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INTRODUCTION

Anyone who has traveled 1-40 between Albuquerque and Grants, New Mexico, must see and wonder about the stretch a few miles east of Grants where the highway passes over and through a basalt field containing rough and contorted black tendrils of lava. Few of the passersby realize that this forbidding bit of primordial landscape is only the last dribble of a large and spectacular badlands that extends southward for another 48 km (30 mi) or more and widens out to 29 km (18 mi) or more. This piece of tortured earth is known as El Ma!pais, or as the Grants Malpais, to distinguish it from other malpais areas in New Mexico. El Malpais was long known only to the Acoma Indians, or the Anasazi, whose ancient footpaths snake across the badlands following routes that avoid the sink holes, chasms, and fields of aa lava liberally sprinkled over the area. They marked their paths with blocks of sandstone or low rock cairns, many of which are still visible.

Pottery fragments and molds of corn cobs in and under the lava prove that humans occupied the area before the lava did. And, indeed, Acoma legends include many tales about the fire-rock and its effect on their lives. Folklore of the Malpais, generated after the European and American invasions of the region, includes many intriguing treasure tales such as the story of a pair of silver church bells hidden in a cave, a stolen gold-laden mule train hidden in the Malpais, and many other stories of lost treasures including even the lost "Adams Diggings." And, of course, no one was ever able to recover the caches because of the deceptive sameness of the terrain. Many treasures of another sort have been recovered from the Ma!pais—uncounted and unreported numbers of pottery vessels of various sizes, shapes, and decoration have been found over the years and have been carried out of the Malpais by residents of the region. The pottery was undoubtedly hidden there by the Indians for storage of food and water against an incursion of marauding nomads.

The Malpais provides a fascinating area of study for geologists, biologists, and archeologists alike, and for anyone with curiosity, interest, or adventurous spirit. Most of the physical features of lava eruptions including cinder cones, spatter cones, blocky flows, grooved lava, squeeze-ups, pahoehoe, aa, ropes, collapse depressions, pressure ridges, lava tubes, and ice caves, are present at one place or another.

Wildlife abounds in the Malpais, though many of the "sport" animals have been decimated by hunting and poaching. The region is host to more than 100 species of birds, both resident and migratory, 39 species of mammals, and 9 species of reptiles and amphibians (Bureau of Land Management, 1981). Larger animals are restricted to areas where water is readily available, mostly from wells pumped by windmills, but water is present in caves and sinks in many of the depressions. These areas host enclaves of wildlife especially adapted to conditions in the Malpais, including some animals not commonly seen in the region.

Rock structures, presumably built by the Indians, can be found throughout the region. Many are in unlikely places deep inside the Malpais. Most are simple little shelter walls or half walls across cave mouths but some are large, complex, well-built structures which might look like gateposts and flanking curved walls at the entrance to a ranch, or like large, symmetrical beehive cairns. Perhaps they are the work of bored sheepherders.

Several concerted efforts were made during the past 20 years to have the Malpais declared a National or State Park or Monument in order to preserve the area from development or vandalism and to make the area more accessible for recreation. Formal action began in 1969 when the Bureau of Land Management declared the area eligible to be a National Natural Landmark. It was designated an Outstanding Natural Area in 1974, and during 1978-80, studies were made to determine the feasibility of incluidng El Malpais in the National Wilderness Preservation System. It is currently a Proposed Wilderness Area (Bureau of Land Management, 1981).

GEOLOGIC FEATURES

The Malpais was the subject of geologic mapping by Dutton in 1885 and by Darton in 1915 and of an extensive geomorphic study by Nichols (1946). The northern part was mapped by Goddard (1966) and Thaden and others (1967a, b), and detailed petrochemical studies were made by Renault (1970), Lipman and Moench (1972), Laughlin and others (1971, 1972), Cardin and Laughlin (1974), and by many others.

