Gold mineralization associated with mid-Tertiary magmatism and tectonism, Ortiz Mountains, Santa Fe County, New Mexico

Stephen R. Maynard

1995, pp. 161-166. https://doi.org/10.56577/FFC-46.161

in:

Geology of the Santa Fe Region, Bauer, P. W.; Kues, B. S.; Dunbar, N. W.; Karlstrom, K. E.; Harrison, B.; [eds.], New Mexico Geological Society 46 th Annual Fall Field Conference Guidebook, 338 p. https://doi.org/10.56577/FFC-46

This page is intentionally left blank to maintain order of facing pages.

GOLD MINERALIZATION ASSOCIATED WITH MID-TERTIARY MAGMATISM AND TECTONISM, ORTIZ MOUNTAINS, SANTA FE COUNTY, NEW MEXICO

STEPHEN R. MAYNARD
210 C San Pasquale, NW, Albuquerque, NM 87104

Abstract—Since the 1820s approximately 350,000 oz of gold have been recovered from the Ortiz Mountains. Reserves of 1.17 million oz at Carache Canyon and 180,000 oz at Lukas Canyon have been delineated. Gold in the Ortiz Mountains occurs in five distinct geologic environments: breccia pipes, skarns, veins, porphyry-related stockworks and placers. Lode mineralization is associated with the latest stages of alkaline magmatism, about 28 Ma, and is concentrated along strands of the Tijeras-Cañoncito fault system (TCFS). Intrusions in the Ortiz Mountains are of two petrochemical types, an older calc-alkaline suite and a younger alkaline suite. The calc-alkaline rocks are characterized by extensive andesite-porphyry sills, dikes and laccoliths. The alkaline rocks consist of a hornblende-augite monzodiorite/augite monzonite stock, a latite porphyry stock, the Ortiz diatreme (vent breccia) and trachyte dikes. K-Ar age determinations suggest the calc-alkaline suite to be 34 ± 2.2 Ma whereas the alkaline rocks range from about 30 to 28 Ma. The NE-trending TCFS passes through the southeastern Ortiz Mountains where its principal structure is the asymmetric Ortiz graben. The graben's northwest and southeast bounding faults displace stratigraphic contacts by up to 4000 and 2000 ft, respectively. Overall separation on the TCFS is left lateral and down to the north. The augite monzonite stock intrudes the Ortiz graben, therefore timing of major movement on the TCFS is constrained to 34 to 30 Ma.

INTRODUCTION

About 350,000 oz of gold have been produced from the Ortiz Mountains since the 1820s. Gold production during the mid- to late 19th century from the original lode discovery, the Ortiz Mine, probably exceeded 20,000 oz. Consolidated Gold Fields recovered approximately 250,000 oz of gold from the Cunningham Hill Mine from 1979 to 1987. Placer deposits, principally worked during the early 19th century, contributed the balance of gold production. Exploration by Conoco, LAC Minerals, USA, Inc., and Pegasus Gold, Inc. during the 1970s, 1980s, and 1990s resulted in the delineation of potentially minable resources at Carache Canyon and Lukas Canyon totalling approximately 1.35 million oz of gold. This paper summarizes the geology of the Ortiz Mountains with emphasis on the relationship of the Tijeras–Cañoncito fault system (TCFS) and intrusive rocks to lode gold mineralization in breccias, skarns, veins and porphyry-related bodies. Placer deposits are briefly discussed.

REGIONAL GEOLOGIC SETTING

The Ortiz Mountains are about 25 mi south of Santa Fe, New Mexico and are part of the Ortiz porphyry belt, a NNE-trending group of Oligocene stocks, laccoliths, sills, and dikes that intrude Pennsylvanian

