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# *Qualitative relationships of late Cenozoic cinder cones, southern Rio Grande rift, utilizing cone morphology and landsat thematic imagery: A preliminary assessment*

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# QUALITATIVE AGE RELATIONSHIPS OF LATE CENOZOIC CINDER CONES, SOUTHERN RIO GRANDE RIFT, UTILIZING CONE MORPHOLOGY AND LANDSAT THEMATIC IMAGERY: A PRELIMINARY ASSESSMENT

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**Abstract**—The Potrillo and Palomas basalt fields, located in southern New Mexico and northern Chihuahua, respectively, contain abundant cinder cones and basaltic lava flows. Radiometric dates indicate the volcanic activity in the Potrillo field is much younger (20–916 ka) than in the Palomas field (2960–5170 ka). Measurements of cinder cone morphology, including maximum slope angle and radius/height ratios, correlate well with individual ages from both of the fields. The maximum slope angles of the Potrillo cones average 19° versus 6° for the older Palomas cones; radius/height values show a similar relationship, 5.1 for the former, and 9.8 for the latter. In addition, Landsat thematic mapper images of the cinder cones in the Potrillo and Palomas fields increase in apparent reflectance in visible through short wavelength infrared with increasing age. The older Palomas cones display higher reflectance values than the younger Potrillo cones. The spectral reflectance in the visible and infrared wavelengths is due to the alteration of magnetite and/or ilmenite in the basaltic cinder to hematite and goethite.

## INTRODUCTION

Two moderate-sized late Cenozoic volcanic fields occur within the Rio Grande rift in southern New Mexico and northern Chihuahua. The Potrillo basalt field includes Quaternary basalt flows and associated cinder cones that crop out over an area of approximately 405 mi$^2$ in western Doña Ana and eastern Luna Counties in southern New Mexico. The field includes, from west to east, the West Potrillo Basalt, Aden-Afton Basalt and the Black Mountain-Santo Tomas Basalt (Fig. 1). The lava flows are predominantly alkali-olivine basalt (normative nepheline and olivine) and basanite (normative nepheline exceeds 5%) (Hoffer, 1988).

The West Potrillo Basalt is defined as the Quaternary basalt that crops out in the West Potrillo Mountains, a broad topographic high composed almost entirely of volcanic materials. The range rises 400–800 ft above the surrounding desert floor and consists of older fissure-fed lava flows capped by numerous younger cinder cones and associated flows. Two maar volcanoes, Mount Riley and Malpais, have been described in the central and southern sections of the field (Hoffer, 1976).

The Aden-Afton basalt field, east of the West Potrillos, consists of a series of thin basaltic lava flows, a small shield cone (Aden Crater), several cinder cones (Gardner cones), and three maar volcanoes (from north to south, Kilbourne Hole, Hunts Hole, and Potrillo Maar, the latter straddling the International border).

The Black Mountain-Santo Tomas basalt field refers to four small volcanic centers on the eastern margin of the La Mesa surface; from south to north the centers include Black Mountain, Little Black Mountain, San Miguel, and Santo Tomas. The Black Mountain and Santo Tomas both display multiple eruptions from cinder cones, but the two intervening centers display only a single extrusion of olivine basalt from a cinder cone (Hoffer, 1971).

The Palomas basalt field is located approximately 30 mi west-southwest of the Potrillo basalt field and covers an area of about 380 mi$^2$ in southern New Mexico and northern Chihuahua, México (Fig. 2). The lavas in the Palomas basalt field are more variable chemically than those in the Potrillo field as they include both alkalic and tholeiitic types (Frantes and Hoffer, 1982). The tholeiitic lavas include both olivine basalt (normative olivine and hypersthene) and tholeiite (normative hypersthene greater than 3%) (Hoffer, 1988).

