FIGURE 30. Crater Elegante and the east side of the Pinacate Mountains as seen looking southwest from the air. Dark colored younger flows in middle ground beyond Crater Elegante and on left slopes of Cerro Pinacate. Photo by Tad Nichols.

CRATERS OF THE PINACATES

F. W. Galbraith
University of Arizona

The Pinacate region is one of the least known desert areas in the southwestern United States and northwestern Mexico. The Pinacate Mountains (fig. 1) are in Mexico, about 50 miles southwest of Ajo and a few miles west of the highway to Punta Penasco (Rocky Point), and the fishing town of Puerto Penasco (fig. 60). The Pinacate Mountains (fig. 30) form the central part of the area and consist of a great black or reddish-brown mass of lavas and volcanic cinders surmounted by two cone shaped peaks, Los Picos del Pinacate, which rise to an altitude of 4, 235 feet. Most of the mountain mass is composed of volcanic rocks that apparently are considerably older than the flows surrounding the range. The surfaces of some of the younger flows are so fresh that they would appear to have been formed only yesterday. Some of these younger flows emerged from vents high on the flanks of the mountains and have partially filled deeply eroded valleys in the older flows. Other young flows are associated with cinder cones along the margins of the mountains which lie at altitudes considerably below 1,000 feet. The lavas and cinder cones occupy an area of approximately 600 square miles and are almost completely surrounded by a belt of dune sands. The belt of sand dunes is narrowest on the east side of the Pinacates where the sand is only 3 or 4 miles wide. On the west side, the belt of sand widens to 20 miles or more and extends to the Gulf of Lower California (fig. 1).

The old Spanish highway, the "Camino Real", which connected Caborca, Sonora, with Yuma, Arizona, passed within 15 miles of the Pinacates, and the twin peaks can be seen from many points on this old trail. The general location of the "Camino Real" is now occupied by the paved highway from Sonoyta to San Luis Rio Colorado, Sonora, and is in part covered by the road log (Trip VI, mi. 167.0 to 199.2). The "Camino Real" from Sonoyta to Yuma was known as the Camino del Diablo and the journey over it was referred to as the Jornada del Muerto (Journey of Death) in memory of the hundreds of people who died of thirst on this route. This trail could not have been established without the help of the Papago Indians, who knew the location of the few sources of water. The Jesuit fathers were probably the first white men to pass over the trail in the seventeenth century. The accounts of Father Kino indicate that he passed south of the Pinacates in 1701 and led a party which ascended to the summit of the mountain in 1706 (Ives, 1942). There is no record of exploration in the country surrounding the Pinacates for about the next 200 years, although Sonoyta was inhabitated during the entire period.

In recent years the Pinacate region was undoubtedly penetrated by prospectors, but they left little or no record of their visits. In 1882, Sykes Crater, or Crater Grande (fig. 60) was visited by Sr. Y. S. Bonillas, a mining engineer from Nogales, Sonora. In 1908 a party headed by Dr. D. T. MacDougal of the Carnegie Desert Laboratory, Tucson, and including W. T. Hornaday, J. M. Phillips and Godfrey Sykes, explored the Pinacates (Hornaday, 1908). During the years 1909-10 Carl Lumholtz also explored a good deal of the Pinacate region while studying the Papago Indians (Lumholtz, 1912). Both parties made the climb to the top of the Pinacates -- Lumholtz from the east side and the MacDougal group from the west.

Undoubtedly the most interesting feature of the Pinacate region is the presence of at least ten large volcanic craters (fig. 60). Two of these, Elegante and Cerro Colorado, lie 5 and 15 miles, respectively, northeast of the Pinacate Peaks. MacDougal, Sykes, and Molina Craters are about 10 to 15 miles northwest

of the peaks and the newly named Moon Crater was recorded by Mr. Glenton Sykes about two years ago. The MacDougal party visited and named MacDougal, Molina and Sykes Craters, pauging at Cerro Colorado on their way. Lumholtz visited Elegante and Sykes Craters and noted Cerro Colorado at some distance to the northeast.

There seems to be little doubt that the latest volcanic activity in the Pinacate region took place in very recent time and a Papago legend (Lumholtz, 1912) refers to volcanic eruptions in the area: "Elder Brother (The Creator of the Papagos) lived in Baboquivari before he came to Pinacate. At that time there were many people in Pinacate. The mountains were very high then, and the sun used to set soon after it had risen, so the days were very short. Elder Brother saw that this did not suit the people, and he decided to lower the mountains. He built two fires, where the two peaks are found today, making fire by drilling one stick into another. The wind blew the ashes about to all parts and made the mountains lower, covering the country so as to look as seen today. After that the people lived contented, and there was not so much shade from the west."

The most detailed scientific investigation of the Pinacate craters has been made by Dr. R. H. Jahns (27). Studies of the Pinacate craters have been carried on by the Department of Geology of the University of Arizona since 1952 and in December 1957 a university group was accompanied by Mr. Eugene M. Shoemaker, of the U. S. Geological Survey, who has made detailed studies of similar volcanic craters on the Navajo and Hopi reservations in Arizona, New Mexico, and Utah (Shoemaker, 1956).

Shoemaker (oral communication, 1957) interprets the Pinacate craters as diatremes. The craters of Elegante and Cerro Colorado are partly filled by beds of tuff which dip steeply toward the center of the craters. In the tuff-filled pipes of the Schwabian Alb and in similar volcanic pipes on the east coast of Scotland, such inward dips are believed to be partly the result of fall-out or in-fall of debris produced by explosive activity after the main crater was formed. At Cerro Colorado, superimposed volcanic debris is thin, and the fine grained alluvial deposits underlying the Sonoyta valley are exposed in some of the lower parts of the crater wall.

