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GLG 490/598 Field Trip to the Pinacate Volcanic Field

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INTRODUCTION

This is a two-day field trip to the Pinacate Biosphere Reserve in Sonora, Mexico. The Pinacate volcanic field has been active for the past 2–3 million years. Lavas are derived from melting of deep, garnet-bearing asthenosphere, possibly as a mini-plume that welled up near, but distinct from, a spreading center in the adjacent Gulf of California (Sea of Cortez) to the south (*Goss et al*., 2008). The Pinacates contain diverse volcanic landforms, including a shield volcano, a tuff cone, maars, cinder cones, and lava flows. Two different alkalic rock series are represented: One constitutes the >400 monogenetic cones and craters formed over the last 1.2 Ma or more; the other forms the extinct Santa Clara shield volcano. The former consists of basalts and hawaiites, whereas the latter constitutes an entire alkaline differentiation series: basalt, hawaiite, mugearite, benmorite, and trachyte.

This trip will focus on the deposits and morphologic expressions of explosion craters, volcanic cones, and lava flows.

Cover: The Pinacate volcanic field as imaged by the Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) carried onboard the space shuttle Endeavour on April 18, 1994. Image is centered at 31.84°N, 113.47°W. The colors are assigned to different radar frequencies and polarizations of the radar as follows: red is L-band (23.5 cm), horizontally transmitted and received; green is L-band, horizontally transmitted, vertically received; and blue is C-band (4-8 cm), horizontally transmitted, vertically received. NASA Photojournal PIA 01852.

DAY 1

Mile 0	**Depart Tempe**: Head south on Rural Road to Broadway Road.
Mile 1	Turn right on Broadway.
Mile 3.5	At the junction with I-10, head south toward Tucson for ~8.5 miles.
Mile 12	Take the Maricopa road exit and head south for 29 miles.
Mile 43	At the junction with Hwy 84, turn west.
Mile 49	Take I-8 west.
	Stop 1. Rest area (or Gila Bend). Overview of geology of the area.
Mile 83	Take exit 116 at Gila Bend, turn south on Hwy 85.
Mile 126?	**Stop 2.** Mining pit in Ajo. Discussion of mineral deposits and mining operations.
Mile 160?	**Stop 3** (optional). Organ Pipe National Monument visitor center.
Mile 163	**Stop 4**. Mexican border at Lukeville. After crossing, proceed to Sonoyta.
Mile 165	Turning right onto Route 8, heading southwest towards Puerto Peñasco. The oldest volcanic center (Volcan Santa Clara) of the Pinacate volcanic field will become visible to the west.

EXERCISE 1. Remote sensing of the Pinacate region.

En route to the PVF, examine the color SIR-C/X-SAR radar image of the volcanic field (the front cover of your field guide). Based on your understanding of how microwave radiation interacts with surface materials, together with what you see from the van, suggest answers to the following questions:

1.1 What are the anastamosing channels in the southeast portion of the image? **Riverbed/ washes/ drainage channels.** What causes the bright radar return?

Surfaces that are 'rough' at the scale of the radar appear bright in radar images (L-band: 23.5 cm, C-band: 4-8 cm). At this locality cobbles and gravels in riverbeds, vegetation, and the clinkery tops of 'a'ā lava flows appear bright.

1.2 What might compose the broad, dark patterned surface in the far southwest of the image?

Dunes, composed of sand-sized particles smaller than the wavelength of radar, and dusty playa deposits appear dark in these images.

1.3 What causes the reddish hues in the image?

Differences in radar reflectivity caused by variations in the sizes of sediment types (boulders and cobbles to sand, silt and dust)

1.4 Within the main volcanic area, how many prominent (>500 m diameter) craters can you identify? Comment on the variations in morphology and crater floor brightness/color.

10–15. Most have some combination of radar bright & dark surfaces, indicating

rough/smooth and/or scattering/absorbing surfaces.

1.5 What are the lobate, bright yellowish features prominent in the eastern part of the field? **Lava flows.** What is the cause of their radar brightness?