Volcanic features include cinder cones, lava flows, and exposed dikes. The cones, ranging from 100 to 350 ft in height, display single or multiple vents and are typically breached on one or more sides where lava flows have been extruded. A number of olivine basalt dikes are associated with the cinder cones. The dikes dip nearly vertically, are several feet in width, and average 400 ft in length. The dikes display two different orientations. The majority are linear and strike in a generally northern direction for distances up to 2000 ft. The remaining dikes, approximately 20°, occur as curving ring dikes near the top of several cinder cones. The dikes dip nearly vertically and partially encircle the vent area. The outcropping dikes are thought to represent the exposed plumbing system of the highly eroded cinder cones (Frantes, 1981).

A summary of the major volcanic features in both the above volcanic fields, along with recently published dates, are included in Table 1.

This study reports on the correlations among cone morphology, Landsat thematic imagery spectra, and geochronology.

## CINDER CONE MORPHOLOGY

### Introduction

Several studies have been reported on the morphology of cinder cones. Porter (1972), Bloomfield (1975), Luhr and Carmichael (1981), and Scott and Trask (1971) investigated morphological variations among Quaternary basaltic cinder cones in Hawaii, central México, eastern México, and central Nevada, respectively. All the above studies concluded that the cone slope angle, which decreased with time, is the most easily measured and reliable age indicator.

TABLE 1. Summary of volcanic features and ages, Potrillo and Palomas basalt fields, southern New Mexico and northern Chihuahua ([1] = $^{40}$Ar/$^{39}$Ar; Williams et al., 1994; [2] = $^{3}$He Surface exposure dates; Anthony and Poths, 1992, [3] = K/Ar, Seager et al., 1984).

| | **West Potrillo Basalt** | **Aden Basalt** | **Afton Basalt** | **Black Mountain Santo Tomas Basalt** | **Palomas Basalt** |
|---|---|---|---|---|---|
| Lava flows | numerous | 5-10 | 3 | 11 | numerous |
| Maar | 2 | 0 | 3 | 0 | 0 |
| Cinder cone | > 130 | 0 | 5 | 7 | 34 |
| Spatter cone | 0 | 7 | 1 | 3 | 0 |
| Lava cone | 0 | 1 | 0 | 0 | 0 |
| Age dates | 262 ± 12–<br>916 ± 67 ka[1] | 20 ± 3–<br>24 ± 4 ka[2] | 66 ± 6–<br>120 ± 8 ka[2] | 79 ± 7–<br>137 ± 9 ka[2] | 2960 ± 70–<br>5170 ± 110 ka[3] |

