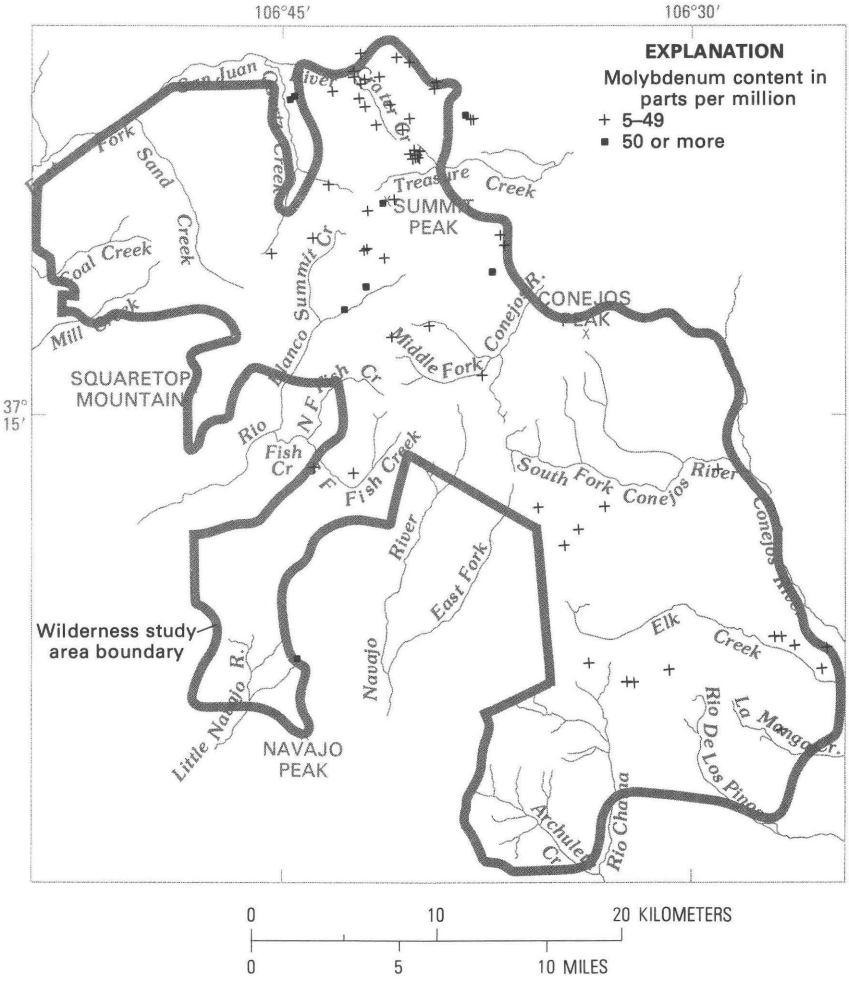


FIGURE 6.—Locations of rock samples containing 5 ppm or more molybdenum.

Gold was detected in 18 samples, but all values are at or slightly below the determinable limit (0.05 ppm) for the standard atomic-absorption method of analysis. None of the widely scattered occurrences, which are listed in table 6, are considered to represent economical concentrations of gold. Rock samples in which gold was detected are from mineralized zones in Crater Creek and Quartz Creek basins. The remainder of the samples are of stream sediments from the drainages listed in the table.

All prior searches for uranium within and near the study area failed to find deposits of commercial value and none were found during this

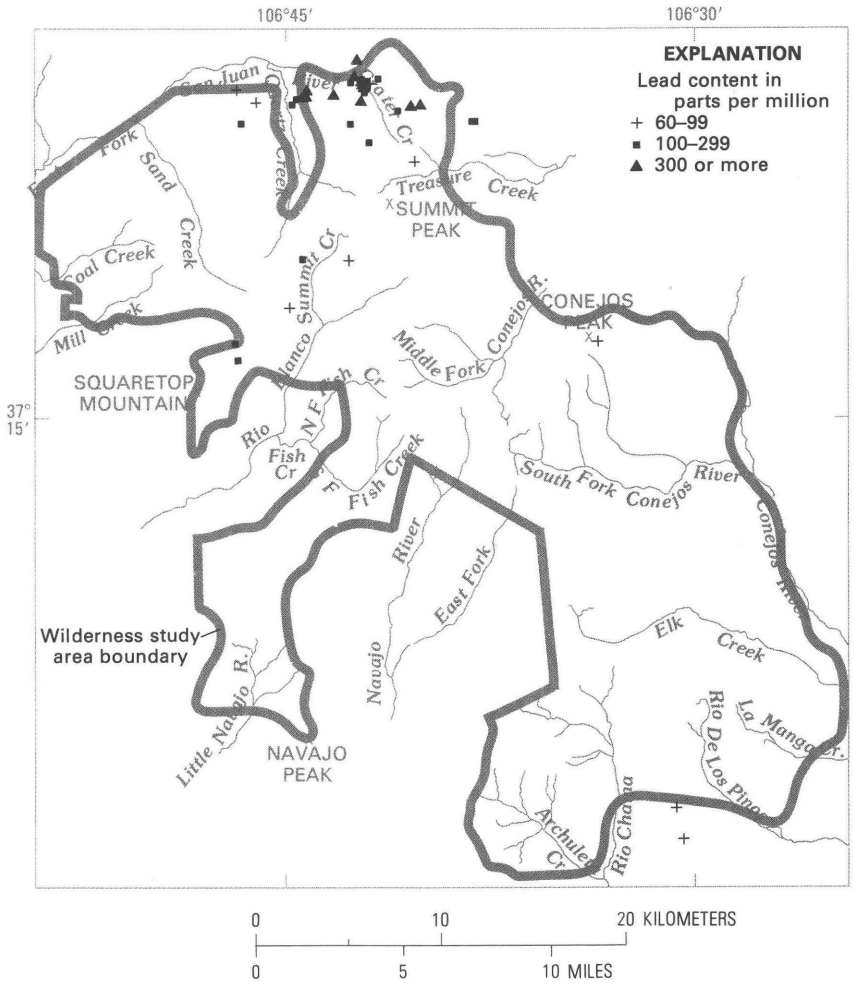


FIGURE 7.—Locations of rock samples containing 60 ppm or more lead.

study. Prior to their transmittal to the laboratory, 943 samples from throughout the area were scanned for anomalous radioactivity by using a hand-held scintillation (gamma-ray) counter. No anomalous radioactivity was detected. In addition, uranium and thorium were determined by the delayed-neutron (neutron activation) technique on 70 of the rock samples, including both fresh and altered rock, and 59 of the stream-sediment samples. The highest value of uranium, 8.99 ppm, from an unaltered sample of Summitville Andesite, is far below ore grade. Other altered and unaltered rocks contain between 0.81 and 7.59 ppm uranium.

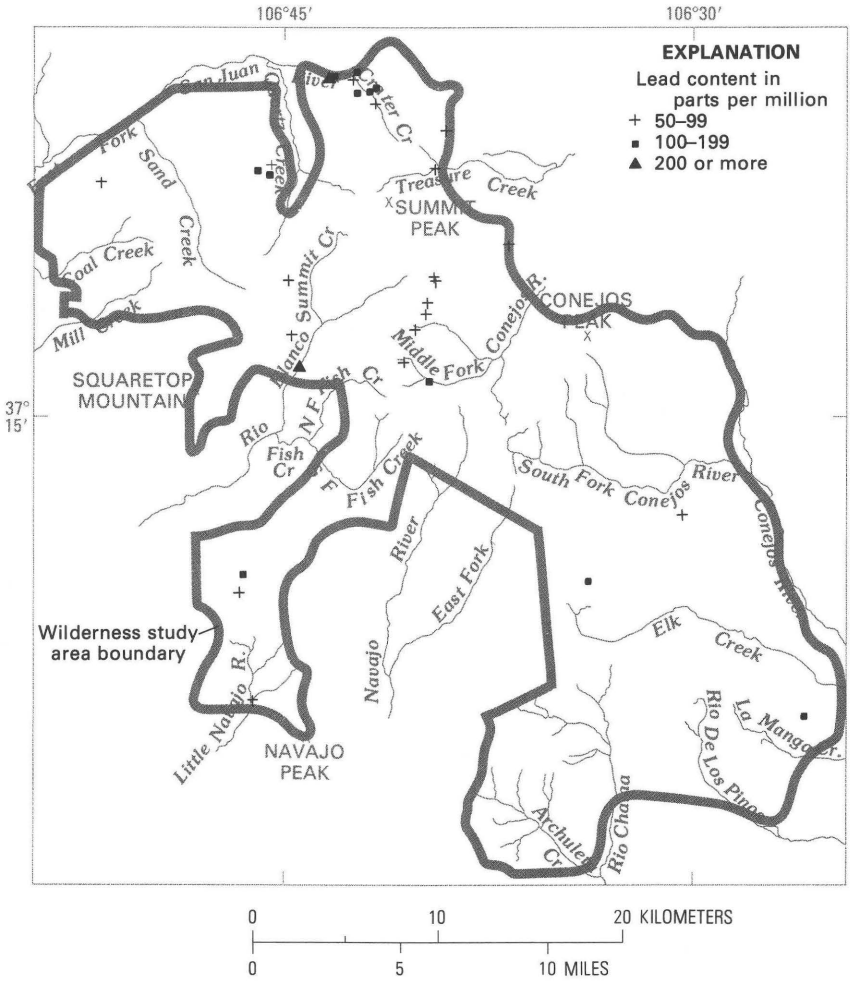


FIGURE 8.—Locations of stream-sediment samples containing 50 ppm or more lead.

Thorium values in the same rocks range between 2.29 and 30.99 ppm. The maximum and minimum uranium values in stream-sediment samples are 4.01 ppm and 0.79 ppm, respectively. Thorium in stream sediments ranged between 2.05 to 12.04 ppm. The uranium and thorium analyses are far too low to reflect deposits of potential value.

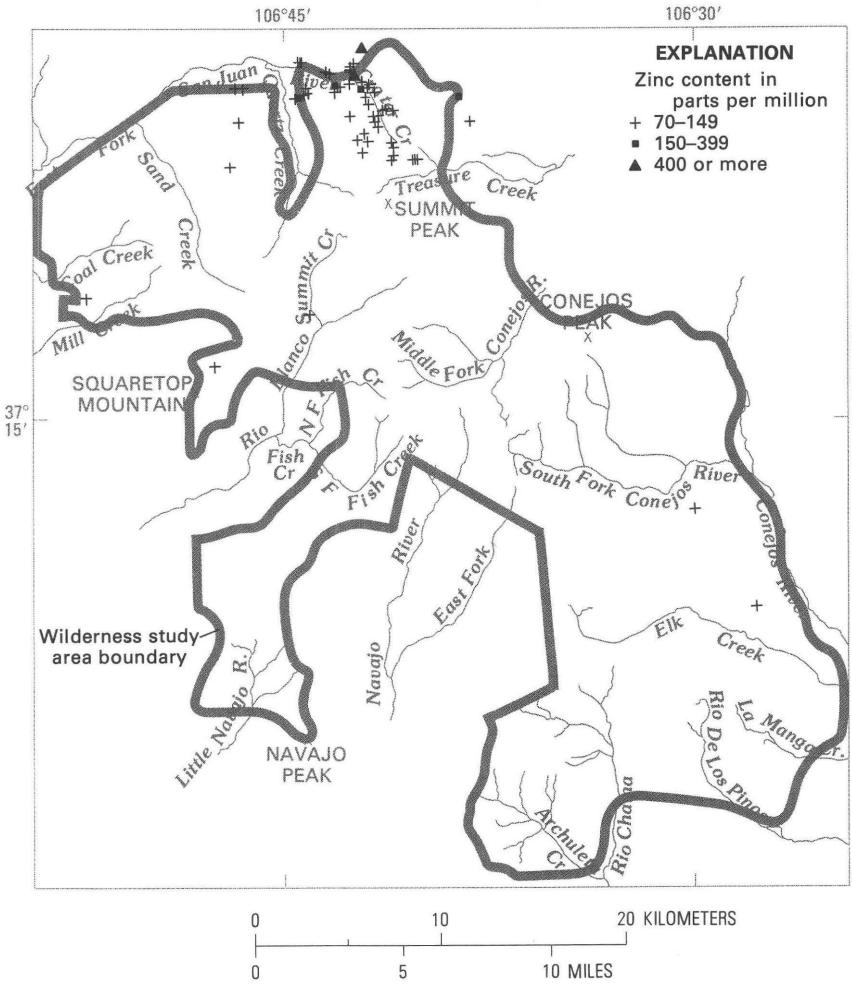


FIGURE 9.—Locations of rock samples containing 70 ppm or more zinc.

GEOCHEMICAL EVALUATION OF A POSTULATED PORPHYRY-COPPER DEPOSIT IN THE CRATER CREEK AREA

The possible presence of concealed mineral deposits in the Crater Creek area was assessed by comparing the exposed altered and mineralized rocks of the area with those in copper-molybdenum por-

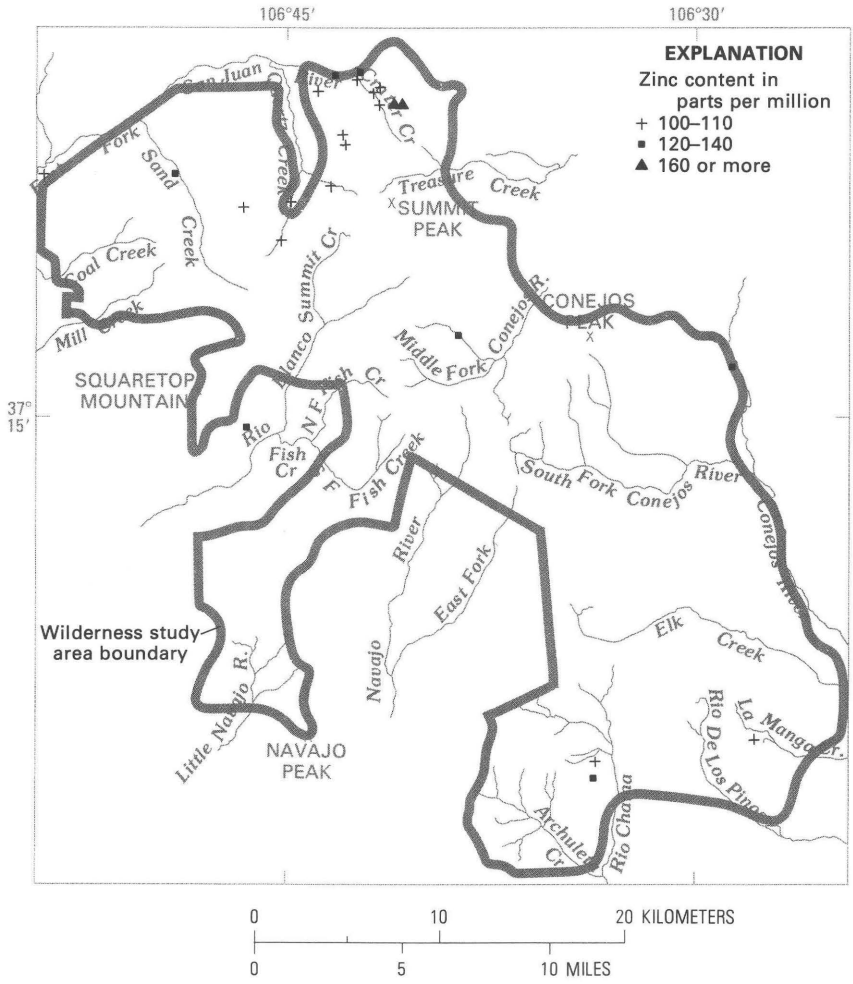


FIGURE 10.—Locations of stream-sediment samples containing 100 ppm or more zinc.

phyry models developed from better known mineralized areas in the western United States (Lowell and Guilbert, 1970; Wallace and others, 1968; Neuerbug and others, 1974). The results of this study indicate a porphyry copper or molybdenum deposit, or both, lies concealed beneath lower Crater Creek basin at a projected depth of about 1,500 m.

Outcrops were sampled at 202 localities (pl. 2) in and around conspicuously iron-stained rock within the hydrothermally altered areas (pl. 1) to determine patterns of alteration zoning and ore-element dispersion and the relation of these patterns to geology. The most

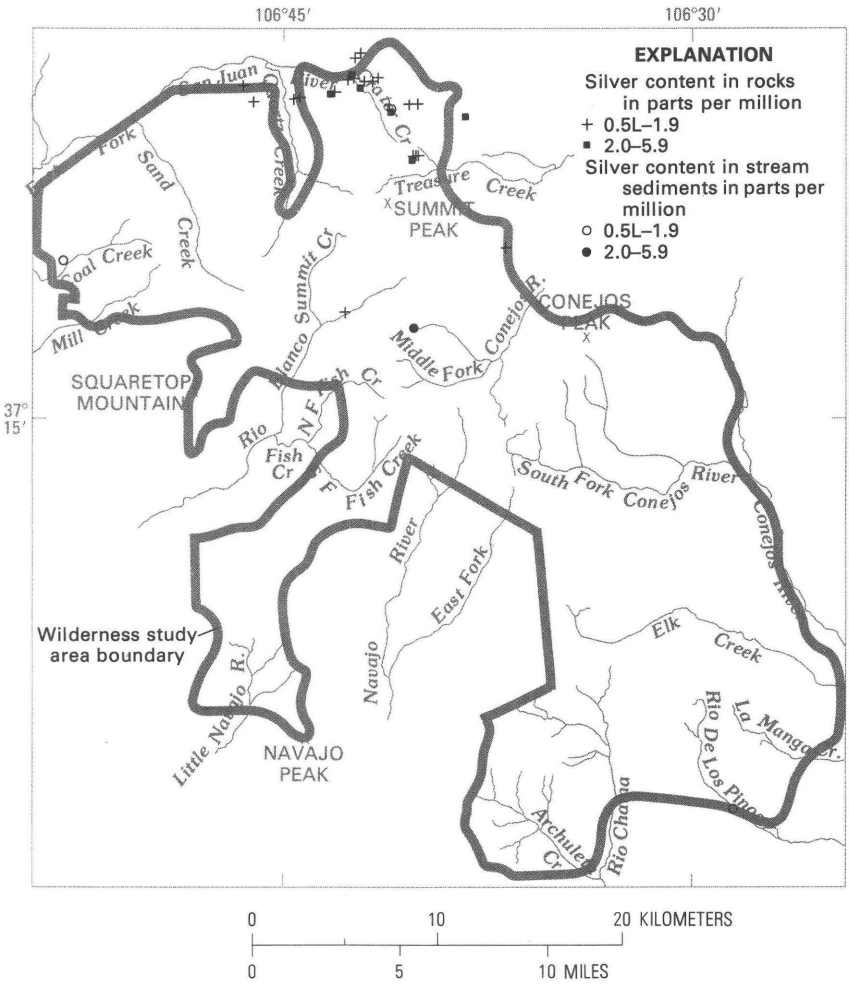


FIGURE 11.—Locations of samples containing detectable amounts of silver. L in analytical ranges indicates the metal was detected but in amounts too low to determine quantitatively.

highly altered rocks at each locality were sampled to determine the maximum degree of local metallization. Other less altered rocks were also sampled at many of the localities to further establish the relation of ore-element abundance to degree of alteration.

In the Crater Creek area, particular attention was given to the mineralized zones in the monzonite stocks and their internal zones of intrusive breccia (fig. 12), rocks particularly identified with porphyry-copper systems (Gilmour, 1977). The hydrothermal phase that marked the close of the intrusive activity in the Crater Creek area is

represented at the surface by propylitic and chloritized monzonite plutons and adjacent country rock, by disseminated pyrite, chalcopyrite, molybdenite, and pyrrhotite, and by a few thin veins. The exposed products are characteristic of mineralization above a large porphyry copper or molybdenum deposit. The serrate pattern of alteration shown in the north-central part of figure 12 suggests the presence at depth of a mineralized chimney that projects above the porphyry deposit along a zone of northwest-trending fractures. Such mineralized extensions are fairly common above porphyry deposits, and many contain silver-lead-zinc veins.

ALTERATION-MINERALIZATION ZONES

Altered rock is the most obvious expression of the porphyry-copper system and provides a framework to which most other characteristics can be related; altered rocks are concentrated along structural breaks, and their mineralogy varies systematically with distance from mineral deposits. The altered rocks can be usefully divided into zones, each defined by an assemblage of alteration minerals, chemical composition, textural characteristics, physical properties, or by some combination of these. Changes in alteration are sequential and primarily proportional to the temperature and chemistry of the hydrothermal fluid with which the rock has reacted. The fluids are channeled through permeable rocks and structures and the configuration of alteration zones delineates these conduits.

Figure 13 is a schematic cross section modified from Lowell and Guilbert (1970, fig. 3a) depicting the concentric alteration zoning that enclosed the Kalamazoo segment of the faulted San Manuel-Kalamazoo porphyry-copper orebody in Arizona. Their generalized model has been found applicable in describing alteration halos enclosing porphyry-copper and molybdenum deposits in many parts of the world and is being widely used as an exploration guide to porphyry-type ores. The zones compare in a general way to the zoning sequence mapped in the Crater Creek area (fig. 12), where the innermost exposed zone is the upper part of the phyllitic zone. A potassic core is believed to be concealed below the Crater Creek area. The generalized descriptions of the zones that follow include Lowell and Guilbert's dipicted sequence plus additional ones recognized in the Crater Creek area.

PYROGENIC ZONE

This is the innermost zone in which the hydrothermal fluid separated from magma; it is characterized by primary igneous minerals and by very small amounts of ore elements and minerals.

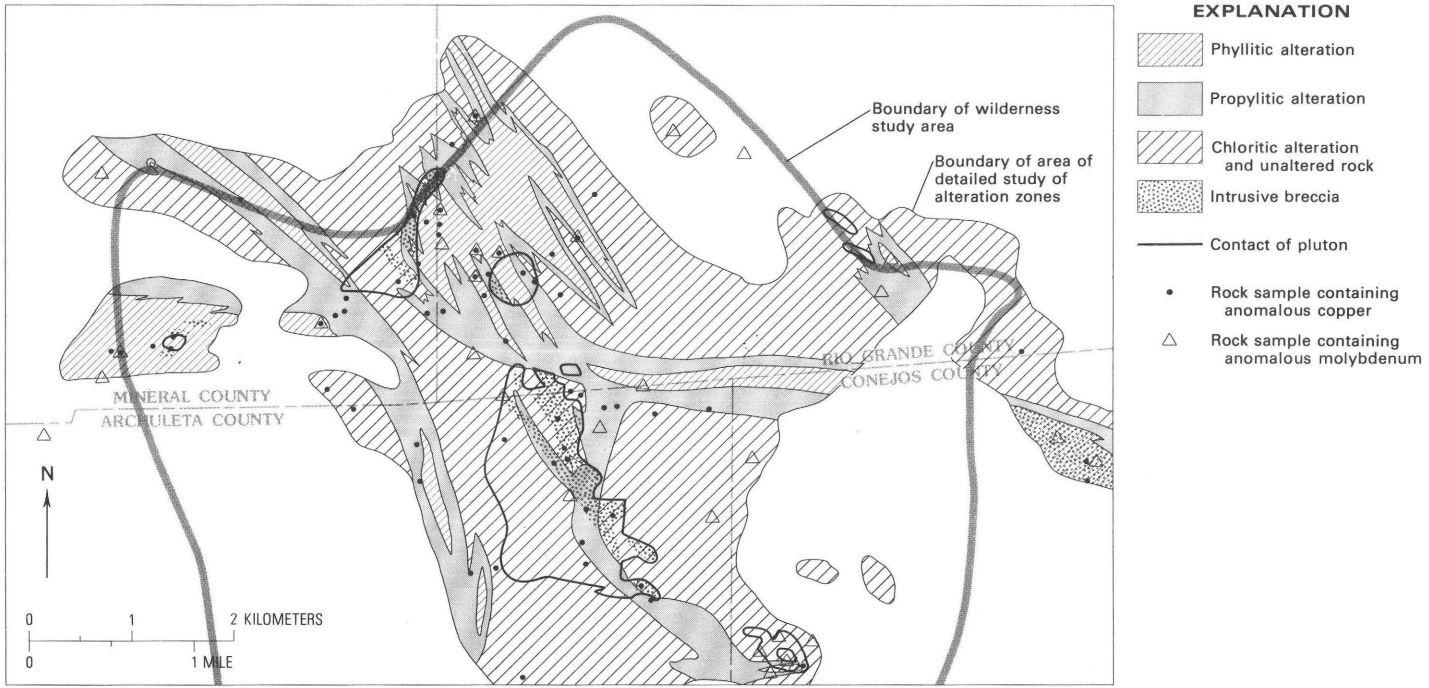


FIGURE 12.—Distribution of rock samples having anomalous copper and molybdenum values in relation to alteration zones and plutons in the Crater Creek area.

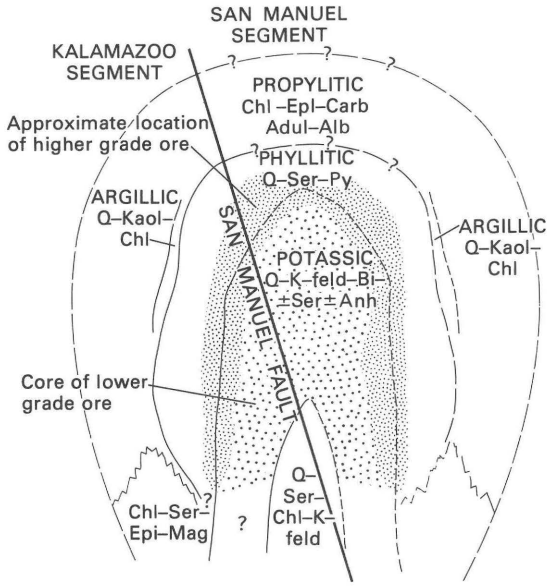


FIGURE 13.—Schematic cross section of the concentric zoning associated with the Kalamazoo segment of the San Manuel-Kalamazoo ore deposit, Arizona (modified from Lowell and Guilbert, 1970, fig. 3). Adul, adularia; Alb, albite; Anh, anhydrite; Bi, biotite; Carb, carbonate; Chl, chlorite; Epi, epidote; Kaol, kaolin; K-feld, potassium feldspar; Mag, magnetite; Py, pyrite; Q, quartz; Ser, sericite.

The hydrothermal fluid removed most of the ore elements and some potassium from the magma. This zone does not crop out in the study area and is not depicted in fig. 13, but it is believed to lie beneath and within the lower part of the postulated orebody.

