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Little Ice Age debris lobes and nivation hollows inside Ubehebe Crater, Death Valley, California: Analog for Mars craters?

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ABSTRACT

The 250 m-deep, Ubehebe Crater is the youngest (<1000 years) and largest (800 m-wide) phreatomagmatic crater of the Ubehebe maar field of northern Death Valley, California, USA. The crater is blanketed by loose, unconsolidated ejecta debris and prominent tongue-shaped, steep-fronted debris lobes up to 200 m long occur at the base of the crater's steep northeast-facing interior slope. Geomorphological observations, sedimentological analysis of outcrops and a ground penetrating radar survey, show the largest lobe to be composed of downslope-dipping progradational beds of ejecta resulting from repeated downslope avalanching ('grain flow') and cohesive debris flow inconsistent with an origin of the lobe as a singular coherent slump or flow. Large oval depressions on the upper surface of lobes are interpreted as relict nivation hollows occupied by former seasonal snow patches during recent Little Ice Age cooling (c. ~700 year BP) when numerous rock glaciers and other periglacial landforms formed at high elevations in surrounding mountains. Lobes are interpreted as protalus ramparts formed when loose, non-cohesive ejecta from the steep unstable backwall of the crater moved downslope across snow patches and accumulated around their outer margins. Snow patch and lobe formation is considered to be a function of the local aspect-related meteorology of the crater's interior involving shading of northeast-facing interior slopes, radiative cooling and ponding of cold air, enhanced snow accumulation in the lee of the steep backwall combined with the availability of large volumes of loose ejecta. Ubehebe Crater and its lobes expand the geomorphic record of cool climate processes in Death Valley, the most well-known being the winter-ice facilitated 'sliding boulders' of Racetrack Playa. Having formed in an extreme environment, lobes offer an accessible terrestrial analog for poorly-understood debris lobes within Martian impact craters.

1. Introduction

The primary purpose of this paper is to describe steep-fronted and distinctly tongue-shaped debris lobes within the 250 m deep Ubehebe Crater in northern Death Valley, California, USA (37.02° N, 117.45° W; Number 1203-16 of the Global Volcanism Program; Figs. 1, 2, 3). This crater was formed by a violent phreatomagmatic eruption less than 1000 years ago. A prominent feature of the crater's ejecta-covered and highly unstable northeast-facing inner slope is the presence of large debris lobes reported as 'crescentic debris flows' by Sharp and Glazner (1997). This paper describes the geomorphology of these landforms and presents data on their composition and stratigraphy gained by sedimentological descriptions of outcrops and ground penetrating radar (GPR) surveys. We confirm a mass flow origin but in addition highlight the paleoenvironmental significance of surface depressions on the lobes and show how lobes are comparable to protalus ramparts formed at the margins of snow patches lying below unstable talus slopes and cliffs. We speculate on the paleoclimatic significance of these features emphasizing the peculiar meteorological conditions inside Ubehebe Crater during recent Little Ice Age cooling. Finally, we briefly highlight the importance of Ubehebe Crater as an accessible terrestrial analog for certain Mars impact craters having comparable interior debris lobes.

2. Physical setting and age of Ubehebe Crater

Ubehebe Crater forms part of the 3 km^2 Ubehebe Maar Field which consists of 16 tuff cones and craters ('maars') formed by a succession of violent short-lived phreatomagmatic eruptions along the intersection of the Tin Mountain and the Northern Death Valley faults in northern Death Valley, California (von Engeln, 1932; Klinger, 2001; Knott et al., 2005; Fig. 1). Ubehebe Crater is the largest and youngest of the maar field with a diameter of 800 m and is excavated into coarse-grained alluvial fan conglomerates and sandstone facies of the Miocene Navadu Formation (Sasnett et al., 2009). A thick (<50 m) blanket of loose, non-cohesive granular ejecta consisting of air fall tephra and base surge deposits blankets an extensive area of about 15 km^2 around the maar field and partially infills Ubehebe Crater (Crowe and Fisher, 1973; Cagnoli and Russell, 2000; Dyer and Smith, 2009). The presence