The surface roughness of the flows. The rough, clinkery surface of 'a'ā flows results in a brighter radar return than the smooth, flat surface of pāhoehoe flows.

Now examine the false-color Landsat image of the Pinacates (Fig. 1). This was constructed with band 7 (2.08-2.35 μm), band 4 (0.76-0.90 μm), and band 2 (0.52-0.60 μm) in the red, green and blue channels, respectively. By referring to Fig. 2, which shows spectra of common rocks and minerals, answer the following questions.

1.6 What are the abundant circular red features? Why are they red?

Cinder cones. Oxidized scoria reflects strongly at longer wavelengths (2-2.5 microns).

1.7 Note that many of the craters and other features that are prominent in the radar image are less distinct in visible to near infrared wavelengths. Why is much of the volcanic field dark?

Basalt has low reflectivity and is spectrally flat (has little variability) in the vis-NIR region, appearing dark. In contrast, basalt can be bright or dark in radar depending on its form ('a'ā -bright, pāhoehoe-intermediate, cinders and ash-dark).

1.8 What is the material making up the yellowish surface to the southwest?

Quartz-rich dunes. Quartz is whitish in visible light.

Mile 200 At the sign for the Pinacate Biosphere Reserve, turn right off Route 8 onto dirt road, stop at Visitor Center to register and obtain a camping permit. Continue north on the dirt road for ~10 miles.

Mile 210 Bear left at fork in road, following the sign to Crater Elegante.

Mile 217 **Stop 6**. **Crater Elegante.** Lunch.

Crater Elegante is approximately 1600 m in diameter and 244 m deep, and formed some 32,000 years ago. The rim affords a great perspective of the surrounding geology: Volcan Santa Clara dominates the western horizon. To the northeast are the cones of Tecolote, Mayo and Cerro Colorado. The low-lying area to the south hosts abundant small cones. Lava flows are clearly visible to the west and northeast.

EXERCISE 2. Crater Elegante.

Walk up to the crater rim and (with caution) scramble a few meters down the slope towards the crater floor to examine the outcrops.

2.1 Describe the deposits in terms of their components, bedding structures, dip, etc.

Tuff breccia: Thinly bedded outward-dipping layers showing dune-forms, pinch&swell structures, bombsags (indicating sticky and cohesive material), poorly sorted, sometimes reverse-graded. Poorly indurated, partly palagonitized. Juvenile material: tan basaltic ash – vitric/vesicular. Lithic material: predominantly angular basaltic bocks, 50% derived from exposed precursor lava flows and 50% from deeper in volcanic pile. Lithics include quartzofeldspathic sand, silt, clay, few pebbles/cobbles forming pale buff matrix. Low porosity & permeability indicate a 'dryer' eruption relative to Cerro Colorado.

2.2 What eruption mechanism do these deposits represent?

Surge deposits produced in explosive phreatomagmatic activity. Relatively little H_2O – only partial palagonitization/induration; no accretionary lapilli; little construction around crater.

Walk west along the crater rim for 500–1000 m. Look across to the highest point along the rim on the opposite side

2.3 What do you notice about the structure in the opposite wall?

Bedding dips change; reddish in color; presence of dikes/intrusions (Devil's pitchfork)

Now backtrack and walk east around the crater towards the highest point. Along the way, note the relief of the crater rim in relation to the surrounding area, the dip of the beds, and the depth to crater floor. Also note the variety of large ejecta types.

2.4 Describe the material comprising the highest point of the rim. **Tuff breccia (32 ka).** How does it differ from that found elsewhere? What is the relationship of this structure to the crater?

The larger, juvenile, vesicular, oxidized, deformed spatter is part of a ca. 430 ka cinder cone. The initial magmatic volatile-driven phase, prior to onset of phreatomagmatic activity and formation of crater, can be seen in the younger gray cinders exposed in the south wall of the crater. For sequence of eruptions at Elegante see (Gutmann, 2002).