POTASSIC ZONE

This zone is a principal site for ore in large classical porphyry-copper deposits. A stockwork of shrinkage cracks formed in this zone during cooling of the underlying magma, causing increased rock permeability. Alteration is characterized by addition of potassium and removal of calcium and sodium. Biotite and potassium feldspar are the principal alteration minerals, although muscovite and quartz commonly line the fractures. Chalcopyrite and molybdenite occur in the extensive stockwork fractures and form disseminated grains in rock adjacent to the fractures. No rocks of the potassic zone are exposed in the Crater Creek area.

PHYLLITIC ZONE

This is the zone of maximum exchange between rock and fluid. Cations are extensively leached from the rock in exchange for water and sulfur, producing a pyritic quartz-sericite rock in which feldspar is largely destroyed. Some ore minerals occur in the innermost limits of the phyllitic zone. Phyllitic-altered cores of major conduits that extend upward from the phyllitic zone of alteration also contain ore minerals. These conduits are in the form of extensively altered fracture zones and breccia pipes and, in part, are referred to as chimney deposits. Deposits of this type are exposed in the area of Crater Creek along with parts of the phyllitic zone.

SILICIC ZONE

Quartz veining and replacement is irregularly superimposed on the phyllitic and potassic zones. Except for a few quartz-bearing veins and silicified fracture zones, quartz is not an important mineral of the alteration halo exposed in the Crater Creek area. The principal silicic zone is believed to lie below the surface.

PROPYLITIC ZONE

This is a zone of net addition of ingredients to the rock and the principal site of veins containing pyrite, argentiferous galena, and sphalerite. Albite, calcite, chlorite, and epidote are the main alteration minerals, all derived from the breakdown of plagioclase and ferromagnesian minerals. Permeability was reduced, restricting subsequent fluids to the fracture openings where sulfide minerals were deposited in veins in the outer reaches of the propylitic zone. Figure 12 shows that most of the exposed phyllitic zones are clad by propylitic rock. Several other wider propylitic zones parallel northwest-trending zones of joint and faulting in the Crater Creek and adjoining areas.

CHLORITIC ZONE

This is the outermost zone of visibly recognizable hydrothermal alteration. Common alteration minerals are chlorites, carbonates, celadonite, montmorillonitic clays, silica minerals, and zeolites, partly replacing rock minerals and partly lining fractures and other rock cavities. Pyrite and traces of ore elements and minerals were sporadically added here and in otherwise unaltered rocks beyond this zone. Vein deposits continue into and through this zone, but are uncommon and widely separated; metal-enriched fracture coatings are the final expression of mineralization beyond the chloritic zone.

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Oil and Gas Potential of the Chama–Southern San Juan Mountains Wilderness Study Area, Colorado

By ROBERT T. RYDER, U.S. GEOLOGICAL SURVEY

MINERAL RESOURCES OF THE CHAMA–SOUTHERN SAN JUAN MOUNTAINS WILDERNESS STUDY AREA, MINERAL, RIO GRANDE, ARCHULETA, AND CONEJOS COUNTIES, COLORADO

GEOLOGICAL SURVEY BULLETIN 1524–D

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MINERAL RESOURCES OF THE CHAMA-SOUTHERN SAN JUAN MOUNTAINS WILDERNESS STUDY AREA MINERAL, RIO GRANDE, ARCHULETA, AND CONEJOS COUNTIES, COLORADO

OIL AND GAS POTENTIAL OF THE CHAMA-SOUTHERN SAN JUAN MOUNTAINS WILDERNESS STUDY AREA, COLORADO

By ROBERT T. RYDER, U.S. Geological Survey

INTRODUCTION

The Chama-southern San Juan Mountains wilderness study area is approximately 50 mi (mile) northeast of major oil and gas fields in the San Juan Basin in New Mexico and Colorado (fig. 14). Although oil and gas production is sparse in southwest Colorado, there are two small oil fields in Archuleta County adjacent to the wilderness study area. The largest of these is the Gramps oil field in the Navajo River valley 3 mi southeast of Navajo Peak and 3.5 mi southwest of Banded Peak (pl. 2). The smaller is the Chromo oil field near Chromo, Colo., approximately 7 mi southwest of Navajo Peak (pl. 2). The proximity of these oil fields to the wilderness study area prompted this investigation of the oil and gas potential.

The purpose of the study is threefold: (1) Characterize the types of oil and gas accumulations that may occur within the wilderness study area, (2) locate the areas having the greatest potential, and (3) estimate the likelihood of future oil and gas discoveries. Because the wilderness study area is covered by volcanic strata and has not been tested by drilling, the oil and gas evaluation relied largely on outcrop and subsurface data collected from outside the wilderness study area. The total area of approximately 625 mi^2 (square miles) from which information was gathered in support of the oil and gas evaluation of the Chama-southern San Juan Mountains wilderness study area, is hereafter referred to as the oil and gas study area (fig. 14).

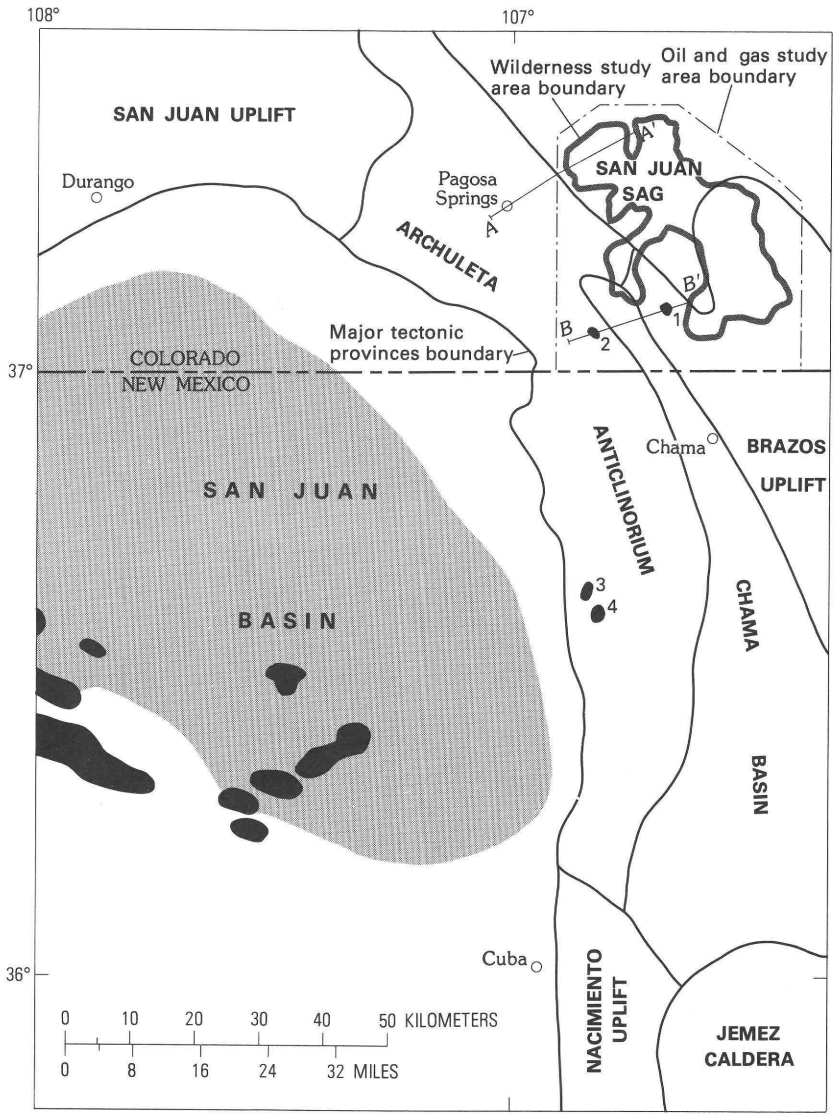


FIGURE 14.—Index map showing the oil and gas study area, the wilderness study area, major tectonic provinces, and major oil and gas fields. Oil fields are shown in black: 1, Gramps field; 2, Chromo field; 3, Boulder field; 4, Puerto Chiquito field. Dakota-Basin gas field is stippled. Lines *A-A'* and *B-B'* locate the restored stratigraphic sections in figs. 15 and 16, respectively.

HISTORY OF OIL AND GAS EXPLORATION

A total of 174 drill holes and wells were drilled in the oil and gas study area between 1925 and 1975. The locations of the drill holes and wells are plotted on plate 2, and data about them are in table 7.

Approximately 70 percent of the drill holes and wells are located away from known production, and the remaining 30 percent are development wells in the Gramps and Chromo oil fields. Most were located on well-defined or suspected anticlinal structures. Prior to the discovery of the Gramps oil field on December 3, 1935, only 17 drill holes and wells had been drilled in the oil and gas study area, but between then and the Chromo discovery in February 1947, the number had increased by 52. The drilling activity continued to increase, so that between March 1947 and December 1959 an additional 87 wildcat and production drill holes and wells were drilled. Between January 1960 and December 1969, however, only 10 drill holes and wells were drilled. During the next 5 years (1970-75) there was a slight upswing in exploration activity, which resulted in the drilling of eight drill holes and wells. Most of the current drilling activity is in the vicinity of the Gramps oil field. Nearly half of the drill holes and wells in the oil and gas study area either yielded commercial quantities of oil and gas or had good hydrocarbon shows.

The majority of the 174 drill holes and wells are less than 750 m deep and test only Cretaceous strata or the uppermost Morrison Formation. Nine drill holes and wells were drilled into or bottomed near the top of the Precambrian basement. Assuming that one wildcat drill hole or well evaluates 1 mi^2, less than 5 percent of the oil and gas study area has been explored to the base of the Cretaceous System, and less than 1 percent has been tested between the uppermost Jurassic strata and the Precambrian basement. Seismic data have not been collected in the oil and gas study area, and drilling has not been done within the wilderness study area.

STRATIGRAPHIC FRAMEWORK AND POTENTIAL RESERVOIR UNITS

Sedimentary rocks in the oil and gas study area range in age from Late Jurassic to Eocene and, for purposes of discussion, they are here grouped into three major units. The lower unit consists primarily of Upper Jurassic strata as much as 1,000 ft (feet) thick that rest unconformably on Precambrian igneous and metamorphic rocks. In ascending order, the lower unit consists of the Entrada Sandstone, Todilto Limestone, and Morrison Formation. The middle unit, at most about 5,250 ft thick, rests unconformably upon the lower unit and consists of Upper Cretaceous rocks formally assigned, in ascending order, to the Dakota Sandstone, Mancos Shale, Mesaverde Group, Lewis Shale, Pictured Cliffs Sandstone, and Fruitland Formation. Unconformably overlying the middle unit is the upper unit, which ranges from 100 to 1,000 ft thick and which is assigned to the Animas (uppermost Cretaceous and Paleocene) and Blanco Basin (Eocene) Formations. The entire sedimentary section is overlain unconformably

TABLE 7.—*Well and drill hole data for the Chama-southern San Juan Mountains wilderness study area*

[Wells shown on pl. 2. N/SL, north of south line; S/NL, south of north line; E/WL, east of west line; W/EL, west of east line; C/NL, center of north line; C/SL, center of south line; C/EL, center of east line. API, American Petroleum Institute; BOPD, barrels of oil per day; BW, barrels of water; D&A, dry and abandoned; DST, drill stem test; FWTR, freshwater; HO&GCM, highly oil- and gas-cut mud; HSMCO, heavy, slightly mud-cut oil; IPF, initial production flow; IPP, initial potential pump; MCFD, thousand cubic feet of gas per day; NA, not applicable; SMCFWTR, slightly mud-cut freshwater; SUS, suspended; TA, temporarily abandoned]

Reference No.	Location	Sec.	T.	R.	Name	Total depth (ft)	Formation at total depth	Status	Hydrocarbon shows	Depth of shows (ft)	Year Spudded 19__	Miscellaneous data
1	NW 1/4 SE 1/4 NE 1/4	5	36 N.	2 E.	Benson-Montin-Greer No. 1 Quartz Creek	2,044	Igneous rock	D&A	None	NA	70	Core 2,038-2,044 ft.
2	SW 1/4 NW 1/4	4	36 N.	2 E.	Harvey Francis No. 1 Government	1,221	--do----------	D&A	--do---	NA	53	Core 1,207-1,221 ft.
3	C/SW 1/4 NW 1/4	9	36 N.	2 E.	Harvey F. Bell No. 2 Quartz Creek	906	--do----------	D&A	--do---	NA	54	None.
4	SE 1/4 SE 1/4	14	36 N.	1 W.	Locke-Taylor No. 1 O'Bannon	4,049	Mancos Shale	D&A	--do---	NA	51	None.
5	NW 1/4 NW 1/4 SE 1/4	6	34 N.	2 E.	Holmes, Wm. No. 1 Stevens	3,032	Unknown	TA	--do---	NA	47	None.
6	NW 1/4 SE 1/4	6	34 N.	2 E.	Bert Smith No. 2	220	Igneous rock	D&A	Oil	Unknown	Unknown	None.
7	C/NE 1/4 SE 1/4	7	34 N.	2 E.	Yeakley Oil No. 1 Shahan	2,576	Mancos Shale	D&A	None	NA	47	None.
8	SW 1/4 SE 1/4 NW 1/4	12	34 N.	1 W.	Turner No. 1 Tinker Flough	1,470	Dakota Sandstone	D&A	--do---	NA	54	None.
9	NW 1/4 NW 1/4 NW 1/4	13	34 N.	1 W.	Barron No. 1 Tinker	1,099	--do----------	TA	--do---	NA	58	None.
10	NE 1/4 NW 1/4	26	34 N.	1 W.	Owen B.B. No. 1 Pagosa Springs	1,362	Unknown	D&A	--do---	NA	28	None.
11	C/SW 1/4 SW 1/4	26	34 N.	1 W.	Benson-Montin-Greer No. 1 Newton	1,608	Morrison Formation	D&A	Oil	719-728 1,139-1,221	58	None.
12	SW 1/4 SE 1/4 SW 1/4	8	33 N.	1 E.	Bigbee Bros. No. 1 Bigbee	1,631	Mancos Shale	D&A	Gas	1,276-1,293 1,565-1,581	52	None. None.
13	NE 1/4 SW 1/4 NW 1/4	17	33 N.	1 E.	Florence and others No. 1 Federal	2,501	Dakota Sandstone	D&A	None	NA	47	Sulfur water at 2,431-2,510 ft.
14	SW 1/4 SW 1/4 NE 1/4	18	33 N.	1 E.	Gled Oil No. 1 Davis	2,274	Unknown	D&A	--do---	NA	44	None.
15	SW 1/4 SE 1/4 NE 1/4	17	33 N.	1 E.	Bigbee Bros. No. 1 Bigbee	1,624	Dakota Sandstone	D&A	--do---	NA	47	None.
16	SE 1/4 NW 1/4 SE 1/4	18	33 N.	1 E.	Boone Development No. 1 Newton	1,211	Mancos Shale	D&A	--do---	NA	38	None.
17	NE 1/4 NW 1/4	19	33 N.	1 E.	Clark, E. B., Sr. No. 1 Boone Creek Government	2,382	Dakota Sandstone	D&A	--do---	NA	67	DST 2,362-2,385 ft, record. 1,421 ft FWTR.
18	SE 1/4 SE 1/4 SE 1/4	26	33 N.	1 W.	Southern Colorado Exploration Company No. 1 Coyote-Government	1,457	Unknown	SUS	--do---	NA	69	None.
19	SE 1/4 SW 1/4 SE 1/4	28	33 N.	1 E.	Wheeler No. 3 Sims	450	--do----------	D&A	--do---	NA	50	None.
20	SW 1/4 SE 1/4 SE 1/4	28	33 N.	1 E.	Wheeler No. 8 Sims	909	Dakota Sandstone	TA	Oil	705	54	None.

Reference No.	Location	Sec.	T.	R.	Name	Total depth (ft)	Formation at total depth	Status	Hydrocarbon shows	Depth of shows (ft)	Year Spudded 19__	Miscellaneous data
21	C	28	33 N.	1 E.	Wheeler No. 1 Government	1,266	Morrison Formation	D&A	None	NA	51	None.
22	C/SE 1/4 NW 1/4	27	33 N.	1 E.	Sherwin and Cochran No. 1 Caulk	955	Unknown	D&A	--do---	NA	47	None.
23	SE 1/4 SE 1/4 SE 1/4	32	33 N.	1 E.	Stearns No. 1 Federal	1,565	Morrison Formation	D&A	--do---	NA	50	None.
24	NW 1/4 NW 1/4 NE 1/4	33	33 N.	1 E.	Wheeler No. 5 Sims	450	Mancos Shale	D&A	--do---	NA	52	None.
25	NW 1/4 NW 1/4 NE 1/4	33	33 N.	1 E.	Wheeler No. 2 Sims	699	--do----------	Oil	Oil	650-699	50	IPP-65BOPD.
26	NE 1/4 NW 1/4 NE 1/4	33	33 N.	1 E.	Wheeler No. 4 Sims	666	--do----------	Oil	Oil	614-666	52	IPP-12BOPD.
27	NE 1/4 NW 1/4 NE 1/4	33	33 N.	1 E.	Wheeler No. 1 Sims	669	--do----------	Oil	Oil	571-669	50	IPP-25BOPD.
28	NW 1/4 NE 1/4 NE 1/4	33	33 N.	1 E.	Teague No. 12 Fitzhugh	1,214	Morrison Formation	D&A	Oil	509	51	None.
29	SE 1/4 NW 1/4 NE 1/4	33	33 N.	1 E.	Oriental Refining No. 1 Sims	719	Mancos Shale	D&A	Oil	Unknown	48	None.
30	NE 1/4 SE 1/4 NE 1/4	33	33 N.	1 E.	Teague No. 13 Fitzhugh	889	--do----------	TA	None	NA	51	None.
31	C/SW 1/4 NE 1/4	33	33 N.	1 E.	Teague No. 16 Fitzhugh	791	Mancos Shale	D&A	--do---	NA	52	None.
32	NE 1/4 NW 1/4 SW 1/4	33	33 N.	1 E.	Teague and others No. 18 Fitzhugh	991	Dakota Sandstone	D&A	--do---	NA	54	None.
33	NE 1/4 NE 1/4 SW 1/4	33	33 N.	1 E.	Oriental Refining No. 3 Fitzhugh	591	Mancos Shale	Oil	Oil	568-591	48	IPP-5BOPD.
34	SW 1/4 NW 1/4 SE 1/4	33	33 N.	1 E.	Teague No. 3 Fitzhugh	607	--do----------	Oil	Oil	476-607	48	IPP-3BOPD.
35	SE 1/4 NW 1/4 SE 1/4	33	33 N.	1 E.	Teague No. 8 Fitzhugh	889	--do----------	Oil	Oil	692-889	49	IPP-6BOPD.
36	SE 1/4 NW 1/4 SE 1/4	33	33 N.	1 E.	Teague No. 6 Fitzhugh	659	--do----------	Oil	Oil	659	49	IPP-50BOPD.
37	SW 1/4 NE 1/4 SE 1/4	33	33 N.	1 E.	Oriental No. 2 Ewell	472	--do----------	Oil	Oil	469-472	47	IPP-15BOPD.
38	NE 1/4 SE 1/4	33	33 N.	1 E.	Teague No. 14 Fitzhugh	748	--do----------	Oil	Oil	551-728	51	IPP-25BOPD.
39	NE 1/4 SE 1/4	33	33 N.	1 E.	Oriental and Wheeler No. 5 Fitzhugh	679	--do----------	Oil	Oil	509-679	52	IPP-15BOPD.
40	SE 1/4 NE 1/4 SE 1/4	33	33 N.	1 E.	Oriental No. 2 Fitzhugh	561	--do----------	D&A	None	NA	48	None.
41	NE 1/4 SW 1/4 SW 1/4	33	33 N.	1 E.	Teague and others No. 1 Fitzhugh	1,201	Dakota Sandstone	D&A	None	NA	48	None.
42	NE 1/4 SE 1/4 SW 1/4	33	33 N.	1 E.	TW&H Drilling No. 2 Fitzhugh	1,211	--do----------	D&A	--do---	NA	48	None.
43	C/SE 1/4 SW 1/4	33	33 N.	1 E.	Oriental Refining No. 1	899	--do----------	D&A	Oil	Unknown	47	None.
44	C/SW 1/4 SE 1/4	33	33 N.	1 E.	Teague No. 4 Fitzhugh	597	Mancos Shale	Oil	Oil	509-597	48	IPP-15BOPD.
45	NE 1/4 SW 1/4 SE 1/4	33	33 N.	1 E.	Great Western No. 19 Fitzhugh	659	--do----------	Oil	Oil	466-499	57	IPP-38BOPD.
46	NE 1/4 SW 1/4 SE 1/4	33	33 N.	1 E.	Teague No. 17 Fitzhugh	659	--do----------	D&A	None	NA	52	None.
47	SW 1/4 SE 1/4	33	33 N.	1 E.	Teague No. 15 Fitzhugh	751	--do----------	Oil	Oil	699-751	51	IPP-50BOPD.
48	NW 1/4 SE 1/4 SE 1/4	33	33 N.	1 E.	Teague No. 7 Fitzhugh	689	--do----------	Oil	Oil	469-479	49	IPP-15BOPD.
49	C/SE 1/4 SE 1/4	33	33 N.	1 E.	Oriental No. 4 Fitzhugh	591	--do----------	Oil	Oil	581-591	48	IPP-3BOPD.
50	SW 1/4 SE 1/4 SE 1/4	33	33 N.	1 E.	Teague No. 5 Fitzhugh	827	--do----------	D&A	None	NA	48	None.

TABLE 7.—*Well and drill hole data for the Chama-southern San Juan Mountains wilderness study area*—Continued

Reference No.	Location	Sec.	T.	R.	Name	Total depth (ft)	Formation at total depth	Status	Hydrocarbon shows	Depth of shows (ft)	Year Spudded 19__	Miscellaneous data
51	NW 1/4 SW 1/4	34	33 N.	1 E.	Standard Oil of Colorado No. 1 Fitzhugh	617	Morrison Formation	Oil	Oil	299-322	29	IPP-10BOPD.
52	NE 1/4 NW 1/4 SW 1/4	34	33 N.	1 E.	Fitzhugh and Teague No. 1 Teague	1,109	--do----------	D&A	Oil	965-984	57	None.
53	SW 1/4 SE 1/4 NW 1/4	34	33 N.	1 E.	Standard Oil of Colorado No. 1 Wirt	Unknown	Unknown	D&A	None	NA	30	None.
54	SW 1/4 SW 1/4 NE 1/4	34	33 N.	1 E.	Sherwin and Jenkins No. 1 Gardner	1,401	Morrison Formation	TA	--do---	NA	48	None.
55	NE 1/4 SE 1/4 NE 1/4	34	33 N.	1 E.	Great Western Drilling No. 1 Gardner	1,266	Mancos Shale	D&A	Gas	Unknown	58	None.
56	NW 1/4 NE 1/4 SW 1/4	34	33 N.	1 E.	Outwest Investment No. 2 Fitzhugh	85	--do----------	D&A	Unknown	--do---	30	None.
57	SW 1/4 NE 1/4 SW 1/4	34	33 N.	1 E.	Wheeler No. 6 Sims	325	--do----------	TA	--do---	--do---	Unknown	None.
58	NW 1/4 NE 1/4 SE 1/4	34	33 N.	1 E.	Great Western Drilling No. 1 Sims A	1,719	Entrada Sandstone	TA	None	NA	58	Core 1,266-1,316 ft, DST 1,109-1,142 ft, record 2 mud 6.6 ft.
59	SW 1/4 NE 1/4	36	33 N.	1 E.	Big Horn Powder River No. 1-A Federal	3,153	Dakota Sandstone	D&A	Oil	3,058-3,071 3,084	65	Cores 3,058-3,097 ft, 3,130-3,156 ft, DST 3,084-3,156 ft, record 1,136 ft SMCFWTR.
60	NE 1/4 NE 1/4 NW 1/4	4	32 N.	1 E.	Ewell and others No. 1 Shahan	751	Unknown	TA	None	NA	50	None.
61	NW 1/4 NW 1/4 NE 1/4	4	32 N.	1 E.	Ewell No. 1 Shahan	515	Mancos Shale	Oil	Oil	Unknown	51	None.
62	SE 1/4 NE 1/4 NW 1/4	4	32 N.	1 E.	Teague No. 2 Shahan	1,014	Dakota Sandstone	D&A	None	NA	47	None.
63	NW 1/4 NW 1/4 NE 1/4	4	32 N.	1 E.	Great Western #9	509	Mancos Shale	D&A	--do---	NA	30	None.
64	NE 1/4 NW 1/4 NE 1/4	4	32 N.	1 E.	Teague and others No. 10 Fitzhugh	1,175	--do----------	D&A	--do---	NA	50	None.
65	C/NW 1/4 NE 1/4	4	32 N.	1 E.	Great Western No. 20 Fitzhugh	600	--do----------	Oil	Oil	469-472	57	IPP-42BOPD.
66	C/NE 1/4 NE 1/4	4	32 N.	1 E.	Florence and Teague No. 1 Fitzhugh	472	--do----------	Oil	Oil	459-472	47	IPP-250BOPD.
67	NW 1/4 SW 1/4 NW 1/4	4	32 N.	1 E.	Shula and Stone No. 6 Ewell	558	Dakota Sandstone	Oil	Oil	171-558	50	IPP 1/2 BOPD.
68	NE 1/4 SE 1/4 NW 1/4	4	32 N.	1 E.	Florence and Teague No. 1 Shahan	141	Mancos Shale	D&A	None	NA	47	None.
69	NW 1/4 SW 1/4 NE 1/4	4	32 N.	1 E.	Oriental No. 1 Ewell	892	Dakota Sandstone	D&A	--do---	NA	47	None.
70	NE 1/4 SW 1/4 NE 1/4	4	32 N.	1 E.	Stearns No. 2 Bramwell	810	--do----------	D&A	--do---	NA	51	None.
71	SW 1/4 SW 1/4 NE 1/4	4	32 N.	1 E.	Ewell and others No. 2 Shahan	564	--do----------	D&A	--do---	NA	50	None.
72	SE 1/4 SE 1/4 NE 1/4	4	32 N.	1 E.	Stone and Shula No. 2 Uhl	420	Mancos Shale	D&A	Gas	Unknown	49	None.
73	SE 1/4 SE 1/4 NE 1/4	4	32 N.	1 E.	Shula and Stone No. 3 Ewell	420	--do----------	D&A	Oil	154-161	50	None.
74	SW 1/4	4	32 N.	1 E.	Stearns No. 1 Bramwell	732	Unknown	D&A	None	NA	51	None.
75	C/NW 1/4 SE 1/4	4	32 N.	1 E.	Uhl No. 1 Shahan	361	--do----------	D&A	--do---	NA	48	None.