The Malpais area was mapped in some detail during recent wilderness evaluation studies (Maxwell, 1981), and five flow units have been delimited within the lava field (fig. 1). The flow units were identified initially using aerial photographs. Subsequent field checks at many localities resulted in considerable revision of the units based on lithology and petrography, flow characteristics, type and amount of weathering, and differences in vegetation. None of the criteria for separation of flow units were consistent everywhere, and designation of the units shown on Figure 1 was based on cumulative observations of all criteria.

Quaternary basalt flows in the region are divided into two groups, an older group and the younger Malpais flows. The older group, exposed west and south of the Malpais field, is deeply weathered and mostly covered by relatively well-developed soil and eolian deposits. The oldest flows are locally overlain by slightly younger flows, which may be contemporaneous with the oldest flows of the Malpais, and by pyroclastic debris and cinder cone deposits, some of which could also be as young as the Malpais.

Pyroclastic debris deposits are composed mostly of basaltic lava mixed with and covered by cinders, bombs, scoria blocks, and flow breccia. They appear to have been deposited by violent explosions prior to development of the cinder cones.

The cinder cones are composed of basaltic ash, cinders, bombs, angular blocks of scoria, and minor flows of glassy lava. The most prominent but most inaccessible cinder cones form the Chain of Craters west of the Malpais. There are 30 cones in the Chain of Craters compared with eight cones plus two shield volcanoes in the Malpais field. The cinder cones range in height from about 1 meter to more than 170 m, and many are a kilometer or more in diameter. A few cones are symmetrical with a central depression as much as 80 m deep over the vent, but most cones have been breached on one side and are more or less crescent shaped. Bandera Crater, adjacent to State Highway 53 at Ice Cave, is the most accessible and one of the largest of the cinder cones. It is breached but still nearly symmetrical.

Chemical analyses show that basalts of both alkalic and tholeiitic affinities are present in the Malpais field. Most tholeiitic types are high-

