Geology and mineral resources in the Cornudas Mountains, Otero County, New Mexico and Hudspeth County, Texas

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GEOLOGY AND MINERAL RESOURCES OF THE CORNUDAS MOUNTAINS, OTERO COUNTY, NEW MEXICO AND HUDSPETH COUNTY, TEXAS

VIRGINIA T. McLEMORE and JAMES R. GUILINGER


Abstract—The Cornudas Mountains form the northern part of the Trans-Pecos magmatic province in southern New Mexico and northern Texas. Ten larger intrusive bodies and numerous dikes, sills and smaller plugs have intruded Permian and Cretaceous limestones and other sedimentary rocks. The intrusives range in age from 33 to 36 Ma. The Cornudas Mountains have been examined for potential economic deposits of gold, silver, beryllium, rare-earth elements, niobium and uranium but no economic deposits have been found. However, Addwest Minerals, Inc. recently began exploration and development of the Wind Mountain nepheline syenite for use in amber-colored beverage containers and ceramics. Production is expected within a few years. The Cornudas Mountains alkalic igneous rocks form the eastern limit of a progressive change from alkalic-igneous rocks in the eastern Trans-Pecos magmatic province to less alkalic and calc-alkalic igneous rocks in western Trans-Pecos Texas, Mexico and southwestern New Mexico. This change in magmatism corresponds in time to the transitional interval between Laramide compressional tectonics and younger Basin and Range extensional tectonics. Great Plains Margin gold-silver deposits (i.e., alkalic-related gold deposits), including those elsewhere in New Mexico and along the North American Cordilleran alkalic-igneous belt, appear to be related to back-arc extension, hot spots and complex, multiple cycles of magmatic differentiation resulting in both alkalic and calc-alkalic igneous rocks. If these constraints are required to form Great Plains Margin gold-silver deposits, the Cornudas Mountains may be unfavorable for such deposits.

INTRODUCTION

The Cornudas Mountains are a cluster of Tertiary intrusive bodies that stand above the Otero and Diablo platforms as tall, rounded peaks (Fig. 1). The Otero and Diablo platforms are part of the Basin and Range physiographic province in Otero and Hudspeth Counties (Fig. 2; King and Harder, 1985). The Cornudas Mountains have been examined for potential economic deposits of gold, silver, beryllium, rare-earth elements, niobium and uranium. There has been no production to date. Recently, Addwest Minerals, Inc. began exploration and development of the nepheline syenite at Wind Mountain for use in amber-colored beverage containers and ceramics. Production of nepheline syenite by open-pit methods is expected to occur within the next few years.

The Cornudas Mountains form part of the northern portion of the Trans-Pecos magmatic province, a regional belt of igneous rocks that lie within an area defined by the Rio Grande on the west and south, the Pecos River on the east and an east-west line approximately 12 km north of the boundary between New Mexico and Texas (Fig. 2). This province contains more than 200 intrusive bodies, each with an outcrop area exceeding 1 km² (Barker, 1977, 1987).

The Cornudas Mountains and the Trans-Pecos magmatic province are part of a diffuse belt of Cenozoic alkalic-igneous rocks that extends along the eastern margin of the North American Cordillera and Basin and Range provinces (Fig. 3). This belt extends from southeast Alaska and British Columbia southward into Trans-Pecos Texas (Mutschler et al., 1991a; Woolley, 1987) and continues southward for approximately 200 km into eastern Mexico (Barker, 1977; Woolley, 1987). The southern part of the North American Cordilleran alkalic igneous belt overlaps the gradational boundary between the Cordillera (including the Basin and Range) and the Great Plains provinces.
igneous belt has been explored and exploited for numerous types of mineral deposits, especially gold and silver (Fig. 3; North and McLemore, 1986, 1988; Clark, 1989; Mutschler et al., 1991a, b; Thompson, 1991, 1992), fluorite (van Alstine, 1976), rare-earth elements (Woolley, 1987) and uranium.

