ADDAMS CRATER, VENUS: OUTFLOW ANALOGOUS WITH A SUBMARINE DEBRIS FLOW?

Philip Purdie[1] and Nick Petford[1], [1]Centre for Earth and Environmental Science Research, Kingston University, Surrey, KT1 2EE, UK (n.petford@kingston.ac.uk)

Introduction: The Magellan mission to Venus (1989 to 1994) recorded over 900 impact features on the surface of the planet [1]. Due to the relative lack of erosion, recent volcanism and other tectonic activity, the mostly complete impact record allows for a detailed study of crater and outflow mechanics. From an initial vapour cloud formation scenario, the origin of the outflow as a cometary impact event sems unlikely. Vapour cloud modelling for iron and stony meteorite impacts correlate well with predicted source cloud emplacement and point to catastrophic emplacement of the distal outflow deposits. The extraordinary outflow length and morphology of Addams crater deposits are comparable to that of the Saharan submarine debris flow off Northwest Africa. Comparison of sonar data with radar images of the Addams crater outflow lead us to postulate that both flows were formed from a similar two-tiered flow regime.

Addams Crater (56.1ºS, 98.9ºE): Addams crater is situated on an unnamed corona-chain complex (eastern edge) between Lada Terra and Aino Planitia [2]. It has the largest crater outflow feature associated with any Venusian impact [3]. New surface area and linear measurements of the outflow features have been made to better understand its formation. The extraordinary outflow length and morphology of Addams crater is comparable to that of the Saharan submarine debris flow off Northwest Africa. In this article we draw comparisons between both flows, and speculate on the possible mode of emplacement of the Addams crater outflow deposits.

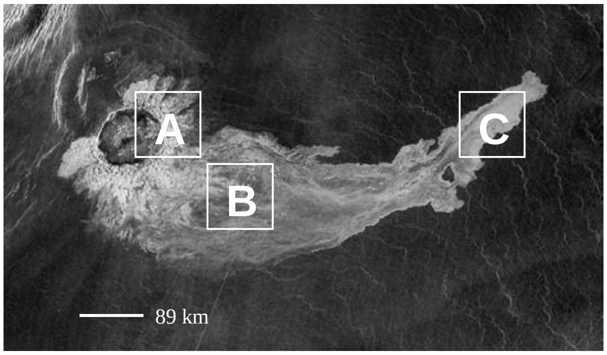

Fig. 1. Addams crater, showing proximal (A), medial (B) and distal (C) ejecta outflows.

Crater outflows: The thick Venusian atmosphere accounts for the lack of impact craters below approximately 2 km in diameter, as small impactors tend to be catastrophically disrupted and vaporized before reaching the surface [4]. Crater formation on Venus is characterized a combination of ejecta deposits, classified into three distinct morphologies (proximal, medial and distal ejecta flows [3,5], and associated lava flows [1,2]. Observational evidence suggests the crater outflows navigate fluidly around obstacles and that their distant margins have a rough nature, indicated by increased (brighter) radar backscatter. In comparison with the other terrestrial planets, the Venusian ejecta deposits appear relatively easy to define, possibly reflecting emplacement from a cloud rather than purely ballistic processes [6].

Vapour cloud modelling: Early impact experiments [8] on vapour/debris clouds produced from impacts show the atmosphere clearly limits cloud development. Instead of expanding to many times the volume of the impactor in a largely vertical direction (as in a vacuum), atmospherically-emplaced vapour/debris clouds assume a ground hugging, lateral downstream displacement. Due to the dense atmosphere on Venus, most of the vaporised impactor material should be retained [7].

We now calculate the total vapour cloud travel distance (*L*) for Addams crater from:

$$\frac{L}{r_p} = 13\left(\frac{\rho_{air}}{67kg/m^3}\right)^{1/3}\left(\frac{\rho_{vap}}{3g/cm^3}\right)^{0.4}\left(\frac{M_{vap}}{M_{proj}}\right)^{1/3} \times\left(\frac{\varepsilon_{vap}}{50MJ/kg}\right)^{-1}\left(\frac{V_{tr}}{10km/s}\right)^{1/3}, \qquad (1)$$

where, *L* is the total travel distance of the first wave of the vapour cloud, r_p is the radius of the impactor, ρair is the ambient air density (65 kg/m^3), ρ_{vap} is impact vapour density, M_{vap} is the mass of impact vapour, M_{proj} is the mass of the impactor, ε_{vap} is 25 MJ/kg (for oblique impacts), and V_{tr} is downstream translational velocity (12 km/s). In order to gauge impact vapour density, the volume of a hemisphere was calculated using a base diameter of 237 km, which is scaled from the centre of the interfered ejecta blanket of the outflow deposit [7]. It is important to note that the distance (*L*) is taken to mean the distance that the cloud travels in its first wave and where its velocity reaches 0 km/s and *not* the terminal cloud position. The equation also takes into account the mass of vapour produced, as well as any melt from the impactor. Impactor types of varying mass and density (iron, stony, comet) were chosen for comparison. Both the impacts from the meteorites modelled closely the terminal position of the first wave of lateral cloud movement, the comet less so.