2.5 Based on everything you've observed, what type of feature is Elegante? How did it form?

Elegante has been called a maar, tuff-ring and mini-caldera. It has a complex history and multiple formative events. The eruption started with lava effusion, then explosive construction of the cinder/scoria cone commenced. At some point groundwater gained access to the magma and more powerful phreatomagmatic explosions occurred, producing the tuff breccia. Probably eruption and collapse (deepened and widened the crater) occurred roughly synchronously.

2.6 Examine the enlargement of the radar image covering Elegante (Fig. 3). Explain the variation in radar brightness in the crater floor.

Dark area represents the smooth/absorbing playa deposit in the center. Brighter regions are rougher floor/talus deposits.

2.7 What features does Elegante have or lack compared to impact craters?

Open-ended question: Has lavas, scoria cone, steep walls, depth/diameter ratio (d/D)=0.15 (cf 0.1 for impacts).
Lacks: overturned beds, etc.

Returning to the vans, we will leave Elegante, and travel north around Tecolote cone.

Mile 221 **Stop 7. ‘**A‘ā lava flow front. We will examine the lava textures and discuss the emplacement processes of ‘a‘ā flows.

Walk up and examine the textures of the lava surface and flow front. How do these characteristics relate to the radar brightness?

Noting the characteristics of the surrounding surfaces, examine the enlarged radar image (Fig. 3) to locate our position.

Mile 224 **Stop 8.** Continuing along the road, we will turn left into the Tecolote campground.

EXERCISE 3. Lava flows.

Walk west along the short road through the campground for ~500 m until you enter a broad basin surrounded by thick lava flows. One flow emanates from Mayo cone, immediately to the north of the campground, another comes from the Tecolote cone complex to the south. Walk clockwise around the margins of the basin to examine the different lava flows.

3.1 Locate the pāhoehoe flow. Note the surface textures. What is its stratigraphic relationship and age relative to the ‘a‘ā flow?

Pāhoehoe lies below the ‘a‘ā and is therefore older.

3.2 From the radar image, what can you say about the abundance of pāhoehoe flows relative to ‘a‘ā in the Pinacate volcanic field?

‘A‘ā is far more abundant.

DAY 2

EXERCISE 4. Mayo Cone.

Starting from the campground, skirt westward along the base of the Mayo cone, and head up over the saddle into the interior of the breached cone complex.

4.1 Describe the characteristics of the pyroclastic material comprising the cone outer flanks. How does this differ from the material you saw at Elegante?

Vesicular, scoriacous, juvenile lapilli. Larger than the juvenile material (ash-sized) at Elegante.

4.2 Describe the characteristics of the pyroclasts and deposits within the interior of the breached cone.

Large bombs up to ~0.5 m and larger. Some breadcrusted, some deformed. Dense, poorly vesicular, juvenile.

4.3 Based on your observations of the cone complex and pyroclastic material, describe the eruption mechanisms responsible for the deposits. How do you think the eruption evolved through time?

(1) Initial lava effusion (magma contained too few volatiles to exsolve sufficiently to fragment magma), or alternatively, the initial lava effusion was essentially degassed during storage or ascent, and it was only as the eruption progressed that more volatile-rich magma was tapped for stage 2 – Note that the results of these processes are more clearly visible at La Laja Cone. (2) Transition to strombolian activity (ascent of a more volatile-rich magma, including exsolution, bubble growth and fragmentation). (3) Transition back to effusion as volatiles become exhausted, lava piles up inside cone, cone is breached, and lava flows off to the west. (4) Lava cooling and crystallization in vent/conduit induces further exsolution in liquid phase, and final late-stage ejection of large, dense bombs, producing spatter collars on cone tops and around interior vents. There are some small, late explosion pits in Mayo & Tecolote Craters.

Returning to the vans, we will leave the campground and head west to Cerro Colorado.

Mile 230 **Stop 9**. View of Cerro Colorado to the north. Note the relief of the structure and dip of the bedding.

