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ADEN LAVA FLOW, DOÑA ANA COUNTY, NEW MEXICO

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Abstract—Aden Crater is a small volcanic shield in the Potrillo Volcanic Field approximately 40 km southwest from Las Cruces. The shield and surrounding flow field are mapped as volcanic facies in which the morphology is governed by the rheology of the lava. The flow field which spreads east and south from the vent consist of early, fluid basalts that inflated to various thicknesses determined by the strength of the outer crust. Flows inflated to form steep-margined, flat-topped plateaus. The field is a rugged accumulation of inflation plateaus in which adjacent flow margins form deep intervening ravines. The Aden shield was formed as viscosity increased to the point that the lavas began to accumulate over the vent. The shield facies consist of basal thin scabby flows, very low sloping lobate flows, and an upper slope of steeper channeled flows, with a wide shallow crater at the top.

INTRODUCTION

Aden Crater lava field encompassing 75 km^2 in south-central New Mexico, offers excellent examples of features of low viscosity basalt flows associated with an Icelandic-type shield volcano. We defined five distinct flow facies based on examination of recent images (2009), numerous field trips, and field studies in 2012 and 2014. Flow physiography is described in terms of inflation in which a fluid interior acts on a thickening crustal layer. The five flow facies are a function of the rheology and timing of flow emplacement.

The Aden shield volcano is located south of I–10 (N32°04', W107°03'), approximately 40 km southwest of Las Cruces (Fig. 1). Aden is accessible by county maintained graded roads. From Las Cruces, take E. Union Ave. (NM 373) west to Snow Road (NM 372). Take Snow Road 1.5 mi south to the Mesilla Dam Road (NM 374). Take Mesilla Dam Road one mile to River Levee Road. Turn south 0.16 mi to Dona Ana County Road B006. Cross dam and follow B006 6.2 mi until it connects with B007. Follow B007 south for 11 mi and take the right fork onto B004. Follow B004 southeast 2.6 mi and cross the railroad track. On the west side of the track take the road B002 7.9 mi north. This road skirts a patch of the Afton-Gardner flow and continues to intersect a prong of the Aden flows. After the road crosses the basalt, a small unimproved dirt track heads west away from the railroad. The track skirts the northern edge of the flows for 5 mi to the west and circles around to approach the crater from the southwest.

REGIONAL SETTING

Aden Crater and its associated flows are among the youngest features in a diverse, monogenetic basalt field known as the Potrillo Volcanic Field (Fig. 1). The Potrillo Volcanic Field (PVF) occupies the southernmost part of the Rio Grande Rift, where it merges with the New Mexico portion of the Basin and Range Province (Seager and Morgan, 1979; Keller and Cather, 1994; Baldridge 2004; Fig.1). The Potrillo Volcanic Field is included in the Organ Mountain-Desert Peaks National Monument established by presidential proclamation on May 21, in 2014.

The Potrillo Volcanic Field includes within its boundaries: West Portillo cinder field; scattered maar craters; Gardner cinder cone complex and flows; Black Mountain chain of cinder cones; and Aden shield volcano and flow field. The West Potrillo field covers an area of 590 km^2 and includes more than 100 cinder cones averaging 60–150 m high with ages between 80 to 17 Ka (Thompson et al., 2005). There are at least five maar-type craters in the area. Kilbourne Hole (28 Ka, Williams, 1999); Hunts Hole (16±0.7 Ka, Williams and Poths, 1994); and Potrillo Maar are east of the field (De Hon 1965a, Reeves and De Hon, 1965,