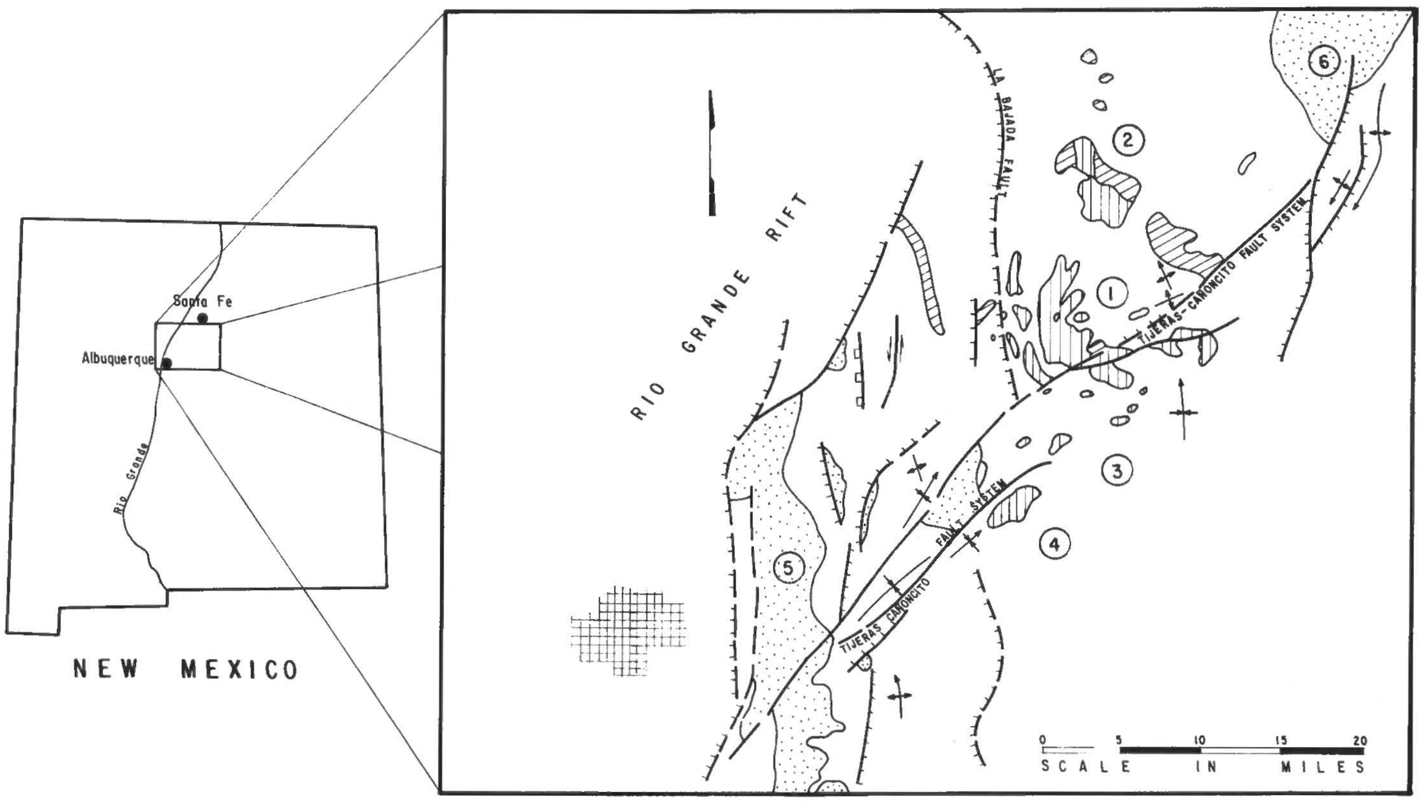

FIGURE 1. Location and tectonic setting of the Ortiz Mountains and Ortiz Porphyry Belt. 1 = Ortiz Mountains, 2 = Cerrillos Hills, 3 = San Pedro Mountains, 4 = South Mountain, 5 = Sandia Mountains, 6 = Sangre de Cristo range. Patterns: vertical = Oligocene intrusive rocks; diagonal = Oligocene volcanic rocks (Espinaso Formation); stipple = Precambrian rocks; blank = Phanerozoic sedimentary rocks; cross hatch = Albuquerque.

through Tertiary sedimentary rocks (Fig. 1). Progressively higher levels of intrusions and younger stratigraphic units are exposed from south to north in the Ortiz porphyry belt (Disbrow and Stoll, 1957; Atkinson, 1961). Volcanism, contemporaneous with the Ortiz Mountains and Cerrillos Hills intrusions, resulted in deposition of the Oligocene Espinaso Volcanics (Fig. 1; Stearns, 1953a and 1953c; Kautz et al., 1981).

The Ortiz porphyry belt lies near the eastern margin of the Rio Grande rift. Pre-rift doming is presumed to be the cause of the 10° to 30° eastward dip of strata throughout the Ortiz porphyry belt. The NE-trending TCFS (Fig. 1) intersects the porphyry belt in the Ortiz Mountains. The TCFS has a history of recurrent movement, ranging from Precambrian to Holocene (Kelley and Northrop, 1975; Lisenbee et al., 1979). Woodward (1984) suggested that the TCFS provided basement control for intrusions and base- and precious-metal mineralization.

GEOLOGY OF THE ORTIZ MOUNTAINS

Sedimentary rocks

Permian through Eocene sedimentary rocks are exposed in the Ortiz Mountains (Fig 2). Regional stratigraphy was described in detail by Stearns (1943, 1953a,b,c), Disbrow and Stoll (1957), Atkinson (1961), Kautz et al. (1981), and Picha (1982). Sedimentary units serving as important hosts for mineralization are described in the context of individual prospects and mines.

Igneous rocks

In the Ortiz Mountains, igneous rocks are divided into an earlier calc-alkaline group and a later alkaline group. Andesite porphyry sills, dikes, and laccoliths and a quartz-hornblende monzodiorite stock compose the