The Trans-Pecos magmatic province forms part of the southern portion of the North American Cordilleran alkalic igneous belt. This southern area is now recognized as the eastern limit of a Tertiary "magmatic sweep" of decreasing age of magmatic activity from the California coastline eastward to the Great Plains Margin. This "magmatic sweep" is linked to the progressive shallowing of the subduction of the Farallon plate beneath the North American plate with time (Coney, 1972; Sillitoe, 1972; Barker, 1977, 1987; Damon et al., 1981; Clark et al., 1982; Campy and Coney, 1983; Clark, 1989; Henry et al., 1989). However, the northern portion of the belt (including Colorado and northward) may be related to back-arc extension rather than subduction (Thompson, 1991, 1992; Mutschler et al., 1991a; EGGLE and Furlong, 1991). Some areas of alkalic magmatism in this belt may be a result of deep-seated asthenospheric mantle plumes or hot spots (Mutschler et al., 1991b).

The Cornudas Mountains and Trans-Pecos Texas are critical areas for understanding the tectonic and magmatic evolution of western North America (Henry et al., 1991). This region is the eastern limit of Cenozoic magmatic activity, which has occurred in this area nearly continuously from 48 to 17 Ma and overlaps the change in tectonic style from Laramide compression to Basin and Range extension. Compositions of igneous rocks are alkalic in the eastern portions of the Trans-Pecos belt, including the Cornudas Mountains, and become progressively less alkaline and more calc-alkaline westward into Mexico (Fig. 2; Barker, 1977, 1987; Price and Henry, 1984; Cameron and Cameron, 1985; Price et al., 1987; Clark, 1989).

Earlier interpretations by Barker (1977) suggested an analogy between the Trans-Pecos magmatic province and the Kenya portion of the East African rift. However, subsequent work has shown that much of the Cenozoic faulting in Trans-Pecos Texas thought to be associated with riftting postdates most igneous activity (Barker, 1987; Henry et al., 1991). Trans-Pecos magmatism began during the Laramide compressional period, prior to igneous activity associated with the Rio Grande rift. The magmatism in Trans-Pecos Texas and adjacent New Mexico appears to be related to subduction rather than continental rifting (Barker, 1987; Henry et al., 1991).

GEOLGY

The Cornudas Mountains are a group of Late Eocene to Oligocene laccoliths, sills, plugs and dikes of predominantly nepheline syenite, phonolite and trachyte (Fig. 4; Table 1). Ten larger intrusive bodies and numerous dikes, sills and smaller plugs have intruded the relatively flat-lying limestones and other sedimentary rocks of Permian and Early Cretaceous age (see Kues and Lucas, this volume). Most of the Permian sedimentary rocks belong to the Hueco Limestone and Bone Springs Limestone. Undoubtedly, numerous sills, dikes and plugs remained buried by the sedimentary cover and are inferred or detected by subsurface drilling (King and Harder, 1985), geophysical surveys and perhaps by structural anomalies (i.e., folds, synclines, faults) in the overlying sedimentary rocks.

The larger laccoliths and sills, except for the Cornudas Mountain laccolith, are composed predominantly of dark gray to pink, fine- to coarse-grained to porphyritic nepheline syenites, syenites and phonolites (Table 1). Cornudas Mountain is a deeply weathered and eroded laccolith or plug consisting of light gray to pink gray quartz syenite to syenite and trachyte (Table 1; Zapp, 1941).

The laccoliths are texturally and compositionally zoned. Extremely diverse compositions and textures of varying grain size are found within single intrusive bodies. Detailed geologic mapping of possible textural and compositional zones within the laccoliths is hampered by steep terrain, talus-covered slopes and locally poor exposure. Wind Mountain displays excellent zoning. A medium-grained nepheline syenite porphyry forms a rim surrounding a coarse-grained nepheline syenite porphyry, which surrounds a central core of fine-grained syenite porphyry.

REGIONAL SETTING

Lindgren (1915) first noted that a belt of alkalic igneous rocks extends from Canada into eastern Mexico and that these rocks contain relatively large quantities of chlorine, fluorine, strontium, zirconium and rare-earth elements. Since then, the North American Cordilleran alkalic...
Younger dikes, some pegmatitic, others aphanitic, intruded many of the laccoliths. Mapping of other laccoliths is needed to determine if they too are zoned.

Numerous dikes, sills and small plugs of varying textures and lithologies intrude the sedimentary rocks throughout the Cornudas Mountains. Some smaller intrusives can be traced into major laccoliths, where they either remain as discrete dikes or become gradational zones within the laccolith. Silicification and brecciation of some dikes and plugs occur in the Chess Draw area.