Reference No.	Location	Sec.	T.	R.	Name	Total depth (ft)	Formation at total depth	Status	Hydrocarbon shows	Depth of shows (ft)	Year Spudded 19__	Miscellaneous data
76	SW 1/4 NE 1/4 SE 1/4	4	32 N.	1 E.	Hefner and Christensen No. 2	715	Unknown	D&A	None	NA	50	None.
77	NW 1/4 NW 1/4 SE 1/4	2	32 N.	1 E.	Kendrick No. 1 Crowley	1,168	Morrison Formation	D&A	--do---	NA	35	None.
78	NW 1/4 NE 1/4 NW 1/4	9	32 N.	1 E.	Great Western Drilling No. 1 Bramwell	705	Mancos Shale	TA	Oil	Unknown	58	None.
79	C/SW 1/4 NW 1/4	9	32 N.	1 E.	Cameron Drilling No. 1 Bramwell	2,477	Precambrian rocks.	D&A	Oil and gas	899-942	57	DST 899-942 ft, record 59.1 ft, HSMCO, 89 ft, HO and GCM.
80	NE 1/4 SE 1/4 SE 1/4	9	32 N.	1 E.	Great Western Drilling No. 1 Shahan	853	Mancos Shale	D&A	None	NA	58	None.
81	2,970 ft S/ML; 330 ft F/WL	11	32 N.	1 E.	Butler No. 3 Crowley	299	Unknown	TA	None	NA	52	None.
82	NE 1/4 SW 1/4 SW 1/4	11	32 N.	1 E.	Navajo Oil No. 1 Crowley	390	Dakota Sandstone	D&A	--do---	NA	25	None.
83	SW 1/4 SW 1/4 NE 1/4	11	32 N.	1 E.	Navajo Oil No. 1 Crowley	1,139	Morrison Formation	D&A	Oil	Unknown	34	None.
84	C/SL	11	32 N.	1 E.	Oil City Petroleum No. 4 Crowley	512	Dakota Sandstone	D&A	Oil	--do---	33	None.
85	SW 1/4	12	32 N.	1 E.	Owen No. 1 Crowley	1,624	Precambrian quartzite.	D&A	None	NA	43	None.
86	NE 1/4 SE 1/4 NE 1/4	7	32 N.	2 E.	Yeakley No. 1 Shahan	2,346	Dakota Sandstone	Oil	Oil	2,326-2,346	48	18 BOPD.
87	NE 1/4 SE 1/4	7	32 N.	2 E.	Schmitz and Shaffer No. 1	2,654	Mancos Shale	TA	None	NA	63	None.
88	NW 1/4 SW 1/4	8	32 N.	2 E.	Butler No. 1 Crowley	4,111	Todilto Limestone	TA	--do---	NA	51	None.
89	C/NE 1/4 NW 1/4	14	32 N.	1 W.	Kimbell No. 1 Griego	2,825	Morrison Formation	D&A	Oil	1,765-1,775	58	None.
90	NE 1/4 NW 1/4	14	32 N.	1 W.	Kimbell and Western No. 1 Griego-A	2,241	Mancos Shale	D&A	Oil	1,732	59	None.
91	SE 1/4 NE 1/4 NE 1/4	14	32 N.	1 E.	Oil City Petroleum No. 7	600	Dakota Sandstone	D&A	None	NA	33	None.
92	SE 1/4 NE 1/4 NE 1/4	14	32 N.	1 E.	Oil City Petroleum No. 4 Crowley	600	--do----------	D&A	Oil	Unknown	34	None.
93	SE 1/4 NW 1/4 NW 1/4	13	32 N.	1 E.	Oil City Petroleum No. 6 Crowley	233	--do----------	D&A	None	NA	34	None.
94	NE 1/4 NE 1/4	18	32 N.	2 E.	Schmitz and others No. 2 Crowley	1,690	--do----------	D&A	--do---	NA	63	None.
95	NW 1/4 NE 1/4 SW 1/4	17	32 N.	2 E.	Butler and others No. 5 Crowley	1,595	Unknown	D&A	--do---	NA	33	None.
96	SE 1/4 NE 1/4	16	32 N.	2 E.	Osterhoudt No. 1 Ant Hills	1,729	--do----------	TA	--do---	NA	Unknown	None.
97	SW 1/4 NW 1/4	15	32 N.	2 E.	Osterhoudt No. 2 Ant Hills	702	--do----------	TA	--do---	NA	--do---	None.
98	SE 1/4 NE 1/4	19	32 N.	2 E.	Butler No. 2 Crowley	1,739	Entrada Sandstone	D&A	Gas	Unknown	51	None.
99	C	1	33 N.	2 E.	Hughes Brothers No. 50 Hughes	4,426	Dakota Sandstone	D&A	None	NA	62	None.
100		12	33 N.	2 E.	Prospect Oil Syndicate No. 1 Garnett	171	Unknown	D&A	--do---	NA	30	None.

TABLE 7.—*Well and drill hole data for the Chama-southern San Juan Mountains wilderness study area*—Continued

Reference No.	Location	Sec.	T.	R.	Name	Total depth (ft)	Formation at total depth	Status	Hydrocarbon shows	Depth of shows (ft)	Year Spudded 19__	Miscellaneous data
101	C/SW 1/4 NE 1/4	14	33 N.	2 E.	Byrd-Frost Incorporated No. 1 Taylor	2,891	Dakota Sandstone	D&A	Oil Gas	2,720 1,499	46	None.
102	SE 1/4 SW 1/4 NW 1/4	13	33 N.	2 E.	Hughes No. 14 Gramps	2,549	--do----------	D&A	None	NA	37	None.
103	NW 1/4 SW 1/4 NE 1/4	13	33 N.	2 E.	Prospect Oil Syndicate No. 2 Garnett	1,536	Unknown	D&A	--do---	NA	37	None.
104	3,599 ft N/SL; 1,463 ft W/EL	23	33 N.	2 E.	WE No. 3	2,202	Dakota Sandstone	D&A	--do---	NA	75	None.
105	4,128 ft N/SL; 521 ft E/WL	24	33 N.	2 E.	WE No. 2	1,299	--do----------	D&A	Oil	Unknown	75	None.
106	NE 1/4 NW 1/4 NW 1/4	24	33 N.	2 E.	Hughes Brothers No. 49	2,195	Morrison Formation	D&A	Oil	1,184	61	Tested 15 BOPD for three days.
107	5,090 ft N/SL; 811 ft E/WL	24	33 N.	2 E.	Hughes Brothers No. 49-A	1,463	Mancos Shale	D&A	Unknown	Unknown	Unknown	None.
108	SE 1/4 NE 1/4 NW 1/4	24	33 N.	2 E.	Hughes No. 12 Gramps	801	Unknown	D&A	None	NA	36	None.
109	4,331 ft N/SL 2,091 ft E/WL	24	33 N.	2 E.	Hughes No. 12-27	Unknown	Dakota Sandstone	D&A	--do---	NA	Unknown	None.
110	SW 1/4 NW 1/4 NE 1/4	24	33 N.	2 E.	Hughes No. 26	1,929	Mancos Shale	D&A	--do---	NA	--do---	None.
111	NE 1/4 NE 1/4 NE 1/4	24	33 N.	2 E.	Hughes Brothers No. 9 Hughes	3,274	Dakota Sandstone	D&A	--do---	NA	60	None.
112	SW 1/4 SE 1/4 NW 1/4	24	33 N.	2 E.	Hughes Brothers No. 45	1,575	Morrison Formation	Oil	Oil	Unknown	59	None.
113	SE 1/4 SE 1/4 NW 1/4	24	33 N.	2 E.	Hughes No. 41	1,680	--do----------	D&A	None	NA	Unknown	None.
114	3,730 ft N/SL; 2,655 ft E/WL	24	33 N.	2 E.	Hughes No. 11 Gramps	899	Mancos Shale	D&A	--do---	NA	36	None.
115	3,360 ft N/SL; 2,730 ft E/WL	24	33 N.	2 E.	Hughes No. 40 Lafayette	1,260	Dakota Sandstone	TA	Oil	1,050-1,056	55	None.
116	3,036 ft N/SL; 2,797 ft E/WL	24	33 N.	2 E.	Hughes No. 19	1,260	Morrison Formation	Oil	Oil	Unknown	Unknown	None.
117	2,994 ft N/SL; 3,114 ft E/WL	24	33 N.	2 E.	Hughes No. 31	1,201	Dakota Sandstone	Oil	Oil	--do---	--do---	None.
118	C/SW 1/4 NE 1/4	24	33 N.	2 E.	Hughes No. 29	1,404	Morrison Formation	Oil	Oil	--do---	--do---	None.
119	NE 1/4 SW 1/4 NE 1/4	24	33 N.	2 E.	Hughes No. 28	2,021	--do----------	D&A	None	NA	--do---	None.
120	SE 1/4 SW 1/4 NE 1/4	24	33 N.	2 E.	Hughes No. 10 Gramps	1,440	--do----------	Oil	Oil	Unknown	36	None.
121	SE 1/4 SW 1/4 NE 1/4	24	33 N.	2 E.	Hughes No. 37	1,585	--do----------	Oil	Oil	--do---	Unknown	None.
122	2,812 ft N/SL; 3,760 ft E/WL	24	33 N.	2 E.	Hughes No. 25	1,490	--do----------	Oil	Oil	--do---	--do---	None.
123	2,590 ft N/SL; 3,805 ft E/WL	24	33 N.	2 E.	Hughes No. 34	Unknown	Dakota Sandstone	Oil	Oil	--do---	--do---	None.
124	3,617 ft N/SL; 4,713 ft E/WL	24	33 N.	2 E.	Hughes No. 8 Gramps	801	Mancos Shale	D&A	None	NA	36	None.
125	SW 1/4 SE 1/4 NE 1/4	24	33 N.	2 E.	Hughes No. 46 Hughes	1,785	Morrison Formation	D&A	--do---	NA	59	None.
126	2,862 ft N/SL; 4,187 ft E/WL	24	33 N.	2 E.	Hughes No. 38	3,206	Precambrian rocks.	Oil	Oil	Unknown	Unknown	None.
127	2,621 ft N/SL; 4,252 ft E/WL	24	33 N.	2 E.	Hughes No. 6 Gramps	1,335	Dakota Sandstone	Oil	Oil	--do---	36	None.
128	2,623 ft N/SL; 4,600 ft E/WL	24	33 N.	2 E.	Hughes No. 35	1,496	Morrison Formation	Oil	Oil	--do---	Unknown	None.
129	2,488 ft N/SL; 1,236 ft E/WL	24	33 N.	2 E.	Hughes No. 1 Gramps	1,404	Dakota Sandstone	D&A	None	NA	35	None.
130	2,336 ft N/SL; 2,767 ft E/WL	24	33 N.	2 E.	Hughes No. 20	1,175	--do----------	Oil	Oil	Unknown	Unknown	None.

Reference No.	Location	Sec.	T.	R.	Name	Total depth (ft)	Formation at total depth	Status	Hydrocarbon shows	Depth of shows (ft)	Year Spudded 19__	Miscellaneous data
131	2,471 ft N/SL; 3,117 ft E/WL	24	33 N.	2 E.	Hughes No. 33	2,247	Precambrian rocks.	Oil	Oil	Unknown	Unknown	None.
132	2,423 ft N/SL; 3,404 ft E/WL	24	33 N.	2 E.	Hughes No. 16	1,624	Morrison Formation	Oil	Oil	--do---	--do---	None.
133	NE 1/4 NW 1/4 SE 1/4	24	33 N.	2 E.	Hughes No. 51 Gramps	2,270	Precambrian rocks.	Oil	Oil	1,155-1,204 1,227-1,230	71	IPF-98OPD, 9BW.
134	2,266 ft N/SL; 3,845 ft E/WL	24	33 N.	2 E.	Hughes No. 13	1,303	Dakota Sandstone	Oil	Oil	Unknown	36	None.
135	2,294 ft N/SL; 4,205 ft E/WL	24	33 N.	2 E.	Hughes No. 39	1,545	Morrison Formation	Oil	Oil	--do---	Unknown	None.
136	NE 1/4 NE 1/4 SE 1/4	24	33 N.	2 E.	Hughes No. 43	1,942	--do----------	D&A	None	NA	--do---	None.
137	SW 1/4 NW 1/4 SE 1/4	24	33 N.	2 E.	Hughes Brothers No. 47 Hughes	1,959	Dakota Sandstone	Oil	Oil	1,093-1,096	59	IPP-19BOPD API gravity 30.9°.
138	1,657 ft N/SL; 3,861 ft E/WL	24	33 N.	2 E.	Hughes No. 5 Gramps	1,408	Morrison Formation	Oil	Oil	Unknown	36	None.
139	1,975 ft N/SL; 3,893 ft E/WL	24	33 N.	2 E.	Hughes No. 32	Unknown	Unknown	Oil	Oil	--do---	Unknown	None.
140	1,690 ft N/SL; 3,404 ft E/WL	24	33 N.	2 E.	Hughes No. 15	1,358	Morrison Formation	Oil	Oil	--do---	--do---	None.
141	1,908 ft N/SL; 4,432 ft E/WL	24	33 N.	2 E.	Hughes No. 17	1,440	--do----------	Oil	Oil	--do---	--do---	None.
142	1,442 ft N/SL; 4,455 ft E/WL	24	33 N.	2 E.	Hughes No. 18	Unknown	Unknown	Oil	Oil	--do---	--do---	None.
143	1,706 ft N/SL; 4,882 ft E/WL	24	33 N.	2 E.	Hughes No. 36	2,208	Entrada Sandstone	D&A	None	NA	--do---	None.
144	SW 1/4 NE 1/4 SE 1/4	24	33 N.	2 E.	Hughes No. 44 Gramps	1,539	Morrison Formation	D&A	--do---	NA	58	None.
145	1,221 ft N/SL; 4,050 ft E/WL	24	33 N.	2 E.	Hughes No. 22	1,214	--do----------	Oil	Oil	Unknown	Unknown	None.
146	873 ft N/SL; 3,745 ft E/WL	24	33 N.	2 E.	Hughes No. 21	1,119	Dakota Sandstone	Oil	Oil	Unknown	Unknown	None.
147	NW 1/4 SW 1/4 SE 1/4	24	33 N.	2 E.	Hughes Brothers No. 48 Hughes	1,153	--do----------	Oil	Oil	1,089-1,152	60	IPP-11BOPD.
148	508 ft N/SL; 3,961 ft E/WL	24	33 N.	2 E.	Hughes No. 24	1,132	--do----------	Oil	Oil	Unknown	Unknown	None.
149	805 ft N/SL; 435 ft W/EL	24	33 N.	2 E.	Hughes No. 7	1,253	--do----------	D&A	None	NA	36	None.
150	SW 1/4 SE 1/4 SW 1/4	24	33 N.	2 E.	Oil City Petroleum No. 2 Garnett	1,089	Unknown	D&A	--do---	NA	34	None.
151	250 ft N/SL; 3,570 ft E/WL	24	33 N.	2 E.	Hughes No. 3 Gramps	1,139	--do----------	Oil	Oil	Unknown	35	None.
152	142 ft N/SL; 4,232 ft E/WL	24	33 N.	2 E.	Hughes No. 2 Gramps	1,171	--do----------	Oil	Oil	--do---	35	None.
153	87 ft N/SL; 4,672 ft E/WL	24	33 N.	2 E.	Hughes No. 4 Gramps	1,473	--do----------	D&A	None	NA	36	None.
154	103 ft S/NL; 3,933 ft E/WL	25	33 N.	2 E.	Hughes No. 23	Unknown	--do----------	Oil	Oil	Unknown	Unknown	None.
155	371 ft S/NL; 4,353 ft E/WL	25	33 N.	2 E.	Hughes No. 30	1,161	Morrison Formation	D&A	None	NA	--do---	None.

TABLE 7.—*Well and drill hole data for the Chama-southern San Juan Mountains wilderness study area*—Continued

Reference No.	Location	Sec.	T.	R.	Name	Total depth (ft)	Formation at total depth	Status	Hydrocarbon shows	Depth of shows (ft)	Year Spudded 19__	Miscellaneous data
156	NW 1/4 NE 1/4 SW 1/4	25	33 N.	2 E.	Oil City Petroleum No. 1 Garnett	1,516	Dakota Sandstone	D&A	Oil, gas.	971, 1,139, 1,125	34	None.
157	1,500 ft N/S; 1,500 ft W/E	25	33 N.	2 E.	Hughes No. 42 Hughes	1,624	Morrison Formation	D&A	None	NA	56	None.
158	C/S 1/2 SE 1/4	34	33 N.	2 E.	Sharp and others No. 1 Walcott	249	Unknown	D&A	None	NA	36	None.
159	C/NL/SW 1/4	31	33 N.	3 E.	Hughes No. 2 Miller	3,091	Morrison Formation	D&A	Oil	Unknown	75	None.
160	C/EL/NW 1/4	31	33 N.	3 E.	Hughes No. 3 Miller	1,860	Mancos Shale	TA	None	NA	75	None.
161	SW 1/4 SW 1/4 SW 1/4	3	32 N.	2 E.	Oil City No. 1 Russell	463	Unknown	D&A	Gas	Unknown	33	None.
162	1,980 ft N/SL; 540 ft W/EL	3	32 N.	2 E.	Texaco No. 1 Osterman	2,264	Morrison Formation	D&A	None	NA	66	None.
163	NE 1/4 NE 1/4 NW 1/4	2	32 N.	2 E.	Navajo No. 1 Brooks	1,079	Unknown	D&A	--do---	NA	41	None.
164	C/NE 1/4	2	32 N.	2 E.	Outwest Investment No. 1 Crowley	249	--do----------	D&A	Gas	Unknown	30	None.
165	NE 1/4 NE 1/4	2	32 N.	2 E.	Cortez No. 1-A Crowley	2,149	--do----------	D&A	None	NA	36	None.
166	NE 1/4 NE 1/4 NE 1/4	2	32 N.	2 E.	Standard Oil of Colorado No. 1 Crowley	Unknown	Mesaverde Group	Gas	Gas	Unknown	30	750 MCFD.
167		2	32 N.	2 E.	Axelind Oil No. 1 Crowley	2,464	Unknown	D&A	None	NA	36	None.
168	C	6	32 N.	3 E.	Hughes No. 1 Miller	4,170	Precambrian rocks.	TA	Unknown	Unknown	73	None.
169		12	32 N.	2 E.	Axelind No. 1 East Chromo	2,471	Dakota Sandstone	D&A	None	NA	38	None.
[1]170	Lot 2	4	32 N.	1 E.	Langerak No. 1 Ewell	699	--do----------	D&A	--do---	NA	49	None.
[1]171	Lot 2	4	32 N.	1 E.	Langerak No. 2 Ewell	561	Mancos Shale	D&A	--do---	NA	49	None.
[1]172		34	33 N.	1 E.	Chromo No. 1 Fitzhugh	Unknown	Unknown	D&A	Unknown	Unknown	38	None.
[1]173		24	33 N.	2 E.	Oil City Petroleum No. 1 Reeder	1,184	Mancos Shale	D&A	None	NA	38	None.
[1]174	NE corner, Lot 3.	24	33 N.	2 E.	Oil City Petroleum No. 3 Garnett	1,089	Dakota Sandstone	Oil	Oil	Unknown	33	None.

[1]Not shown on plate 1 because precise locations not available.

by as much as 4,100 ft of Oligocene volcanic rocks. The lithology and interpreted depositional environments of the above sedimentary units are discussed in Chapter A.

Figure 15 represents a restored stratigraphic section extending northeast from the Kimbell No. 1 Griego drill hole to Banded Peak (89 on pl. 2). The diagram depicts the major depositional environments, stratigraphic nomenclature, and the lateral distribution of the above-mentioned strata. A similar type of reconstruction is drawn for the strata between the Wirt No. 1 Sullenberger drill hole (located outside the oil and gas study area) (sec. 28, T. 35 N., R. 2 W.) and the outcrop along Quartz Creek (fig. 16).

The Entrada Sandstone shows an onlap relation with the Precambrian basement (Read and others, 1949), and it thins northward from 250 ft in the Cameron Drilling No. 1 Bramwell drill hole (79 on pl. 2)

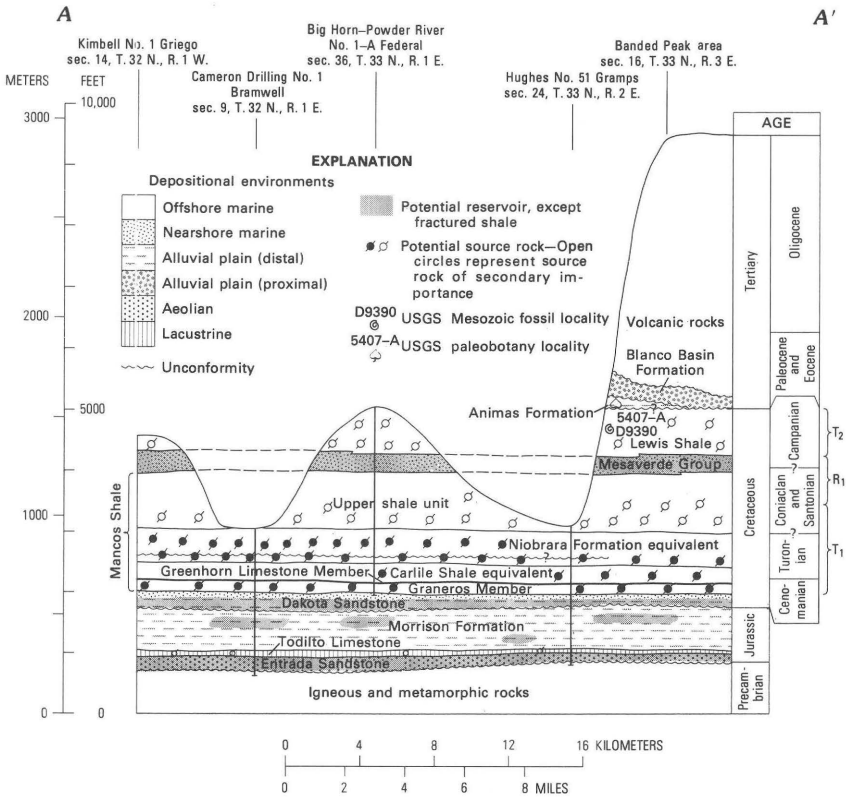


FIGURE 15.—Restored stratigraphic section between Kimbell No. 1 Griego drill hole and Banded Peak, showing present-day erosional surface. T_1, first major transgressive episode; T_2, second major transgressive episode; R_1, first major regressive episode. Datum is top of Greenhorn Limestone Member. See figure 14 for line of section.

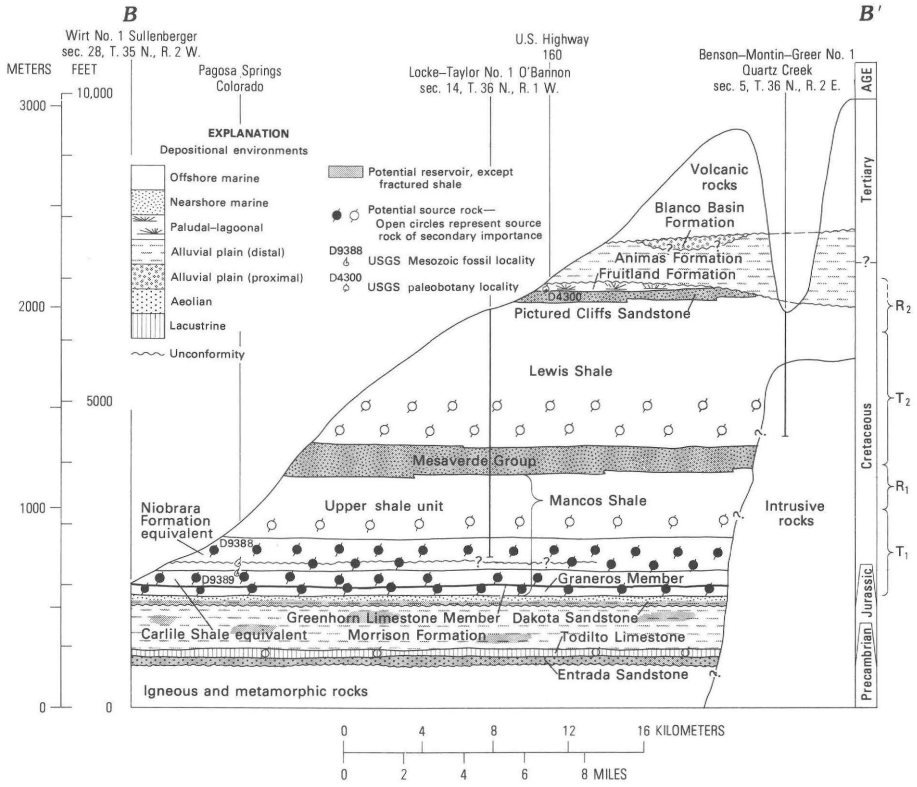


FIGURE 16.—Restored stratigraphic section between Wirt No. 1 Sullenberger and Quartz Creek, showing present-day erosional surface. T_1, first major transgressive episode: T_2, second major transgressive episode; R_1, first major regressive episode; R_2, second major regressive episode. Datum is top of Greenhorn Limestone Member. See figure 14 for line of section.

to 170 ft in the Hughes No. 51 Gramps well (133 on pl. 2) and 155 ft in the Wirt No. 1 Sullenberger drill hole (figs. 15 and 16). At this rate of thinning, the Entrada should be at least 20 ft thick beneath most of the wilderness study area. A 10–20-ft thick segment of the upper part of the Triassic Dolores Formation may exist between the Entrada and the Precambrian basement in the vicinity of the Wirt No. 1 Sullenberger and Kimbell No. 1 Griego drill holes (Wood and others, 1948). However, the identity of the unit is still in question, and thus it is included here with the Entrada Sandstone. The Todilto Limestone thins northeastward from 108 ft in the Wirt No. 1 Sullenberger to 100 ft in the Cameron Drilling No. 1 Bramwell drill hole and 40 ft in the Hughes No. 51 Gramps well (figs. 15 and 16). It probably pinches out beneath the wilderness study area. Of these units, the Entrada Sandstone offers the best reservoir potential because of its well-sorted, friable, and clay-free characteristics. Locally, however, the Entrada Sandstone is tightly cemented with silica and calcite. There are no reported hydrocarbon shows from the Entrada in the oil and gas study area.