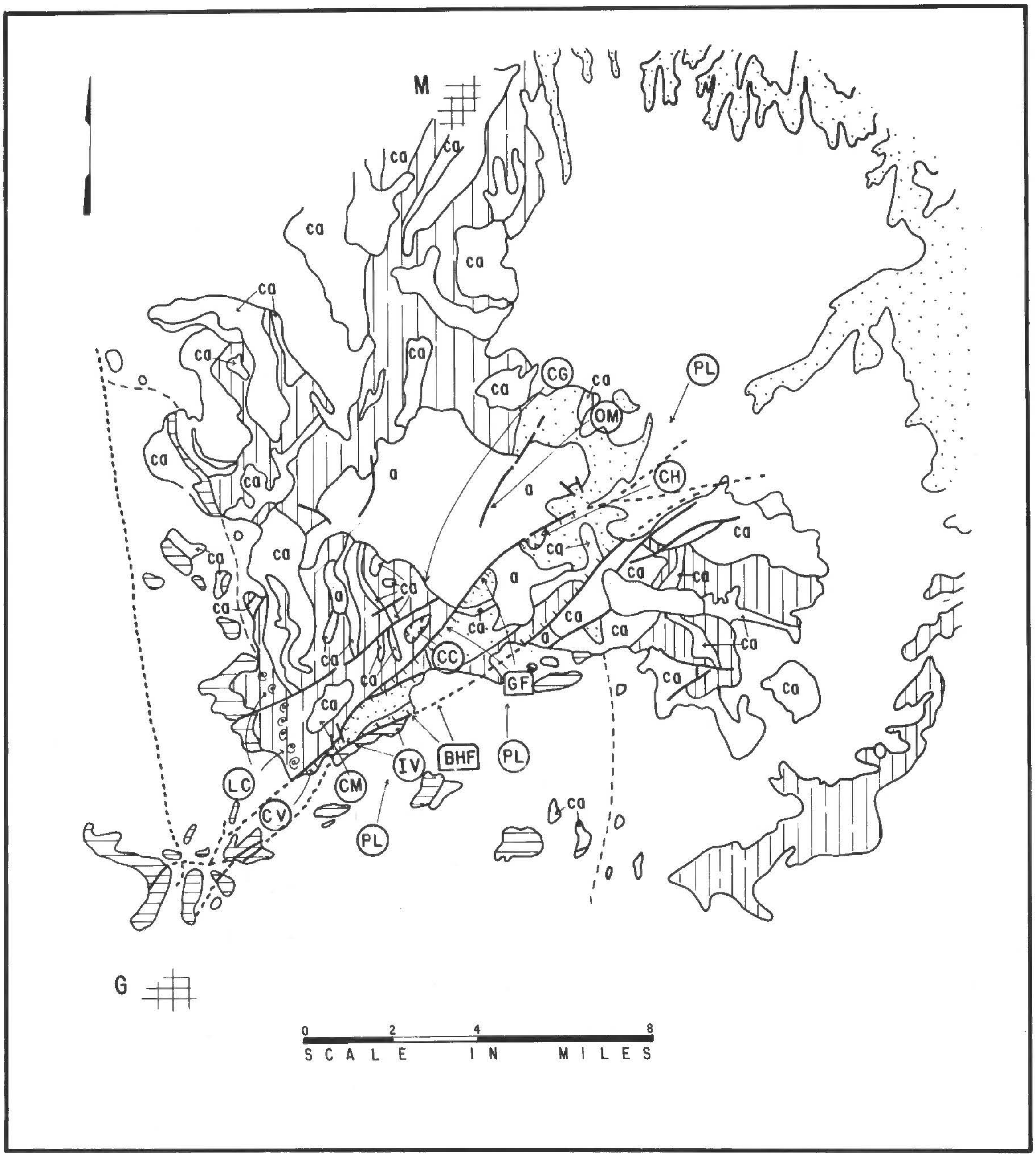

FIGURE 2. Simplified geologic map of the Ortiz Mountains. Stipple = Eocene Galisteo Formation; vertical = Upper Cretaceous sedimentary rocks; horizontal = Pennsylvanian through Jurassic sedimentary rocks. D = base of Dakota Formation; ca = calc-alkaline rocks; a = alkalic rocks; CH = Cunningham Hill; CC = Carache Canyon; LC = Lukas Canyon; IV = iron "vein"; OM = Ortiz mine; CV = Candelaria mine; CG = Cunningham Gulch; CM = Candelaria monzodiorite stock; PL = placer workings; @@@ = Lukas Canyon skarn trace; M = Madrid; G = Golden; GF = Golden fault; BHF = Buckeye Hill fault; the Ortiz Graben lies between the Golden and Buckeye Hill faults.

calc-alkaline group. Alkaline rocks are represented by a hornblende-augite monzodiorite/augite monzonite stock, a latite porphyry stock, the Ortiz diatreme (vent breccia) and trachyte dikes. Ortiz gold mineralization is spatially and temporally related to alkaline igneous rocks. Petrography and geochemistry of the igneous rocks from the Ortiz Mountains were discussed by Coles (1990).

Calc-alkaline group

Andesite porphyry sills apparently propagated from exposed laccolithic masses in the western and southeastern Ortiz Mountains and are offset by the TCFS (Fig. 2). These sills generally intrude less competent lithologies, particularly shale and mudstone of the Upper Cretaceous Menefee and Mancos, the Jurassic Morrison, and the Triassic Chinle formations, showing minor evidence of thermal metamorphism at the contacts. Andesite porphyry sills are important brecciated hosts for gold mineralization at Carache Canyon.

The K-Ar age determination most consistent with geologic relations on the andesite porphyry is 34 ± 2.2 Ma (Bachman and Mehnert, 1978). This date was determined from hornblende in unaltered rocks in the western Ortiz Mountains. Older age determinations of 43 ± 2.3 Ma (Kay, 1986) and 47.1 ± 3.2 Ma (Bachman and Mehnert, 1978) are older than the youngest strata of the Eocene Galisteo Formation, which is intruded by andesite porphyry sills, and may represent contamination by upper crustal material.

The quartz-hornblende monzodiorite stock that forms Candelaria Mountain (Fig. 2) is probably the youngest phase of calc-alkaline magmatism, although direct evidence, such as cross-cutting relationships with andesite porphyry sills, is not available. A hornfels aureole that includes the garnet-pyroxene skarn-altered Greenhorn Limestone at Lukas Canyon extends laterally up to 2000 ft away from the stock. The Candelaria monzodiorite is the presumed thermal source for both the hornfels aureole and the skarn.

Alkaline group

A stock composed of hornblende-augite monzodiorite and augite monzonite forms the rugged central part of the Ortiz Mountains (Fig. 2).