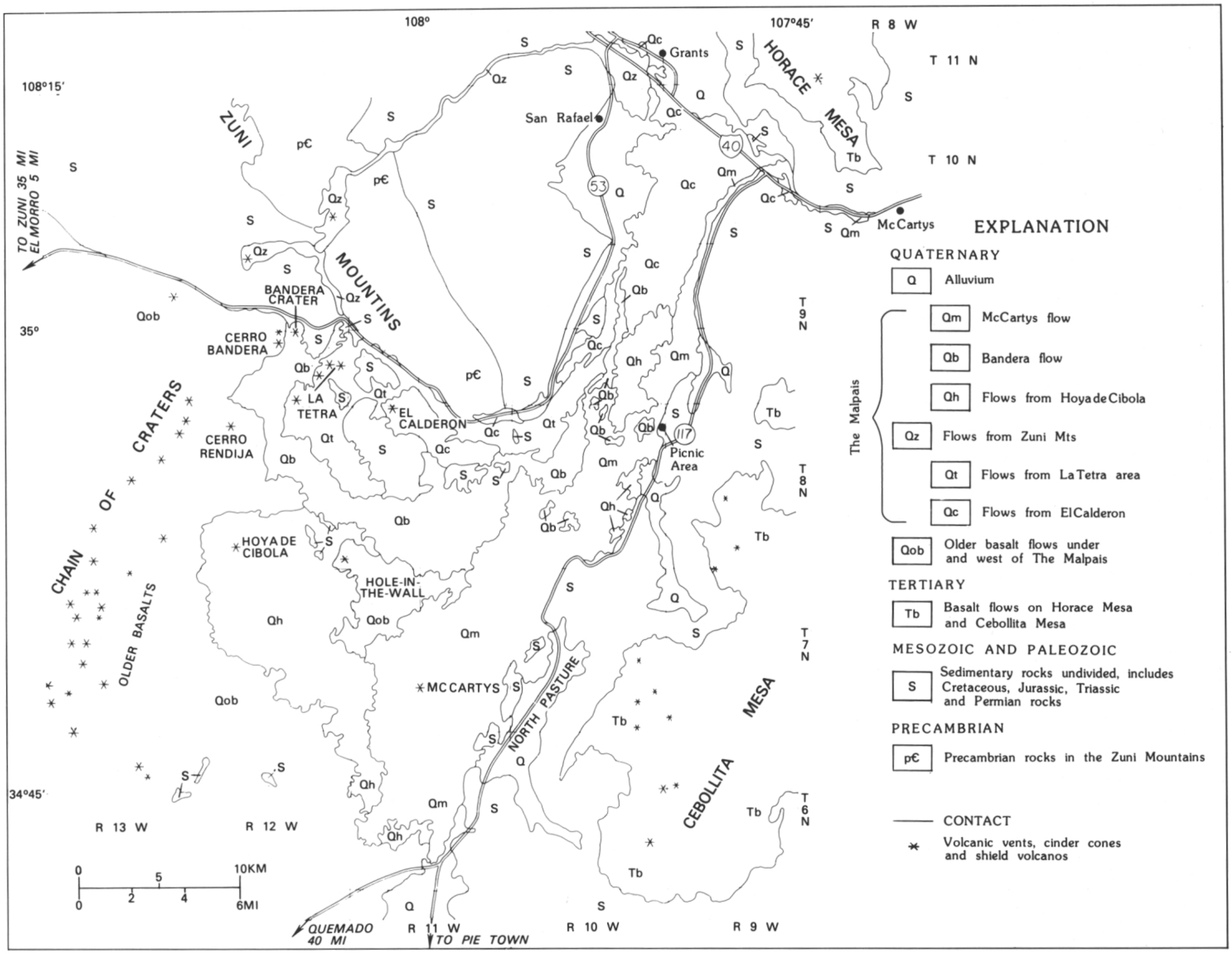

Figure 1. Geologic map of El Malpais and surrounding area, New Mexico.

alumina tholeiites and verge on being calc-alkaline. The Paxton Springs flow is sodic-alkalic basalt. Basalts are impoverished in total strontium, and the strontium isotope ratios are low (Laughlin and others, 1972). Various authors who have studied these basalts generally believe that they are derived from fractionation of mantle material at depth, with little or no differentiation and little crustal contamination.

FLOW UNITS

The youngest flow unit is McCartys flow (Qm on fig. 1); it originated at a small cinder cone in the southern part of the Malpais field, about 40 km south-southwest of highway 1-40. Some lava from this vent flowed south for about 10 km, but most of the lava flowed northward to the Rio San Jose and then eastward for about 8 km. Although this flow has not been dated accurately, Nichols (1946) inferred the age to be about 1,000 years on the basis of Acoma Indian legends and on the presence of archeological material in nearby valley fill that was correlated with the alluvium underlying McCartys flow. The flow could be as young as 400 years.

The McCartys flow unit is generally unweathered, uneroded, and relatively barren of vegetation, and it shows in excellent exposures most of the physical features of basalt flows (Nichols, 1946). The rock is hypocrystalline and porphyritic with subhedral to euhedral phenocrysts of plagioclase and olivine in a groundmass of subhedral plagioclase, anhedral olivine, pyroxene, and tachylite heavily dusted with opaque minerals. Near the vent the rock is a quartz-normative tholeiite containing plagioclase phenocrysts, and at distances greater than 4 km from the vent it is an olivine-normative tholeiite containing olivine phenocrysts (Carden and Laughlin, 1974).

The next-youngest flow unit, the Bandera flows (Qb on fig. 1), originated at Bandera Crater and flowed south and east around the Zuni Mountains and then north to a point about 12 km south of Grants. Bandera Crater is an ideal example of a breached cinder cone. It is steep sided and symmetrical, more than 1 km in diameter and 150 m high, and has a central depression 180 m below the rim and 80 m below the breach on the southwest side of the cone. A large lava tube begins in the flows at the breach and extends to the south and east for 20 km, possibly continuing as far as 30 km from the crater (Hatheway and Herring, 1970). The tube is totally collapsed for the first half mile and has smaller collapse areas all along its length. Ice Cave, with its deposit of perpetual ice, developed in the lava tube near the crater; other ice caves occur at other localities in the tube. Ice forms where the cave mouth is shielded from the summer sun, where air circulation through the cave is minimal, and where the overlying rock is thick enough to maintain a temperature low enough that less ice melts in the summer than freezes in the winter.