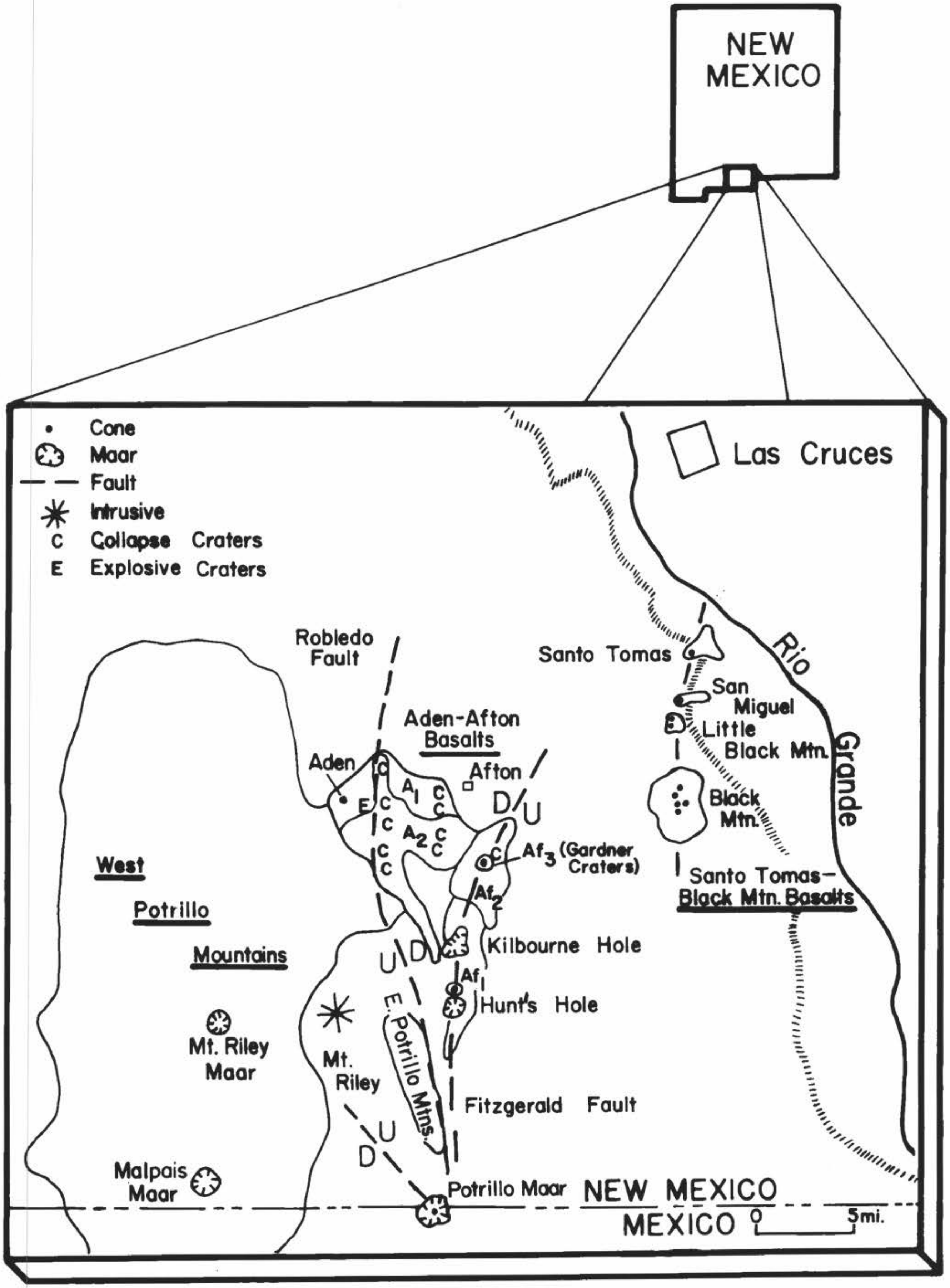

FIGURE 1. Index map of the Potrillo basalt field.

