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Development and growth of recently-exposed fumarole fields near Mullet Island, Imperial County, California

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ABSTRACT

New field observations, aerial surveys, LiDAR measurements and laboratory studies of mud samples (2006 to 2012) are reported of several formerly submerged fumarole complexes that are presently undergoing surface exposure as the Salton Sea level drops. Some remain submerged as of this writing (2012). The fumarole fields range in area from 1000 to ~50,000 m^2. They consist of hundreds of warm to boiling hot gryphons (mud volcanoes), salses (mud pots), and countless active gas vents. Unusually-shaped mud volcanoes in the form of vertical tubes with central vents were observed in many places. Since exposure began in ~2007, the surface morphology has changed dramatically, with a trend toward more and growing gryphons, larger mud pots and the development of sulfur vents. Chemical analysis of mud from several gryphons revealed the presence of the ammoniated sulfate minerals boussingaultite and lecontite among other more common sulfates. With other geothermal features, the fumaroles define a well-defined lineament marking the trace of a probable fault. A model for the development of gryphon morphology is presented.

1. Introduction

Mud volcanoes are formed by the upward migration of fluidized sediment driven by subsurface over-pressured gas. Rising viscous mud is forced upward though a narrow vent where it accumulates, creating a conical mound around the central conduit (Ives, 1951; Jakubov et al., 1971; Macdonald, 1982; Hovland et al., 1997; Delisle et al., 2002; Kopf, 2002; Martinelli and Behrouz, 2003; Planke et al., 2003; Etiope et al., 2004; Bonini, 2008, 2009; Mazzini et al., 2009a, b; Svensen et al., 2009; Onderdonk et al., 2011). The process is mechanically analogous to igneous volcanoes. Though some mud volcanoes can be hundreds of meters high, those smaller than about 2 m in height are called “gryphons”. On the earth's surface where water is abundant, bubbling water sometimes stands in the calderas of gryphons, where they are termed “salses”. Salses are often called “mud pots”, and may vary in fluid content between water with small amounts of sediment to thick, viscous mud. Gryphons and salses associated with fumaroles and high geothermal gradients are “hot” (boiling and steaming) and emit gasses such as CO_2, H_2O, SO_2, H_2S, NH_3, and CH_4 (Dimitrov, 2002). Others are “cold” and emit primarily CO_2. Cold gryphons with central salses are sometimes termed “mound springs”. Mud volcanoes are relatively rare geological structures and tend to occur at active plate margins like the Salton Trough (Dimitrov, 2002; Martinelli and Behrouz, 2003).

The Salton Trough is a topographic low in southern California and northern Baja & Sonora Mexico (Fuis and Mooney, 1990; Dangermond, 2003) representing a tectonically active, sedimentary pull apart basin (Elders et al., 1972; Mann et al., 1983; Lonsdale, 1989; Brothers et al., 2009; Gurbuz, 2010). Except for minor contributions from the surrounding mountains and aeolian sources, most of the sediments in the Salton Trough represent Colorado River sediments and are as thick as 6 km (Muffler and White, 1969). The structurally controlled depression lies in the transition between the right lateral San Andreas Fault system and a series of oblique spreading centers of the northern extension of the Gulf of California (Macdonald, 1982). It is dominated by a number of contiguous right lateral, right stepping (releasing) transform faults including the Imperial and Cerro Prieto faults (Magistrale, 2002; Meltzner et al., 2006) and those of the Sierra Cucapah in Mexico where the Mw 7.2 April 4th, 2010 El Mayor–Cucapah earthquake recently occurred (Hauksson et al., 2010).

Within the Salton Trough lies the Salton Sea Geothermal Field. Here the geothermal gradient averages ~0.3 °C/m (Younker et al., 1982; Elders and Cohen, 1983), reaching a maximum of 4.3 °C/m (Lee and Cohen, 1979), enough to support a number of commercial geothermal electricity generating plants. The high geothermal gradient is the result of a shallow magma body from one or more spreading centers (Lachenbruch et al., 1985; Schmitt and Vazquez, 2006). Extruded

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Fig. 1. Reference map of the study area in Imperial County, California. An annotated Google Earth image of the study area showing the locations of the fumaroles discussed in this paper is shown in Fig. 2.

Table 1
Locations and descriptions of the major vent fields.