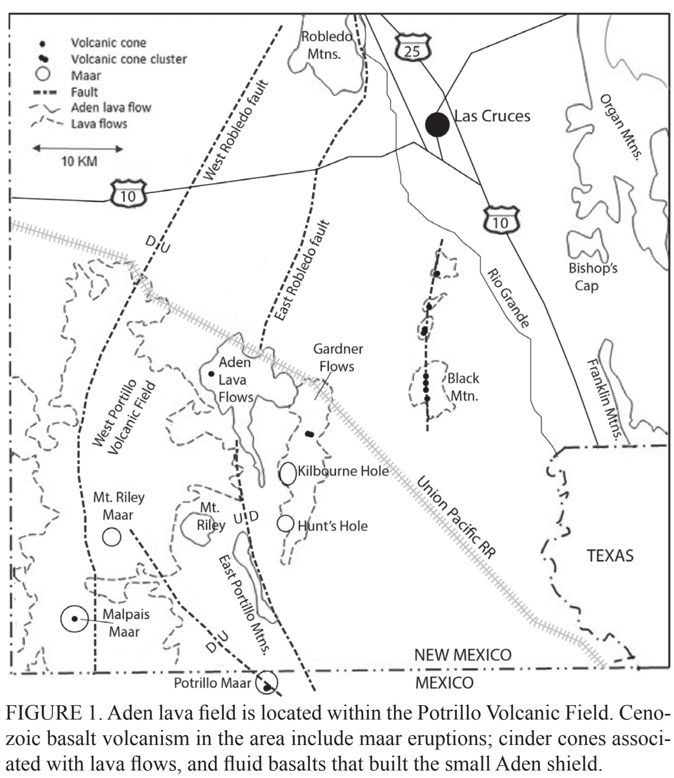

FIGURE 1. Aden lava field is located within the Potrillo Volcanic Field. Cenozoic basalt volcanism in the area include maar eruptions; cinder cones associated with lava flows, and fluid basalts that built the small Aden shield.

Hoffer, 1971, Padovani and Reid, 1989). Riley Maar (Bersch, 1977) is located in the interior of the field, and the Malpais Maar (Page, 1975) near the south end of the field, is almost completely buried beneath a 75-m-high cinder cone that was built on its floor. The Gardner cinder cone complex is a small cluster of cinder cones associated with an 80-km^2 Afton lava field that extends 4 km north of the cluster to 13 km southward. The basalt is partial obscured by eolian sand cover and low scrub brush. It is best exposed in its northern reaches near the Afton railroad crossing and in vertical sections in Kilbourne and Hunts Holes. The Afton-Gardner flow, dated at 72–81 Ka (Williams and Poths, 1994) is overlain by the Aden flows northwest of the cone cluster. The Black Mountain-Santo Tomas cinder cones and flows are an isolated chain of volcanoes near the eastern edge to La Mesa. The Aden flows at 22 Ka, are the youngest in the region (Williams and Poths, 1994; Dunbar, 2005).

STRUCTURAL SETTING

The Aden flows overlie the La Mesa surface of aggraded Rio Grande sediments of the Camp Rice Formation (ca. 700 Ka) which is part of the Mesilla Basin, one of the asymmetrical interconnected fault-bound basins along the Rio Grande Rift (Mack and Seager, 1995; Hawley, 1981; Hawley and Kennedy, 2005; Mack, 2004; Mack et al., 2006). Except for the faulting responsible for the uplift of the East Potrillo Mountains (Fig. 1), faults on La Mesa were originally proposed based on the alignment of volcanic features and possible control of local deflation basins. Improved fault traces are now provided by well log and geophysical methods (Seager, 1995; Seager et al., 1997). Alignment of various pits on the flanks of Aden was presumed to be formed by venting along the fault traces of the Robledo Fault beneath the flows (De Hon, 1965b: Hoffer, 1976a and 1976b). It was also thought that the Gardner cone complex, Kilbourne and Hunts Holes were aligned along the Fitzgerald Fault (De Hon, 1965a; Hoffer, 1976a and 1976b). Surface mapping and subsurface evidence (Seager, 1995; Seager et al., 1987) shifts the location of the Robledo fault, and observations of De Hon and Earl (2018) do not support fault control for the features at Aden.