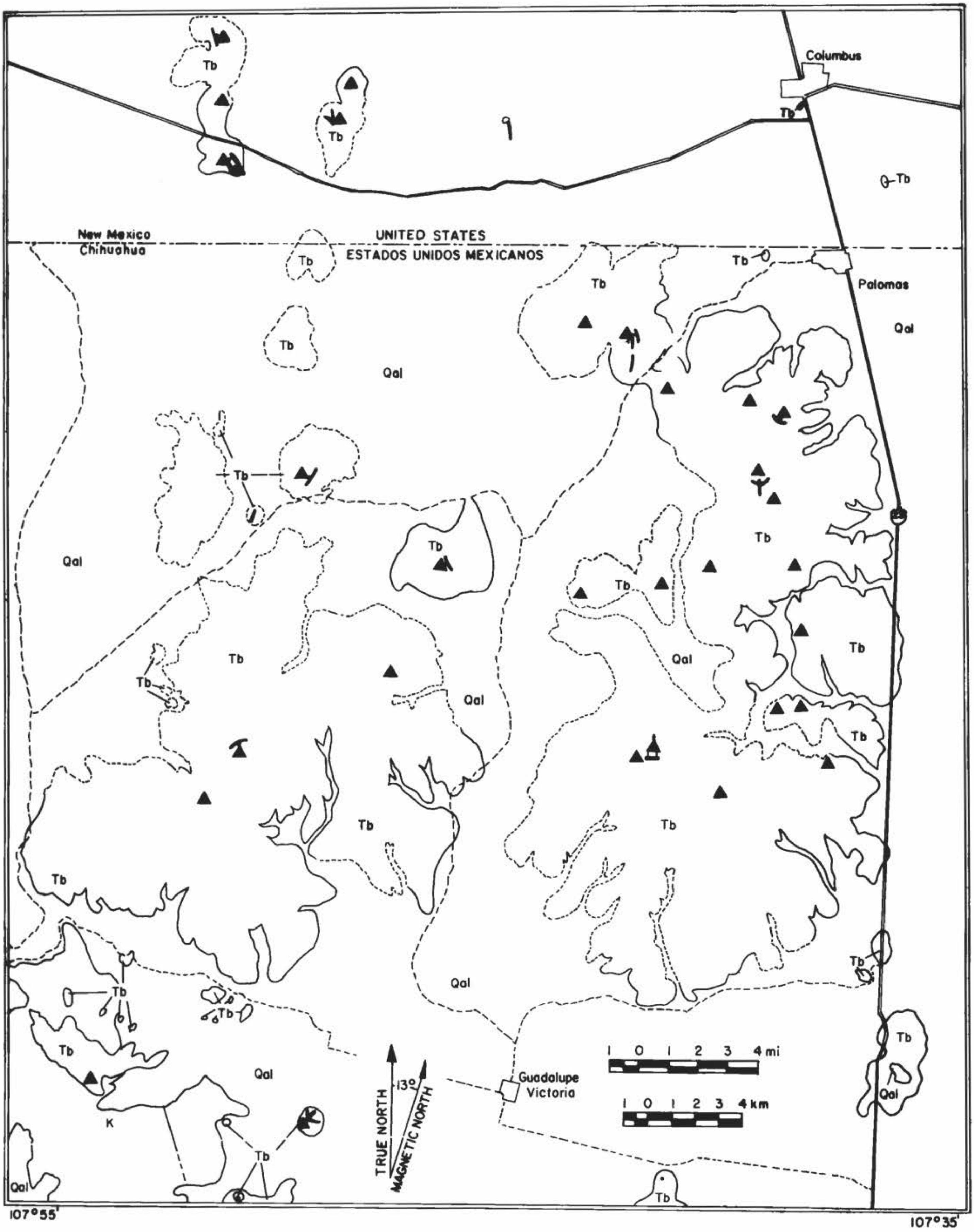

FIGURE 2. Index map of the Palomas basalt field (Tb = Tertiary basalt, ▲ = cinder cone, / = dike).

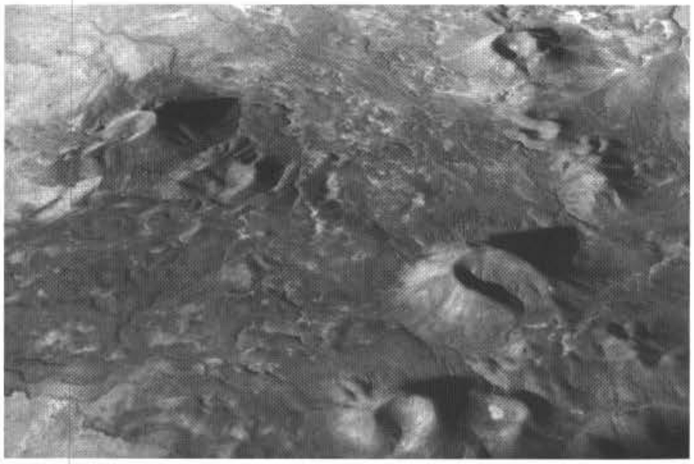

FIGURE 3a. Aerial view of cinder cones in the Potrillo basalt field (West Potrillo Mountains), note their more youthful appearance, steeper slope angles, compared to the older Palomas cone in Figure 3b.

Because the rate of slope decrease with time is strongly dependent upon climate, the criteria utilized on the cinder cones in the arid Lunar crater field by Scott and Trask (1971) were selected for analysis of the southern New Mexico and northern México cinder cones. Scott and Trask (1971) measured cone radius, cone height and maximum slope; they reported that the most useful parameters were the ratio of cone radius/height and maximum slope which increase and decrease, respectively, with age.