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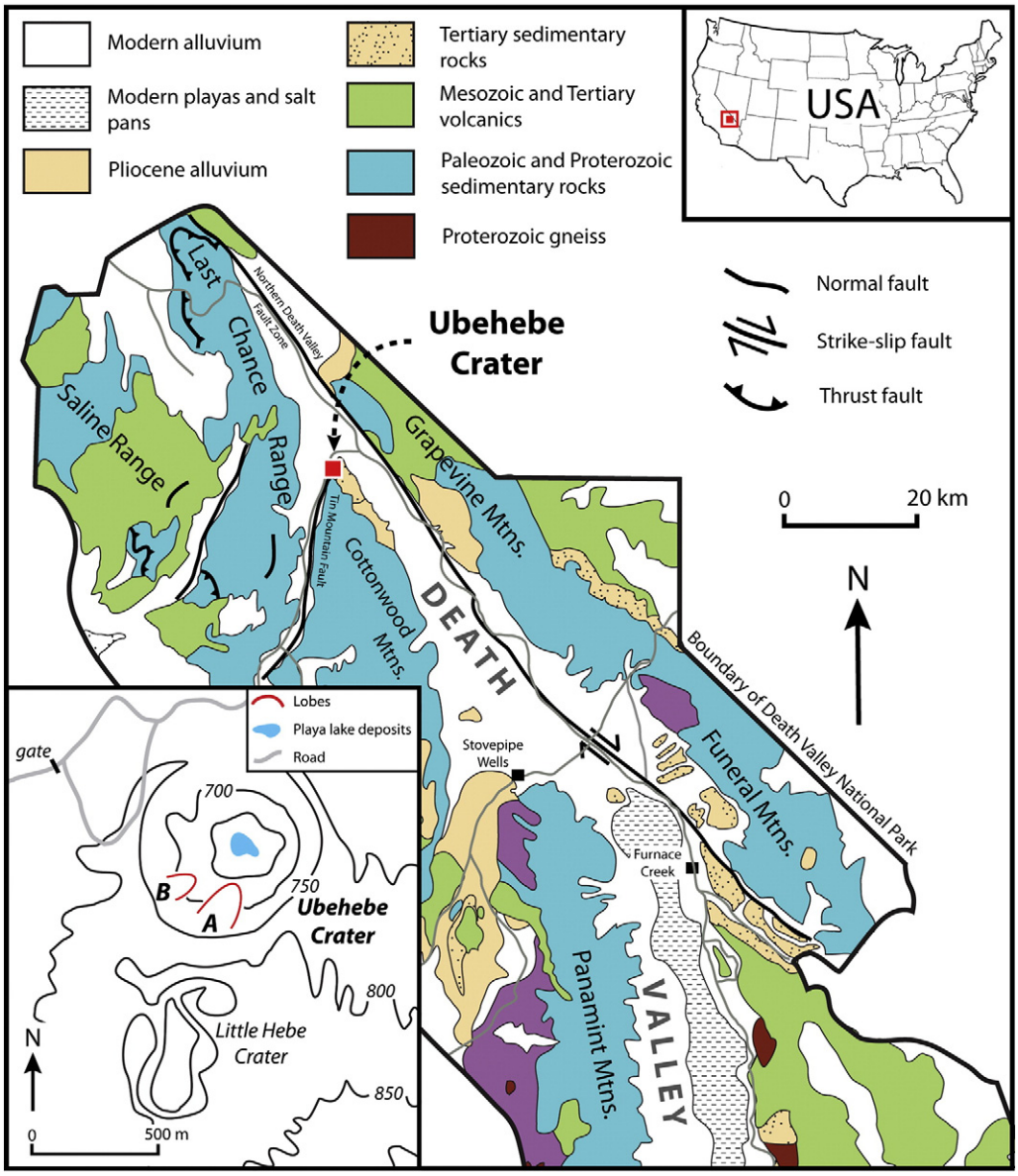

Fig. 1. Simplified geology of Death Valley National Park after Miller and Wright (2004) with (inset) location of tongue shaped lobes A and B (Figs. 2 and 3) on the northeast facing inner slope of Ubehebe Crater.

of enriched Nd and Sr isotopes and distinctive trace-elements in these deposits suggests the maar field is part of a wider volcanic realm around Death Valley that includes Yucca Mountain and which was named the 'Amargosa Valley Isotope Province' by Yogodzinski and Smith (1995). While the age of the maar field is not precisely known several lines of evidence suggest it is of very recent age and no more than 1000 years old. Charcoal preserved in alluvium buried under Ubehebe tephra 4 km distant from the crater has yielded an age of 210 ± 30 ^{14}C years before present (Puseman, 1997; Klinger, 2001). Sasnett et al. (2009, 2012) report ^{10}Be surface exposure dates of 0.9, 1.9 and 3.1 ka for Navadu sandstone cobbles on the surface of ejecta surrounding Ubehebe Crater and suggested the crater is substantially less than 1000 years old.

Within Ubehebe Crater there is a marked contrast between opposing slopes with regard to the extent of ejecta cover (Fig. 3). South- and west-facing slopes consist of steep, commonly vertical and deeply gullied walls of exposed orange- and yellow-coloured conglomerates and sandstones, and red mudstones of the Navadu Formation. Only vestigial patches of ejecta debris remain as talus cones between gullies; any pre-existing cover of ejecta infilling this part of Ubehebe Crater has been stripped from the crater wall and redeposited downslope on the crater floor now occupied by a small playa lake basin. In contrast, the opposing interior slopes of the crater are composed of very loosely consolidated and low density ejecta dominated by vesicular basalt (scoria) clasts, which completely buries the Navadu Formation. These slopes have a distinct asymptotic profile consisting of a steep (30°) upper backwall immediately below the crater rim that progressively flattens (26–20°) downslope to merge with the playa lake basin of the crater floor. These slopes are winnowed by strong winds that are a common characteristic of Death Valley, easily disturbed by human traffic and subject to frequent downslope avalanching as non-cohesive 'sheet flows' or 'grain flows' that are typical of unstable talus slopes close to the angle of repose. Parts of the slope are furrowed by shallow (<1 m) and narrow (<3 m wide) parallel gullies that record episodes of enhanced surface runoff and a small alluvial channel flows northeastward down to the crater floor. An unusual feature of the backwall slope and the focus of this paper are two tongue-shaped debris lobes terminating at a mean elevation of about 675 m asl (above sea level) that create distinct bulges