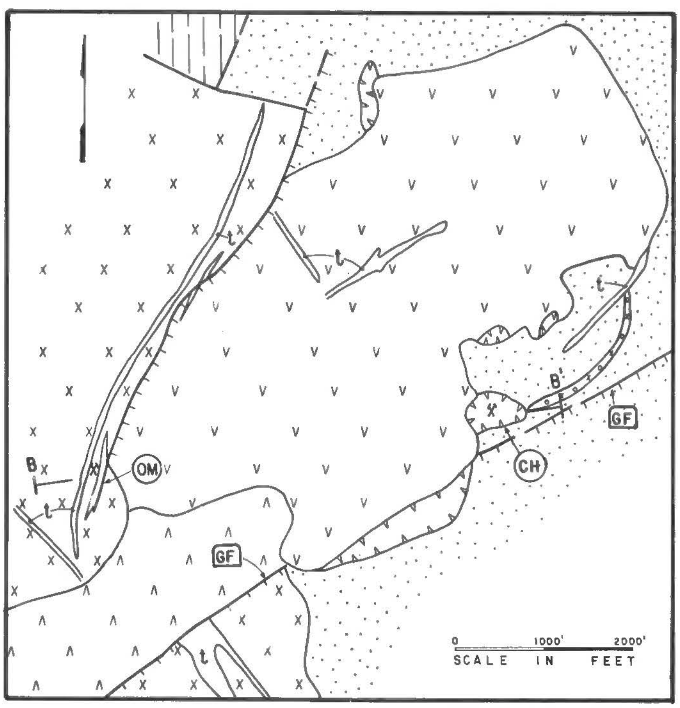

FIGURE 3. Geologic map of the Ortiz diatreme. Diatreme (VV pattern) erupted through Eocene Galisteo Formation (stipple pattern), is faulted against augite monzonite (XX pattern) and is intruded by latite porphyry (^^^). Trachyte dikes (t) intrude all lithologies. xoxo = andesite porphyry; blank = Plio-Pleistocene gravels; OM = Ortiz mine; CH = Cunningham Hill mine. Dapple pattern = breccia. GF = Golden Fault.

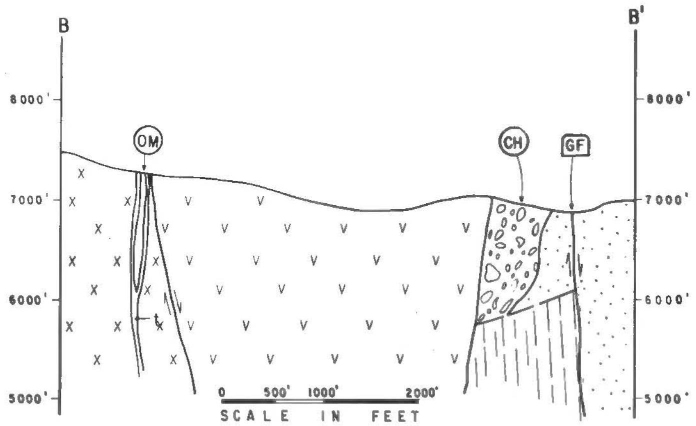

FIGURE 4. Cross section B - B', Ortiz diatreme. Symbols as in Figure 3. Vertical pattern = Upper Cretaceous sedimentary rocks.

Ogilvie (1908) and McRae (1958) noted the presence of nepheline in the augite monzonite. Kay (1986) reported a K-Ar age of 29.6 ± 1.5 Ma on the augite monzonite stock. Based on a presumed thickness of 5000 ft for the Eocene Galisteo Formation (Stearns, 1943; Gorham, 1979), the augite monzonite stock intruded the Galisteo Formation to within 3500 ft of its projected surface. The augite monzonite stock cut across the Ortiz graben and produced a contact-metamorphic aureole in the surrounding sedimentary rocks.

The Ortiz diatreme consists of lithic tuff that fills a steep-sided elliptical basin that measures 3900 ft by 6900 ft (Figs. 2, 3). It has been drilled to a depth of 1600 ft. The diatreme is composed of tuff, lithic tuff and volcanic breccia. Lithic clasts include augite monzonite, latite-andesite porphyry, and Cretaceous and Eocene sedimentary rocks. The diatreme is interpreted to be one of the sources of the Oligocene Espinaso Formation volcanics (Stearns, 1953a).

Quartz latite and latite porphyry form an elongate stock that intrudes both the Ortiz diatreme and the augite monzonite, and a small plug northwest of Carache Canyon (Fig 2). The latite was dated by K-Ar at 30.3 ± 1.2 Ma (Kay, 1986). Trachyte dikes, ranging in composition from feldspathoid- to quartz-bearing, fill fractures and faults generally parallel to the TCFS. They intrude the quartz latite and latite-porphyry stock, the Carache Canyon breccia pipe, and the Cunningham Hill breccia (Figs. 3–6). Trachyte/latite porphyry was dated by K-Ar at 29.9 ± 1.2 Ma (Kay, 1986).

Structure

The TCFS dominates the Ortiz Mountains' structural geology. Most gold mines and prospects in the Ortiz Mountains lie on or within a few hundred feet of strands of the TCFS (Figs. 2, 3, 5). The Ortiz graben, the principal structure of the TCFS in the Ortiz Mountains, contains several tilted blocks of Eocene Galisteo and Upper Cretaceous Menefee Formations. These blocks are juxtaposed with Cretaceous rocks on the north side of the graben and against Triassic to Cretaceous rocks on the south side. Vertical stratigraphic separations of 2000 to 4000 ft are estimated on the graben's bounding faults.

Left-lateral stratigraphic separation of the Upper Cretaceous Dakota Formation measures about 3 mi across the TCFS. The northern side of the TCFS is downthrown relative to the southern side. Due to the lack of piercing points on the fault surfaces, the true amount and direction of displacement are unknown.