Barker et al. (1977) divided the lithologies found in the Trans-Pecos magmatic province into nine types based on mineralogy and texture: (1) nepheline-bearing augite syenite, (2) nepheline-bearing trachyte, (3) syenite, (4) nepheline syenite, (5) porphyritic nepheline syenite, (6) phonolite, (7) foliated porphyritic nepheline syenite, (8) quartz-bearing syenite and (9) quartz-bearing trachyte. All nine types are found in the Cornudas Mountains. The Cornudas Mountains also contain less common minerals that are typically found in alkalic-igneous rocks throughout the world (Table 3). Several of these minerals (georgechaoite, parakeldyshite, catapleiite; Boggs and Ghose, 1985; Barker and Hodges, 1977) are extremely rare and found elsewhere in only a few localities in the world.

Chemical analyses of igneous rocks from the Cornudas Mountains (Table 4) show that they are similar in composition to other alkalic-igneous rocks in the Trans-Pecos magmatic province (Figs. 6, 7; Barker et al., 1977; Barker, 1987). Skarns adjacent to some intrusions are present in the Cornudas Mountains. Small dikes and plugs intrude the adjacent limestone and have produced a mineral assemblage of calcite, grossularite, idocrase, apophyllite and wollastonite, with local prehnite and chondrodite (Barker et al., 1977). Zones of marble and diopside-bearing hornfels are also locally common (Figs. 8, 9).

### Table 1. Description of igneous intrusive bodies within the Cornudas Mountains. Bodies shown in Fig. 4.

<table>
<thead>
<tr>
<th>Name</th>
<th>Predominant lithology</th>
<th>Form</th>
<th>Age</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alamo Mountain</td>
<td>phonolite, foliated porphyritic nepheline syenite</td>
<td>discordant sheet or sill</td>
<td>36.8 ± 0.6 (K/Ar on biotite)</td>
<td>Barker et al. (1977); Clabaugh (1941); Henry et al. (1986)</td>
</tr>
<tr>
<td>Flat Top Mountain</td>
<td>phonolite, augite syenite dike</td>
<td>sill</td>
<td></td>
<td>Barker et al. (1977); Clabaugh (1941)</td>
</tr>
<tr>
<td>Cornudas Mountain</td>
<td>quartz-bearing syenite, syenite, trachyte</td>
<td>plug or laccolith</td>
<td>34.6 ± 1.5 (K/Ar on biotite)</td>
<td>Barker et al (1977); Zapp (1941); Henry et al. (1986)</td>
</tr>
<tr>
<td>Wind Mountain</td>
<td>nepheline syenite, phonolite, porphyritic nepheline syenite</td>
<td>laccolith</td>
<td></td>
<td>Barker et al. (1977); Warner et al. (1959); This report (Fig. 5)</td>
</tr>
<tr>
<td>San Antonio Mountain</td>
<td>nepheline syenite</td>
<td>laccolith</td>
<td></td>
<td>Timm (1941); Barker et al. (1977)</td>
</tr>
<tr>
<td>Deer Mountain (Little Wind Mountain)</td>
<td>nepheline syenite</td>
<td>plug or laccolith</td>
<td>33.0 ± 1.4 (K/Ar on biotite)</td>
<td>Barker et al. (1977); Clabaugh (1941, 1950); Henry et al. (1986)</td>
</tr>
<tr>
<td>Chattfield Mountain</td>
<td>phonolite</td>
<td>sill</td>
<td></td>
<td>Timm (1941); Barker et al. (1977)</td>
</tr>
<tr>
<td>Black Mountain</td>
<td>porphyritic nepheline syenite</td>
<td>sill</td>
<td></td>
<td>Barker et al. (1977)</td>
</tr>
<tr>
<td>Washburn Mountain</td>
<td>porphyritic nepheline syenite</td>
<td>sill</td>
<td></td>
<td>Timm (1941); Barker et al. (1977)</td>
</tr>
<tr>
<td>Unnamed hill</td>
<td>nepheline-bearing augite syenite</td>
<td>plug</td>
<td>36.8 ± 0.6 (K/Ar on biotite)</td>
<td>Barker et al. (1977); Clabaugh (1941); Henry et al. (1986)</td>
</tr>
</tbody>
</table>

### MINERAL DEPOSITS

**Uranium**

In the 1950s, prospectors located several areas of anomalously high radioactivity in the Cornudas Mountains and attributed it to the presence of uranium. Shallow prospect pits were dug on many of the claims in the area, but assay results were very low and the claims were dropped with no production. In 1956, the U.S. Atomic Energy Commission examined the area to evaluate the potential for uranium (Collins, 1958).
**Nepheline Syenite Porphyry**—medium grained K-feldspar phenocrysts in a matrix of dominant plagioclase with moderate interstitial nepheline and minor analcite plus accessory aegerite-soda amphibole-biotite and minor magnetite.