FLOW FIELD

The extent of lava flows associated with Aden was mapped by Seager (1987, 1995). The flows extend approximately 4 km to the north-northeast, 10 km to the east-southeast to the Afton crossing of the Union Pacific (formerly the Southern Pacific) railroad, and a narrow arm extends 13 km to the south in the vicinity of Kilboune Hole. The Aden flows are alkaline olivine basalt and basanite (Kahn 1987; Hoffer, 2001). At low elevations, the thin flows are partially obscured by an eolian sand cover, low scrub growth, and grasses. Higher elevations are generally free of cover and much fresher in appearance. Depressions in the flows and ravines formed between adjacent flow margins are generally floored by sand and buffalo gourd.

Relative age is difficult to determine in lava flow fields as much of the lava moves beneath a hardened basalt crust and may emerge from several outbreaks along the crusted margin. We define five distinct flow facies associated with Aden based on the morphology of the flows as determined by the rheology of the lavas (Fig. 2). Initial thin, fluid flows are mapped as scabby facies (unit sc) that spread eastward and northward from the vent. The bulk of the field is mapped as subfacies of inflated flows (unit if). The Aden shield consist of lobate flow materials (unit lo), channeled flow materials (unit ch), and crater materials (unit cr).

Early scabby facies flows are characterized by ropy pahoehoe surfaces that are now partially obscured by eolian sand and low vegetation. The flows near the vent contain various early, failed inflation features (Fig. 3), including rootless shields and blocky rimmed pits (De Hon and Earl, 2018). Rootless shields, 3–10 m in diameter, are formed by local tumuli on the flow surface that lifted the semi-hardened crust into a positive relief dome rising 2–4 m above the surrounding flow. Lava channels, formed by escaping lava, radiate away from the domes. Blocky rimmed depressions are the largest of the pits on the flanks of the cone. These large pits are unique in that they are irregularly shaped in plan view, and they are surrounded by a raised rim of blocky basalt. The pits are floored by relatively smooth flow material that is crossed by one or more large, open fractures. Blocky rim material overlies both floor material and floor fractures. Previously interpreted as explosion pits based on the presence of blocky, raised rims (De Hon, 1965b; Hoffer, 1975), these irregularly shaped pits are reassessed as collapsed lava-rise tumuli that failed to form inflation plateaus (De Hon and Earl, 2018). Inflation occurs when fluid lavas begin to develop a brittle crust underlain by a ductile layer. Once the crust at the edge of the flow becomes thick enough to impede the flow, the fluid interior begins to exert pressure to lift the upper surface to produce an inflation plateau (Walker, 1991, 2009; Hon et al., 1994). At the blocky rimmed pits, congealed lava margins lacked sufficient strength to retain the internal fluid lava. Fluid lavas spilled out around the raised margin allowing the plateau surface to deflate. The blocky raised rims are remnants of flow margins surrounding the deflated interior. Lava channels radiate away from the collapsed plateaus in all directions.

The preflow surface of La Mesa around the Aden vent had a gentle slope to the east. South of the vent a shallow trough was formed by the eastward sloping La Mesa surface and the basalt of the Gardner basalt field. The surface was largely sand with some cinder wash from the West Portillo Field to the west. Local relief was on the order of 1–1.5 m.

Scabby flows (unit sc) transition into the distal flow field in which the flows are in various stages of inflation (unit if). Distal flows consist of thick, flat-surfaced flows intermingled with thinner flows. The flows have reached their current thicknesses by the process of inflation as described by Walker, (1991, 2009) in Hawaii. The inflated flows are subdivided into three subfacies (units if_1, if_2, and if_3) based on the extent of inflation (Fig. 4).

Unit if_1 consist of the thinnest flows which spread across the surface filling small depressions and surrounding small rises in the surface. They have uneven surfaces with 0.3- to 0.5-m micro-relief. Much of this low elevation flow surface is partially obscured by blow sand and scrub growth. Locally if_1 flows