A Saharan debris flow emplacement mechanism for the outflow deposits at Addams crater? The Saharan debris flow off Northwest Africa, noted for its long runout length of c. 700 km, provides an interesting terrestrial counterpart to the Addams crater deposits. Using sonar images [8], it is possible to compare the morphology and geometries of both flows. A simple analysis involves a comparison of the height (*H*) of the outflow source region (vertical difference between source elevation and final deposit elevation) with the flow length (*L*), measured horizontally from the source region to the flow's distal limits [9]. The resulting division (*L/H*) is the efficiency.

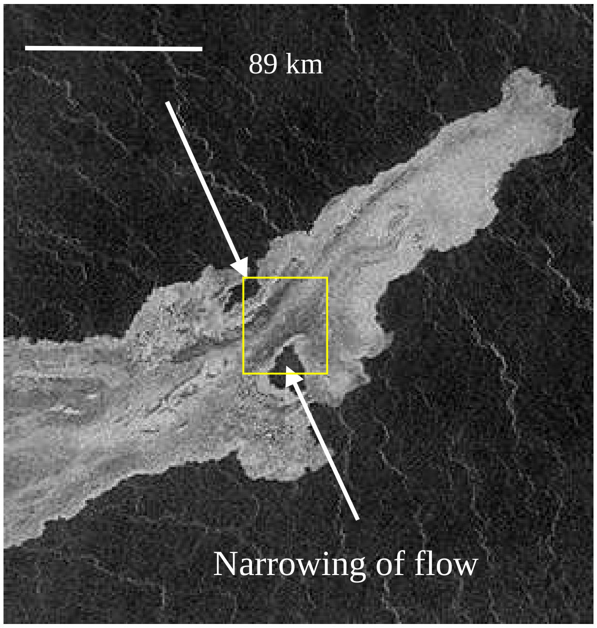

Fig. 2. Radar image of the distal end of Addams crater outflow indicating flow through a constriction.

For Venus, the relevant topographic information is gleaned from the altimetry data collected by the Magellan probe. However, this data is relatively course and the best approximation of vertical height from the crater rim to the distal end elevation is 2 km. The length however is more easily constrained at 640 km. Bathymetry data for the Saharan debris flow [10] is better constrained and the height difference (*H*) has been calculated also as 2.0 km. The accompanying flow length (*L*) is 700 km. The resulting efficiency (*L/H*) values are 320 for Addams crater and 300 for the Saharan debris flow. When compared to other efficiency readings taken from a range of debris flows [9], both the Saharan and Addams crater flows show remarkably high runout efficiency values. Although the origin of the two flows is different, it is the contention of this report that they are the result of the same flow processes.

Discussion: Superfical similarities exist between the Addams outflow and the Saharan debris flow. Both were required to overcome geometrical constrictions [e.g. 10 and Fig. 2]. Lateral margin deposits appear to be characteristic of both flows, and their width dimensions and the presence of onlap sequences correlate well (Fig. 3). Both flows can be judged to be flowing through high pressure "atmospheres", with atmospheric pressure on Venus at 92 bar and the Saharan debris flow under approximately 2 km of water proximally and nearly 5 km distally. How these two atmospheres interacted with the flows, and whether or not entrainment acted to prolong them, is an open question. If the Addams crater outflow started as a vapour/debris cloud, rapid collapse and condensation may have helped provide the high pore fluid pressures required for long runout lengths in terrestrial settings.

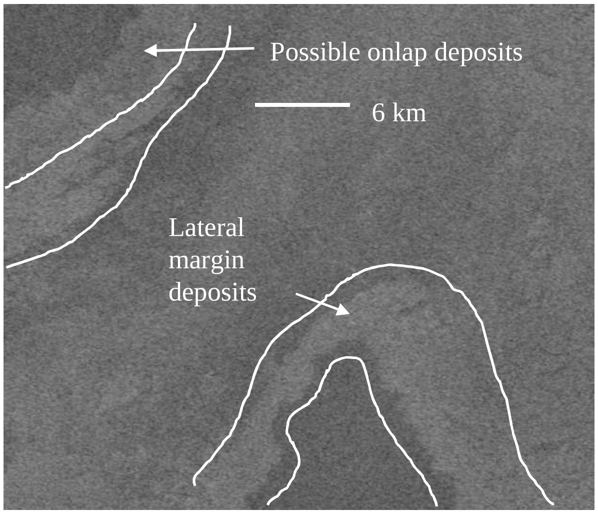

Fig. 3. Lateral margin and possible onlap deposits (darker) in the distal end of Addams crater outflow (yellow square, Fig. 2).

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