The Morrison Formation maintains a rather uniform thickness in the southwest part of the oil and gas study area. It is 720 ft thick in the Wirt No. 1 Sullenberger drill hole, 650 ft thick in the Cameron Drilling No. 1 Bramwell drill hole, and 710 ft thick in the Hughes No. 51 Gramps well (figs. 15 and 16). The Morrison probably shows this same range in thickness beneath most of the wilderness study area. The Brushy Basin, Westwater Canyon, and Recapture Members of the Morrison Formation are probably present in the oil and gas study area but were not identified in the subsurface. Moreover, strata treated here as the Morrison Formation may contain units belonging to the Middle Jurassic Summerville Formation and Upper Jurassic Bluff Sandstone (Sears and others, 1974) and the Lower Cretaceous Burro Canyon Formation (Saucier, 1974). Several calibration drill holes, with mechanical- and lithologic-log ties to well-defined outcrop sections, are required before the detailed stratigraphy of the Morrison Formation and adjacent units can be established along the northeast flank of the San Juan Basin.

Sandstone units in the Morrison Formation are potential hydrocarbon reservoirs. According to Flesch and Wilson (1974), the porosity of the sandstone units of the Morrison in Sandoval County, N. Mex. (about 100 mi south of the oil and gas study area) ranges from 1 to 20 percent. Major diagenetic alterations affecting the porosity include feldspar and quartz overgrowths, clay-grain coatings, calcite cement, feldspar dissolution, and kaolinite infill. An undetermined quantity of oil has been produced from sandstone units in the uppermost part of the Morrison at the Gramps field. In addition, several drill holes

throughout the oil and gas study area found oil staining in the Morrison interval (for example, Fitzhugh and Teague No. 1 Teague drill hole, sec. 34, T. 33 N., R. 1 E.).

Upper Cretaceous rocks between the Morrison and Animas Formations range in age from Cenomanian to uppermost Campanian and show two major transgressive-regressive cycles (figs. 15 and 16). The first transgressive event (T_1) is manifested by strata of the Dakota Sandstone and the lower two-thirds of the Mancos Shale. Sediments of the Dakota were deposited over a post-Morrison erosion surface as the Western Interior seaway encroached upon the Four Corners area from the east and northeast (Young, 1973). Thickness values for the Dakota range from 280 ft in the Cameron Drilling No. 1 Bramwell drill hole to 160 ft in the Wirt No. 1 Sullenberger drill hole. The overlying Mancos Shale represents later and generally more seaward stages of the T_1 transgression. In this study, the Mancos Shale is subdivided into five units that include, in ascending order, the Graneros Member (200 ft), Greenhorn Limestone Member (36 ft), Carlile Shale equivalent including the Juana Lopez Member near the top (377 ft), Niobrara Formation equivalent (490 ft), and upper shale unit (1,050 ft)(figs. 15 and 16). During the maximum stages of the T_1 transgression, the seaway extended into westen Utah, central Arizona, and west-central New Mexico.

Dane (1960), McCubbin (1969), Molenaar (1973), and others have proposed that an unconformity exists in the San Juan Basin between rocks equivalent to the the Carlile Shale and the Niobrara Fomation. The most compelling evidence for the unconformity is the apparent truncation of progressively older Carlile Shale-equivalent beds from south to north across the westen margin and center of the basin. In the south-central part of the San Juan Basin, sandstone units of early Niobrara age are about 420 ft above the Juana Lopez Member (Dane and others, 1966), whereas 50 mi to the north these units are separated by less than 20 ft of strata and locally are in direct contact with one another. Some of the thinning is undoubtedly depositional in nature, but in order to explain all of it by this mechanism one would expect to observe greater rates of convergence of marker beds in the Carlile-equivalent strata (Molenaar, 1973, fig. 11).

The unconformity also appears to be present along the northeast flank of the basin; however, here faunal data must be used to recognize it. For example, near El Vado, N. Mex., the unconformity appears at the base of a thin coarse-grained sandstone unit assigned to the Cooper Arroyo Sandstone Member of the Mancos Shale. According to King (1974), the Cooper Arroyo contains fossils representative of zone 19 in the Western-Interior sequence (fig. 17) and is 25 ft above an unnamed shale member of the Mancos Shale containing fossils indicative of zone 15. Thus, as many as three faunal zones in

the Western-Interior sequence have probably been eroded or were never present prior to the deposition of the Cooper Arroyo Sandstone Member.

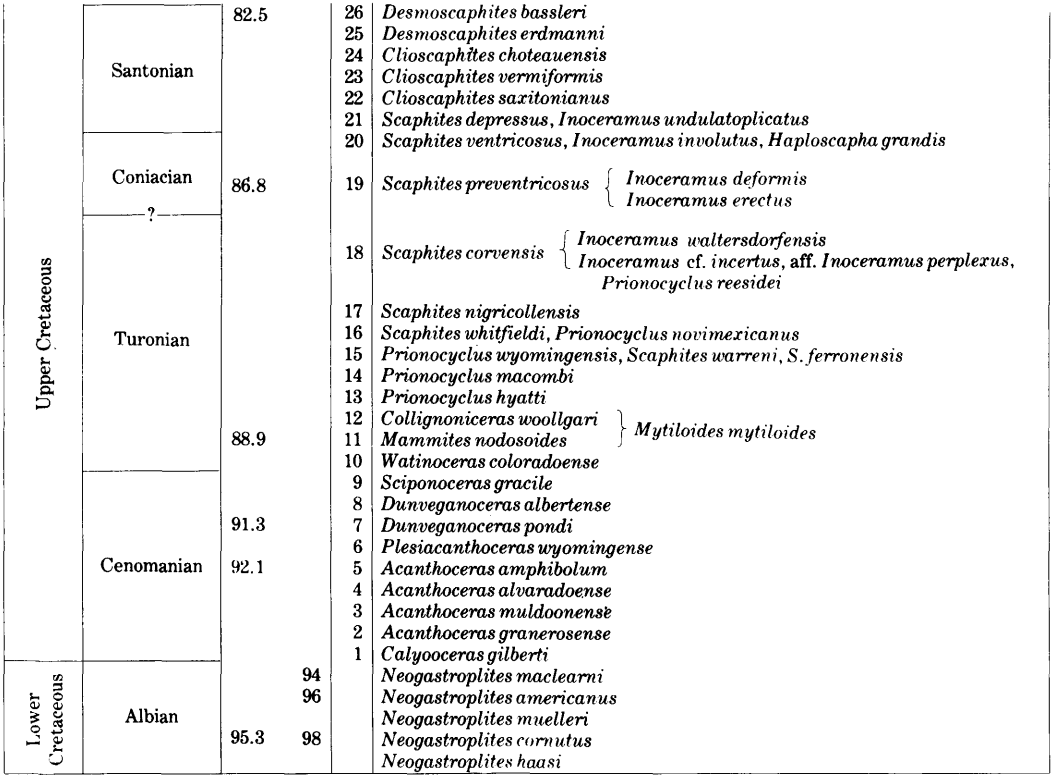
On the basis of faunal data, King (1974) suggested that the unconformity extends northward to Pagosa Springs; there, however, it is within the lower part of the Niobrara Formation equivalent rather than at the Carlile-Niobrara contact (figs. 15 and 16). Macrofossils collected by the author (USGS Mesozoic locs. D9387, D9388, and D9389, NE¼ sec. 25, T. 35 N., R. 2 W.) and W. A. Cobban (USGS Mesozoic loc. D3681, NW¼ sec. 30, T. 35 N., R. 1 W.) approximately 2.5 mi south of Pagosa Springs tend to support the conformity of the Carlile-Niobrara contact as proposed by King (1974), but are insufficient to confirm or deny his postulated stratigraphic position of the unconformity (W. A. Cobban, written commun., 1975). More work is probably required to fully resolve the unconformity question at this locality.

Potential reservoirs in the T_1 transgressive event include the Dakota Sandstone and fractured shale and carbonate units of the Mancos Shale. Both the Dakota and the Mancos are expected to be present beneath the majority of the Chama-southern San Juan Mountains wilderness study area. The Dakota Sandstone is a major gas producer (Deischl, 1973) and a secondary oil producer in the San Juan Basin and it is the main reservoir unit at the Gramps field. Oil shows are relatively common in the Dakota Sandstone throughout the oil and gas study area. Oil has been produced from fractured Mancos Shale in the Chromo field and also in the Boulder and Puerto Chiquito fields (London, 1972) about 40 mi southeast of Pagosa Springs.

Regressive sedimentation representing the R_1 cycle began in southwest Colorado by earliest Campanian time (about zone 28) and formed the nearshore sandstone units of the Mesaverde Group and the open marine shale units of the uppermost Mancos Shale (figs. 15 and 16). The Mesaverde Group in the study area correlates approximately with the Point Lookout Sandstone and Menefee Formation in the central part of the San Juan Basin. The thickness of the Mesaverde Group ranges from 320 ft in the Big Horn-Powder River No. 1-A Federal drill hole (fig. 15, 59 on pl. 2 and table 7) to 450 ft in the Locke-Taylor No. 1 O'Bannon drill hole (fig. 16, 4 on pl. 2 and table 7).

Petrographic studies on rocks from the Chama Quadrangle, N. Mex., (Muehlberger, 1967) show that the Mesaverde Group contains 8-26 percent sericite matrix and 3-32 percent calcite cement. The Mesaverde Group near the Chromo field contains between 11 and 43 percent calcite (Conley, 1964). Therefore, porosity and permeability of the sandstone units in the Mesaverde are probably rather low, and they would be poor oil reservoirs. Despite these low values, the

Series	Stage	K-Ar ages (m.y.)	Zone Nos.	Western Interior Zone fossils
Paleocene		[1]64.3 [2]64.8		
Upper Cretaceous	Maestrichtian		56	*Triceratops*
			55	*Discoscaphites cheyennensis, Discoscaphites nebrascensis*
			54	*Discoscaphites roanensis, Hoploscaphites nicolleti*
		67.4	53	*Hoploscaphites* aff. *H. nicolleti, Sphenodiscus (Coahuilites)*
			52	*Baculites clinolobatus*
		69.5 68.6	51	*Baculites grandis*
		69.6	50	*Baculites baculus*
			49	*Baculites eliasi*
			48	*Baculites jenseni*
		69.7	47	*Baculites reesidei*
		69.9	46	*Baculites cuneatus*
		71.8 71.8	45	*Baculites compressus*
			44	*Didymoceras cheyennense*
		72.0	43	*Exitcloceras jenneyi*
			42	*Didymoceras stevensoni*
		72.4	41	*Didymoceras nebrascense*
			40	*Baculites scotti*
			39	*Baculites gregoryensis*
			38	*Baculites perplexus* (late form)
			37	*Baculites gilberti*
			36	*Baculites perplexus* (early form)
			35	*Baculites* sp. (smooth)
	Campanian		34	*Baculites asperiformis*
		77.9	33	*Baculites maclearni*
		77.5	32	*Baculites obtusus*
		78.2	31	*Baculites* sp. (weak flank ribs)
			30	*Baculites* sp. (smooth)
			29	*Scaphites hippocrepis* III
			28	*Scaphites hippocrepis* II
			27	*Scaphites hippocrepis* I



[1]From Obradovich and Cobban (1975).
[2]From other investigators.

FIGURE 17.—Fossil zones of the Cretaceous System of the Western Interior of North America (modified from Obradovich and Cobban, 1975).

Mesaverde is a good gas reservoir in the center of the San Juan Basin (Pritchard, 1973). Commercial quantities of gas have been recovered from the Mesaverde Group in only one well in the oil and gas study area (Standard Oil of Colorado No. 1 Crowley, 166 on pl. 2 and table 7, sec. 2, T. 32 N., R. 2 E.).

The Lewis Shale represents the second major invasion (T_2) of the Western Interior seaway into southwesten Colorado (figs. 15 and 16). The Lewis Shale is late Campanian in age and spans zones 32 through 45 of the Western Interior faunal sequence (fig. 18; Cobban and others, 1974). Fossils collected by the author from the Lewis Shale (USGS Mesozoic loc. D9390), about 500 ft above the base were tentatively assigned to zone 39 by W. A. Cobban (written commun., 1975). Several intervals in the Lewis Shale may contain fractured-shale reservoirs. For example, the upper part of the Lewis Shale (zone 42) correlates with the Tepee zone in the Florence oil field of the Canon City embayment of central Colorado, which is a major fractured-shale reservoir. Additional reservoirs in fractured shale may exist in the lower part of the Lewis Shale that is equivalent to the organic-rich Sharon Springs Member of the Pierre Shale in the Denver Basin (Gill and Cobban, 1966).

The Western Interior seaway made its final exit from southwest Colorado during latest Companian time (Fassett and Hinds, 1971). Strata deposited during this regressive episode (R_2) include the Pictured Cliffs Sandstone and the overlying Fruitland Formation (fig. 16). These units are probably present only beneath the northwest part of the oil and gas study area, where along Coal Creek (sec. 36, T. 36 N., R. 1 W.) the Pictured Cliffs Sandstone is about 75 ft thick and the Fruitland Formation is nearly 60 ft thick (C. S. V. Barclay, written commun., 1968). Palynomorphs recovered from a coal bed in the Fruitland Formation near Coal Creek (USGS Paleobot. loc. D4300, SW¼SW¼sec. 36, T. 36 N., R. 1 W.) suggest a Maestrichtian age for this unit (R. H. Tschudy, written commun., 1969). No drill holes for oil and gas have penetrated the Pictured Cliffs Sandstone and Fruitland Formation in the oil and gas study area; however, sandstone units in the Pictured Cliffs and Fruitland probably contain similar products of diagenesis as those in the Mesaverde Group and are thus regarded as poor oil reservoirs. The Pictured Cliffs Sandstone is a major gas producer in the San Juan Basin (Brown, 1973), and it may have some potential in the oil and gas study area. The Fruitland Formation has yielded rather small quantities of gas in the San Juan Basin, and, with the exception of the Ignacio field (Fassett and Hinds, 1971), it is considered to have little potential in the oil and gas study area.

The Animas Formation rests unconformably on Upper Cretaceous strata ranging from the Lewis Shale to the Fruitland Formation (figs.

15 and 17). The Animas Formation thins from about 1,000 ft along U.S. Route 160 (fig. 16) where it rests on the Fruitland Formation, to around 200 ft near Banded Peak where it presumably rests on the Lewis Shale (fig.15) (Lipman and Hail, 1975). About 4.5 mi southeast of Banded Peak along Archuleta Creek, the Animas is absent and the Blanco Basin Formation rests directly on the Mancos Shale (Lipman and Hail, 1975). A thin coal bed in the lower part of the Animas near Banded Peak (USGS Paleobot. loc. D5407-A, sec. 7, T. 33 N., R. 3 E.) yielded a palynomorph assemblage indicative of a Paleocene age (R. H. Tschudy, written commun., 1975). The nature of the contact between the Animas Formation and the underlying Lewis Shale at Quartz Creek (fig. 16) is uncertain. Sinclair (1963) suggested that the contact is conformable and that the lower part of the Animas Formation at Quartz Creek is laterally equivalent to the Pictured Cliffs Sandstone and Fruitland Formation exposed along U.S. Route 160. On the other hand, this author favors an unconformable contact for several reasons (fig. 16). First of all, the geologic map of the Durango Quadrangle (Steven and others, 1974) indicates that the Fruitland Formation and Lewis Shale are probably overlain unconformably by the Animas approximately 10 mi southwest of Quartz Creek. Secondly, Fassett and Hinds (1971, fig. 11) suggested that more than 900 ft of the Fruitland Formation and overlying Kirtland Shale have been removed by erosion in the northeast part of the San Juan Basin prior to the deposition of the Animas. The trend and rate of thinning they proposed for the Fruitland Formation-Kirtland Shale interval would be enough to account for the missing Pictured Cliffs Sandstone and Fruitland Formation at Quartz Creek. Finally, in the course of this study, the mapping of the coal beds shown in plate 1 in the westernmost extremity of the wilderness study area revealed erosion of the uppermost coal beds in the Fruitland Formation on a very local scale. The channels that removed parts of the coal beds are now filled with conglomerate units of the Animas Formation.

The Blanco Basin Formation crops out discontinuously along the western boundary of the wilderness study area, and it rests unconformably on progressively older rocks toward the southeast. Between the San Juan River (T. 36 N., R. 1 W.) and Rio Blanco (T. 34 N., R. 1 E.) the Blanco Basin locally overlies the Animas Formation. Here, the Blanco Basin cannot be easily differentiated because outcrops are scarce except near Sand Creek (sec. 4, T. 36 N., R. 1 E.) and Squaretop Mountain (secs. 18 and 19, T. 35 N., R. 2 E.). The thickness of the Blanco Basin Formation in this area probably ranges from 100 to 200 ft. Near the Gramps oil field the Blanco Basin is about 50 ft thick and overlies the Lewis Shale; along Archuleta Creek it is more than 655 ft thick and rests on the Mancos Shale. The Blanco Basin Formation is probably Eocene in age.

Neither the Animas nor Blanco Basin Formation is considered to be a potential reservoir unit in the oil and gas study area.

STRUCTURAL SETTING AND POTENTIAL TRAPS

Four tectonic provinces meet in the southwest quarter of the oil and gas study area: (1) Brazos uplift, (2) Archuleta anticlinorium, (3) Chama basin, and (4) San Juan sag (fig. 14). The Brazos uplift is best developed in north-central New Mexico where it is expressed as a faulted core of Precambrian basement rocks overlain by a veneer of Tertiary volcanic and sedimentary strata (Muehlberger, 1968; Woodward, 1974). From there, it plunges northwestward into Colorado and terminates beneath the Chama–southern San Juan Mountains wilderness study area. The Archuleta anticlinorium, named by Wood, Kelley, and MacAlpin (1948), is a north-trending, slightly convex-eastward, 10–25-mi-wide system of folds and normal faults that bounds the northeast flank of the San Juan Basin. Woodward (1974) referred to this province as the Gallina–Archuleta arch. Northward, the Archuleta anticlinorium merges with the southeast-plunging, basement-cored San Juan uplift, and southward it connects with the north-plunging basement-cored Nacimiento uplift. That segment of the anticlinorium which extends across the oil and gas study area includes stuctural aspects of both the San Juan and Nacimiento uplifts. The Brazos uplift and Archuleta anticlinorium are separated by the north end of the Chama basin in the southwest part of the study area. Farther south, in north-central New Mexico, the Chama basin is a broad relatively featureless structural terrace (Muehlberger, 1967; Woodward, 1974). The basin begins to narrow near Chama, N. Mex., but its synclinal axis can be traced northward into the oil and gas study area for a distance of more than 12 mi. The San Juan sag, named by Kelley (1955), is a broad northwest-oriented structural depression that crosses the northern half of the oil and gas study area.

Many of the structures in the oil and gas study area were strongly influenced by the differential movement of fault-bounded blocks of Precambrian basement. Dunn (1964, fig. 7) suggested that the strata either resting directly on or 600–700 ft above Precambrian basement were deformed by faulting, whereas stratigraphically higher units were folded. This gradual change from folding to faulting at depth is also described by Muehlberger (1967) in the Chama quadrangle, N. Mex.

The Brazos uplift, Chama basin, San Juan sag, and Archuleta anticlinorium are primarily Laramide features (that is, prevolcanic and possibly pre-Blanco Basin Formation). However, they have experienced varying degrees of structural modification owing to middle

and late Tertiary uplift and tilting (Muehlberger, 1967; Woodward, 1974).

Plate 3 illustrates the structural framework of the oil and gas study area. This reconnaissance map was compiled from well data, strike-and-dip measurements, and previously mapped geologic structures. Major sources of information for this map include studies by Wood, Kelley, and MacAlpin (1948), Sinclair (1963), Dunn (1964), Muehlberger (1967), Steven and others (1974), Lipman and Hail (1975), and C. S. V. Barclay (written commun., 1968).

BRAZOS UPLIFT

The Brazos uplift is manifested by northwest-plunging, upright to slightly inclined cylindrical folds, north- to northwest-trending longitudinal faults, and east-to northeast-trending transverse faults. The faults record normal dip separation between less than 100 ft to more than 1,000 ft.

The best-documented fold associated with the Brazos uplift is the Gramps anticline. This anticline is doubly plunging, and it has been severed near its crest by a major transverse fault referred to here as the Gramps fault (pl. 3). The maximum dip separation along this fault is about 1,000 ft, and, according to Waldschmidt (1946), the fault dips 75° to the north. North of the Gramps fault, the Gramps anticline appears to be relatively unbroken, has limited closure, and plunges north-northwest. However, south of the fault, the anticline plunges generally southward and is broken into numerous fault-bounded blocks. Bounding the east flank of the Gramps anticline are two major longitudinal faults here called the Fall Creek fault (pl. 3) and the Divide fault (pl. 3).

The Divide fault trends northwest between the Hughes No. 2 Miller and Hughes No. 3 Miller wells (159 and 160 on pl. 2 and table 7); these wells provided data indicating a dip separation of about 400 ft. This fault probably extends southeastward into New Mexico, but thus far it has not been mapped that far south.

The Fall Creek fault was located on the basis of major lineaments in the Conejos Formation at the headwaters of Fall Creek (sec. 13, T. 34 N., R. 2 E.) and opposing dips in the Animas and Blanco Basin Formations west of Banded Peak (secs. 17 and 18, T. 33 N., R. 3 E.). Outcrops of the Morrison Formation and Mesaverde Group have been reported (William E. Hughes, oral commun., 1975) on the eastside of the fault (sec. 17 and 18, T. 33 N., R. 3 E.), implying that there has been more than 1,475 ft of dip separation along it. The author visited several of these outcrops and believes that they belong to the Animas and Blanco Basin Formations rather than the Mesaverde Group and

Morrison Formation, suggesting that the dip separation along the Fall Creek fault is closer to 300 ft. The sense of movement along the Fall Creek fault has not been well defined; however, the configuration of the structure contours appears to favor an upthrown west block. Southeast of its juncture with the Gramps fault, the Fall Creek fault merges with several small faults which may be associated with a larger network of faults extending northwestward from the center of the Brazos uplift (Muehlberger, 1967, 1968).

The east block of the Fall Creek fault contains a northwest-plunging anticline referred to here as the Chama Peak anticline (pl. 3). This fold is not very well documented, but the southwest-dipping strata in sections 17 and 18, T. 33 N., R. 3 E. and the north- to northeast-dipping strata near Archuleta Creek suggest that it is probably present. The Chama Peak anticline is flanked on the northeast by the synclinal axis of the San Juan sag that plunges into the center of the oil and gas study area (pl. 3). Both folds are cut by a system of north-trending normal faults, the largest of which is here named the Chama Lake fault. In this report, the Chama Lake fault (pl. 3) is tentatively extended south of Archuleta Creek to connect with a small north-trending fault in sections 3 and 10, T. 32 N., R. 3 E.

The main axis of the Brazos uplift extends across the eastern part of the wilderness study area in the form of a broad northwest-plunging anticline (pl. 3). This structure is defined on the gravity map by higher Bouguer values (fig. 3) and discussed by Wynn in Chapter B of this report. Outcrops along the Conejos River (sec. 36, T. 34 N., R. 5 E.) near the main axis of the Brazos uplift show Tertiary volcanic rocks resting on Precambrian rocks. On the basis of this field evidence, the position of the erosional edge of the Dakota Sandstone was drawn across the extreme southeast corner of the oil and gas study area (pl. 3). The main axis of the Brazos uplift is cut by several transverse faults (pl. 3). The largest of these faults is about 15 mi long, and it is referred to here as the La Manga fault (pl. 3).

Anticlines and faulted anticlinal noses offer the best potential for structural traps in the Brazos uplift province. Traps of specific interest include an untested segment of the Gramps anticline (pl. 3) and a small unnamed anticline to the west of it. An unnamed anticline associated with the Divide fault is also a potential target. Another trap could exist along the nose of the Chama Peak anticline where it is downdropped along the possible southern extension of the Chama Lake fault. Other presently undefined structural traps probably accompany the Gramps anticline, Chama Peak anticline, Divide fault, Fall Creek fault, and the Chama Lake fault.

Ground-water flow could alter an existing hydrocarbon accumulation in the oil and gas study area by tilting it or completely flushing it out of the area. The large quantities of freshwater produced with the

oil at Gramps field (W. E. Hughes, oral commun., 1975) testify to a significant hydrodynamic gradient in the Brazos uplift province. The major flow direction of the ground water is probably southwest from the Chama Lake fault system, which serves as the major recharge area. This pattern may be locally modified by flow to the northeast, north, and northwest from the core of the Brazos uplift. If faults or other permeability barriers trend normal to the general pattern of ground-water movement, the water will tend to flow around them and create a shadow zone where hydrocarbons may be protected. The Gramps oil field appears to be an example of this phenomenon. In general, the numerous faults between the Gramps anticline and the Chama Lake fault may divert the regional ground-water flow into local flow pattens that protect hydrocarbons from being flushed out of the area. Local areas of northwest-flowing ground water would tend to increase the sealing capacity of faults, such as those cutting the nose of the Chama Peak anticline, and thus prevent the escape of hydrocarbons that may be trapped here.

Fractured-shale units and unconformity traps offer some potential. Too little is known about the depositional framework of the Dakota Sandstone to assess possible facies-change stratigraphic traps. The best potential for fractured-shale reservoirs are along the plunging noses of the Gramps and Chama Peak anticlines. Unconformity traps should occur along the nose of the main axis of the Brazos uplift where the sedimentary section onlaps the Precambrian basement. The potential for this type of trap is probably limited because the adjacent Precambrian rocks are commonly fractured and form a poor lateral seal.

CHAMA BASIN

The synclinal axis of the Chama basin (pl. 3) trends northwest across the southwest corner of the oil and gas study area; near its northernmost extremity, the axis coincides with a structure named the Benson syncline (pl. 3) by Wood, Kelley, and MacAlpin (1948). Farther south, near the New Mexico border, the main axis of the Chama basin merges with a subsidiary axis that bounds the southeast flank of the Gramps anticline. The axial surface of the Chama syncline is intruded by a laccolith in the vicinity of Navajo Peak.