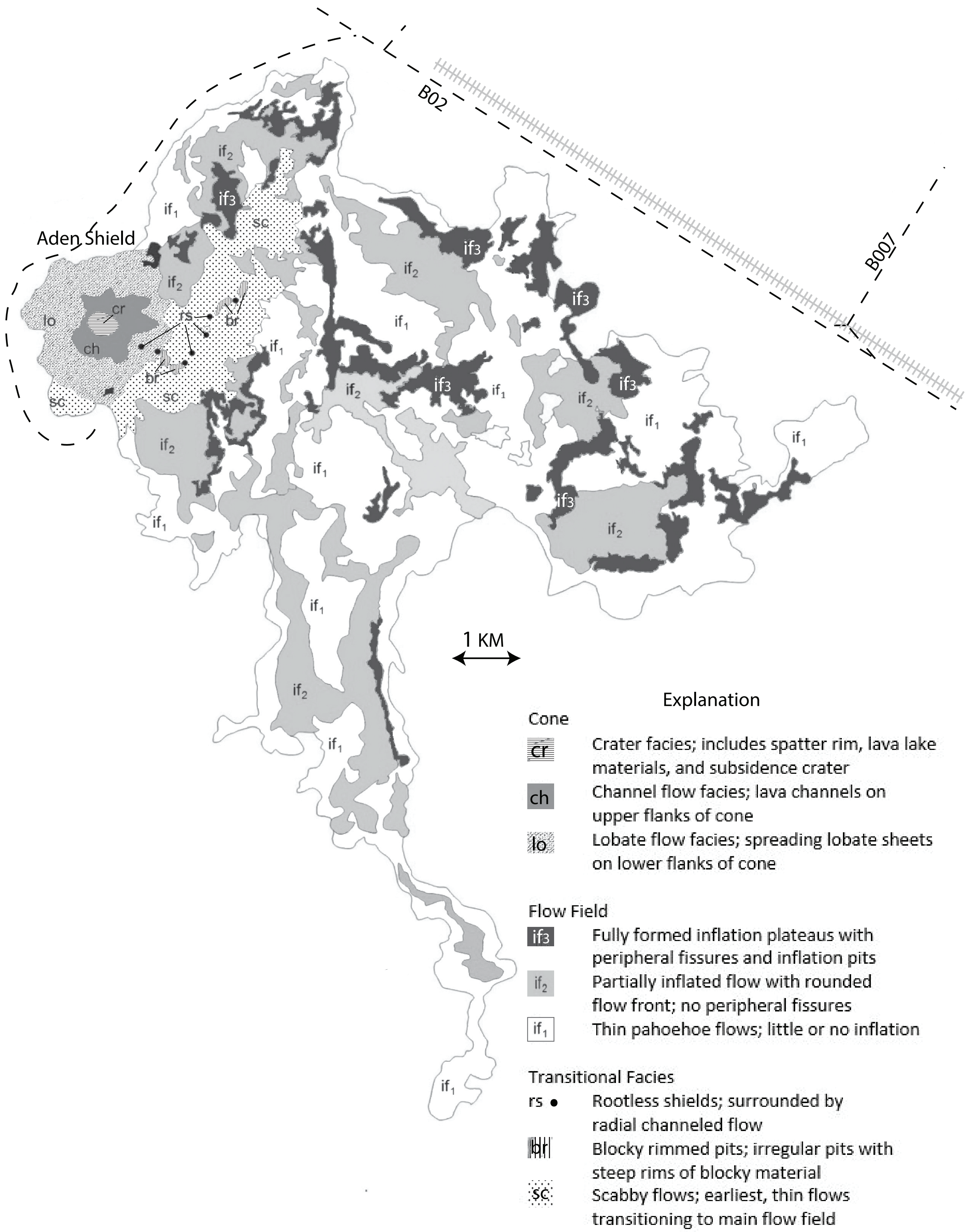

FIGURE 2. The Aden flows are mapped as facies based on morphology control by lava rheology. The basal unit consists of thin, scabby flows and some early failed inflation features. The bulk of the field is composed of lava flows in varying stages of inflation which account for a very rugged relief. Later, slightly less fluid flows built the shield over the vent.