## Methods

The morphology of the cinder cones north of the border were calculated from USGS 7.5-min topographic maps, scale 1:24,000 and contour interval 10 ft, and to the south from the México Detenal topographic maps, scale 1:50,000 and contour interval of 10 m. The morphological parameter of the two cinder cones within Potrillo maar were determined from a planetable topographic map (scale 1:5000 and contour interval of 10 ft) completed by Chester Callahan and Chuck Terrazas in 1971.

The cone height was read directly from the map whereas the basal radius was determined by averaging the maximum and minimum basal cone radius. The base of the cone was picked at the point where the horizontal distance between successive contour lines suddenly increased. Three or four slope measurements were calculated for each cone, and the maximum slope angle represents the maximum of at least three measurements.

FIGURE 3b. View of a typical cinder cone, Palomas basalt field, note the low slope angle and large basal diameter compared to the younger Potrillo cones in Figure 3a (Tres Hermanas Mountains in the background).

## Results

To date, 110 cinder cones have been analyzed morphologically in the Potrillo and Palomas basalt fields; the results are summarized in Table 2.

The cinder cones in the West Potrillo Mountains show significantly higher maximum slope angles (19° vs. 6°) and radius/height ratios (5.7 vs. 9.8) than the Palomas cinder cones, which correlates with their younger age. Seager et al. (1984) reported three K-Ar dates from the northern end of the Palomas field which range from 2960 ± 70 to 5170 ± 110 ka. The 3910 ± 180 ka date is from a lava flow associated with a cinder cone displaying a maximum slope angle of only 7° and radius/height ratio of 8.4.

A number of dates have been published on lava flows from the West Potrilllo Mountains, indicating ages ranging from 262 ± 12 to 916 ± 76 ka (Anthony and Poths, 1992; Williams et al., 1994). These dates support their younger age, compared to the Palomas cones, based upon morphology (see Fig. 4).

In several areas of the West Potrillo Mountains, cinder cones do not occur as distinct and isolated features but form clusters composed of two or more overlapping cones. Clusters composed of as many as four to five cinder cones are common.

Approximately 3 mi west of Mount Riley, on the eastern edge of the West Potrillo field, occurs a cluster of three cinder cones (Fig. 5). Field relationships show that cones 1 and 3 have been partially buried by cinder from the eruption of cone 2, the youngest cone. Cone morphology measurements also indicate a similar conclusion. The maximum slope angle and the radius/height ratio of the three cones are: cone 1 = 15°, 3.6; cone 2 = 20°, 2.7; and cone 3 = 14°, 4.1.

TABLE 2. Cinder cone morphology Potrillo and Palomas basalt fields ([1] = ages from lava flows not related directly to cinder cones; [2] and [3] = ages from lava flows erupted from cinder cones; see Table 1 for source of age dates).

| Location | Cones measured | Average height (ft) [range] | Average radius (ft) [range] | Average radius/height [range] | Average maximum slope angle (°) [range] | Age date |
|---|---|---|---|---|---|---|
| POTRILLO BASALT | | | | | | |
| West Potrillo | 85 | 191 [93–435] | 847 [450–1700] | 5.1 [2.6–12.3] | 19 [7–30] | 262 ± 12–916 ± 75 ka[1] |
| Aden-Afton | | | | | | |
| Gardner Cones | 3 | 151 [113–220] | 345 [240–450] | 3.1 [3.2–3.8] | 20 [15–25] | < 91 ± 5–110 ± 7 ka[2] |
| Potrillo Maar | 2 | 40 [30–50] | 96 [66–125] | 2.3 [2.2–2.5] | 23 [22–24] | 66 ± 6–28 ± 6 ka[2]<br>59 ± 10 ka[3] |
| Black Mtn Santo Tomas | | | | | | |
| Black Mtn. | 1 | 132 | 400 | 3.0 | 18 | 79 ± 7–104 ± 9 ka[2] |
| Little Black Mtn. | 1 | 90 | 350 | 3.9 | 14 | 117 ± 7–137 ± 9 ka[2] |
| PALOMAS BASALT | 18 | 139 [65–260] | 1228 [650–1880] | 9.8 [5.0–15.0] | 6 [4–10] | 2900 ± 70–5170 ± 110 ka[3] |