Mile 233 **Stop 10. North rim of Cerro Colorado.**

Cerro Colorado is >27,000 years old, based on Ar/Ar dating of overlying Tecolote lapilli. The crater is approximately 1000 m in diameter, with the crater floor lying >100 m below the highest point on the south rim. The morphology of the crater records multiple centers of activity. Note the presence of Diaz Playa to the north of Cerro Colorado.

EXERCISE 5. Cerro Colorado.

Walk down a few meters inside the crater rim onto the benches to examine rim deposits.

5.1 Describe the characteristics of these deposits (clast types, bedding, dip, etc.)

Palagonitized tuff with diverse lithics. Well indurated. Laterally extensive (along crater rim), normally graded beds, with steep outward dips. Accretionary lapilli present. Lithics include quartzofeldspathic gravels.

5.2 How were these deposits formed?

Fall deposits, from phreatomagmatic explosions.

5.3 What do the lithic clasts say about the pre-eruption environment?

Rounded lithics indicate fluvial environment.

5.4 How do these deposits differ from those at Elegante?

More indurated/palagonitized, accretionary lapilli – more water involved in explosions. Beds are planar and laterally extensive (absence of duneforms, etc.) indicating fall not surge deposits.

Looking down into the crater, note the pinkish tan deposits exposed at the bottom of the crater's north wall. These are mudstones, which probably represent pre-existing playa deposits.

5.5 What does the morphology of the crater interior suggest regarding the focus of eruptive activity?

Scalloped margins and inward dipping beds suggest several foci of activity.

Return to the crater rim. Walk counterclockwise around to the northwest part of the rim. Note the presence of long-wavelength radial dune-forms on the outer flanks. Examine the deposits in the crater wall.

5.6 What do these deposit characteristics suggest about their mechanism of emplacement?

Turbulent emplacement produced differential deposit thicknesses (dunes), i.e. they are surge deposits. (One of only a few known localities for longitudinal dunes w/surge deposits.)

5.7 What do your observations of cone relief, deposit characteristics, and bedding dip suggest about eruption style and the role of external water? What type of feature is Cerro Colorado?

Larger accumulation of material at rim suggests sticky, cohesive material. More water (than Elegante) also indicated by accretionary lapilli and palagonitization/induration. Surface water (rather than groundwater) may have been involved here. Cerro Colorado is a tuff cone.

Return to the crater rim and head back to the vans.

5.8 Locate Cerro Colorado on the radar image (front cover). Explain the radar-dark apron.

Smooth, flat-lying apron of fine pyroclastics from Cerro Colorado.

5.9 Study the radar image to determine the locations of major craters. Given what you now know about the formation of volcanic craters at Pinacate, what inferences might you make about the paleohydrology of this region?

Ideas: Water was displaced by the growing volcanic field and concentrated around the north and east margins, where the maars and tuff rings/cones are located. Alternatively, magma could have pierced a unit of water-saturated sand & gravel in an abandoned channel of Sonoyta River, Strombolian activity & lava flows would have changed to phreatomagmatic activity and maar formation (Jahns, 1959; Gutmann, 2002).

5.10 How might one distinguish between impact craters and volcanic craters such as Cerro Colorado and crater Elegante in remotely sensed data?

Cerro Colorado has significant accumulation of material in cone, would be easier than Elegante to distinguish from an impact crater. Scalloped margins might also provide a clue. Cerro's floor is only 10 m below surrounding terrain, in contrast to impact craters. Multispectral imaging data could also yield clues as to composition and hence point to a volcanic vs. impact origin.
Many other points can also be made here, as for 2.7.

Lunch at the vans. We will leave Cerro Colorado and head north out of the Reserve.
Mile 234 Head north through Playa Diaz.
Mile 239 Head north on cinder road.
Mile 240 Exit Pinacate Biosphere Reserve, Join Route 2 heading east.
Mile 272 Turn left at junction with Route 8. Head north through Sonoyta to border.
Mile 274 Border crossing. Reverse the outbound route to return to Tempe.

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