Malic zoning/lamination

**Nepheline Syenite Porphyry**—medium grained K-feldspar is present as subhedral blocky prisms. Interstitial nepheline plus accessory arfvedsonite-aegerite and minor magnetite are present in a plagioclase rich groundmass. The orientation of the feldspar crystals are vertical rather than flat (as in the main intrusive mass), suggesting a different intrusive phase.

**Nepheline Syenitic Dikes**—fine grained massive crystalline dike-like bodies outcrop around the stock in the hornfels facies of the limestone.

**Limestone**—Huerra Fm. and Bone Spring Fm. limestone undifferentiated. Near the contact with the stock, the limestone is altered to a hornfels facies by contact metamorphism.

**Prospect**

**FIGURE 5.** Geologic map of Wind Mountain (P. Grasch, field mapping, July 1992).

<table>
<thead>
<tr>
<th>Unit</th>
<th>Albite</th>
<th>K-feldspar</th>
<th>Nepheline</th>
<th>Amphibole</th>
<th>Pyroxene</th>
<th>Zeolite</th>
<th>Magnetite</th>
<th>Mica</th>
<th>FeO and clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knob Tsp1</td>
<td>50</td>
<td>32</td>
<td>6</td>
<td>8</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>Pit 2 Tsp2</td>
<td>64</td>
<td>15</td>
<td>10</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Coarse Tsp1</td>
<td>42</td>
<td>30</td>
<td>8</td>
<td>2</td>
<td>6</td>
<td>10</td>
<td>2</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Upper Tspf4</td>
<td>65</td>
<td>18</td>
<td>3</td>
<td>7</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Upper Tspf3</td>
<td>55</td>
<td>20</td>
<td>4</td>
<td>5</td>
<td>14</td>
<td>3</td>
<td>1</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Top Tspf1</td>
<td>60</td>
<td>20</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

FIGURE 6. Na₂O + K₂O–SiO₂ diagram, showing the similarity in composition of igneous rock samples from Cornudas Mountains and Trans-Pecos magmatic province (Price et al., 1987; Barker et al., 1977). Squares represent samples from Cornudas Mountains. Line separating alkaline and subalkaline fields from Irvine and Baragar (1971).

FIGURE 7. Na₂O + K₂O–SiO₂ diagram, showing the similarity in composition of igneous samples from Cornudas Mountains and Sierra Blanca older suite (SBOS) in the Lincoln County porphyry belt (Allen and Foord, 1991; Moore et al., 1991; McLemore et al., 1991). Note the difference in composition of samples from the Cornudas Mountains and Sierra Blanca younger suite (SBYS). Squares represent samples from Cornudas Mountains. Line separating alkaline and subalkaline fields from Irvine and Baragar (1971).