The Ortiz diatreme, or vent breccia, erupted on the northwest graben-bounding fault and partly occupies it. Breccia bodies occur in two principal zones on the southeastern and northwestern diatreme margins. The northwestern margin is a fault contact of the vent breccia with the augite monzonite. The southeastern margin is an intrusive contact characterized by intense brecciation of the wall rocks, as at the Cunningham Hill mine (Figs. 3, 4; Lindqvist, 1980; Wright, 1983; Kay, 1986). The southeastern margin of the Carache Canyon breccia pipe lies about 400 ft to the northwest of the Ortiz graben margin (Figs. 5, 6). The pipe is about 2000 by 1000 ft, elongate in a northeast-southwest direction and plunges 75°SW.

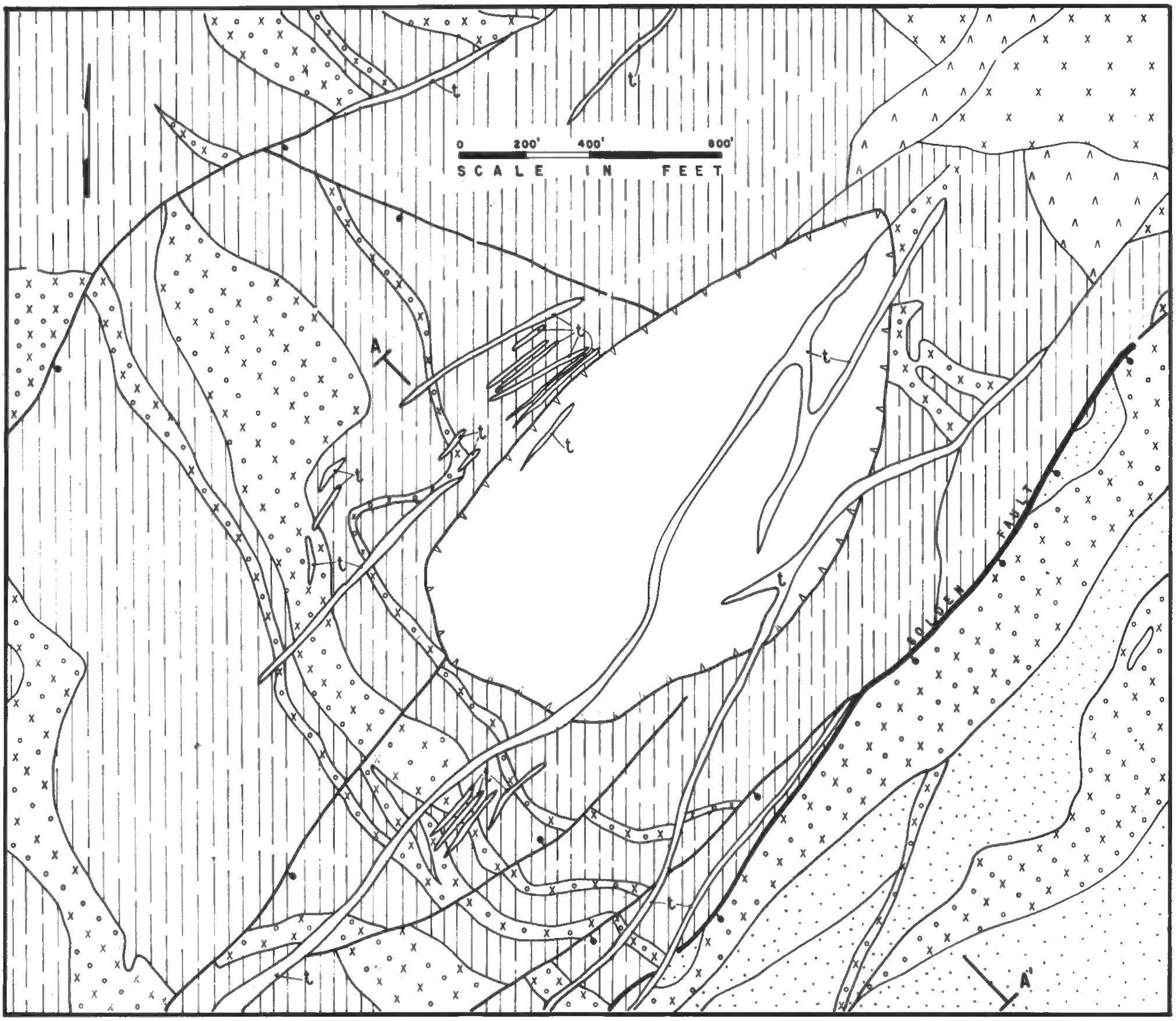

FIGURE 5. Simplified geologic map of Carache Canyon. Vertical pattern = Upper Cretaceous sedimentary rocks. $x^{o}_{x}o$ = Andesite porphyry. Stipple = Galisteo Formation. t = Trachyte dikes. XX = Augite monzonite. ^^ = Latite porphyry. Toothed line is outline of Carache Canyon breccia pipe. Upper Cretaceous sedimentary rocks and andesite porphyry sills dip approximately 30° to the east. Andesite porphyry sills host gold mineralization in open space fractures adjacent to the southern margin of the breccia pipe.

GOLD MINERALIZATION

Ortiz Mountains lode gold prospects and deposits in the Ortiz Mountains generally occur along or near TCFS strands (Fig 2). Four styles of lode mineralization occur: breccias at Carache Canyon and Cunningham Gulch, skarns at Lukas Canyon and iron "vein", veins at the Ortiz and Candelaria Mines, and porphyry-type occurrences at Candelaria Mountain and Cunningham Gulch. Placer gold deposits in Plio-Pleistocene gravels lie on the eastern and southern mountain flanks.