An extensive deposit of fine cinders extends north, east, and south of the crater, covering older sedimentary rocks and lava flows. The cinders are well exposed in highway cuts, in pits adjacent to the highway, and along the road to Ice Cave.

Rocks of the Bandera field are alkali basalts that are typically holocrystalline and microporphyritic with euhedral phenocrysts of olivine, rare clinopyroxene, and plagioclase, in a vesicular groundmass of plagioclase (An.), pyroxene, opaque minerals, and very minor olivine (Laughlin and others, 1972). Ultramafic rock fragments of dunite and pyroxenite, interpreted to have a mantle origin, are found as cores in bombs that were ejected in the final eruptions from Bandera Crater (Laughlin and others, 1971).

A large area of flows in the southwestern part of the Malpais field originated from Hoya de Cibola crater and shield volcano (Qh of fig. 1). Lavas from these vents flowed east-northeast and southeast where they are overlain by the Bandera and McCartys flows. Several small windows of similar rocks under the McCartys flow, north of the Los Pilares area, and a large area in the northeastern part of the field (Maxwell, 1977) are correlated with the Hoya de Cibola flows on the basis of similarity of composition, flow characteristics, weathering, and vegetation. The Hoya de Cibola flows are tholeiites similar to the McCartys flow but are slightly higher in aluminum and alkalis and lower in magnesium and titanium.

The map unit shown as Qt on Figure 1 is made up of several overlapping flows that emanated from different vents and that were difficult to separate into units because all have similar flow and weathering characteristics. Most of the flows along Highway 53 belong in this unit. The flows comprising this unit issued from several cinder cones in the La Tetra area that form a northeast-trending line of vents from the Lost Woman center on the southwest, Twin Craters near the center, and La Tetra—Cerro Candelaria to the northeast. In several areas, mixed deposits of pyroclastic rocks and lava surround the cinder cones and partially obscure sedimentary rocks. Causey (1970) classified rocks from Twin Craters and Lost Woman center as alkalic basalt and those from La Tetra as tholeiite. Laughlin and others (1972) state that the basalt from La Tetra plots slightly within the alkalic field although it is hypersthene normative and should probably be termed a tholeiite.

The oldest flows in the Malpais field (Qc of fig. 1) originated in part from El Calderon crater and perhaps from other centers to the west that are now covered by younger flows. The Laguna flows of Nichols (1946) are interpreted to be from the same sources based on similarities of lithology, morphology, weathering, and stratigraphic position. Some rocks included with the older basalts west of the Malpais field (notably Cerro Bandera and Cerro Rendija) also have similar morphology and weathering to the El Calderon flows and possibly should be correlated with this unit. Rocks of the El Calderon unit are relatively coarse-grained and porous, with small voids between groundmass plagioclase and subophitic augite, and with interstices between plagioclase laths filled with brownish glass dusted with abundant opaque minerals. Chemically, these basalts plot within the tholeiitic field (Lipman and Moench, 1972).

Flows from the Zuni Mountains (Qz of fig. 1) are not properly part of the Malpais field. Two separate flow units are included here. The older flow originated from a lava cone on Oso Ridge, northwest of Bandera Crater, and flowed eastward to Agua Fria Creek and then southward almost to the Malpais flows. This older flow is overlain by the Paxton Springs flows, which originated from a small center in the Precambrian core of the Zuni Mountains, then flowed about 2 km south and 25 km northeast, down Zuni Canyon, to the area between Grants and San Rafael. The rock is a nepheline normative alkali-olivine basalt containing microphenocrysts of euhedral olivine, rare clinopyroxene, and plagioclase in a holocrystalline and vesicular groundmass of plagioclase, pyroxene, and opaque minerals (Laughlin and others, 1972). The older basalt flows (Qob) west of the Malpais field are generally deeply weathered and are mostly covered with soil and alluvium that produces open grasslands surrounding small outcrops of basalt. These rocks were dated at 788,000 years (Qc?) and 1.38 my. near Cerro Bandera, several miles west of the map area (Luedke and Smith, 1978). The basalt flows (Tb) on Cebollita and Horace Mesas, east and north of the Malpais field, are silicic alkali-olivine basalts with potassium-argon ages of 2.3 to 3.5 m.y. (Bassett and others, 1963).