TABLE 3. Selected less common minerals reported from the Cornudas Mountains.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Chemical formula</th>
<th>Occurrence</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>analcime</td>
<td>NaAl Si₃O₆ · H₂O</td>
<td>replaces nepheline, lines vugs, vescicles and mafic lacunae.</td>
<td>Barker and Hodges (1977); Boggs (1985)</td>
</tr>
<tr>
<td>natrolite</td>
<td>Na₂AlSi₃O₁₀ · 2H₂O</td>
<td>replaces nepheline and feldspars</td>
<td>Barker and Hodges (1977)</td>
</tr>
<tr>
<td>olivine</td>
<td>(Mg,Fe)₂SiO₄</td>
<td>mineral aggregates of ferromagnesium minerals and magnetite</td>
<td>Barker and Hodges (1977)</td>
</tr>
<tr>
<td>aegirsite</td>
<td>Na₂Fe₄⁺TiSi₂O₉₀</td>
<td>in nepheline syenite</td>
<td>Barker and Hodges (1977)</td>
</tr>
<tr>
<td>eudialyte</td>
<td>Na₂(Ca,Co)₃(Fe²⁺⁺Mn⁺⁺)Y ZrSi₂O₆(OH,Cl)₂</td>
<td>in dikes, sills, and laccoliths and in mafic lacunae.</td>
<td>Barker and Hodges (1977); Clabaugh (1950); Boggs (1985, 1987)</td>
</tr>
<tr>
<td>catapleite</td>
<td>Na₂Zr₂Si₂O₈ · 2H₂O</td>
<td>mafic lacunae</td>
<td>Boggs (1985)</td>
</tr>
<tr>
<td>georgeochoite</td>
<td>Na₂KZr₂Si₂O₈ · 2H₂O</td>
<td>mafic lacunae</td>
<td>Boggs (1985); Boggs and Ghose (1985)</td>
</tr>
<tr>
<td>aegirine (acmite)</td>
<td>NaFe⁺⁺Si₂O₇</td>
<td>mafic lacunae</td>
<td>Boggs (1985, 1987)</td>
</tr>
<tr>
<td>monazite</td>
<td>(Ce,La,Th,Nd)PO₄</td>
<td>mafic lacunae</td>
<td>Boggs (1985)</td>
</tr>
<tr>
<td>thomsonite</td>
<td>Na₂Ca₂Al₆Si₂O₈ · 6H₂O</td>
<td>mafic lacunae</td>
<td>Zapp (1941); Boggs (1985)</td>
</tr>
<tr>
<td>chabazite</td>
<td>Ca₂(Al₂Si₃O₁₀) · 6H₂O</td>
<td>mafic lacunae</td>
<td>Boggs (1985)</td>
</tr>
<tr>
<td>parakeldyshite</td>
<td>Na₂Zr₂Si₂O₈</td>
<td>nepheline syenite, Wind Mountain</td>
<td>This report</td>
</tr>
<tr>
<td></td>
<td>AS-2</td>
<td>AS-5</td>
<td>DE-1</td>
</tr>
<tr>
<td>------</td>
<td>------</td>
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<tr>
<td>SiO₂</td>
<td>54.10</td>
<td>55.15</td>
<td>56.90</td>
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<tr>
<td>TiO₂</td>
<td>1.81</td>
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<td>Al₂O₃</td>
<td>18.60</td>
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<td>Fe₂O₃</td>
<td>3.46</td>
<td>3.24</td>
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<td>CaO</td>
<td>4.38</td>
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<td>Na₂O</td>
<td>3.67</td>
<td>4.71</td>
<td>5.55</td>
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<tr>
<td>K₂O</td>
<td>5.33</td>
<td>5.85</td>
<td>6.76</td>
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<tr>
<td>MgO</td>
<td>0.17</td>
<td>0.17</td>
<td>0.16</td>
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<tr>
<td>P₂O₅</td>
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<td>0.62</td>
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<tr>
<td>LOI</td>
<td>1.14</td>
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<tr>
<td>CO₂</td>
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<td>0.22</td>
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</tr>
<tr>
<td>TOTAL</td>
<td>100.39</td>
<td>99.01</td>
<td>99.93</td>
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<tr>
<th></th>
<th>Rb</th>
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<th>Zr</th>
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<th>Ni</th>
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<tr>
<td></td>
<td>82</td>
<td>970</td>
<td>29</td>
<td>520</td>
<td>59</td>
<td>90</td>
<td>85</td>
<td>260</td>
<td>52</td>
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<table>
<thead>
<tr>
<th></th>
<th>Na₂O</th>
<th>K₂O</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>9</td>
<td>10.57</td>
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</tbody>
</table>

### Table 4: Chemical analyses of the alkaline rocks in the Cornudas Mountains. AS, CH, De, SA, WS, Z, AL, CO and WN from Barker et al. (1977) and Barker (1987). CORN, FTZSPG2 and FSTNSD samples collected by V. T. McLemore and analyzed by C. M. McKee (NMBRMR, x-ray laboratory). TSNP, PIT 1 and PIT 2 from Addwest Minerals, Inc. (analyses by The Mineral Lab., Inc.). PIT 1 and PIT 2 are analyses of the nonmagnetic fraction only. Fe₅O₄ is total iron calculated as Fe₂O₃. Description of samples in Appendix.
Subsequent assays ranged from 0 to 0.08% U_3O_8 (Collins, 1958). No further work was recommended.