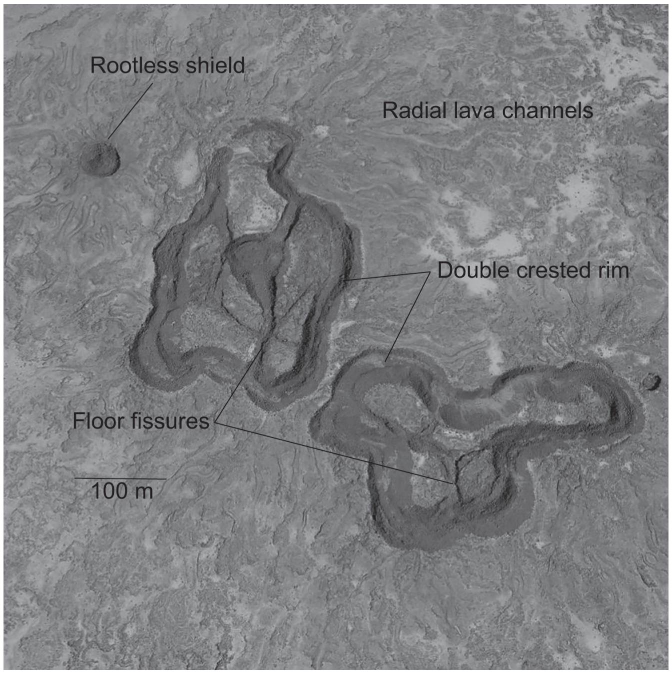

FIGURE 3. Early attempts at inflation are seen as rootless shields surrounded by radiating lava channels and doubly crested blocky-rimmed craters with smooth floored interiors and radiating lava channels.

develop inflation (pressure) ridges that rise 1–2 m above the surface. These ridges typically have steep, rounded profiles; are 1–3 m wide; 10–100 m long; and many have an axial fissure along their crests.

Unit if_2 consists of partially inflated flows that are 2–3 m thick (Fig. 4). They have steep, rounded flow margins and a flat-topped surface. The upper surface is cut by a rectilinear pattern of tension joints. The flow margins are fractured or slabby, but not noticeably blocky. The flow surface is pocked by inflation pits 10–20 m across and 2–3 m deep. Inflation pits form where a flow has surrounded a slight rise in the preflow surface. The flow inflates around the rise to become a steep-sided depression in the inflated flow.

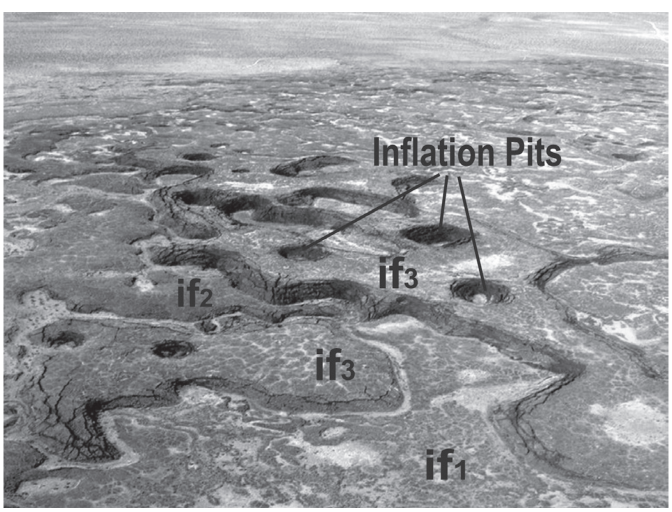

FIGURE 4. The distal flow field consists of lava flows in varying stages of inflation. It is mapped as three subfacies (units if_1, if_2, and if_3) based on the thickness of the flow units. Unit if_1 is relatively thin with a rugged micro-relief. Unit if_2 is moderately thick with well-defined flow fronts and flat upper surface. Unit if_3 is the thickest unit with blocky flow fronts, flat elevated surfaces, and large peripheral fractures.

Unit if_3 plateaus reach 4–5 m thickness; range from 100–300 m in width, and extend 300–1200 m in length. These inflation plateaus have well-developed marginal fissures that are 1–2.5 m wide and extend downward for 3–5 m (Fig. 4). The flow margins are locally quite blocky as the brittle surface of the flow front was stretched and fractured as the flow inflated. The upper surface of the plateaus is smooth, level and cut by a rectilinear pattern of tension joints spaced 4–11 m apart. Inflation pits occur were the lavas flowed around rises in the preflow surface. The pits in these flows are 40–80 m across, as deep as the lava is thick, and the sides of the inflation pits are blocky lavas as found in flow margins. The floor of the pit is either Camp Rice sediments or earlier if_1 flow material.