Breccias

Cunningham Hill

Micron-size gold is associated with pyrite, magnetite, calcite, siderite, quartz, chalcopyrite, and/or scheelite crystals in open spaces in a clast-supported breccia at Cunningham Hill. Clasts, mainly of quartzite derived from the Eocene Galisteo Formation, are strongly rotated and mixed. Clasts of diatreme volcanics are also present near the diatreme contact.

The sandstone (quartzite) host is coarse to pebbly and locally conglomeratic, and contains petrified wood fragments. It is more than 200 ft thick at Cunningham Hill and more than 1000 ft thick in the Ortiz graben. Comparison to stratigraphy described by Stearns (1943, 1953c), Gorham (1979), and Picha (1982), allows correlation of the sandstone (quartzite) with the lower part of the Eocene Galisteo Formation. Earlier workers (Bachman, 1975; Wright, 1983; Kay, 1986) believed the sandstone to be part of the Upper Cretaceous Mesaverde Group.

Consolidated Gold Fields recovered about 250,000 oz of gold from the Cunningham Hill open pit mine from 1979 through 1987. Mined reserves totaled 0.055 oz per short ton (st) in 6 million st. Gold recovery from ore mined was about 75% (G. Griswold, personal commun., 1995).

Carache Canyon

The Carache Canyon gold deposit is largely contained in open-space fractures around the western and southwestern margins of a breccia pipe measuring 1900 ft by 1000 ft on the surface. Pegasus Gold Corporation published a resource of 16.7 million st averaging 0.070 oz/ton gold or 1.17 million oz gold at Carache Canyon. The pipe has been drilled to a depth of more than 3000 ft. The breccia pipe formed in Mancos Shale and Mesa Verde Group sediments that had been intruded by multiple sills of andesite porphyry (Figs. 5, 6). Clasts of the Point Lookout Sandstone record the amount of collapse of the pipe (Fig. 6). The breccia is clast supported with black rock-flour matrix.

Open-space fractures cut wall rocks and the black-matrix breccia, and are best developed in more competent wall-rock lithologies such as andesite porphyry and sandstone. Free gold with sphalerite, chalcopyrite, ga-