Alkalic rocks are typically enriched in uranium relative to other igneous rocks, and a few alkalic igneous complexes in the world have been exploited for their uranium deposits (Ilimaussaq, Greenland; Pocos de Caldas, Brazil: Murphy et al., 1978). However, the potential for economic uranium deposits in the Cornudas Mountains appears low because of low assays in areas of anomalously high radioactivity and a depressed uranium market (McLemore and Chenoweth, 1989).

**Beryllium**

Beryllium is a strategic mineral used as an alloy and oxide in electronic components, with aerospace and defense applications and other uses (U.S. Bureau of Mines, 1991). A large beryllium deposit occurs near Sierra Blanca, Texas, south of the Cornudas Mountains (Fig. 2), where Cyprus Minerals Inc. announced resources totaling 25 million lbs of beryllium oxide grading greater than 2% BeO (Price et al., 1990; Henry, 1992). Beryllium occurs with fluorite at the contact between Tertiary rhyolite and Cretaceous limestone.

Beryllium was first reported from the Cornudas Mountains during the 1940s, and a few assayed samples contained as much as 0.2% BeO (Warner et al., 1959). Beryllium occurs in feldspar, nepheline, aegirine and eudialite within dikes, sills and laccoliths, but no beryllium minerals have been identified. In the Chess Draw area, northwest of Wind Mountain, only one sample contained 150 ppm Be, whereas the remaining samples from that area contained less than 100 ppm Be (U.S. Borax, written commun. January 1986).

The resource potential for beryllium is moderate to high. Exploration should concentrate along the intrusive contacts between the Tertiary intrusives and Permian limestones for the potential discovery of a beryllium deposit similar to that found at Sierra Blanca, Texas.

**Gold and silver deposits**

A variety of deposits containing gold and silver are associated with alkalic igneous rocks in New Mexico (Great Plains Margin deposits of North and McLemore, 1986, 1988; McLemore, 1991) and elsewhere along the North American Cordilleran belt (Muschler et al., 1991a; Thompson, 1991, 1992). These deposits have produced nearly 13% of the total lode gold production in the United States and Canada (Muschler et al., 1991a). Consequently, numerous private companies have examined the Cornudas Mountains for similar gold-silver deposits, but without success.

Four samples of altered areas in the Chess Draw area, northwest of Wind Mountain, were assayed for gold and silver (Table 5). Only one sample contained a trace of gold (<0.02 oz/ton, 0.7 ppm) and 0.78 oz/ton (27 ppm) of silver. U.S. Borax also sampled and drilled in the Chess Draw area and assayed for gold and silver but their samples contained only trace amounts.

**Rare-earth elements and niobium**

Alkalic igneous rocks may contain high concentrations of rare-earth elements, niobium, zirconium and titanium. Economic deposits are rare but do occur associated with alkalic igneous complexes (Woolley, 1987). A few companies have examined the Cornudas Mountains unsuccessfully for similar deposits. U.S. Borax sampled and drilled in the Chess Draw area, but their assays were low (up to 0.06% total rare-earth oxides; 10-1400 ppm Nb; 10-3000 ppm Zr; 230-13,000 ppm F). An analysis reported by McLemore et al. (1988a, b) contained 1235 ppm Ce, 700 ppm La, 270 ppm Nd and 242 ppm Y. Zirconium silicates are common in the area (Table 2).

The resource potential for economic deposits of rare-earth elements, niobium, zirconium and titanium is unknown in the Cornudas Mountains. Additional geologic, geochemical, geophysical and other exploration techniques are required to properly evaluate this area, especially in dikes and along intrusive contacts with the limestones.

**Nepheline syenite**

Nepheline syenite is a critical ingredient in manufacturing glass and ceramics and also is utilized in filler applications and as roofing granules. There are only two commercial deposits of nepheline syenite in the world, located in Canada and Norway (Potter, 1991), and they average greater than 60% SiO_2, 20-24% Al_2O_3 and less than 0.1% Fe_2O_3. Because a small amount of iron results in colored glass or ceramics, the product sold from a commercial deposit usually

| TABLE 5. Chemical assays of samples from the Chess Draw area (collected by V. T. McLemore and analyzed by L. Brandvold and associates, NMBMMR Chemical Laboratory). |
|-------------------|------------------|-------------------|-------------------|
|                   | 7368             | CORN 16           | CORN 17           | CORN 19           |
| Au                | tr               | 0                 | 0                 | 0                 |
| Ag                | 0.78             | 0                 | 0                 | 0                 |
| Cu                | 10               | 122               | 27                |
| Pb                | 15               | 195               | 22                |
| Zn                | 62               | 122               | 34                |
| Hg                | 0.05             | 0.17              | 0.02              |
must contain small amounts of iron-bearing minerals. Nepheline syenite also imparts the unique quality of toughness to the glass which is more resistant to breakage.