Relief of the entire flow field is rugged. Inflated flow margins form steep slopes on the order of 30°. Abutting flow margins form steep-sided ravines that wander through the field. Where if_3 plateaus are adjacent, ravines have blocky or slabby slopes and are 4–5 m deep. Where if_1 or if_2 margins meet the slopes are just as steep, but less blocky and much shallower. The floors of the ravines are v-shaped but flattened by a thin sand fill. Traversing the flow field is a matter of climbing up and down flow margins, crossing narrow ravines, and walking on smooth elevated plateau surfaces. Walking along ravines is a fairly level, often winding path, made difficult by the profusion of buffalo gourd vines.

ADEN CONE

The young Aden shield is unique to the region as a late-occurring Icelandic-type shield built of very fluid lavas (Fig. 5). From a distance, the Aden appears as a gradual slope with a flat crest. A nontechnical description of the crater atop Aden was published by Perkins (1949). De Hon (1965b) described the crater's features, as did Hoffer (1975, 1990). Kahn (1987) made a more extensive study of the shield with attention to the lava channels. Aden is mapped here as three facies—a lobate flow facies (unit lo), a channeled flow facies (unit ch), and the crater facies (unit cr).

Aden shield is built of less fluid lavas which accumulated near the vent. The low shield is 2.5-km diameter at its base and rises only 50 m above the surrounding surface. The shield has a concave upward profile topped by a wide shallow crater. The upper part of the shield consists of 0.5- to 1.5-m-wide, levied lava channels and lava tubes (unit ch) on a slope of 8–15%. The channels branch in a distributary pattern downslope. The junction formed by branching distributary channels is responsible for the horseshoe shaped lava ridges, *herradura*, described by Hoffer (1971). Flows emerging from channels and tubes downslope spread laterally as overlapping lobate flow fronts (unit lo) as the slope decreases to 3–5% at lower elevations. The lobate flows overlie nearly flat-lying, thin flows of the scabby facies (unit sc) which form the base of the shield.

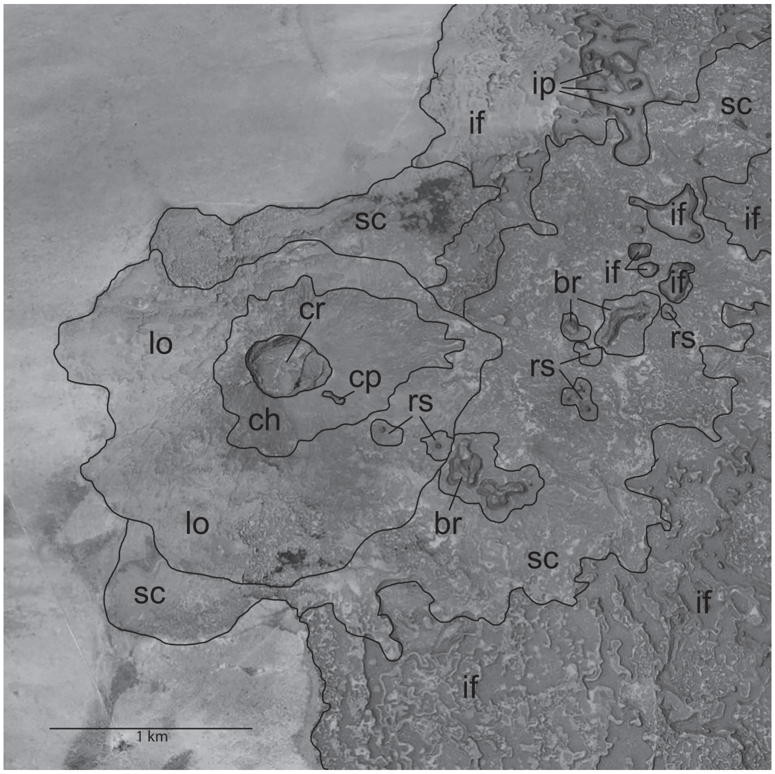

FIGURE 5. Aden crater shield consist of a wide shallow crater atop a broad low shield. The shield exhibits channeled lava flows extending down slope from the crater rim to merge with broad spreading lobate lavas. Rootless shields (rs) and blocky rimmed pits (br) are found in the scabby facies (sc) on the east side of the shield.