Name	Latitude	Longitude	~Size (m)	Comments
F1	N 33.2210	W 115.6036	25 × 50	Boiling hot, exposed, surroundings dry
F2	N 33.2184	W 115.6011	120 × 400	Boiling hot, exposed, surroundings dry
F3	N 33.2135	W115.5931	30 × 50	Hot, steaming, exposed, many salses, surroundings wet and muddy
F4	N 33.2150	W 115.5937	50 × 60	Partially exposed, many salses, a few gryphons, not steaming
F5	N33. 2122	W115.5951	100 × 100	Underwater, many vents flowing mud, not steaming
F3N	N 33.2141	W 115.5935		Possible vent field, under water, not steaming
F3S	N 33.2126	W115.5931		Possible vent field, under water, not steaming

The entire area in the bayou around F3 shows many vents and vent lineaments. F1, F2 & F3 are the only vents observed to be steaming hot.

magma produced the Salton Buttes, five late Quaternary rhyolitic volcanic necks near the southeastern end of the Salton Sea (Robinson et al., 1976; Newark et al., 1988).

The Salton Sea occupies the lowest part of the Salton Trough. It is a saline, eutrophic, endorheic rift lake (Dangermond, 2003; Hurlbert, 2008) that was created when a canal breach diverted the Colorado River into the Salton Trough in March 1905. Fresh water flowed north through the New River and Alamo River (Kennan, 1917). After the canal was repaired in Feb 1907, the high water level of −59 m MSL (−195 ft) decreased rapidly to around −76 m MSL (−250 ft) in 1917. Rain and runoff gradually raised the sea level, reaching a high of about −70 m MSL (−229 ft) in the mid 1980s, after which legislation resulted in a gradual lowering of the sea level that continues to this day (Lynch, 2011).

Where the Salton Sea overlaps the Salton Sea Geothermal Field, the interaction of rising gas and hot water with sediments has produced a number of hot, fumarolic gryphons and salses (LeConte, 1855; Veatch, 1860; Helgeson, 1968; Muffler and White, 1968; Sturz et al., 1992, 1997; Svensen et al., 2007; Lynch and Hudnut, 2008; Manga et al., 2009; Svensen et al., 2009; Rudolph and Manga, 2010; Onderdonk et

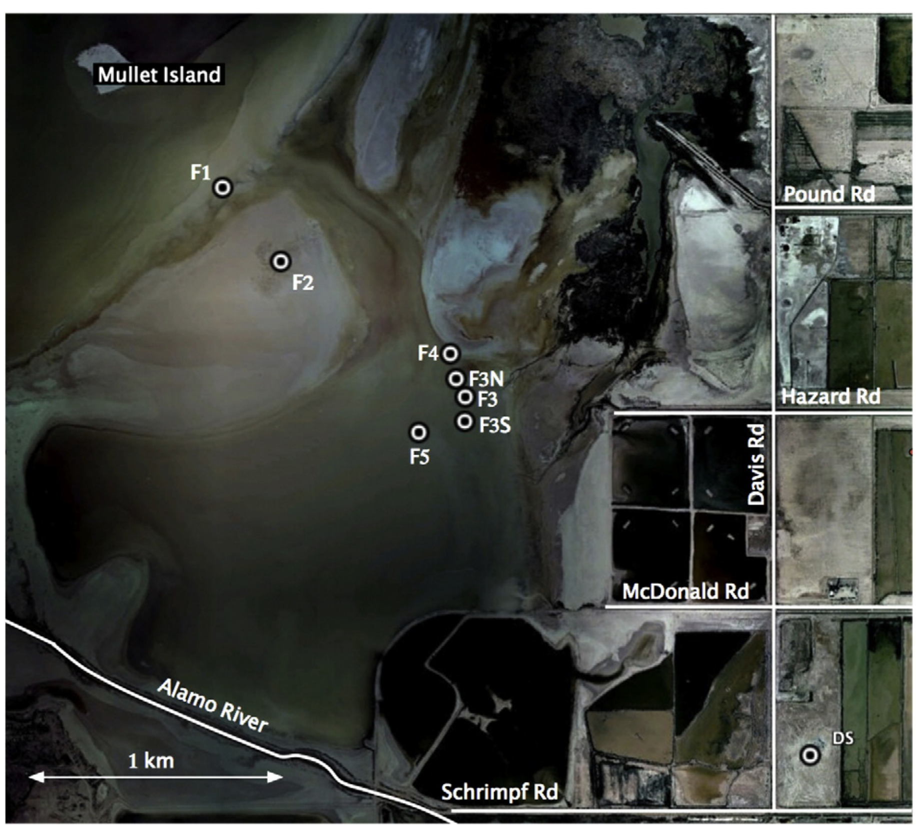

Fig. 2. Annotated Google Earth image of the fumaroles in our study area from Table 1. Mullet Island is upper left, the Davis–Schrimpf gryphons at lower right (DS). The evident NW-trending lineament of the geothermal features is suggestive of a fault, probably the Calipatria Fault (Lynch and Hudnut, 2008).