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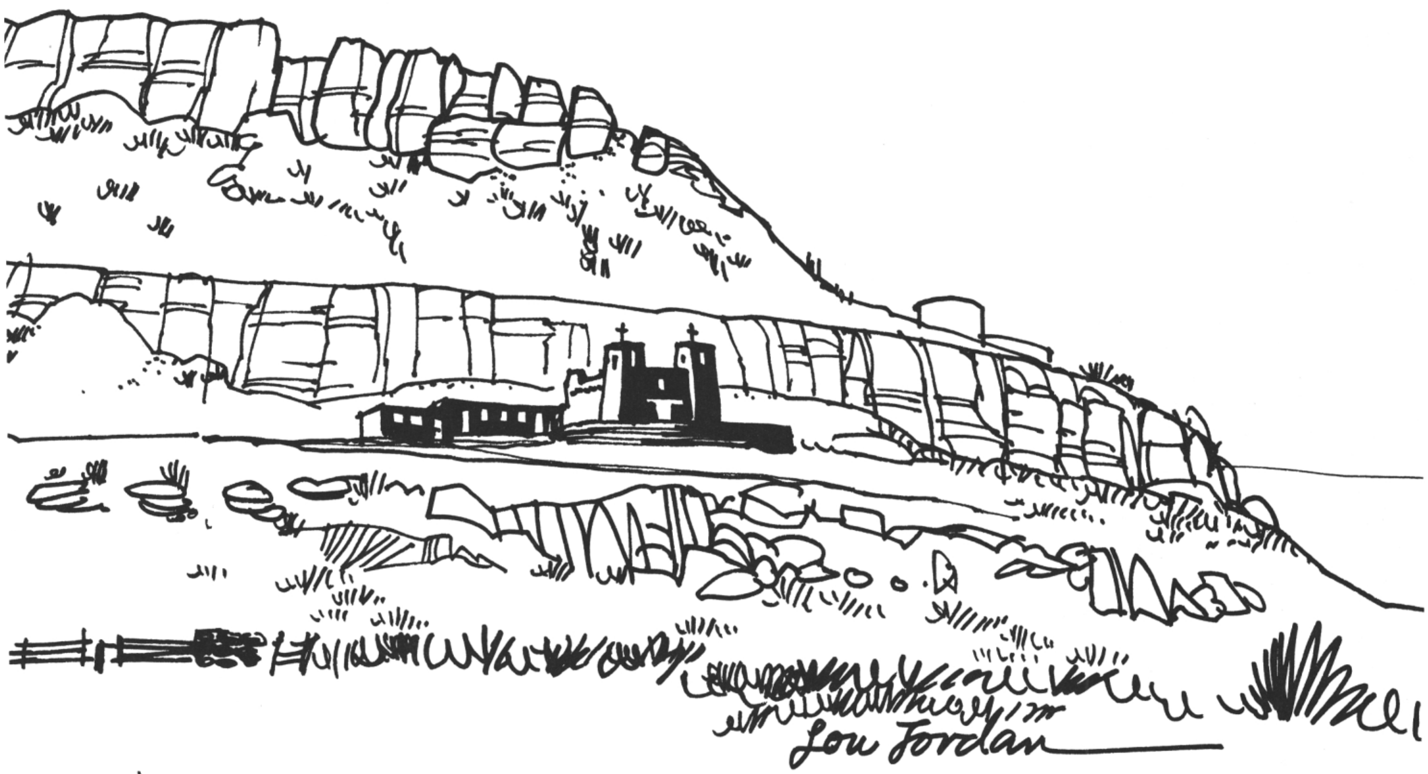

McCartys