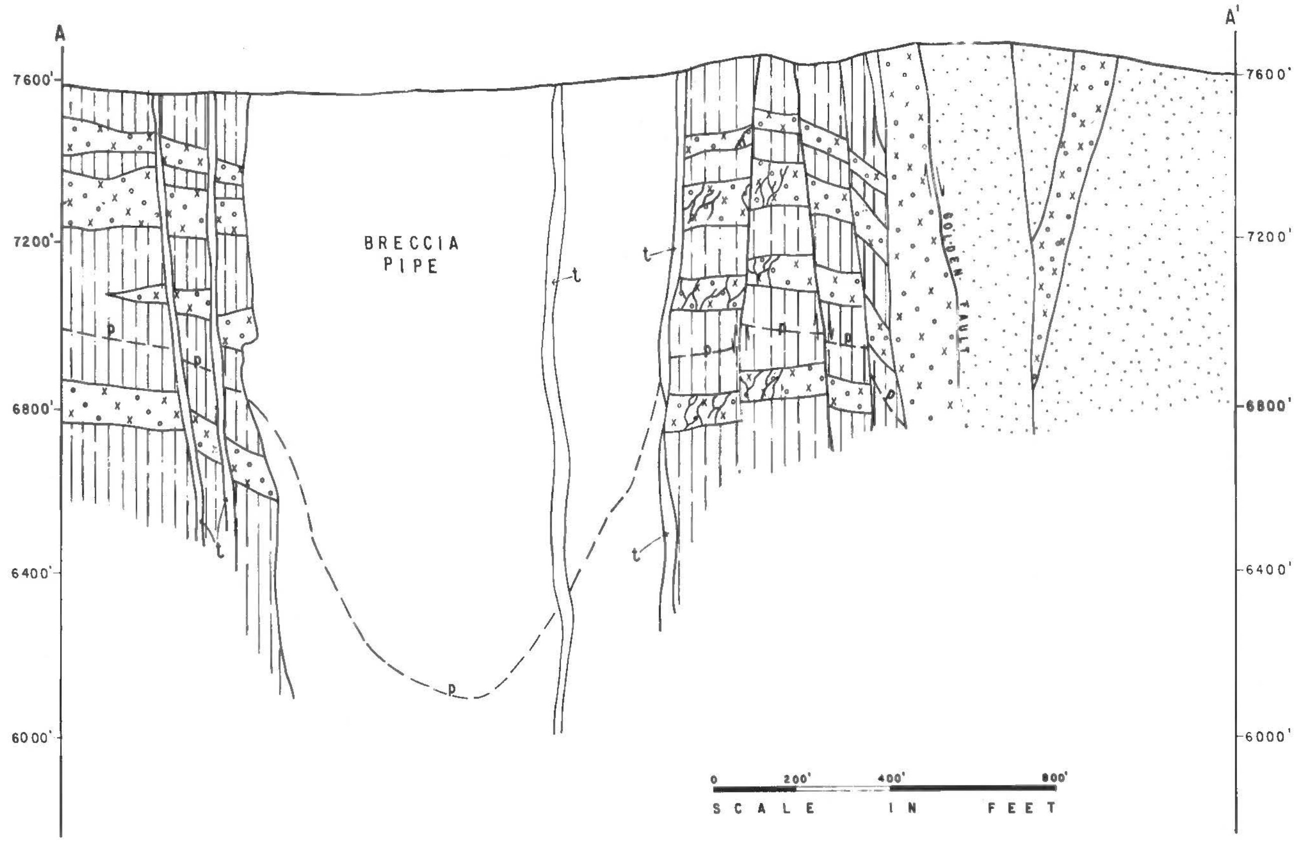

FIGURE 6. Cross section A - A', view N45°E, Carache Canyon breccia pipe. Vertical pattern = Upper Cretaceous sedimentary rocks. xoxo = andesite porphyry; stipple = Galisteo Formation; t = trachyte dikes; P = base of Upper Cretaceous Point Lookout Sandstone. The Carache Canyon breccia pipe propagated through Upper Cretaceous sedimentary rocks that had been intruded by andesite porphyry sills. Note the sagging of the base of the Point Lookout sandstone in the breccia pipe. Trachyte dikes cut the breccia pipe. Note mineralization (stockwork pattern) hosted by andesite porphyry sills on south east side of breccia pipe.

lena, pyrrhotite, pyrite, adularia and/or calcite occurs in open-spaced fractures. Mineralization is concentrated in a series of stacked, tabular bodies that lie outside the breccia pipe (Figs. 5, 6).

Conoco, Inc., LAC Minerals, USA, Inc., and Pegasus Gold, Inc., have drilled more than 200,000 ft at Carache Canyon. Schutz (this volume) describes the mineralogy, alteration and gold distribution of Carache Canyon. Coles (1990) discussed fluid inclusion and petrographic relationships of Carache Canyon mineralization and associated igneous rocks.

Skarns

Lukas Canyon

The Lukas Canyon deposit is a copper-gold, garnet-pyroxene skarn developed in the Greenhorn Member of the Mancos Formation. It contains a 180,000 ounce gold resource averaging 0.03 oz/st gold and 0.25% copper in 6 million st.

The Greenhorn in the Ortiz Mountains is a 50–60 ft thick micritic to bioclastic limestone with thin discontinuous shale beds. Gold and copper mineralization postdates the primary skarn. It is believed to be related to a late retrograde alteration event where the garnet-pyroxene skarn was altered to chlorite-actinolite-epidote. The deposit has been intensely oxidized, resulting in a complex assemblage of copper and iron oxides. Pyrite and chalcopyrite are locally present in portions of the deposit more than 100 ft from the surface. The skarn crops out on a dip slope, making it amenable to surface-mining methods.

Prograde garnet-pyroxene alteration of the limestone is probably related to the Candelaria monzodiorite. However, gold and copper associated with the retrograde assemblage may have its source in or related to trachyte (alkalic) dikes that cut the monzodiorite and other rocks in the vicinity of Lukas Canyon.

Iron "vein"

Gold-bearing magnetite-hematite garnet skarn developed in the limestone member of the Jurassic Todilto Formation along the southeastern Ortiz graben margin, forming the iron "vein". Breccia clasts of Jurassic Morrison Formation sandstone and shale are supported by a yellow-orange sand, calcite, clay and gypsum matrix apparently derived from the gypsum member of the Todilto. Solution breccia in the Todilto gypsum is exposed about 3 mi southwest of the iron "vein" along the TCFS, suggesting that it may be a regional feature. The prospect lies in a zone 100 to 300 ft south of and parallel to the Buckeye Hill fault, the south bounding fault of the Ortiz graben. Iron "vein" gold mineralization appears to be related to faulting and to an underlying stock as suggested by magnetic surveys.

Veins

Ortiz mine

The Ortiz mine was the original lode producer in the Ortiz Mountains. Workings, developed principally in the 1850s to 1860s and in the 1890s, exploited a vein system striking N28°E and dipping 76°W for 400 ft along strike and 350 ft in depth. The vein cuts augite monzonite and is roughly parallel to the augite monzonite/diatreme contact. Oxidation extends to a depth of about 250 ft. The oxidized ore consisted of limonite, calcite, quartz and specularite. Unoxidized ore contained pyrite, quartz, lesser calcite, minor chalcopyrite, minor galena and magnetite.

No production records exist for the Ortiz mine, but a sampling program conducted by Shorey (Ortiz Mining Co., unpubl., 1948) indicates an average grade of the vein at the 350 ft level to be 0.53 oz/t gold. This figure suggests a conservative estimate of 20,000 oz of gold produced, assuming constant grade to the surface and leaving about 50% as unmined pillars.

Candelaria mine

The Candelaria mine was developed to a depth of 250 ft on a group of calcite veins that cut hornfels derived from the Carlile Member of the Mancos Formation on the south side of Candelaria Mountain. Production from the Candelaria vein is unknown, but high-grade coarse gold is said to have been encountered (C. Griswold and G. Griswold, unpubl. report to Ortiz Mining Co., 1950).

Porphyries

Cunningham Gulch

The Cunningham Gulch low-grade, gold-bearing, copper-porphyry mineralization is cored by a barren latite porphyry stock with mineralization developed in surrounding augite monzonite. Crackle breccia and stockwork tenorite + magnetite ± fluorite ± molybdenite veinlets are associated with gold mineralization in oxidized rock at the surface and in shallow drilling. Unoxidized rock contains chalcopyrite instead of tenorite in deep drilling.

Candelaria monzodiorite stock

Magnetite-rich, irregular, discontinuous intrusion breccias developed at the monzodiorite stock contacts in the southwestern Ortiz Mountains. Low-grade gold (0.01 oz/st) mineralization is associated with magnetite.