ARCHULETA ANTICLINORIUM

The Archuleta anticlinorium is characterized by (1) west- to northwest-trending upright and inclined plunging cylindrical folds, (2) northwest-trending longitudinal faults, and (3) northeast-trending

transverse faults. The Chromo anticline is the best documented fold in the part of the Archuleta anticlinorium that is within the oil and gas study area (Wood and others, 1948). It plunges to the northwest and its axial surface is tilted 30° or more to the northeast (pl. 3). The Chromo anticline may have limited structural closure in the vicinity of the Colorado-New Mexico border, but in general this structure rises to the southeast. The northwest-plunging nose of the Chromo anticline is indented by the west-plunging Coyote Park syncline (pl. 3), which was named by Wood, Kelly, and MacAlpin (1948). Many longitudinal faults cut the nose of the Chromo anticline. The largest of these, the Chromo fault (p. 3), bounds the northeast flank of the Chromo anticline and displays a maximum dip separation of about 500 ft. The Chromo fault is part of a 25–30-mi-long fault system which contains the Sargent fault in New Mexico (Muehlberger, 1967) and an unnamed fault near the east end of the Coyote Park syncline.

Two easterly and southeasterly plunging anticlines that bound the northwest extremity of the Chama basin syncline (pl. 3) are also major constituents of the Archuleta anticlinorium. The Blue Creek anticline (pl. 3)(Wood and others, 1948) is the northernmost of the two structures; it plunges eastward beneath the southern part of Blanco Basin and the adjacent Chalk Mountains. The nose is cut by several transverse faults and intruded by two laccoliths. The second anticline was named the Boone Creek anticline (pl. 3) by Wood, Kelley, and MacAlpin (1948). It plunges to the southeast and is cut by many longitudinal faults. The Blue Creek and Boone Creek anticlines merge in the vicinity of sec. 11, T. 34 N., R. 1 W. to form one open fold. Available surface and subsurface data suggest that closure may accompany each of these folds.

As in the Brazos uplift, structural features probably provide the best traps in the Archuleta anticlinorium. Structural traps of particular interest are along the Blue Creek anticline. Possible closure may provide traps near Blue Mountain (sec. 8, T. 34 N., R. 1 E.) and along its faulted nose near Opal Lake (sec. 9, T. 34 N., R. 2 E.) and Flattop Mountain (sec. 10, T. 34 N., R. 2 E.). Areas of possible closure are also associated with the Boone Creek anticline, but the objective reservoir is at least partially tested by the Bigbee Bros. No. 1 Bigbee drill hole (sec. 17, T. 33 N., R. 1 E. on pl. 2).

Structural traps may also be along the southwest flank of the Chromo anticline where uplifted fault blocks have created areas of local closure. Apparently, this was the type of structure that was tested by the Kimbell No. 1 Griego and Kimbell and Western No. 1 Griego-A drill holes (sec. 14, T. 32 N., R. 1 W., 89 and 90 on pl. 2 and table 7) and the Shula and Stone No. 6 Ewell well (sec. 4, T. 32 N., R. 1 E., 67 on pl. 2 and table 7.)

Hydrocarbons that may be trapped within the Blue Creek and

Boone Creek anticlines probably have in part been influenced by southeast-flowing ground water originating from the flanks of the San Juan uplift. Ground water moving down the plunge of these anticlines would tilt existing accumulations and enhance the sealing capacity of transverse faults that may have trapped hydrocarbons along their down-dropped sides. It is possible that all hydrocarbons have been flushed from these structures; however, this possibility is not very probable in view of the many faults which could serve as local barriers to ground-water flow. That local patterns of ground-water flow exist in this faulted terrane is suggested by data from two drill holes; the Clark, E. B., Sr. No. 1 Boone Creek Government (sec. 19, T. 33 N., R. 1 E; 17 on pl. 2 and table 7) produces freshwater from the Dakota Sandstone, whereas the Florence and others No. 1 Federal, less than 1 mi away (sec. 17, T. 33 N., R. 1 E., 13 on pl. 2 and table 7), yields sulfur water from the same formation. A map of the potentiometric surface may help to define these local patterns in ground-water flow and hence predict localities where hydrocarbons may be protected.

Fractured-shale reservoirs in the Mancos Shale, like those of the Chromo field, may occupy parts of the Blue Creek and Boone Creek anticlines. Judging from the Chromo, Puerto Chiquito, and Boulder oil fields, measurable production from fractured shale seems to be closely associated with complexly faulted anticlinal noses. Moreover, London (1972) suggested that production in the Puerto Chiquito field is from fractured dolomite-rich beds. Sandstone and siltstone laminae intercalated with the fractured shale beds would also enhance the productivity of a given oil-bearing zone.

SAN JUAN SAG

The synclinal axis of the San Juan sag is a broad open north-plunging structure. It is clearly shown on the Bouguer gravity map as an indentation of the north-sloping regional gravity gradient (fig. 3). Judging from the gravity data (fig. 3) and the northeast dips of the Fruitland and Animas Formations, the western flank of this structure appears to dip gradually northeastward beneath the northern part of the oil and gas study area.

The anticline in the Quartz Creek drainage (pl. 3) plunges to the north and south and is cut by several longitudinal faults. This anticline is adjacent to the stock at Crater Lake (chapter A, this report) and other nearby intrusive bodies, and its structural configuration at depth is obscure. Three wells drilled near the crest of the Quartz Creek structure bottomed in igneous rock. The deepest of these tests, the Benson-Montin-Greer No. 1 Quartz Creek (sec. 5, T. 36 N., R. 2 E., 1 on pl. 2 and table 7), found quartz diorite at 800 ft and bottomed in

it at 2,040 ft (fig. 16). Sinclair (1963) interpreted the quartz diorite body as a sill or laccolith, whereas Dunn (1964) and Wynn (chapter B, this report) suggested that it is a stock or the flank of a batholith. The author favors the latter interpretation because the intrusive body at Quartz Creek is 2.5 mi or less from the well-documented stock at Crater Lake. Consequently, the Dakota Sandstone and lower sedimentary units are probably absent beneath the Quartz Creek anticline (pl. 3, fig. 16).

The potential for structural traps and fractured-shale reservoirs is limited in this province because of its apparent lack of structural complexity. Some potential for stratigraphic traps may exist between Quartz Creek and Turkey Creek where the Pictured Cliffs Sandstone is thought to be truncated by the Animas Formation.

SOURCE, GENERATION, AND MIGRATION OF HYDROCARBONS

POTENTIAL SOURCE ROCKS

Potential source-rock units in the study area are the Mancos Shale, Lewis Shale, Fruitland Formation, and the Todilto Limestone.

The lower half of the Mancos Shale, comprised of the Graneros Member, Greenhorn Limestone Member, Carlile Shale equivalent, and Niobrara Formation equivalent, represents the greatest volume of potential source rocks in the oil and gas study area. No geochemical measurements have been published for these units in southwest Colorado, but they are known to be organic rich in the northeast part of the State in the Denver Basin (Harnett, 1968; Laplante, 1973; Swetland and Clayton, 1976), Sand Wash and Piceance Creek basins in western Colorado (Harnett, 1968), and the Powder River Basin in Wyoming (Heacock and Hood, 1970). The numerous oil shows and the production from these units in the Chromo and Gramps fields and adjacent areas (pl. 2) tend to confirm their role as a source rock in the oil and gas study area.

The lower one-third of the Lewis Shale may be another poential source-rock unit in the oil and gas study area. This part of the Lewis is equivalent to the organic-rich Sharon Springs Member of the Pierre Shale in the Denver Basin (Swetland and Clayton, 1976). Other parts of the Lewis Shale may also be organic rich.

Coal beds in the Fruitland Formation, as much as 10 ft thick, are capable of generating large volumes of methane. However, owing to prevolcanic uplift and erosion, their distribution appears to be limited to the northwest quarter of the oil and gas study area.

Dark-gray to black, fetid limestone units in the Todilto Limestone

may serve as source rocks for oil and gas. Its best source-rock potential appears to be along a 50-mi-wide zone extending between Durango, Colo., and Santa Fe, N. Mex., (Tanner, 1970, 1974). Limestone in this zone tends to diminish in thickness and organic content toward the northeast and southwest. An oil-stained core of the Todilto Limestone, recovered from the Rhine No. 1 Edwards-Sargent drill hole in New Mexico (sec. 33, T. 32 N., R. 3 E., not in the oil and gas study area), indicates that this unit offers some local potential as a source rock in the oil and gas study area.

HYDROCARBON GENERATION

The oil production and numerous shows from the lower part of the Mancos Shale not only suggest that it is organic rich, but also that it has attained thermal maturity throughout the oil and gas study area. In the vicinity of the wilderness study area, the organic-rich part of the Mancos Shale is at a depth of approximately 6,500–7,500 ft (figs. 15 and 16). Approximately one-third to one-half of the overburden consists of volcanic rocks. The maximum depth of burial of the Mancos, prior to uplift and erosion of the volcanic pile, may have been about 10,000 ft. This thick section of volcanic strata has been removed from the southwest part of the oil and gas study area, but undoubtedly it existed here at one time. Assuming that approximately 7,200 ft of burial is required before maturation of source rocks is achieved (Nixon, 1973; Dow, 1974), it appears likely that significant quantities of oil were generated from the Mancos only after 3,000 ft or more of volcanic rocks blanketed the area in middle to late Oligocene time. This estimate of the timing of oil generation is valid only if the thickness of the Animas and Blanco Basin Formations did not significantly exceed their present-day values and the regional geothermal gradient was not greatly increased by the early phases of volcanism.

In the adjacent San Juan Basin, a thick blanket of uppermost Cretaceous and lower Tertiary sedimentary rocks probably enabled the lower part of the Mancos Shale to attain thermal maturity by middle to late Paleocene time.

Moisture- and ash-free Btu values of coal samples from the Fruitland Formation, in and west of the oil and gas study area, are between 11,610 and 13,960 (fig. 18). Some of the extremely low values are probably related to effects of near-surface weathering. In general, the contours of the Btu values trend northwest and increase toward the San Juan Basin and toward the wilderness study area. According to Hood, Gutjahr, and Heacock (1975), these Btu values are equivalent to LOM (level-of-organic metamorphism) values between

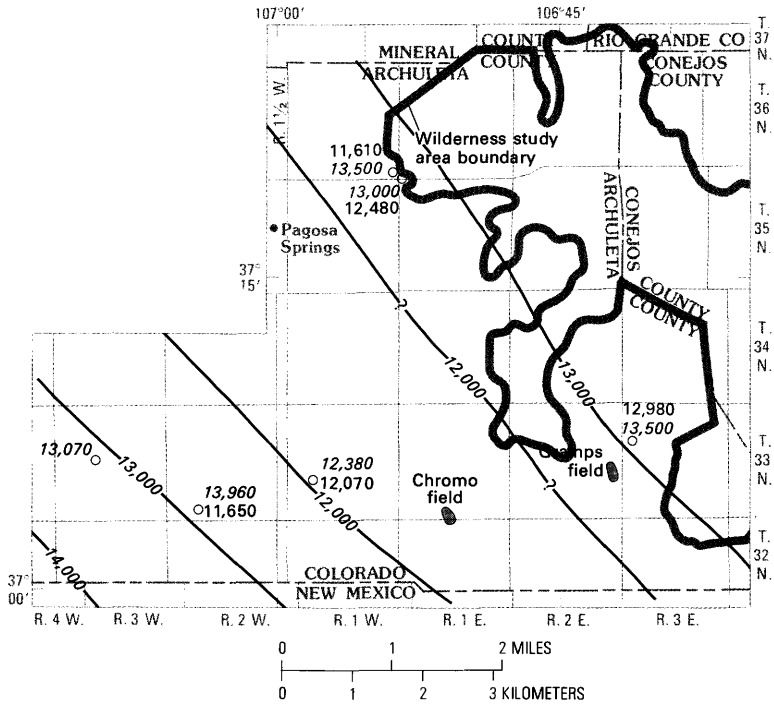


FIGURE 18.—Contour map of the moisture- and ash-free (italic) Btu values of coal units from the Fruitland Formation. Contours are drawn on an average of the Btu values at each locality and are queried where location is uncertain. The 14,000-Btu contour is based on data from Fassett and Hinds (1971). Open circle, sample from the base of the Animas Formation.

7.5 and 9.5 or fixed-carbon content[1] of 55 to 71 percent. The release of methane from coals becomes increasingly important only above a fixed-carbon content of 71 percent (Teichmuller and Teichmuller, 1968). Thus, the humic source beds in the Fruitland Formation in the southwest part of the oil and gas study area probably have not generated measurable amounts of thermal methane. It is possible, however, that the Fruitland Formation, if present, may be mature enough to have generated small amounts of thermal gas beneath the central part of the wilderness study area. In contrast, the Btu data cited by Fassett and Hinds (1971) indicate that the Fruitland coal units were probably a major source of thermal methane in the San Juan Basin. Some early diagenetic (biogenic) methane may also have been generated prior to the attainment of these LOM values (Rice, 1975).

[1]Fixed carbon content is 100 percent of the sample less the percentage of volatile matter.

Judging from the rank of the Fruitland coal units, the lower one-third of the Lewis Shale beneath the central part of the wilderness study area probably has attained LOM values high enough to generate some oil. However, the paucity of hydrocarbon shows in this interval throughout the oil and gas study area make it highly suspect as a major source-rock unit.

Biogenic methane has probably been generated in the Lewis Shale and the upper part of the Mancos Shale. This type of gas may account for the minor gas shows in and production from the Mesaverde Group (for example, Standard Oil of Colorado No. 1 Crowley well; sec. 2, T. 32 N., R. 2 E).

MIGRATION

Hypothetical lateral migration paths for oil generated from the lower part of the Mancos Shale are presented in figure 19. Three patterns of migration, each beginning at a slightly different time, are proposed: (1) long-distance (greater than 15 mi) northeast transport away from the San Juan Basin, (2) local (5–15 mi) southwest and southeast transport away from the San Juan sag, and (3) very local (0–5 mi) migration away from many dispersal centers. The trend and relative ages of these migration paths are based on the present-day regional and local structural configuration and the postulated burial history of the oil and gas study area and adjacent San Juan Basin.

Oil originating from the San Juan Basin probably first reached the southwest part of the oil and gas study area in late Paleocene time. However, little if any of this oil entered potential traps in the wilderness study area and vicinity because it was diverted toward the Nacimiento and San Juan uplifts by northwest-trending Laramide structures occupying the southwest margin of the Archuleta anticlinorium.

Next, oil derived from the Mancos Shale was probably generated in the vicinity of the San Juan sag during early to middle Oligocene time as a result of thick accumulations of volcanic rocks and associated intrusive bodies. Oil generated here was probably expelled into the adjacent Dakota Sandstone, and it eventually migrated southward into available Laramide structures in the Brazos uplift and Archuleta anticlinorium. As the volcanic pile thickened and expanded, the Mancos Shale beneath adjacent parts of the oil and gas study area most likely also generated oil. This oil probably migrated only local distances and was trapped in fractured shale or structures nearby. The temperatures attained in the lower part of the Mancos Shale are not considered to be high enough to have generated significant quantities of thermal methane.

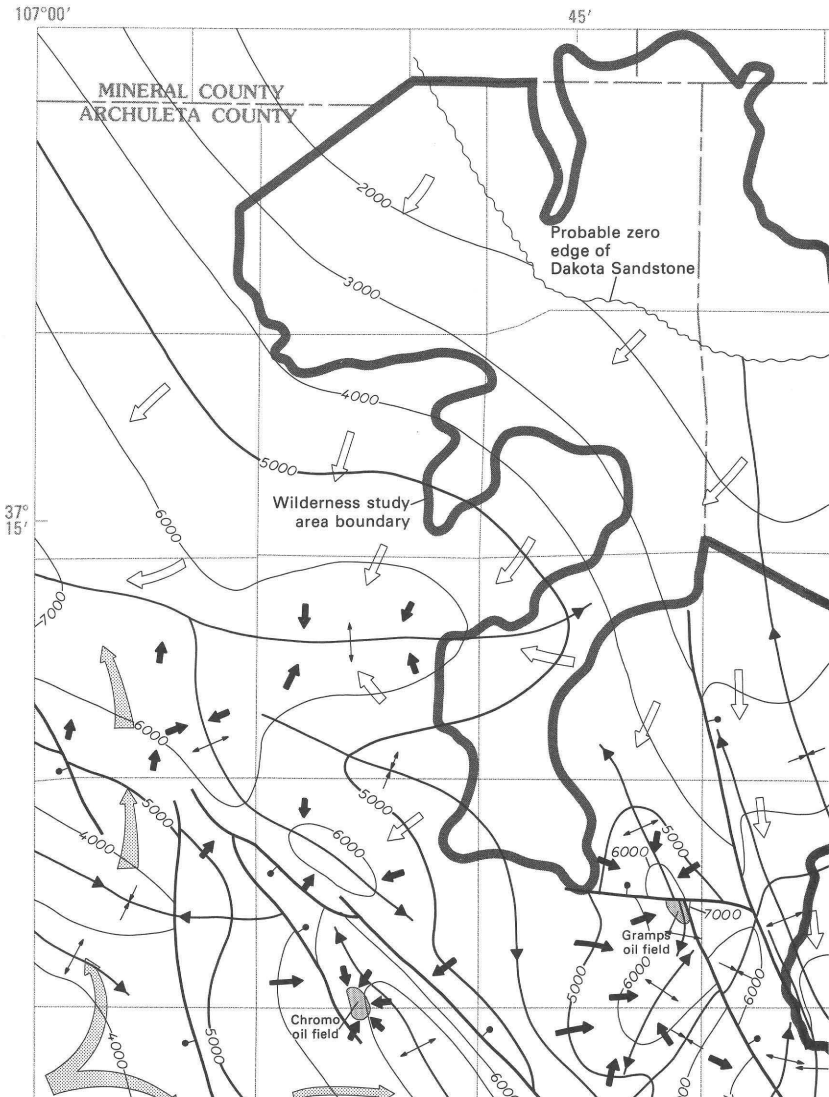


FIGURE 19.—Postulated lateral migration paths of oil expelled from the lower part of Mancos Shale.

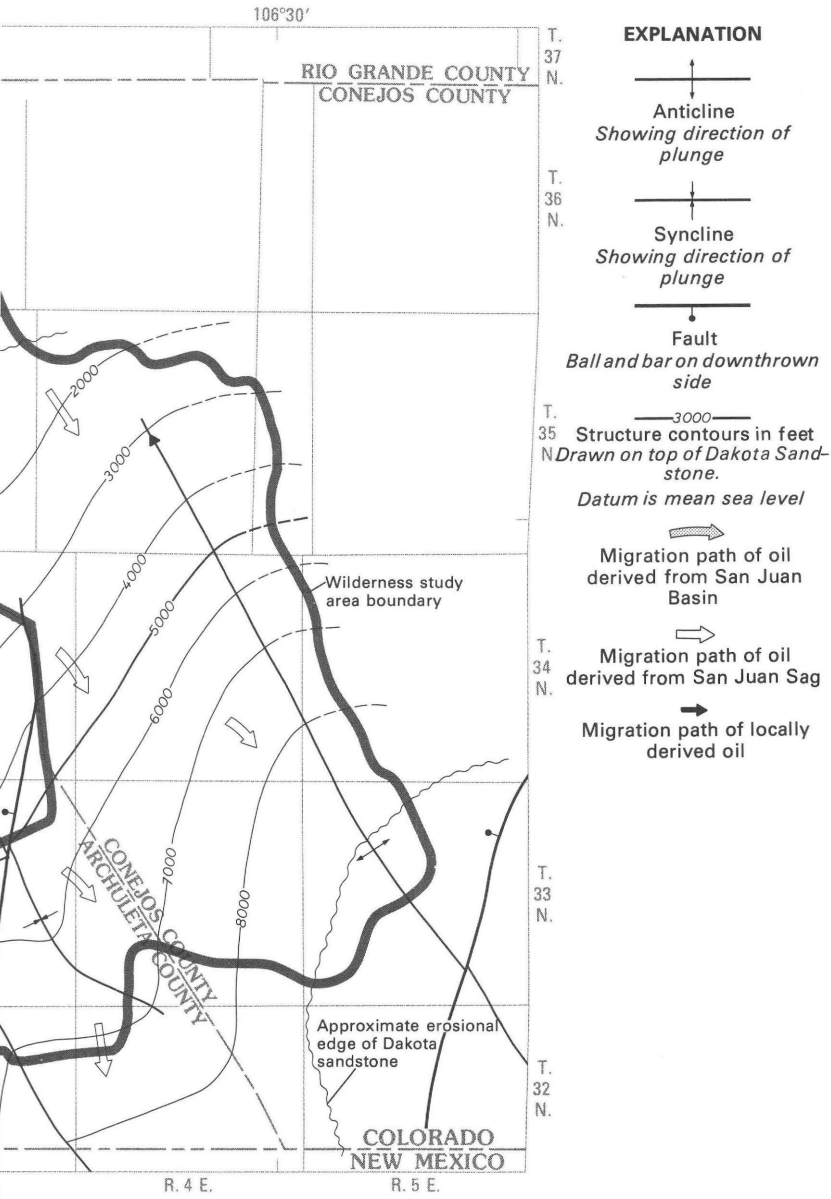


FIGURE 19.—Postulated lateral migration paths of oil expelled from the lower part of Mancos Shale—Continued.

FIELD STUDIES

CHROMO OIL FIELD

The Chromo oil field is on the faulted nose of the Chromo anticline (fig. 20). Because the oil is produced from limestone, siltstone, and shale units, which are normally impervious, and from a part of the anticline lacking closure, it is concluded that the accumulation is controlled by fractures. The trap consists of impervious unfractured or poorly fractured shale and limestone units in the lower part of the Mancos Shale. Also consistent with fracture control are the numerous faults crossing the field and the rapid depletion curves associated with initially high-yield wells (Cox, 1961). The faulting is probably much more extensive than is shown on plate 3.

Major producing zones in the Chromo field include the basal part of the Carlile Shale equivalent and the Greenhorn Limestone Member of the Mancos Shale (Cox, 1961; fig. 20). The lower part of the Mancos Shale is believed to be the source of the oil in the Chromo field. Probably most of the oil was generated in the organic-rich plastic shale units and migrated vertically into the adjacent more brittle and highly fractured limestone and siltstone units of the Greenhorn and basal Carlile (fig. 19). The absence of water in the reservoir units also suggests a closed system with regard to the generation, migration, and entrapment of the oil. Owing to the absence of water, much of the oil in the fractured Mancos Shale probably moved down plunge—under the influence of gravity—along the longitudinal faults and concentrated in the nose of the Chromo structure. Some of the generated oil must have migrated into the underlying Dakota Sandtone as indicated by local shows of dead oil (Cox, 1961). However, owing to the relatively high porosity and permeability of the unit and the lack of an available trap, it migrated southeastward out of the Chromo anticline (fig. 19).

The oil produced from the Chromo field has the following characteristics: paraffin base, greenish-brown color, 31.5°–31.9° API (American Petroleum Institute) gravity, 15°–40°F pour point, and 0–0.16 percent sulfur (Wenger and others, 1957; Cox, 1961). The relatively low API gravity of the oil is probably due to the shallow depth of the reservoir, which has allowed the light fractions to escape to the surface.

Cumulative production through December 1960 totaled 112,455 barrels of oil. The field is now abandoned.

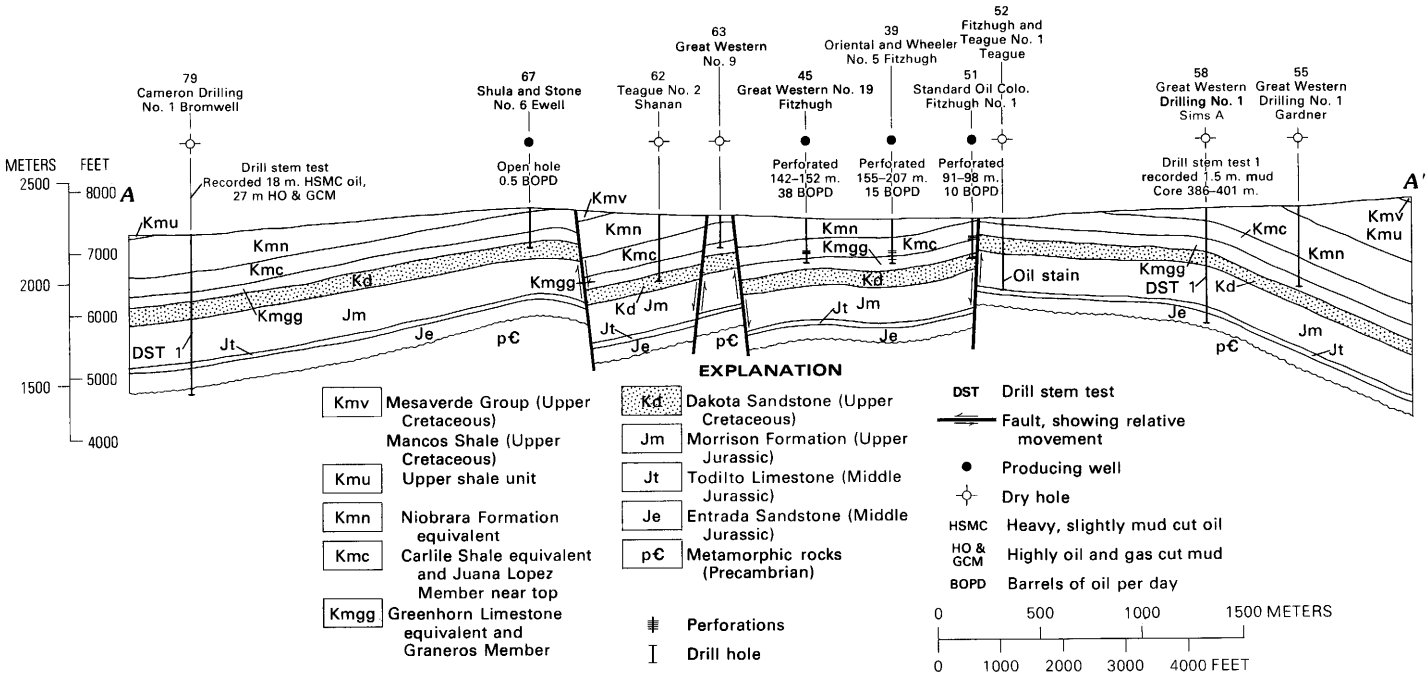


FIGURE 20.—Geologic cross section of the Chromo anticline. Line of section indicated by *A*-*A*' on plate 3. Numbers above well and drill-hole names are the same as in table 7.