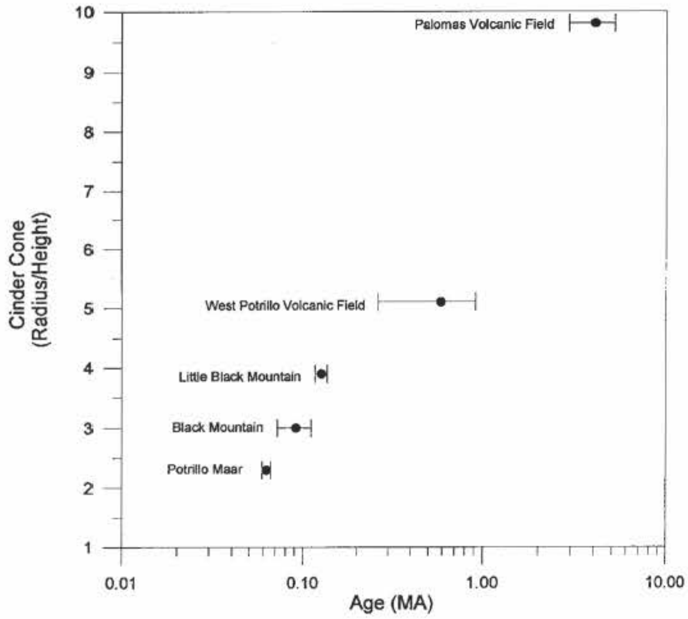

FIGURE 4. Cinder cone radius/height ratios vs absolute age in the Potrillo and Palomas basalt fields, southern New Mexico, and northern Chihuahua, México.

The radius/height ratios suggest the sequence of cone formation from youngest to oldest, is cone 2, cone 1, and cone 3, respectively.

Some of the youngest cinder cones in the Potrillo basalt field include those at Potrillo maar, Gardner cones (north of Kilbourne hole), and Black Mountain and Little Black Mountain to the east. In all the above locations, cinder cone morphology correlates well with the published radiometric dates.

## LANDSAT THEMATIC MAPPER IMAGERY

Spectrally, ferric iron is an important component of earth surface materials like rock, soil and regolith. While not volumetrically significant, ferric iron dominates the reflective spectra range from 0.4 to 1.2 µm (Townsend, 1987). When light impinges on natural surface materials, ferric iron absorbs the shorter blue and green wavelengths (0.35–0.60 µm). This absorption is primarily due to charge transfer among available energy levels; the dominant reflected energy is in the 0.6–0.7µm range producing a strong red color component. The charge transfer among the energy levels are controlled by valence, coordination number, site symmetry, and to a lesser extent by the ligand-type metal-ion distortion, and the magnitude of metal-ligand interatomic distances (Burns, 1970). Absorption features associated with charge transfers are typically several orders of magnitude more intense than an accompanying field effect. Alteration of magnetite ($Fe_3O_4$) and ilmenite ($FeTiO_3$) to hematite ($Fe_2O_3$), goethite ($FeOO_4$), and jarosite ($KFe_3(SO_4)_2(OH)_6$) produce characteristic spectra which can be measured using a multispectral scanner.

False-color (bands 7 [red], 4 [green], and 2 [blue]) thematic images of the Potrillo and Palomas basalt fields show a clear distinction between cinder cones and lava flows. The cones are strong reflectors for wavelengths >0.7 µm while lava flows, regardless of age, have low reflectance values. The difference between these is most likely due to the greater amount of exposed surface area, resulting in greater oxidation of magnetite in the vesicular cinder compared to the dense lava flows.