Placers

Placers produced at least 70,000 oz of gold from the Ortiz Mountains, mainly during the 19th century. These are paleoplacers developed in the Plio-Pleistocene Tuerto Gravel. The most productive placer grounds have been on Cunningham Mesa (east of Cunningham Hill), at the mouths of Carache Canyon and Lukas Canyon, and at the iron "vein". Placer gold potential still exists in the Tuerto Gravel on Cunningham Mesa.

SUMMARY AND CONCLUSIONS

Two stages of magmatism are present in the Ortiz Mountains. The first stage was calc-alkaline laccolith development at about 34 Ma. Alkaline stocks, volcanics, and dikes, whose isotopic ages range from 30 to 28 Ma, cut the calc-alkaline rocks and constitute the second group.

The Ortiz graben formed subsequent to intrusion of the calc-alkaline intrusive rocks. Augite monzonite, part of the alkalic suite, intrudes the bounding faults of the Ortiz graben. Formation of the graben, the principal structure of the Tijeras-Canoncito fault system in the Ortiz Mountains, is thus constrained to the interval 34 to 30 Ma.

Gold mineralization in the Ortiz Mountains occurs in a variety of settings in or near structures associated with the TCFS and is spatially associated with late trachyte dikes. The association with trachyte dikes suggests an age of mineralization of approximately 28 Ma.

ACKNOWLEDGMENTS

The author thanks the management of LAC Minerals, USA, Inc., for permission to publish this information. Many geologists contributed to the understanding of Ortiz Mountains geology; they are too numerous to mention but their contribution is here acknowledged. K. W. Martin and M. S. Fulp reviewed the manuscript.

REFERENCES

Atkinson, W.W., 1961, Geology of the San Pedro Mountains, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 77, 49 p.

Bachman, G.O., 1975, Geologic map of the Madrid quadrangle, Santa Fe and Sandoval counties, New Mexico: U.S. Geological Survey, Geological Quadrangle Map GQ-1268, scale 1:63,360.

Bachman, G.O. and Mehnert, H.H., 1978, New K-Ar dates and the late Pliocene to Holocene geomorphic history of the central Rio Grande region, New Mexico: Geological Society of America Bulletin, v. 89, p. 283–292.

Coles, D.W., 1990, Alteration and mineralization of the Carache Canyon gold prospect, Santa Fe County, New Mexico [MS Thesis]: Fort Collins, Colorado State University, 183 p.

Disbrow, A.E. and Stoll, W.C., 1957, Geology of the Cerrillos area, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 48, 73 p.

Gorham, T.W., 1979, Geology of the Galisteo Formation, Hagan Basin, New Mexico [M.S. thesis]: Albuquerque, University of New Mexico, 136 p.

Kautz, P.F., Ingersoll, R.V., Baldridge, S.W., Damon, P.E. and Shafiqullah, M., 1981, Geology of the Espinaso Formation (Oligocene), north-central New Mexico: Geological Society of America Bulletin, v. 92, p. 2318–2400.

Kay, B.D., 1986, Vein and breccia gold mineralization and associated igneous rocks at the Ortiz Mine, New Mexico, USA [MS thesis]: Golden, Colorado School of Mines, 179 p.

Kelley, V.C. and Northrop, S.A., 1975, Geology of Sandia Mountains and vicinity: New Mexico Bureau of Mines and Mineral Resources, Memoir 29, 136 p.

Lindqvist, W.F., 1980, The exploration of the Ortiz gold deposit, New Mexico—geology and exploration: Colorado Mining Association, 1980 Yearbook, p. 106–112.

Lisenbee, A.L., Woodward, L.A. and Connolly, J.R., 1979, Tijeras-Cañoncito fault system—a major zone of recurrent movement in north-central New Mexico: New Mexico Geological Society, Guidebook 30, p. 89–99.

McRae, O.M., 1958, Geology of the northern part of the Ortiz Mountains, Santa Fe County, New Mexico [M.S. thesis]: Albuquerque, University of New Mexico, p. 112.

Ogilvie, I.H., 1908, Some igneous rocks from the Ortiz Mountains, New Mexico: Journal of Geology, v. 16, p. 230-238.

Picha, M.G., 1982, Structure and stratigraphy of the Montezuma salient–Hagan Basin area, Sandoval County, New Mexico [M.S. thesis]: Albuquerque, University of New Mexico, 248 p.

Schutz, J.L., 1995, Gold mineralization associated with alkaline intrusives at the Carache Canyon breccia pipe prospect, Ortiz Mountains, New Mexico: New Mexico Geological Society, Guidebook 46.

Stearns, C.E., 1943, The Galisteo Formation of north-central New Mexico: Journal of Geology, v. 51, p. 301–319.

Stearns, C.E., 1953a, Early Tertiary volcanism in the Galisteo–Tonque area, north-central New Mexico: American Journal of Science, v. 251, p. 415–452.

Stearns, C.E., 1953b, Tertiary geology of the Galisteo-Tonque area, north-central New Mexico: Geological Society of America Bulletin, v. 64, p. 459–508.

Stearns, C.E., 1953c, Upper Cretaceous rocks of the Galisteo-Tonque area, north-central New Mexico: American Association of Petroleum Geologists Bulletin, v. 37, p. 961–974.

Woodward, L.A., 1984, Basement control of Tertiary intrusions and associated mineral deposits along Tijeras-Canoncito fault system, New Mexico: Geology, v. 12, p. 531–533.

Wright, A., 1983, The Ortiz gold deposit (Cunningham Hill)—geology and exploration: Nevada Bureau of Mines and Geology, Report 36, p. 42–51.