GRAMPS OIL FIELD

The Gramps field is along the faulted crest of the Gramps anticline and is bounded on the north by the Gramps fault (pl. 3; fig. 21). Faults other than those shown in figure 21 undoubtedly occur in the field, but they cannot be readily identified.

The Dakota Sandstone is the major reservoir unit in the Gramps field. Small quantities of oil are also produced from sandstone units in the uppermost Morrison Formation. Attempts to produce oil from probable fractured-shale units in the lower part of the Mancos Shale have been unsuccessful. For example, the Hughes Brothers No. 49 well (fig. 21, 106 on pl. 2) was depleted after producing 15 BOPD (barrels of oil per day) from the Juana Lopez Member for 3 days. Completion problems in the fractured shale could in part be related to the presence of water-sensitive clays in the drilling mud and in the formation (Harnett, 1968). If the wells are not drilled dry, the montmorillonite in the drilling mud and the Mancos Shale expands and commonly seals off existing fractures. Another factor that may reduce fracture porosity is the precipitation of calcite in open fractures. Harnett (1968) suggested that this phenomenon is related to downward-percolating ground water, and it is common to depths of 1,000–1,500 ft below the surface.

The Dakota Sandstone at the Gramps field averages about 61 m thick and consists of very fine to fine-grained gray quartz sandstone units interbedded with thin siltstone and black-shale units as much as 5 ft thick. Quartz overgrowths are on some of the sand grains. Matrix porosity for the Dakota Sandstone ranges from 10.3 to 24.5 percent based on outcrop samples collected north of Chama, N. Mex. (Waldschmidt, 1946). Fracture porosity has probably contributed somewhat to the total porosity of the Dakota. The majority of the oil produced from the Dakota Sandstone is from the lower two-thirds of the unit. The vertical and lateral seals for the accumulation are the respective shale units of the Graneros Member and Niobrara Formation equivalent unit of the Mancos Shale.

The oil in the Gramps field, as in the neighboring Chromo field, was probably generated from the lower part of the Mancos Shale and probably migrated less than 5 mi (fig. 19). Waldschmidt (1946) also favored the lower part of the Mancos Shale for the source of the oil, but, based on the absence of oil north of the Gramps fault, he suggested that the oil migrated an unspecified distance into the Gramps structure from the south. He did not estimate the distance the oil has traveled, although he seemed to imply long-range migration from the center of the San Juan Basin. Long-distance migration is not required to account for the oil in the Gramps field, for several reasons.

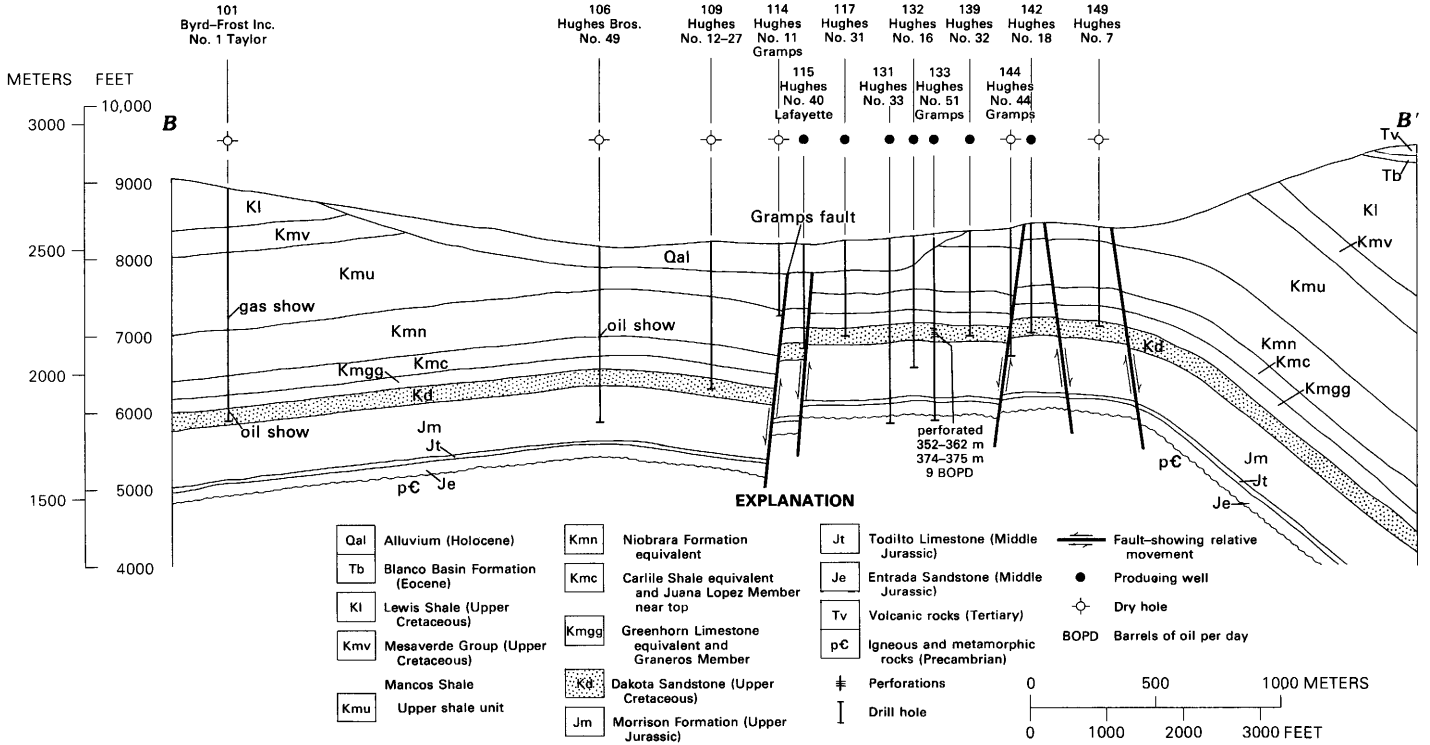


FIGURE 21.—Geologic cross section of the Gramps anticline. Line of section indicated by *B*–*B*' on plate 3. Numbers above drill hole and well names are the same as in table 7.

First, the lower part of the Mancos Shale is mature and has generated oil in this locality. Secondly, assuming a thickness of 200 ft, an average richness of 0.5 gal/ton (gallons per ton) oil, a density of 0.08 lbs/in^3 (pounds per cubic inch) and efficiency of explusion of 0.25 for the main organic-rich part of the Mancos Shale, then only 7 mi^2 of shale would be required to supply enough oil for the Gramps field. Finally, the absence of oil on the north side of the Gramps fault does not require migration from the south. Oil could have been derived from the north, become temporarily trapped against the Gramps fault, and then migrated vertically along the fault to its present location. Whether the oil migrated from the north or south, it was probably locally derived.

Water originally produced from the Gramps field contained an average of 2,945 ppm of dissolved solids (Waldschmidt, 1946). The high bicarbonate content of this ground water (average 1,375 ppm) was probably responsible for the calcite that fills numerous fractures in the Mancos Shale (Waldschmidt, 1946). These fracture fillings affect oil production in the field: (1) by increasing the sealing capacity of the Mancos, and (2) by greatly reducing oil production from fractured shale. Freshwater is now produced in large quantities, and in some wells it exceeds the oil production.

In general, wells produce more water and less oil as time passes. When pumping resumes in a well that has been shut in for several months, the percentage of oil with respect to water increases considerably.

The oil produced from the Gramps field has the following characteristics: intermediate paraffin base, brownish-black color, 31.0°–31.6° API gravity, 55°–60°F pour point, and 0.22–0.38 percent sulfur (Wenger and others, 1957; Waldschmidt, 1946). Waldschmidt (1946) suggested that the low gravity of this oil in comparison to other oil from the Dakota in the San Juan Basin is due to the loss of the light fractions. This interpretation is consistent with the shallow depth and possible fractured nature of the reservoir. The differences between the Gramps and Chromo oils is somewhat bothersome because they are thought to be from the same source. Some of these differences may be attributed to the activity of hydrocarbon-oxidizing bacteria in the reservoir at Gramps field. Oxygen could enter the system with the ground water and permit preferential attack and partial destruction of paraffin compounds. Oil that has been subjected to microbial alteration in the reservoir also has increased sulfur and nitrogen contents (Winters and Williams, 1969). Both low reservoir temperatures (less than 131°F) and oxygen-bearing freshwater are necessary for hydrocarbon-oxidizing bacteria to be effective. Freshwater is apparently excluded from the Chromo

field by the impervious units surrounding the fractured-shale reservoir.

The cumulative production from the Gramps field through April 1975 was 5,909,400 barrels of oil.

OIL AND GAS POTENTIAL OF THE WILDERNESS STUDY AREA

The facts suggest that organic-rich shale units beneath the Chama–southern San Juan Mountains wilderness study area have generated significant quantities of oil. The prime source of the oil is considered to be the lower part of the Mancos Shale, but organic-rich units in the Lewis Shale and the upper part of the Mancos Shale may also have yielded minor amounts of oil. These units and the Fruitland Formation may also have been a source for early biogenic gas. The Todilto Limestone is mature, but it is probably too thin and deficient in organic matter in this area to have generated much oil. Using the parameters listed in the previous section (that is, average richness, 0.5 gal/ton oil; formation thickness, 200 ft; shale density, 0.08 lbs/in^3; and efficiency of explusion, 0.25), the Mancos source rocks beneath the study area could have expelled about 320 million barrels of oil.

The Dakota Sandstone is regarded as the major reservoir unit because its porosity and permeability are adequate, and it is near the Mancos souce rocks. Fractured-shale reservoirs in the Mancos Shale also offer some exploration opportunities. Units such as the Entrada Sandstone, Mesaverde Group, and the Pictured Cliffs Sandstone are believed to be either too impermeable or too far removed from mature source rocks to be seriously considered as oil reservoirs. However, the Mesaverde and Pictured Cliffs units may contain some early biogenic gas.

The most serious obstacle to future discoveries in the wilderness study area is the apparent lack of traps. Most of the potential traps seem to lie outside the area. Areas 3 and 4 outlined on figure 1 offer the best structural traps in the wilderness study area and therefore are considered to have the greatest hydrocarbon potential. Area 4 contains the Chama Peak anticline and several north-trending fault systems. Potential traps in this locality include the faulted nose of the Chama Peak anticline and fractured-shale reservoirs along its crest. Areas of presently undefined closure may be associated with the various fault blocks. Area 3 contains the east-plunging nose of the Blue Creek anticline and possibly the northwest-plunging nose of the Gramps anticline. Oil may have been trapped where the anticlinal noses are faulted. Some oil could also be associated with fractured-shale reservoirs in these structures. These anticlinal structures appear to be too small to have collected significant quantities of biogenic gas.

In addition, oil in many of the potential structural traps in the oil and gas study area, including areas 3 and 4, may have been flushed out by flowing water.

Another factor that may have disturbed hydrocarbon accumulations is intrusion of igneous rocks. Area 3 was particularly vulnerable because it is bounded by the Squaretop and V Mountain laccoliths and is cut by many northeast-trending dikes. No intrusives are known in area 4.

The probability of discovering one or more oil fields is considered good in area 4 and fair in area 3. The potential for gas production from these areas is considered poor. Judging from the proposed volume of generated oil, size of anticlinal structures, distribution of faults, and reservoir characteristics, the maximum field size in both areas is estimated at about 8 million barrels. The potential of area 3 is rated slightly lower than area 4 because of the effects of intrusive igneous activity in area 3.

The estimated potential for areas 3 and 4 represents a small fraction of the approximately 320 million barrels of oil that was probably expelled from the Mancos source rocks. Most of the expelled oil probably migrated laterally out of the wilderness study area. Large quantities of oil also escaped vertically to the surface as is evidenced by the oil seeps located approximately in sec. 2, T. 32 N., R. 2 E., and asphaltic dikes in sec. 19, T. 33 N., R. 3 E., and in float in a drainage west of Banded Peak (W. E. Hughes, oral commun., 1975) near the Gramps oil field. Also, some of the originally trapped oil may have been flushed from the system by ground water. The remainder of the expelled oil was probably trapped by structures in areas 3 and 4.

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Metallic and Coal Resources of the Chama-Southern San Juan Mountains Wilderness Study Area, Colorado

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U.S. BUREAU OF MINES

MINERAL RESOURCES OF THE CHAMA–SOUTHERN SAN JUAN MOUNTAINS WILDERNESS STUDY AREA, MINERAL, RIO GRANDE, ARCHULETA, AND CONEJOS COUNTIES, COLORADO

GEOLOGICAL SURVEY BULLETIN 1524-E

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MINERAL RESOURCES OF THE CHAMA-SOUTHERN SAN JUAN MOUNTAINS WILDERNESS STUDY AREA, MINERAL, RIO GRANDE, ARCHULETA, AND CONEJOS COUNTIES, COLORADO

METALLIC AND COAL RESOURCES OF THE CHAMA-SOUTHERN SAN JUAN MOUNTAINS WILDERNESS STUDY AREA, COLORADO

By ALEC E. LINDQUIST, U.S. Bureau of Mines

METHODS OF INVESTIGATION

The U.S. Bureau of Mines conducted a mineral survey of the Chama-southern San Juan Mountains study area within the Rio Grande and San Juan National Forests of southwestern Colorado. The investigation included the following: literature search for existing mineral-resource data; review of public records for mining-claim locations; field examination and sampling of known mining claims, prospects, and workings; air reconnaissance of the study area; and ground appraisal of additional mineralized sites within the study area.

During the fall of 1974, F. E. Williams of the Bureau of Mines completed a search of courthouse records in Archuleta County and conducted a partial search of Conejos County records of mining-claim data. In June 1975, the author and G. L. Krum of the Bureau of Mines completed the claims-records search in Conejos, Rio Grande, and Mineral Counties.

Field investigations were concentrated within the areas delineated in figure 22. Fieldwork included visits to all known mine workings, dumps, prospect pits, veins, and alteration zones and collection of 181 samples, four of which were coal samples. A helicopter was used to locate additional areas of interest for later inspection.

Plotting of most of the unpatented mining claims on a working map was impossible because many claim locations were poorly or vaguely described in the county records, and those shown in the

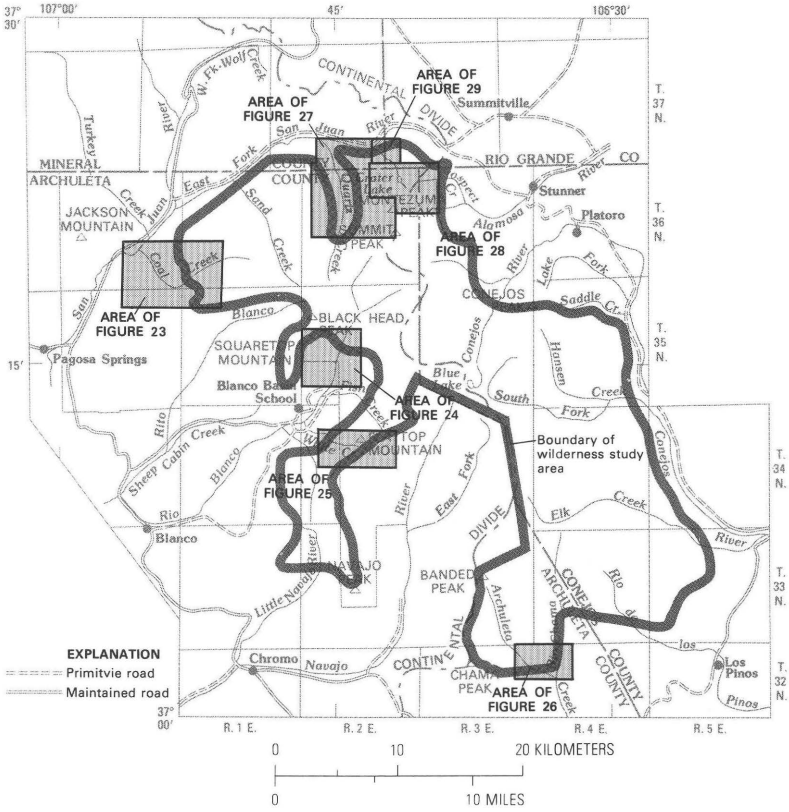


FIGURE 22.—Areas examined by the Bureau of Mines in and near the study area.

figures that follow are, for the most part, approximately located. The area of principal mineral activity, Crater Lake-Crater Creek, is near the indefinite boundary intersection of the four counties, and hence location notices for a given claim were often filed in more than one county, adding to the confusion. Data related to the location of the one patented claim in the study area and a small number of surveyed unpatented claims were obtained from the U.S. Forest Service in Denver, Colo.

MINING HISTORY AND PRODUCTION

Since 1882, an estimated 300 unpatented mining claims have been located in the study area, but only one claim has been patented. The earliest mining activity was in the lower Crater Creek vicinity (fig. 28), where many claims were located in the fall of 1882. This early

prospecting postdates the 1870 discovery of gold at Summitville and was apparently contemporaneous with the discovery of silver at Platoro in the early 1880's. The claim locations are about 7 mi southwest of Summitville and 10 mi northwest of Platoro.

Crater and Elwood are the only two mining districts in the study area and their boundaries are not distinct. The Crater district extends northward from the Crater Lake area beyond the study-area boundaries to the vicinity of Wolf Creek Pass. The principal prospecting activity within the study area was along Crater Creek from its mouth to above Crater Lake. The Elwood district adjoins the Crater mining district on the east. Most early claims in the area often referred to either the Crater or Elwood mining districts.

The Robert Burns claim near the junction of Crater Creek and the East Fork San Juan River was patented in 1895. The Elwood Mining and Separating Co. surveyed a number of claims in 1895 for patenting near the Robert Burns claim, but the patent process was not completed. In 1900, the Elwood Mining Co. surveyed the area near the Robert Burns claim and filed placer, millsite, and lode mining claims; these claims were not patented.

The Colorado Bureau of Mines (1903), stated that 'fabulous finds' were reported in the Crater and Elwood districts; these districts are not mentioned again until the Colorado Bureau of Mines (1970, 1971) reported exploration and development for the Lady Bug mine, which is the only working of consequence in the two districts. The Lady Bug property was inactive during the period of field work in this investigation.

Records of the Bureau of Mines show no production within the study area from 1901 to 1975; any production prior to 1901 probably represented minor quantities of gold and silver. Old adits are caved, but dump size indicates only minor development.

SAMPLING AND ANALYTICAL RESULTS

A total of 181 samples were collected. Within mine workings and prospect pits, chip samples were taken across structures and mineralized areas. Where workings were caved or otherwise inaccessible, dumps were sampled on a grid basis, and specimens of the most promising material were collected and analyzed separately. Chip samples were cut across mineralized outcrops and parts of the more extensive alteration zones.

The coal samples listed in table 8 were subjected to the standard ultimate- and proximate-analysis procedures of the Bureau of Mines.

The rock samples listed in table 9 were analyzed for 43 elements by the semiquantitative spectrographic method. In addition, all samples

TABLE 8.—*Coal analyses from the Coal Creek area, Archuleta County, Colo.*

[Dashes, not determined]

	As received					Moisture free					Moisture and ash free				
	C1[1]	C2	C3	C4	C5	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5
Proximate analysis (percent):															
Moisture	9.5	14.6	13.4	8.5	9.2	--	--	--	--	--	--	--	--	--	--
Volatile matter	34.78	29.8	34.2	34.8	28.7	--	34.9	39.5	38.0	31.6	--	46.9	53.4	46.4	49.8
Fixed carbon	45.75	33.7	29.9	40.2	29.0	--	39.4	34.5	44.0	31.9	--	53.1	46.6	53.6	50.2
Ash	9.97	21.9	22.5	16.5	33.1	--	25.7	26.0	18.0	36.5	--	--	--	--	--
Total	100.00	100.0	100.0	100.0	100.0	--	100.0	100.0	100.0	100.0	--	100.0	100.0	100.0	100.0
Ultimate analysis (percent):															
Hydrogen	--	5.2	5.2	5.0	3.7	--	4.2	4.2	4.6	3.0	--	5.6	5.7	5.6	4.7
Carbon	--	45.4	47.1	58.1	40.7	--	53.2	54.4	63.5	44.8	--	71.5	73.6	77.4	70.6
Nitrogen	--	0.7	0.7	1.0	0.8	--	0.9	0.9	1.1	0.9	--	1.2	1.2	1.3	1.4
Oxygen	--	25.0	22.7	18.9	21.2	--	13.9	12.4	12.3	14.3	--	18.9	16.7	15.0	22.5
Sulfur	1.14	1.8	1.8	0.5	0.5	--	2.1	2.1	0.5	0.5	--	2.8	2.8	0.7	0.8
Ash	--	21.9	22.5	16.5	33.1	--	25.7	26.0	18.0	36.5	--	--	--	--	--
Total		100.0	100.0	100.0	100.0	--	100.0	100.0	100.0	100.0	--	100.0	100.0	100.0	100.0
Btu value	--	7,920	8,340	10,130	6,700	--	9,280	9,630	11,070	7,370	--	12,480	13,020	13,500	11,610

[1]From Gardner (1909).

TABLE 9.—*Analyses of samples from mine workings, prospects, streambeds, outcrops, and alteration zones*

[Samples were analyzed by semiquantitative spectrographic analysis, by fire assay for gold and silver, and by atomic absorption for selected lead and zinc samples. Leaders (---), not detected; less than number shown; L, detected but below sensitivity limit; Tr., trace. Results of semiquantitative spectrographic analyses for other elements were, for the most part, insignificant; exceptions are in footnotes. All analyses by U.S. Bureau of mines, Reno, Nev.]

Sample No.	Oz/ton		Percent			Sample type
	Au	Ag	Cu	Pb	Zn	
1	Tr.	--	<0.002	--	--	Specimen, sediments overlying coal bed.
2	--	--	<.002	--	--	Specimen, float.
3	--	--	<.002	--	--	Coal-bed parting, carbonaceous shale.
4	tr.	--	<.002	--	--	Specimen, parting.
5	--	--	<.002	--	--	2-ft chip.
6	--	--	<.002	--	--	0.3-ft chip.
7	--	--	.008	--	--	2-ft chip.
8	tr.	--	<.002	--	--	Specimen, stream gravel.
9	--	--	<.002	--	--	Do.
[1]10	--	--	<.002	--	--	Panned.
11	--	--	<.002	--	--	2-ft chip.
12	tr.	--	<.002	--	--	0.5-ft chip.
13	tr.	--	<.002	--	--	12.1-ft chip.
14	tr.	--	<.002	--	--	10.2-ft chip.
15	--	--	<.002	--	--	Random chip.
16	tr.	--	<.002	--	--	Do.
17	--	--	<.002	--	--	Do.
18	tr.	--	<.002	--	--	Do.
19	--	--	<.002	--	--	Panned.
20	--	--	<.002	<0.01	--	Specimen, vein.
21	--	--	<.002	<.01	--	100.1-ft chip.
[2]22	--	--	.004	--	--	98.8-ft chip.
[2]23	tr.	0.1	<.002	<.01	--	Random chip, fault gouge.
24	--	Tr.	.006	<.01	--	4.9-ft chip.
25	--	.1	<.002	.01	--	0.2-ft chip.
26	--	.2	.004	<.01	--	44.9-ft chip.
27	tr.	.4	.002	<.01	--	Specimen, sample 26.
28	--	.2	<.002	.01	--	24.9-ft chip.
29	--	tr.	.016	.01	--	1-ft chip.
30	--	.2	.002	.01	--	Specimen.

were fire assayed for silver and gold. Samples having potential economic quantities of lead and zinc were reanalyzed by atomic absorption for more precise results. Results of the atomic-absorption analyses, as well as other potentially economic or anomalous values detected by semiquantitative spectrographic analysis, are listed in the footnotes in table 9.

TABLE 9.—*Analyses of samples from mine workings, prospects, streambeds, outcrops, and alteration zones*—Continued

Sample No.	Oz/ton		Percent			Sample type
	Au	Ag	Cu	Pb	Zn	
31	--	--	<0.002	0.01	--	Chip, random.
32	--	0.2	<.002	.01	--	Do.
33	--	.3	.004	.01	--	Specimen.
34	--	.1	.008	.02	--	Do.
[3]35	--	.1	.02	.1	--	Do.
36	--	--	.008	.04	--	10-ft chip.
37	--	.1	.004	.01	--	Specimen.
38	--	.2	.016	.01	--	Do.
[2]39	--	.1	.004	--	--	Do.
40	--	--	<.002	.01	--	20-ft chip.
41	--	.1	<.002	--	--	10-ft chip.
42	Tr.	.2	<.002	--	--	2-ft chip.
43	--	Tr.	<.002	<.01	--	Specimen.
44	--	tr.	<.002	<.01	--	Do.
45	--	.2	<.002	--	--	100.1-ft chip.
46	--	--	<.002	--	--	1-ft chip.
47	--	--	<.002	--	--	2-ft chip.
48	tr.	.3	<.002	.15	0.2	8-ft chip.
49	--	--	<.002	--	--	4-ft chip.
50	--	.2	<.002	<.01	--	Specimen.
51	--	.1	.01	--	--	Grab, outcrop.
52	--	.2	.002	.02	--	35.1-ft grab.
53	--	1.2	.008	--	--	2.2-ft chip.
54	--	.6	.008	--	--	Specimen, sample 53.
55	--	.6	.006	.02	--	Grab, outcrop.
56	--	.1	.003	<.01	--	Specimen.
57	--	--	.002	<.01	--	Grab, dump.
58	tr.	.1	.004	--	--	7-ft chip.
59	--	--	.005	--	--	150.3-ft chip.
60	tr.	.1	<.002	<.01	--	50.2-ft chip.
61	tr.	.2	<.002	.09	--	7-ft chip.
62	tr.	.2	<.002	--	--	Grab, dump.
63	tr.	.1	<.002	--	--	50.2-ft chip.
64	tr.	.4	<.002	--	--	20-ft chip.
65	--	.2	.002	.01	--	8-ft chip.
66	--	--	<.002	<.01	--	Grab, dump.
67	--	.2	<.002	.01	--	Do.
68	--	.3	<.002	.04	--	25-ft chip.
[4]69	--	.3	.002	.08	--	0.01-ft chip.
[4]70	--	.2	<.002	.1	--	Specimen, sample 69.