It was originally postulated that a diatreme results solely from explosive expansion. Daubree (1891) conceived the process as the drilling of a hole through the crust of the earth by the explosive release of gas from an underlying magma. Shoemaker points out that recent studies of the pipes in the Hopi Buttes region of the Navajo country, where there is a larger number of well exposed pipes than anywhere else in the world, indicate that the pipes were formed by a much more complex mechanism. He suggests that the formation of the Hopi Buttes diatremes takes place in two stages.

The first stage consists of the rapid release of gas from the underlying magma chamber. This gas finds its way to the surface through fractures in the overlying rocks. Once the channelway to the surface is formed, the magma continues to evolve gases, and bits of lava and solid pieces of the underlying rocks are entrained in the gas as it rises along the fracture. The early phases of enlargement of the vent are probably due to abrasion by entrained debris. Once the pipe has been opened up a little, it in effect becomes a Venturi which accelerates the upward moving gases to high velocities. A pressure drop across the wall permits fragments of the wall rocks to fall into the rising column of gas as entrained debris. The crater at this stage is caused primarily by collapse of the walls into the fluidized column.

Depending upon the size and weight of the fragments derived from the walls, some will sink while others will be carried upward in the rising column. Some of the fragments are rounded and polished by this action and the materials within the vent are thoroughly mixed. At the surface, material is constantly being spewed out and the gas is traveling at sufficient velocity to carry the entrained debris to considerable heights above the ground. The volcanic material is scattered and only the coarsest fragments fall near the vent and form a low rim.

The eruption of a diatreme in Chile was observed and described by Mueller (1956). In this instance the total period of explosive activity was about three months and consisted of a staccato eruption of entrained material accompanied by violent ejection of gas for periods of about 30 minutes each, followed by periods of quiescence. The quiescent intervals became longer and longer until the explosive activity ceased entirely. During the brief periods of eruption, debris was ejected to a height of approximately 3 miles and distributed over 100 square miles of surrounding country.

The second stage of crater development in the Hopi Buttes region is believed by Shoemaker to consist of the collapse of the walls due to subsidence of material in the central pipe. After the explosive period is over, the debris filling the vent subsides due to a probable combination of several factors, including possibly 1) the compaction of the fragmental material in the vent, 2) the release of lava through subsidiary vents causing loss of pressure below the main vent, 3) assimilation of fragmental material in the underlying lava column, and 4) contraction that takes place due to freezing of the lava column.

Of the Pinacate craters, Shoemaker considers Cerro Colorado to be a good example of a diatreme of the Hopi Buttes type, except that it does not show evidence of subsidence after the explosive phase of activity. He describes it as a composite of four separate points of discharge which may connect at shallow depths but which make one nearly symmetrical crater at the surface. The latest deposits consist of two series of beds -- the beds within the crater dip steeply toward the main crater and the second series of beds, outside the crater, dip less steeply away from the center. These deposits consist of fragmental debris from the walls of the vent, the underlying older rocks, and new magmatic material.

Crater Elegante is quite different from Cerro Colorado. Its steep, cliff-like inner walls are composed in most places of a series of basaltic or andesitic lava flows. Elegante lacks the tuff beds dipping steeply inward from the crater rim and it has only a low rim of fragmental debris surrounding it. MacDougal and Sykes Craters are similar to, but smaller than, Elegante. Molina Crater is a composite of three separate vents which may be more nearly like Cerro Colorado.

The generally accepted interpretation of the structures called calderas is that they are formed by the collapse of the land surface, usually a volcanic cone, over a magma reservoir at moderate depth which has been partially drained of its magma through eruption. In general, calderas are larger than the Pinacate craters. The largest known is some 30 miles in diameter and examples include La Caldera in the Canary Islands, Krakatoa in the Sunda Strait between Java and Sumatra, and Crater Lake in Oregon. The essential differences between a caldera and a diatreme are 1) that the caldera has a magma reservoir which is shallow compared to the diameter of the crater, whereas the reservoir of the diatreme is deep compared to the crater diameter; and 2) that the caldera depression is formed by the collapse of the roof of the reservoir, whereas the development of the depression of a diatreme is de-

pendent upon the opening of a vertical conduit and the piecemeal subsidence of the walls into the conduit as the eruption proceeds.

It is obvious that there is still much to be learned about the Pinacate craters, including the regional geology of the area in which they are located. From what depths came the fragments of granite, gneiss and other non-volcanic rocks found mixed in the volcanic debris? Why are the fragments of basement rocks so much more numerous at Cerro Colorado than at Crater Elegante? What are the ages of the volcanic eruptions which formed the older lavas, the craters themselves, and the younger lava flows which look as though they were poured out only a few weeks ago?

There is some evidence as to how long ago the craters were formed. Fallout debris on the outer slopes of Elegante are covered in places by alluvium impregnated with caliche to an extent generally developed in the southwest only in deposits of Wisconsin age or older. The center of the crater is filled with lake beds containing fresh-water molluscs, indicating a ground water table higher than at present. This was the case in the late Pleistocene. The lake beds also contain enough caliche to be typical of those of Wisconsin age. Since the end of Wisconsin time, little change has taken place. There has been some dissection of the lake beds in the crater and of the explosive clastic material outside of the crater rim. Elegante would appear to be not much older than the beds we can see. There also appears to be no evidence that the other craters, except for Cerro Colorado, were not formed at about the same time. Cerro Colorado appears to be younger than the other craters and may have erupted within historic or late pre-historic time (Ives, 1956).