To verify the presence of ferric iron minerals, derived from surface weathering of magnetite in the basaltic cinder, three cones were sampled and analyzed with x-ray diffraction. The first sample was obtained from a recently exposed quarry pit in a cinder cone, approximately 50 ft below the former cone surface, and is unweathered. The only opaque mineral identified was magnetite. Surface cinder samples from two nearby cones were also x-rayed and both hematite and goethite were identified; no magnetite was identified in either sample.

Landsat thematic mapper images of the cinder cones in the Potrillo and Palomas basalt fields show an increase in apparent reflectance in bands 7 (2.2 µm) and 5 (1.5 µm) with increasing age. Cinder cones less than 100 ka, for example the Potrillo maar cones, exhibit low reflectance values from visible through short infrared wavelengths. Cinder cones with dates ranging from 100 ka to less than 1000 ka, including Black Mountain, Little Black Mountain, and the West Potrillo cones, show increasing apparent reflectance from visible (false color equals red) through mid-wavelength infrared. The oldest cinder cones, 2900–5200 ka, in the Palomas field show the highest apparent reflectance from visible (subdued reds to orange) through short wavelength infrared. Therefore, it appears that Landsat imagery and cinder cone morphology can be used to determine the relative age of cinder cones.

## SUMMARY AND CONCLUSIONS

Cinder cones are abundant in both the Potrillo and the Palomas basalt fields located in southern New Mexico, and Chihuahua, México. Ages of the cones, derived from radiometric dating of associated basaltic lava flows, range from 20 to 916 ka in the Potrillos and from 2960 to 5170 ka in the Palomas field.

After their initial formation, cinder cones are modified over time by both erosion and weathering. Erosion processes, mainly mass movements, reduce the height of the cone, increase its radius, and thus decrease the maximum slope angle. These morphological changes, including both radius/height ratio and maximum slope angle, increase and decrease, respectively, with age and appear to be useful in estimating qualitative age relationships among cinder cones.

Weathering of the cones includes the oxidation of ferrous minerals in the basaltic cinder, primarily magnetite and/or ilmenite, to ferric minerals such as goethite and hematite. When viewed on Landsat thematic mapper images, the oxidized cones show an increase in apparent reflectance with increasing cone age in both visible (false colors of subdued reds to black) through the short wavelength infrared spectra. The characteristic reflectance spectra from the cones can be measured using a multispectral scanner and

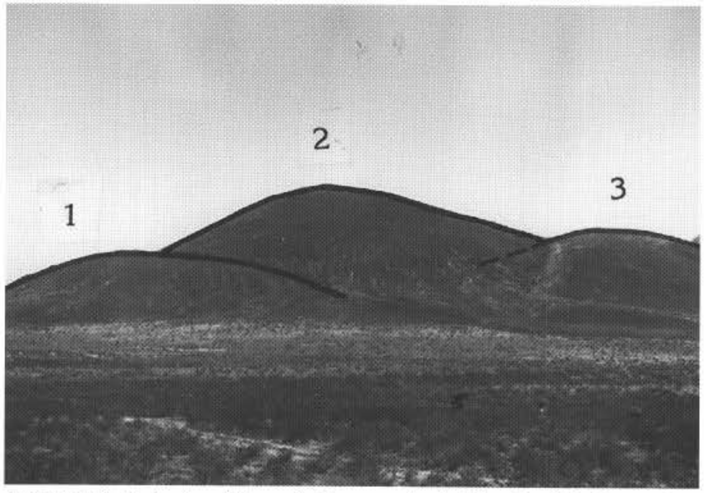

FIGURE 5. A cluster of three cinder cones in the West Potrillo Mountains. The central cone (2) has partially buried the flanks of the other 2 cones (1 and 3); see text for the morphological data on the cinder cones.

the results used to estimate qualitative ages of the cones. One advantage of this remote sensing method is that it can be used in areas that lack adequate topographic maps for cone morphology measurements.

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