TABLE 9.—*Analyses of samples from mine workings, prospects, streambeds, outcrops, and alteration zones*—Continued

Sample No.	Oz/ton		Percent			Sample type
	Au	Ag	Cu	Pb	Zn	
71	Tr.	0.5	<0.002	0.05	--	20-ft chip.
72	--	.1	<.002	--	--	Grab, dump.
73	--	Tr.	<.002	--	--	Specimen.
74	--	--	.002	<.01	--	Specimen, fault.
75	tr.	.7	.004	.07	--	4-ft chip.
76	tr.	--	.003	.04	--	2-ft chip.
77	tr.	--	<.002	.02	--	Specimen, sample 76.
78	tr.	--	<.002	.07	--	Specimen, float.
79	--	--	.008	.04	--	Panned.
80	tr.	--	.004	.02	--	Do.
81	0.21	--	.004	.04	--	Do.
82	tr.	--	.004	.04	--	Do.
83	--	--	.004	.02	--	Do.
84	--	.2	.004	.02	--	Do.
85	--	.1	.004	.04	--	Do.
86	--	--	.004	.02	--	Do.
87	tr.	--	<.002	.02	--	Grab, dump.
[5]88	--	--	<.002	.02	--	Specimen, sample 87.
[5]89	.06	1.0	.008	1.0	4.0	Grab, dump.
[6]90	.04	3.4	.06	5.0	4.0	Specimen, sample 89.
91	--	.1	.016	.07	.1	Specimen.
92	tr.	.2	.004	.07	--	Sample 91, dump.
93	--	--	.008	.07	--	Grab, dump.
94	tr.	tr.	.008	.04	--	Specimen, sample 93.
95	--	.1	.006	.01	--	1.5-ft chip.
96	--	.1	.008	--	--	Specimen, sample 95.
97	--	.3	.01	--	--	2.5-ft chip.
[8]98	--	1.3	.008	.02	--	2.3-ft chip.
[9]99	--	.4	.006	.04	--	2-ft chip.
[10]100	--	.5	.006	.1	--	8-ft chip.
[8]101	--	1.9	.3	.1	--	Grab, stockpile.
[11]102	--	.3	.02	.1	--	Do.
[12]103	--	.8	.03	.04	--	Do.
[13]104	--	.6	.04	.07	--	Grab, dump.
[14]105	--	.4	.03	.05	--	Do.
106	--	--	<.002	<.01	--	5-ft chip.
107	--	--	<.002	.01	--	75-ft chip.
108	--	--	<.002	--	--	15.1-ft chip.
109	--	--	<.002	<.01	--	Grab, outcrop.
110	--	--	.008	--	--	1.5-ft chip.

TABLE 9.—*Analyses of samples from mine workings, prospects, streambeds, outcrops, and alteration zones*—Continued

Sample No.	Oz/ton Au	Oz/ton Ag	Percent Cu	Percent Pb	Percent Zn	Sample type
[15]111	Tr.	0.3	<0.002	<0.03	--	9-ft chip.
[15]112	--	Tr.	.003	.05	--	Specimen, sample 111.
113	tr.	tr.	.004	.04	--	1.5-ft chip.
114	--	.2	.008	.01	--	5-ft chip.
115	--	--	.008	<.01	--	1-ft chip.
116	--	--	.008	--	0.2	8-ft chip.
117	0.01	--	.004	--	--	6.1-m grab, outcrop.
118	--	--	<.002	<.01	--	0.8-ft chip.
119	--	.2	.003	.015	--	2-ft chip.
120	tr.	--	.006	.07	--	6-ft chip.
121	--	--	.006	.07	--	Specimen, sample 120.
122	--	--	.004	.01	--	2.3-ft chip.
123	--	--	--	.04	--	4.5-ft chip.
124	--	--	.006	.02	--	Grab, dump.
125	tr.	--	.008	<.01	--	Specimen, sample 124.
126	tr.	--	<.002	.05	--	Grab, dump.
127	--	--	<.002	.04	--	Specimen, sample 129.
128	tr.	--	.004	.1	--	Do.
129	--	--	.004	.02	--	Grab, dump.
130	--	--	.004	.015	--	Do.
131	--	--	.008	--	--	Specimen, sample 130.
132	--	--	.03	.15	.2	Grab, dump.
133	--	1.4	.03	.1	2.0	Do.
134	--	--	.06	.04	[16]27.2	Specimen, sample 133.
135	tr.	.7	.008	.07	.1	Specimen, vein.
136	--	.1	.008	.02	.2	Grab, rejects.
137	tr.	.7	.03	.15	[16]7.9	Grab, stockpile.
138	tr.	.7	.004	.3	--	Grab, dump.
139	--	.4	.03	.15	.2	1-ft chip, vein.
140	--	tr.	.008	.01	--	4-ft chip, vein.
[17]141	--	--	.008	<.01	--	Specimen, sample 140.
142	--	.2	.004	--	--	Specimen, stringer.
143	--	tr.	.02	.15	.2	1-ft chip.
144	--	tr.	.004	.04	--	4.5-ft chip.
145	--	.2	.002	.04	--	Specimen.
[18]146	--	.6	.008	.08	[16]8.1	2-ft chip, vein.
147	--	.6	.008	.04	2.0	3-ft chip, fault.
148	--	.2	.004	.04	.1	7-ft chip, vein.
149	--	1.9	.008	.6	1.0	3.5-ft chip, fault.
150	--	1.6	.016	1.0	4.0	2.5-ft chip.
151	--	0.1	0.008	0.02	--	20-ft chip.
152	--	.1	.016	.01	--	6-ft chip.
153	--	.1	.008	.02	--	4-ft chip.
154	--	--	.016	.03	--	2-ft chip.
[19]155	Tr.	1.1	.03	.08	[16]6.4	Do.

TABLE 9.—*Analyses of samples from mine workings, prospects, streambeds, outcrops, and alteration zones*—Continued

Sample No.	Oz/ton		Percent			Sample type
	Au	Ag	Cu	Pb	Zn	
[20]156	tr.	1.5	.06	.15	[16]46.8	1-ft chip.
157	--	--	.002	.07	.1	4-ft chip.
158	--	.5	.002	.07	.5	2-ft chip.
159	tr.	.6	.006	.07	2.0	2.5-ft chip.
160	--	.2	.006	.07	.5	5-ft chip.
161	--	.2	.004	.07	.3	1-ft chip.
162	--	.1	.004	.07	.2	5-ft chip.
[21]163	tr.	.3	.03	.15	[16]40.8	1.1-ft chip.
[22]164	tr.	.6	.01	.07	[16]2.5	3.6-ft chip.
[22]165	tr.	.8	.03	.15	[16]3.8	0.8-ft chip.
[1]166	--	3.0	.03	.04	4.4	4-ft chip.
167	--	.6	.006	.15	1.0	5-ft chip.
[23]168	--	3.6	.05	[16].29	[16]8.5	Do.
[21]169	tr.	3.5	.03	[16]3.0	[16]13.1	4-ft chip.
[24]170	tr.	4.3	.05	[16]4.7	[16]10.6	5.5-ft chip.
[18]171	tr.	3.7	.03	[16]4.7	[16]5.5	3-ft chip.
172	--	.3	<.002	.07	--	7-ft chip.
173	--	.4	<.002	.05	--	4-ft chip.
174	--	.1	.006	.04	--	7-ft chip.
175	--	.2	.006	.07	--	4-ft chip.
176	--	.1	.006	.04	--	Do.
177	--	--	.006	.04	--	5-ft chip.

[1]Contains 0.01 percent chromium, 1.5 percent titanium, and 0.05 percent vanadium.
[2]Contains 0.02 percent boron.
[3]Contains 0.01 percent molybdenum.
[4]Contains 0.01 percent bismuth.
[5]Contains 0.005 percent bismuth.
[6]Contains 0.6 percent barium, 0.2 percent bismuth.
[7]Contains 0.008 percent tin.
[8]Contains 0.06 percent tin, 0.2 percent strontium.
[9]Contains 0.04 percent tin, 0.2 percent strontium.
[10]Contains 0.02 percent tin, 0.2 percent strontium.
[11]Contains 0.004 percent tin, 0.2 percent strontium.
[12]Contains 0.006 percent tin, 0.02 percent strontium.
[13]Contains 0.06 percent tin.
[14]Contains 0.03 percent tin.
[15]Contains 0.01 percent chromium.
[16]Content determined by atomic absorption.
[17]Contains 0.6 percent barium.
[18]Contains 0.04 percent cadmium.
[19]Contains 0.1 percent cadmium.
[20]Contains 2.0 percent barium, 0.5 percent cadmium.
[21]Contains 0.3 percent cadmium.
[22]Contains 0.07 percent cadmium.
[23]Contains 0.01 percent bismuth, 0.1 percent cadmium.
[24]Contains 0.02 percent bismuth, 0.2 percent cadmium.

MINES, PROSPECTS, AND MINERALIZED AREAS

Mineralization within the study area occurs in fissure veins and as disseminations. Zinc, silver, and lead are the only metals now known to be present in potentially economic quantities. Anomalous quantities of tin and cadmium were noted in fissure veins.

Most of the known mineralization in the Chama–southern San Juan Mountains study area was in the Prospect Creek–Crater Lake–Crater Creek–Quartz Creek area in the northern part of the study area (fig. 22). The mineralized localities are often associated with faulting and zones of argillized, silicified, and pyritized rocks. The mineralized rock consists of quartz and quartz-pyrite veins ranging in thickness from a feather edge to several meters. Relatively narrow veinlets of calcite, zeolite, and barite are sometimes associated with the quartz and quartz-pyrite veins. Locally, minor but economic concentrations of precious and base metals are associated with the veins.

Eight major areas that have mining-claim coverage or mineralization were examined and are described separately in the text. Outlines of seven of the areas are shown on figure 22. The eighth area, the Lady Bug mine and vicinity, is within the lower Crater Creek area. Each of the eight described areas is shown in detail with approximate localities of samples from mines, prospects, streambeds, outcrops, and alteration zones on the text figures of this report. Sample numbers are used in the text to help identify the particular areas that were examined. Analyzed results of the samples collected are listed in tables 8 and 9.

A number of claims were recorded at Crater Lake in 1967, but little evidence of recent prospecting or metal-mining activity was observed in the area. Several claims were recorded in the Rio Blanco area in 1950, in the White Creek area in 1939 and 1949, and in the Archuleta Creek area in 1956 (fig. 22). These areas show little or no evidence of prospecting or mining.

Coal has been mined in the Coal Creek area near the westernmost boundary of the study area (fig. 23). At least four mines produced coal for local domestic use. Total reported production from these mines, spanning the period of 1923–40, is several thousand tons. No record of coal production is available for mines within the study area.

The market value of coal is principally contingent on the following factors: mining conditions; calorie, ash, and sulfur content; and transportation costs. The selling price is most often negotiated between buyer and seller, and no attempt has been made to evaluate the potential dollar value of the coal that occurs in and adjacent to the study area.

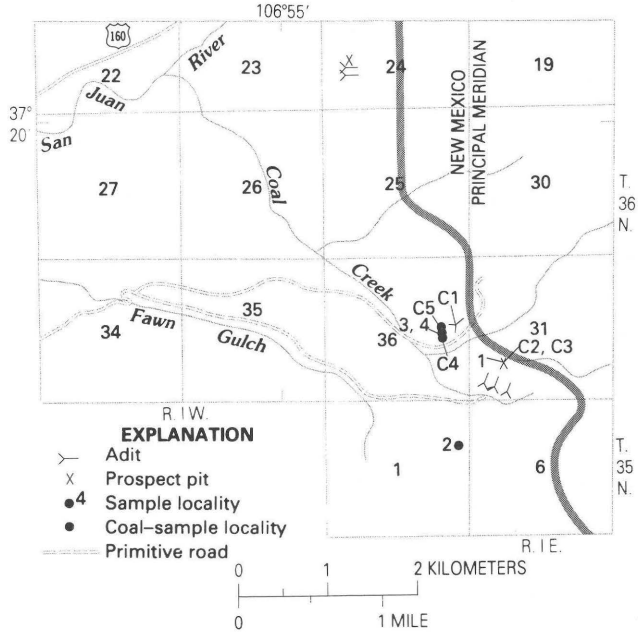


FIGURE 23.—Coal Creek area, showing sample localities 1–4 and coal-sample localities C1–C5.

COAL CREEK AREA (SAMPLES C1–C5 and SAMPLES 1–4)

Coal-bed thickness in this area ranges from 2 to 9.8 ft, and a 5.6-ft thickness was reported by Gardner (1909). Landis (1959), on the basis of analysis C1, table 8, suggested that the coal is high-volatile bituminous C rank. In 1975, major adits in the Coal Creek area were caved. Samples could only be collected in one short adit and from outcrops; coal quality (analyses C2–C5, table 8) has almost certainly been downgraded by weathering and oxidation.

Samples C2 and C3 were taken in a 15.1-ft adit. Both samples were 3-ft chips of the adit walls. The total thickness of the coal bed in the adit was approximately 5 ft.

Sample C4 is a 7.9-ft surface channel sample and is the best quality coal sampled in the investigation. Coal-bed thickness represented by this sample was 6.9 ft.

Sample C5 is a second surface channel sample from 43 ft below the coal bed mentioned above. This second coal bed was 5 ft thick.

Four samples were taken for semiquantitative spectrographic analysis in the Coal Creek area just west of the study-area boundary. Results are shown in table 9. Sample 1 is limonitic arkosic conglomerate capping a coal bed; sample 2 is quartzite containing pyrite

and calcite; sample 3 is a carbonaceous shale parting in a coal bed; and sample 4 is a 0.3-ft layer of ironstone; all contained no mineralization of economic interest.

RIO BLANCO AREA (SAMPLES 5–9)

A search in the Archuleta County courthouse records revealed claims near the ridge between the main stem of the Rio Blanco and a northwesterly trending tributary (fig. 24). Original claim locations were filed for uranium. A ground reconnaissance using a geiger counter failed to detect any anomalous radioactivity.

One small prospect pit exposed a narrow vein striking N. 32° W. and dipping 83° NE. The vein(?) material was principally clay. Sample 6, a 0.3-ft chip of the material, and sample 7, a chip of the sandstone footwall, contained negligible amounts of copper, lead, zinc, silver, and gold. Samples 8 and 9 were collected from specimens of stream gravel that contained pyrite, calcite, and iron-oxide mineralization. The samples contained no values of economic significance.

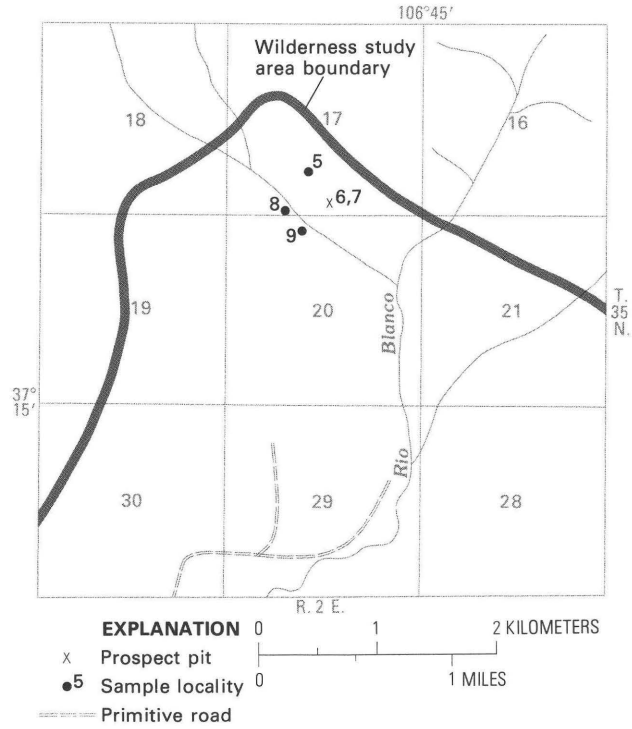


FIGURE 24.—Rio Blanco area, showing sample localities 5–9.

WHITE CREEK AREA (SAMPLES 10-14)

Several unpatented claims have been located in an area near the head of White Creek (fig. 25), but no prospecting or other mining activity was observed.

Sample 10 was a panned concentrate of stream sediments from the mouth of White Creek at the entrance to Opal Lake. Analysis of the panned concentrate, which was principally magnetite, showed no precious metals.

Samples 11 and 12, taken from veins in a silicified and brecciated fault zone of 0.2-0.5 ft in width, contained no indication of economically significant mineralization.

Samples 13 and 14 were chip samples of greenish material in the volcanic breccias and may have been the source of interest to those filing claims in the area. However, analyses showed less than 0.002 percent copper content and insignificant amounts of other metals.

ARCHULETA CREEK AREA (SAMPLES 15-19)

A diligent search was made of the area north of the confluence of Archuleta Creek and the Rio Chama (fig. 26), but no signs of prospecting of other mining activity or evidence of economic mineralization was found.

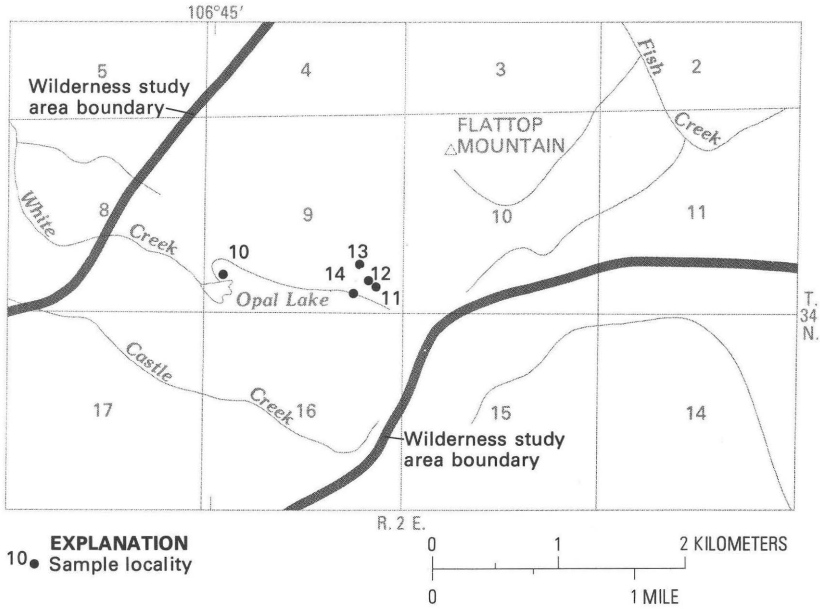


FIGURE 25.—White Creek area, showing sample localities 10-14.

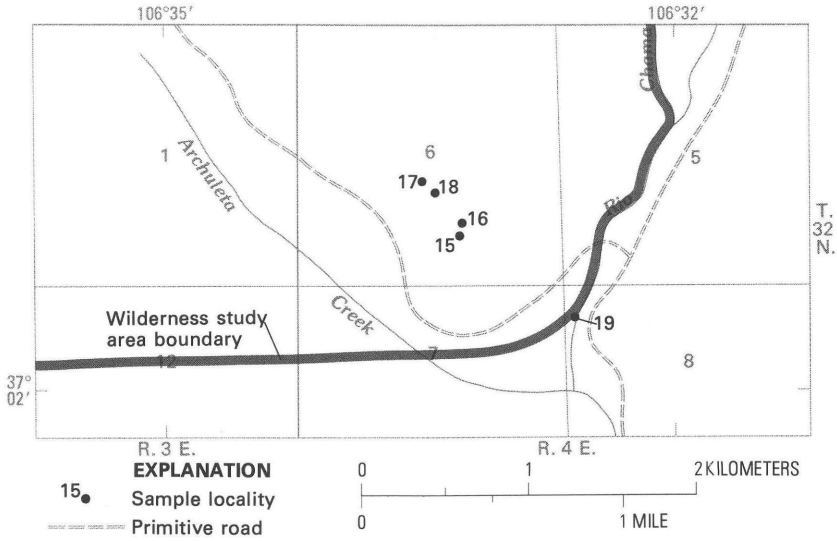


FIGURE 26.—Archuleta Creek area, showing sample localities 15–19.

The deep-red weathering of some zones in conglomerate give the appearance of a high iron oxide content and may have prompted the claim filings. Samples 15 and 17 from these strata contained nothing of economic interest.

Samples 16 and 18, also from the conglomerate, were composed chiefly of iron oxides and quartz fragments. Small weathered fragments of this conglomerate have the appearance of float from a mineralized vein and may have stimulated the claim staking. Analysis of these two samples showed nothing of economic interest.

Sample 19, a panned concentrate of stream sediment from Rio Chama, had no precious metals or other anomalous concentrations.

QUARTZ CREEK AREA (SAMPLES 20–41)

Three zones of hydrothermally altered rock were identified during a helicopter reconnaissance over the Quartz Creek area (fig. 27). Samples from these zones contained erratically distributed pyrite. No claims have been recorded in the area, and a small prospect pit in the vicinity of samples 33–41 was the only evidence of mining activity.

Calcite veins and disseminated calcite are in an alteration zone in the upper Quartz Creek area (samples 20–25); however, assay results for gold and silver were negligible, and the spectrographic analysis for copper, lead, and zinc, indicated no significant concentrations of these metals.

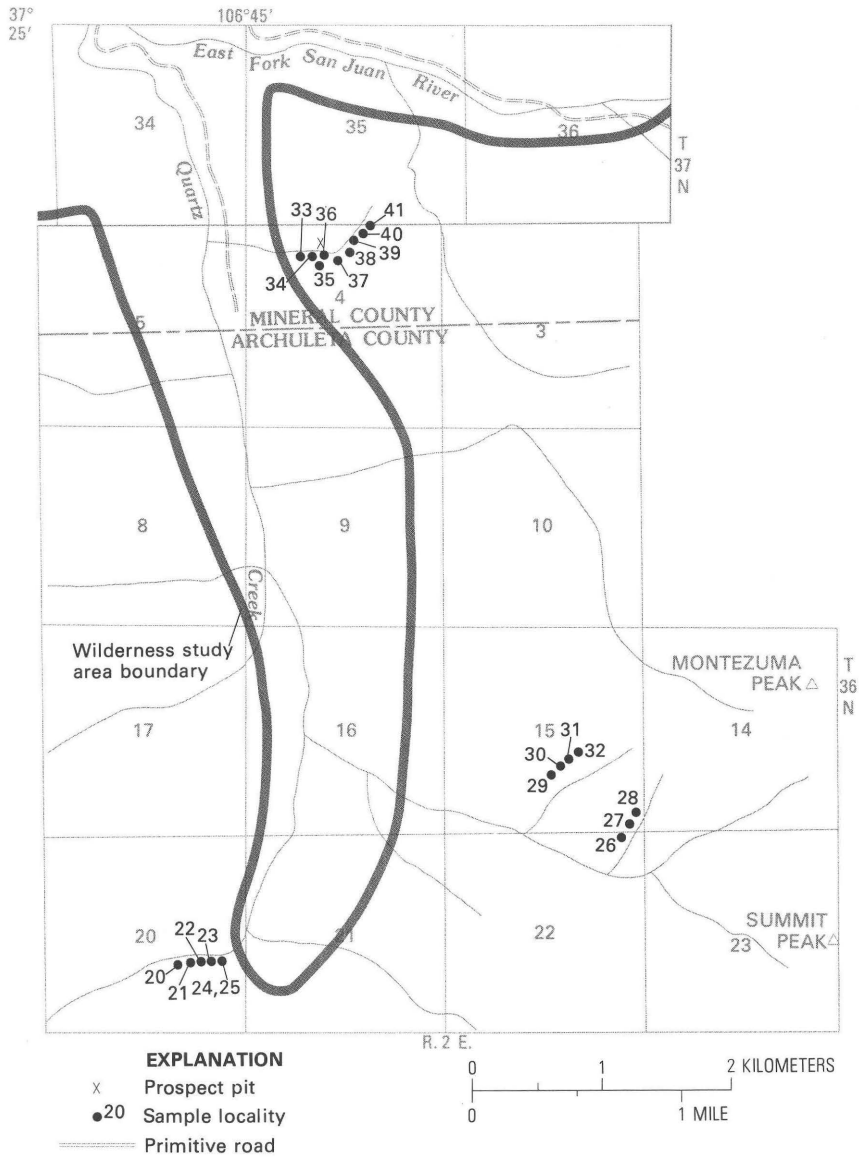


FIGURE 27.—Quartz Creek area, showing sample localities 20–41.

Five of seven samples (26–32) of the alteration zone west of Summit Peak assayed 0.2–0.4 oz/ton (ounces per short ton) silver, but did not contain significant concentrations of copper, lead, or zinc.

Small specks of molybdenite were observed along very narrow quartz-pyrite veinlets in the lower Quartz Creek drainage. Sample 35

assayed 0.01 percent molybdenum and 0.1 percent lead. No molybdenum was detected in the analysis of a 9.8-ft chip sample (36) taken across the zone containing the quartz-pyrite veinlets. However, the presence of visible molybdenite warrants further investigations of the locality as a possible exploration target.

Overall results from the 22 samples in the Quartz Creek area were of little economic interest; maximum values were 0.3 oz/ton silver, 0.016 percent copper, 0.1 percent lead, and negligible zinc.

CRATER LAKE-PROSPECT CREEK AREA (SAMPLES 42-75)

A number of mining claims have been recorded in the Crater Lake-Prospect Creek area; those identifiable as to location were plotted on figure 28.

A very short adit near the shoreline of Crater Lake was sampled. Several prospect pits were examined and sampled south of Crater Lake, on upper Bear Creek, and on the upper parts of Cataract and Prospect Creeks.

A chip sample (42) and two specimen samples (43 and 44) were taken on a fault(?) zone in volcanic tuff west of Bear Creek. This zone strikes N. 25° E. and dips 80° SE. Other than silver assays that ranged from a trace to 0.2 oz/t, no other values of possible economic interest were noted.

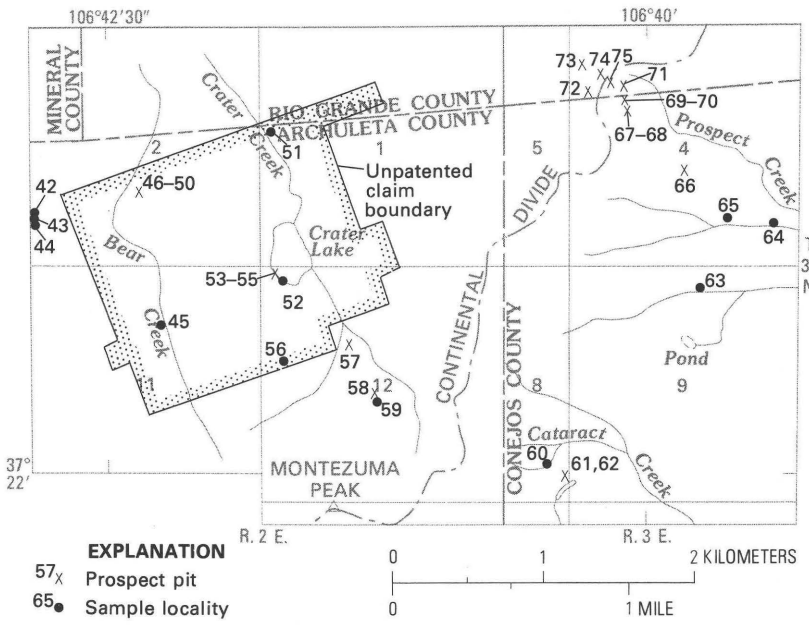


FIGURE 28.—Crater Lake-Prospect Creek area, showing sample localities 42–75.