Addwest Minerals, Inc. has discovered that nepheline syenite from Wind Mountain is suitable for dark-colored beverage bottles, ceramics and several other possible uses. The Wind Mountain nepheline syenite is a zoned pluton that ranges from syenite porphyry to nepheline syenite porphyry (Fig. 5; Table 2). Analcime also is present locally as an alteration of nepheline and feldspar, but must be avoided in commercial deposits because it inhibits the fusion required to produce glass and ceramics. Chemically, the deposit consists of 56-63% SiO₂, 17-21% Al₂O₃ and 0.4-5% Fe₂O₃ (Table 3). Although iron is initially high, when the crushed rock is passed through a specialized rare-earth elements magnetic separator, the iron content drops below commercial maximum standards of less than 0.5% Fe₂O₃ (Table 4). The Wind Mountain nepheline syenite is currently under exploration and testing to determine marketability of the deposit. Production is expected within the next few years. Preliminary examination of other intrusives within the Cornudas Mountains failed to locate any additional nepheline syenite deposits suitable for glass and ceramic use. Additional studies are under way.

**DISCUSSION AND PRELIMINARY CONCLUSIONS**

The alkaline-igneous rocks in the Cornudas Mountains are similar in composition to other alkaline igneous rocks in Trans-Pecos Texas and in the Lincoln County porphyry belt (Figs. 6, 7; Barker et al., 1977; Barker, 1987; Allen and Foord, 1991; Moore et al., 1991). However, the alkaline igneous rocks in the Lincoln County porphyry belt and in other areas of the North American Cordilleran alkaline belt are spatially and, locally, genetically related to less alkaline and calc-alkaline igneous rocks (North and McLemore, 1986, 1988; Mutschler et al., 1991a, b; Thompson, 1991, 1992). Calc-alkaline igneous rocks are not exposed in the Cornudas Mountains.

The progressive change in composition of igneous rocks from alkaline in the eastern Trans-Pecos magmatic province to less alkaline to calc-alkaline in the western Trans-Pecos, Mexico and southwestern New Mexico (Fig. 2; Barker, 1977, 1987; Henry and Price, 1984; North and McLemore, 1986, 1988; Price et al., 1987; Clark, 1989; Henry et al., 1991) is consistent with an origin related to subduction of the Farallon plate beneath the North American plate with time. The resulting igneous rocks in the Cornudas Mountains and the Trans-Pecos magmatic province correspond to the eastern limit of the "magmatic sweep" that occurred during the transition between Laramide compressional tectonics and Basin and Range extensional tectonics (Price et al., 1987; Henry et al., 1991). These alkaline-igneous rocks are a result of partial melting and magmatic differentiation of lower crustal and mantle-derived sources (Barker, 1987; Price et al., 1987; Henry et al., 1991). Once the descending slab becomes dehydrated with depth, generation of calc-alkaline magmas decreases, but there is enough heat to cause melting of the overlying asthenosphere that can result in generation of alkaline magmas from mantle sources (Fittin and Upton, 1987). Magmatic differentiation was greater during the Laramide and the transition period than during the Basin and Range extensional period in the Trans-Pecos magmatic province (Price et al., 1987).

Alkaline-igneous rocks are typically associated with deposits or high concentrations of beryllium, rare-earth elements, niobium and uranium. Economic deposits of these commodities are less common but can occur near or within alkaline-igneous complexes. Geologic mapping, geophysical and geochemical surveys and other exploration techniques are required to locate and delineate any potential deposits in the Cornudas Mountains.

Deposits of nepheline syenite suitable for glass and ceramic use are rare because of high concentrations of iron. In addition, alteration of nepheline and feldspar to analcime is undesirable. Petrographic and geochemical studies are required to locate such deposits. Only the Wind Mountain nepheline syenite in the Cornudas Mountains has thus far proven to be suitable for amber-colored beverage containers and ceramics. Additional studies are under way.