The crater atop Aden (unit cr of Fig. 5) is a broad, shallow crater 350 m in diameter. The crater has received most of the attention of past descriptions (Perkins, 1949, De Hon, 1965b, Hoffer, 1990) and is the destination of many field trips. The crater rim consists of a steep pile of lava agglutinate, 2.5–3.5 m high, built of spatter from a lava lake that occupied the crater. The crater floor consists of multiple layers of lava. Open tension fissures 0.5–1.5 m wide, and up to 3 m deep, ring the floor inside the rim. A small 3-m-high spatter cone near the center of the crater sits atop the lake lavas, and a 120-m-diameter, 20-m-deep funnel-shaped depression cuts through the lavas in the southern part of the crater. The open remnant of a fumarole occurs on the southeast rim. Guano mining from the vent uncovered a well-preserved skeleton of a Shasta Ground Sloth (*Nothrotheriops shastensis*) with two radiocarbon ages of 9840±160 and 11,080±200. It is now on display at the Peabody Museum at Yale University (Lull, 1929; Simons and Alexander, 1964).

FIELD EXCURSION

A typical visit to Aden usually begins with an approach to the crater from the west and crossing lobate flow materials and channeled flows. Numerous small lava tubes are visible on the flanks of the crater. Crossing the rim at one of the low spots allows observation of the spatter lava accumulation. Once in the crater, the circumferential fissures are apparent. A spatter cone, near the center of the crater, sits atop hardened lavas of the lava lake. The spatter cone is of interest because it has a unique grooved surface formed when an unstable pile of lava agglutinate broke loose and slide down the outside of the cone. Approximately fifty meters north of the spatter cone are drill holes from the mid-1960s testing of rock-sample drills for the Apollo program. From the spatter cone head south, skirting the inner pit, to the south rim and the open fumarole, from which the remains of a giant ground sloth were discovered during guano mining operations in the 1920s.

Field trips often continue down the southeast flank to visit small collapse pits, rootless shields and blocky rimmed pits. Entering the closest blocky rimmed pit involves climbing a rugged blocky surface, descending into the rim trough, and climbing the inner raised ring. Once inside, the floor is relatively smooth and unbroken except for large fissure that transverses the floor. An examination of the rim from inside the pit reveals that blocky rim material overlies both floor and a fissure.

The crater and flank feature are often the destination. A visit to Aden would be incomplete without an examination of one or more inflation plateaus. Continuing down the flank of the shield into the flow field allows a close examination of the blocky margins and the upper surface of an inflation plateau.

SUMMARY

Eruptions at the Aden vent were the latest discharge in the Portillo Volcanic Field. Flow morphology reflects a history of increasing flow viscosity during the lifetime of the field. Activity began with the eruption of fluid lavas that spread westward and northward away from the vent. As the outer brittle layer thickened and began to retard flow, rootless shields, and failed inflation plateaus mark early failed attempts to thicken the flow by inflation. Continuing eruption of lava spread southward along a minor declivity and eastward—and as lavas cooled—thickening by inflation became common. The distal flow field is a rugged mix of flat topped, inflated flows and intervening ravines with local relief of 3–5 m. The final stages of eruption are marked by the eruption of slightly less fluid lavas which began to collect at the vent and build a low, wide shield. A wide, shallow crater filled with a lava lake capped the shield. Lava channels and lava tubes trace the overflow from the lava lake down the flanks of the shield. Channels discharge lavas as broad overlapping lobate flows on the lower flanks.

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