A 100-ft random chip sample (45) from the exposed part of a highly siliceous, slightly pyritized conglomerate assayed 0.2 oz/ton silver.

Five samples (46–50) are from a pit on a fault zone striking N. 55° E. and dipping 65° SE. The zone consists of pyrite in quartz, clay, vuggy barite, and calcite. A 2.44-ft chip sample (48) assayed a trace of gold and 0.3 oz/ton silver; it also contained 0.15 percent lead and 0.2 percent zinc.

A small alteration zone occurs on Crater Creek about 0.4 mi below the outlet of Crater Lake. A 1-ft grab sample (51) of fine material from this zone assayed 0.1 oz/ton silver and 0.01 percent copper.

Near the southwest part of Crater Lake, a 3-ft adit was driven on a vein outcropping in monzonite about 15.1-ft above water's edge. The vein, which contains quartz stringers, strikes S. 57° W. and has a vertical dip. Sample 52, a grab sample of material below this prospect, contained 0.2 oz/ton silver and 0.02 percent lead. Sample 53 is a 2.3-ft chip of the vein and assayed 1.2 oz/ton silver. Sample 55, a random grab sample of the outcrop above the adit, yielded 0.6 oz/ton silver.

Sample 56 was from pyrite-magnetite-rich sediment in the bottom of a small stream; the sample was nearly barren. South of Crater Lake (fig. 28), two small prospect pits in the talus apparently did not reach bedrock. Assays were negligible in samples 57 and 58, taken from the pits. Sample 59, a chip sample taken from the alteration zone immediately to the south of the pit from which sample 58 was taken, contained negligible values.

A 50.2-ft chip sample (61) was from a prospect pit in an altered, silicified, and pyritized zone. This sample and a dump grab sample (62) assayed a trace of gold and 0.2 oz/ton silver.

Various alteration zones exposed near the head of Prospect Creek assayed between 0.1 and 0.4 oz/ton silver (samples 63–65). A dump grab sample (66) from a prospect pit dug within another, but similar, alteration zone was negligible in value.

A number of prospect pits explored veins in altered quartz-latite porphyry(?) containing quartz-pyrite and quartz stringers in the upper Prospect Creek-Continental Divide area shown in figure 28. Samples 67–75 contained a trace to 0.7 oz/ton silver. Samples 71 and 75 contained 0.5 and 0.7 oz/ton silver, respectively, and trace amounts of gold. In addition, samples 69 and 70 contained 0.01 percent bismuth.

LOWER CRATER CREEK AREA (SAMPLES 76–119)

The lower Crater Creek area (fig. 29) has been the focus of most of the mining activity in the Chama–southern San Juan Mountains study area. The area is at the headwaters of the East Fork San Juan River near the confluences of Bear, Crater, and Elwood Creeks and

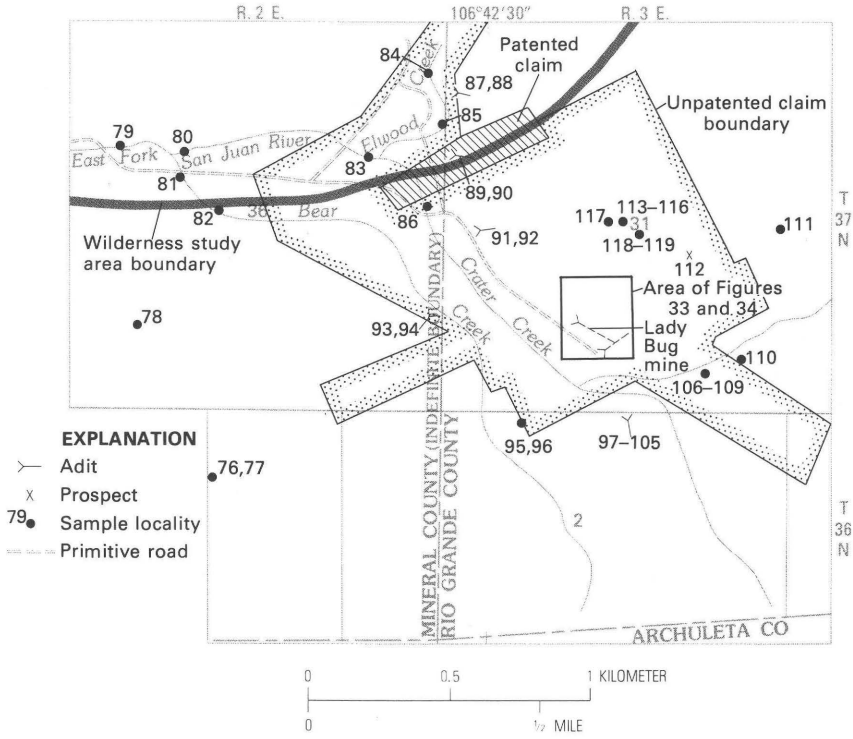


FIGURE 29.—Lower Crater Creek area, showing sample localities 76–119.

within T. 37 N., Rs. 2 and 3 E. Prior to 1900, many placer claims were located near the confluence of Crater and Elwood Creeks, but no evidence of placer mining can be seen today. The lower Crater Creek area has been faulted and hydrothermally altered, particularly in the lower half of sec. 31, T. 37 N., R. 3 E., in the area of Lady Bug mine (fig. 30), the principal site of mining activity within the study area. Other prospects are concentrated along fault-vein systems.

Samples 76 and 77 are from an alteration zone in the northeastern corner of T. 36 N., R. 2 E., containing quartz, limonite, and pyrite (fig. 29). Sample 78 is from mineralized float from the southeastern part of T. 37 N., R. 2 E. The three samples contained only trace amounts of gold.

Panned concentrates (samples 79–86) from East Fork San Juan River, Elwood Creek, Bear Creek, and Crater Creek were fire assayed for gold and silver. Sample 81 contained 0.21 oz/ton gold. About half of the samples did not contain detectable gold.

A caved adit about 0.1 mi north of the study-area boundary near

the western boundary of Rio Grande County (fig. 29) was estimated to be 15.1 ft long. Vein material on the dump consisted of pyrite and limonite in a quartz-clay gangue. Neither a dump grab sample, 87, nor a specimen sample, 88, had any values of significance.

Another caved adit is approximately astride the study-area boundary (fig. 29). The total length of these workings was estimated at 200 ft. Limonite, pyrite, galena, sphalerite, and calcite were identified in specimens of vein material found on the dump. A dump grab sample, 89, assayed 0.06 oz/ton gold, and 1.0 oz/ton silver, 1.0 percent lead, and 4.0 percent zinc. Specimen-sample 90 assayed 0.04 oz/ton gold, 3.4 oz/ton silver, 5.0 percent lead, and 4.0 percent zinc.

A partially caved, water-filled adit was about 1,312 ft northwest of the Lady Bug mine (fig. 29), near a road. The adit was estimated to be 29.5 ft in length. Dump grab sample 92 assayed a trace of gold and 0.2 oz/ton silver, whereas sample 91, which was thought to represent vein material, had negligible values.

A small dump at a caved adit on the west side of Bear Creek in the southeastern corner of T. 37 N., R. 2 E. (fig. 29) contained massive pyrite and lesser quantities of calcite and hematite. Neither dump grab sample 93 nor specimen-sample 94 contained values of economic interest.

Samples 95–119 are from the vicinity of the Lady Bug mine area (fig. 29). Samples 95, 96, and 106–119 are specimen, chip, and grab samples taken from exposures of two alteration zones southwest and southeast of the Lady Bug. Sample 111, a 8.9-ft random chip of silicified, quartz-veined, pyritized outcrop, assayed a trace of gold and 0.3 oz/ton silver. This silver value represents the highest of this group of samples.

A 23-ft adit about 492 ft south of the Lady Bug mine intersects a vein that strikes S. 86° E. and dips 80° SW. A drift, now caved, had been driven on a vein containing quartz, pyrite, and iron oxides. Specimens from a small stockpile also showed azurite, malachite, and calcite. Sample 98, a 2.9-ft chip sample of the vein, contained 1.3 oz/ton silver, 0.06 percent tin, and 0.2 percent strontium. Sample 99, a 2-ft chip, assayed 0.4 oz/ton silver, 0.04 percent tin, and 0.2 percent strontium. A grab sample (101) of vein material on the miner's stockpile yielded 1.9 oz/ton silver, 0.06 percent tin, and 0.2 percent strontium. Samples 97–104 contained silver ranging from 0.3 to 1.9 oz/ton and tin from 0.008 to 0.06 percent.

LADY BUG MINE AREA

The site of the Lady Bug mine is shown in figure 29, and figure 30 is a map of the area. A total of 58 samples was taken in the area: 12 are from older workings north of the mine, 7 are surface samples of

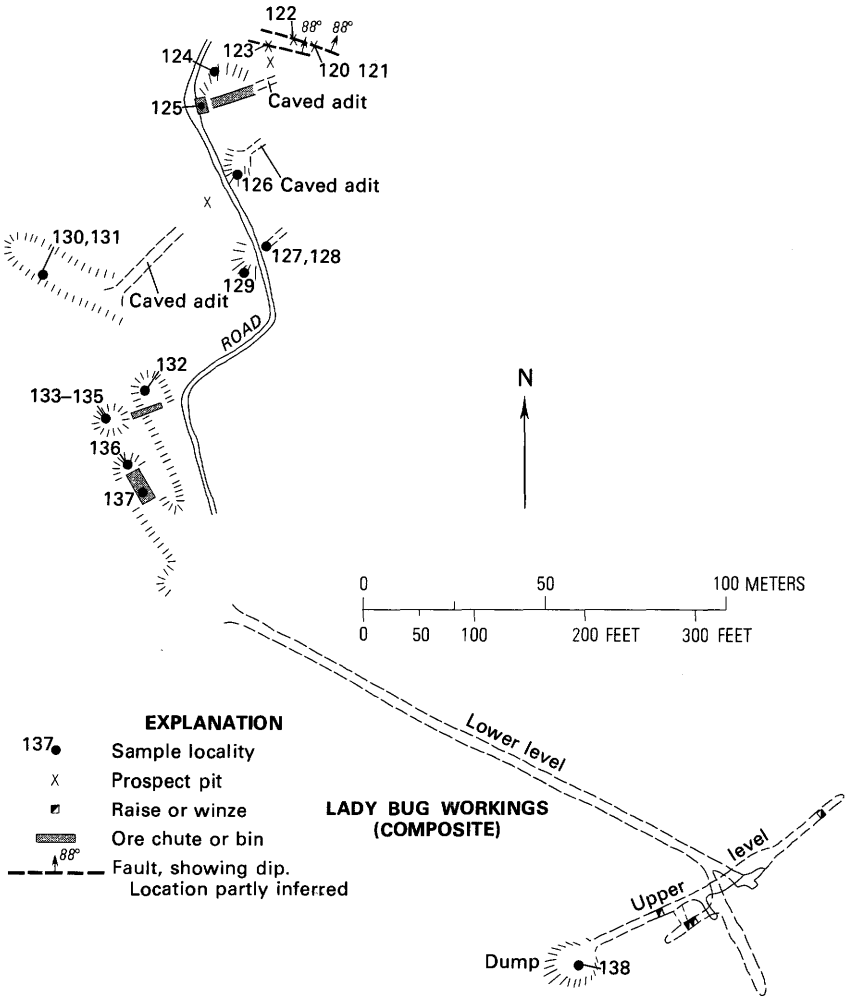


FIGURE 30.—Workings near Lady Bug mine, lower Crater Creek area, showing sample localities 120–137.

mined material, 16 are from the lower adit of the mine, 13 are from the lower-level raise, and 10 are from the upper adit.

AREA NORTH OF THE LADY BUG MINE (SAMPLES 120–131)

Twelve samples taken from dumps, stockpiles, and possible mineralized structures north of the mine contained negligible amounts of metals. Samples 119–122 were from heavily silicified and lightly to moderately pyritized andesite-porphyry outcrops. The size

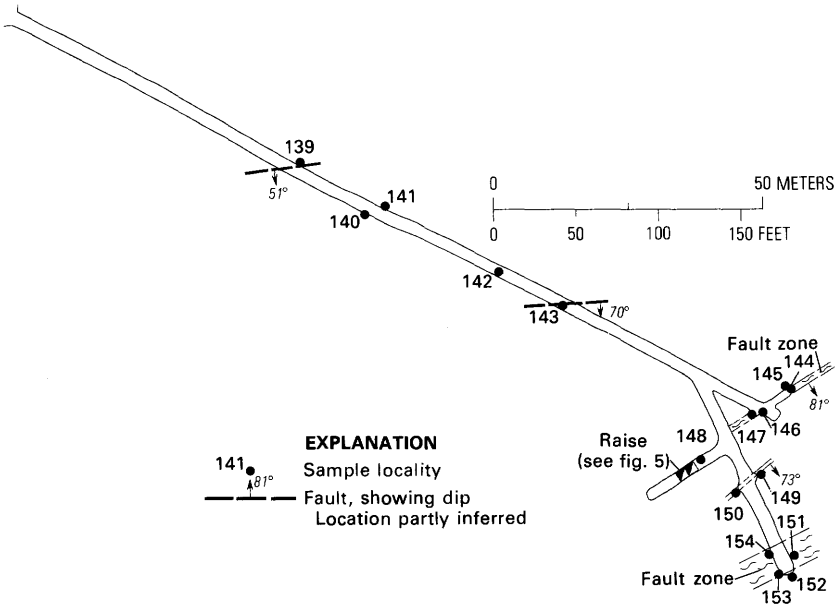


FIGURE 31.—Lower adit, Lady Bug mine, lower Crater Creek area, showing sample localities 139–154.

of the dump from which samples 130–131 were taken indicates adit workings of approximately 151 ft extent, whereas the size of the dumps from which samples 124–129 were taken indicates that other adits do not exceed 20 ft in length.

LADY BUG MINE (SAMPLES 132–177)

Accessible workings of the Lady Bug mine consist of about 742 ft of workings in the lower adit, a 78.7-ft raise, and about 295 ft of workings in the upper adit. The lower adit and the raise were probably completed during 1967–70, whereas the upper adit was completed during earlier mining activity. The lower workings consist of a 525-ft crosscut and a 124.7-ft lateral that intersect several faults, fault veins, and veins (fig. 31) in altered andesite and andesite porphyry. About 88.6 ft of drifting was done on one fault vein, and an approximately 78.7-ft-high raise was driven on the same structure.

SURFACE-SAMPLES 132–138

Sample 137 (fig. 30) was taken from a stockpile of material probably mined from the raise. The material had been screened or grizzlied. The sample contained megascopically visible pyrite and

sphalerite in a fine-grained quartz gangue. Although analysis revealed both a copper and lead content, minerals of neither could be visually observed. Analysis showed a trace of gold and 0.7 oz/ton silver, 0.15 percent lead, and 7.9 percent zinc. Sample 136, a grab sample of rejects apparently from the screening mentioned above, contained negligible metal content. Grab-sample 133 and specimen-samples 134 and 135 were taken from a secondary stockpile. This stockpile probably represents the poorer material mined from the raise or drift. Sample 133 assayed 1.4 oz/ton silver and 2.0 percent zinc. Sample 132, from a dump just east of the stockpile, contained no values of consequence.

LOWER ADIT SAMPLES 139–154

The adit shown in figure 31 intersected several fault veins as well as the principal fault vein. Samples from these features within the crosscut (139–143) had only minor metal contents. The drift shown in figure 31 was driven along a fault striking N. 57° E. and dipping 81° SE. The fault zone contained gouge and minor amounts of pyrite and sphalerite. Samples 144 and 145, taken within the fault zone, obtained minor metal amounts. Sample 147, also taken from the fault, assayed 0.6 oz/ton silver and 2.0 percent zinc. Adjacent and parallel to the fault on the hanging-wall side (fig. 31) is a vein consisting principally of fine-grained, crystalline quartz and discontinuous stringers and pods of sphalerite and minor pyrite. Sample 146, representing a 2-ft chip sample from this vein, contained 0.6 oz/ton silver and 8.1 percent zinc.

Sample 148, a 5.9 ft chip sample from the vein near the raise, contained 0.04 percent lead and 0.1 percent zinc.

A 2.6–3.2-ft fault vein contained sphalerite in the fault gouge. Chip-sample 149 assayed 1.9 oz/ton silver and 1.0 percent zinc. Chip-sample 150 contained 1.6 oz/ton silver, 1.0 percent lead, and 4.0 percent zinc. As shown in figure 31, the lateral appears to have intersected and terminated within a large fault zone. Analyses of chip samples (151–154) of this zone indicate negligible metal content.

LOWER ADIT RAISE SAMPLES 155–167

The Lady Bug raise (fig. 32) is fully timbered for 29.5 ft, stulled for almost 29.5 ft, and not timbered for the last 19.7 ft. Because air movement was detected in the raise, it probably connects with the winze (fig. 33) in the upper level, but both the top of the raise and the

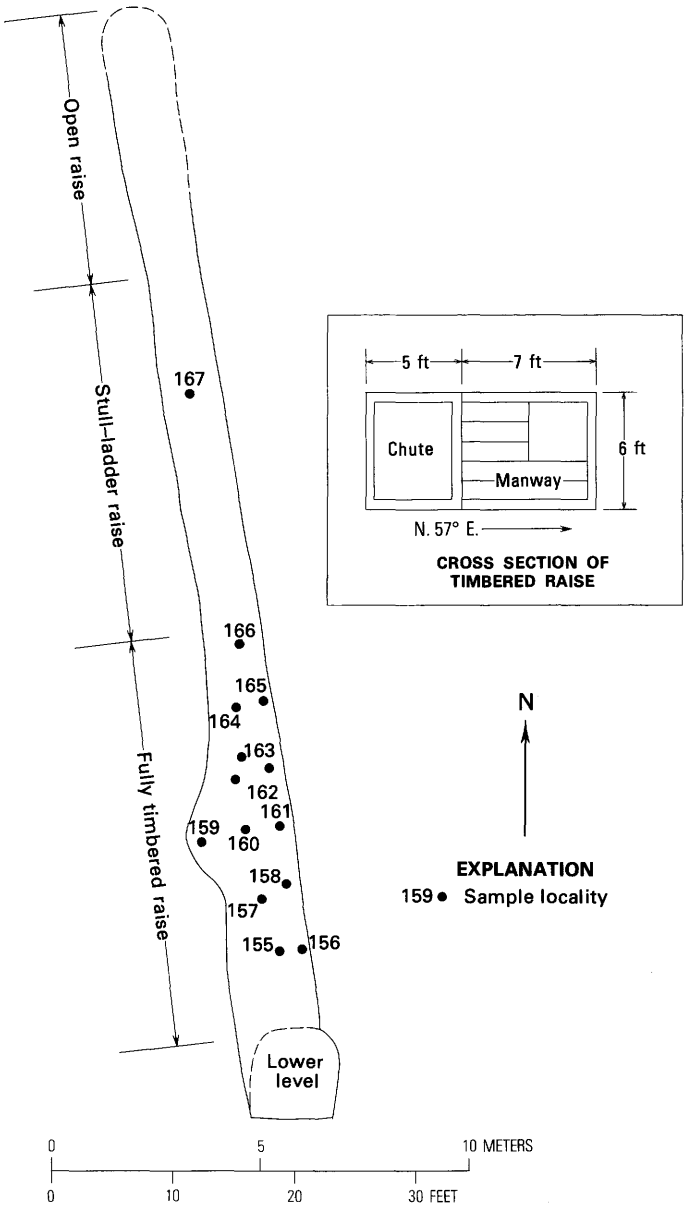


FIGURE 32.—Cross section of the lower adit raise, Lady Bug mine, lower Crater Creek area, showing sample localities 155–167. Top of raise probably connects with upper level (fig. 30). Plane of section is S. 33° E.

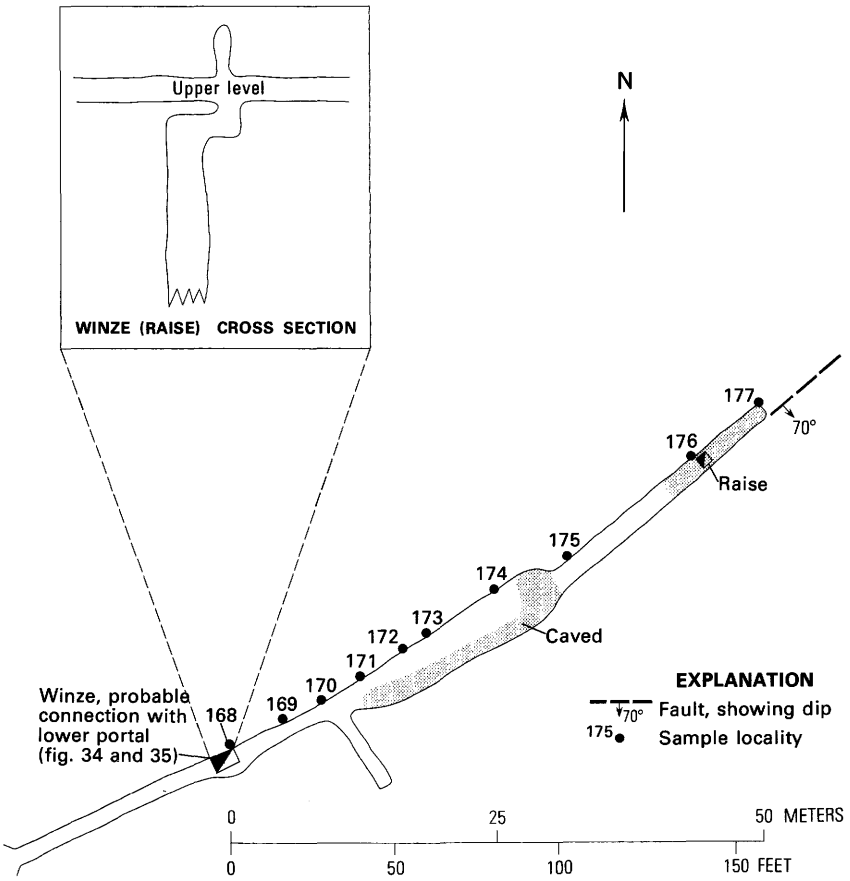


FIGURE 33.—Map of upper adit, Lady Bug mine, lower Crater Creek area, showing sample localities 168–177.

bottom of the winze are inaccessible. The mineralized zone in the raise is similar to that previously described for the vein in the drift below in the lower level of the Lady Bug mine (fig. 32). Pods and discontinuous seams composed almost entirely of sphalerite were found within the vein in the raise.

Weighted averages of 14 samples (155-167) taken over a length of 44.9 ft within the raise (fig. 32) are shown below:

Average vein width (ft)	Silver (oz/ton)	Lead (percent)	Zinc (percent)
5.31	0.72	0.06	4.5

Development of the mineralized vein was insufficient to estimate the continuity and frequency of the sphalerite pods. If, for example, sample 163 (a pod of sphalerite found within the sampling interval) were removed from the weighted average, average zinc content would fall to 3.2 percent.

Five of the samples from the Lady Bug raise (155, 156, 163, 164, and 165) contain from 0.07 to 0.5 percent cadmium. Cadmium is a common associate of sphalerite and probably would be concentrated with that mineral in any milling process.

UPPER-ADIT SAMPLES 168-177

The upper level (fig. 33) consists of a 269-ft adit and a 29.5-ft crosscut, and is approximately 111.5 ft above the lower level. Both levels were driven for exploration and development of the same fault-vein structure. Two short raises (fig. 33), neither one exceeding 9.8 ft have been driven from this drift. A grab sample (138) of the dump outside the portal of the upper level (fig. 30) contained a trace of gold, 0.7 oz/ton silver, and 0.3 percent lead.

The weighted assay averages of chip samples 168-171 taken along 49.2 ft of the drift are shown below:

Average vein width (ft)	Silver (oz/ton)	Lead (percent)	Zinc (percent)
4.40	3.8	3.1	11.2

In addition, samples 168 and 170 contained 0.01 and 0.02 percent bismuth, respectively. Samples 168-171 contained between 0.04 and 0.3 percent cadmium. Chip samples 172-177 taken along the vein indicated that the total metal content of the vein abruptly changed to low values ranging from 0.1-0.4 oz/ton silver to 0.04-0.07 percent lead.

APPRAISAL OF MINERAL COMMODITIES

Known metallic-mineral deposits in the Chama-southern San Juan Mountains study area consist principally of zinc, silver, lead, gold, and copper. All are small, erratically distributed, and largely noneconomic under present conditions. The only deposit for which reserves can be determined is at the Lady Bug mine, where 898.4 short tons of indicated ore reserves averaging 1.65 oz/ton silver, 0.97 percent lead, and 6.52 percent zinc were estimated. The vein has been

explored by a few hundred feet of underground workings and shows rapid changes in values both vertically and horizontally.

There are extensive areas of alteration within the Quartz Creek-Crater Creek-Prospect Creek drainages (pl. 1). Chip samples from these areas showed anomalous but noneconomic concentrations of silver. Molybdenite was noted in one altered area in lower Quartz Creek. Present data are not sufficient to determine the extent and grade of this occurrence; further investigation is warranted. The existence of at least one continuous 4.9-ft coal bed in sec. 36, T. 36 N., R. 1 W., and sec. 31, T. 36 N., R. 1 E., was well established by mine workings and outcrops. This deposit contains an indicated coal-reserve base of 8 million short tons, of which approximately 7.2 million short tons underlie the study area. These reserve estimates are based on a single 4.9-ft bed dipping 10° east to a depth of 1,000 ft. Coal also occurs in secs. 13, 14, and 24, T. 36 N., R. 1 W. The continuity of the coal measure or measures in these sections and south to the aforementioned deposit has not been established, but it is probably continuous. If so, an additional 33 million metric tons are inferred to lie downdip beyond the indicated reserves to a depth of about 2,953 ft below the surface.

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