Gold and silver are likewise associated with alkaline igneous com-
plexes, especially along the eastern margin of the North American Cordillera. Gold and silver occur in several types of deposits that have been classified together as Great Plains Margin deposits (North and McLemore, 1986, 1988; McLemore, 1991) and alkalic-related gold deposits (Thompson, 1991, 1992; Mutschler et al., 1991a, b; Woodward and Fulp, 1991). However, in many areas of the North American Cordillera where gold-silver deposits are related to alkaline-igneous rocks, the gold-silver deposits are also associated with less alkaline to calc-alkaline igneous rocks (North and McLemore, 1986, 1988; Mutschler et al., 1991a, b; Thompson, 1991, 1992). The igneous rock assemblages in these mineralized areas appear to be related to complex and multiple intrusive cycles of partial melting and differentiation of lower crustal or mantle-deep crustal sources (Thompson, 1991; Mutschler et al., 1991a, b). Hot spots may also be involved. Their tectonic setting appears to be related to back-arc extension rather than to subduction (Eggler and Furlong, 1991; Thompson, 1991).

A combination of tectonic setting (back-arc extension) and complex, multiple intrusive cycles of magmatic differentiation resulting in both alkaline and calc-alkaline igneous rocks may provide constraints on the genesis of alkalic-related gold deposits. If these constraints do apply, the Cornudas Mountains and the Trans-Pecos magmatic province may be unfavorable for the occurrence of Great Plains Margin gold-silver deposits. This theory needs to be investigated further.

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APPENDIX—DESCRIPTION OF SAMPLES

AS-2
called selvage, nepheline-bearing augite syenite
nepheline-bearing augite syenite

AS-5
deleteriously glass dikes in nepheline syenite

DE-1
nepheline syenite, Deer Mountain

DE-5
devitrified glass dikes in nepheline syenite

DE-10
development of groundmass of phenolite dikes, 1 km WSW Deer Mountain

DE-12
Deer Mountain

CH-1
phono-olite, Chaffield Mountain

SA-1
nepheline syenite, San Antonio Mountain

SA-12
porphyritic pitchstone, SE flank San Antonio Mountain

SA-15
phenolite plug, 3.7 km west of Wind Mountain

SA-16
phenolite, Wind Mountain

WN-11
nepheline syenite, Washburn Mountain

Z-2
nepheline syenite

WS-1
nepheline syenite

AL-11
foliated porphyritic nepheline syenite, Alamo Mountain

AL-10
nepheline syenite, Alamo Mountain

CORN-10
nepheline syenite, Alamo Mountain

CORN-11
nepheline syenite, Washburn Mountain

CORN-12
nepheline syenite, Washburn Mountain

CORN-13
nepheline syenite, Washburn Mountain

CORN-14
nepheline syenite, Washburn Mountain

CORN-15
nepheline syenite, Washburn Mountain

CORN-18
nepheline syenite, Washburn Mountain

CORN-19
nepheline syenite, Washburn Mountain

CORN-20
nepheline syenite, Washburn Mountain

CORN-21
nepheline syenite, Washburn Mountain

CORN-22
nepheline syenite, Washburn Mountain

CORN-23
nepheline syenite, Washburn Mountain

F2TSIF62
core sample nepheline syenite, TNSP, Wind Mountain

F2TSIF63
core sample nepheline syenite, TNSP, Wind Mountain

TNSP
nepheline syenite, Washburn Mountain

PTT-1
nonmagnetic separate

PTT 2
nonmagnetic separate
West Dog Canyon in southern Brokeoff Mountains. View is upstream, 582°E. The canyon is about 150–240 m deep. Cliffs and ridges are Grayburg Formation. Lower slopes are San Andres/Cherry Canyon tongue. Creosote bush (medium to dark gray shrub) is confined mainly to the alluvial terrace at right and the alluvial fan at base of canyon wall just above center of photograph. Rugged ground on flood plain at left of center is boudery mudflow or streamflow deposit. The deposit is overgrown with grass and shrubs. The present channel has been diverted south around the deposit. Camera station is in NW¼ sec. 17, T26S, R20E, about 9.5 km southwest of El Paso Gap. Altitude is approximately 1524 m. W. Lambert photograph No. 85L.113. November 16, 1985, 12:25 p.m. MST.