

SEDIMENTARY ROCKS IN BECQUEREL CRATER: ORIGIN AS POLAR LAYERED DEPOSITS DURING HIGH OBLIQUITY. J. C. Bridges¹, J. R. Kim², D. G. Trugheim³, J-P. Muller², M. R. Balme⁴ and D. Pullan¹, ¹Space Research Centre, Dept. of Physics & Astronomy, University of Leicester, Leicester LE2 7AQ, UK. ²Mullard Space Science Laboratory, Dept. of Space and Climate Physics, University College London, Surrey RH5 6NT, UK. ³British Geological Survey, Nottingham NG12 5GG, UK. ⁴Dept. of Earth Sciences, Open University, Milton Keynes MK7 6AA, UK j.bridges@le.ac.uk

Introduction: Many of the large impact craters in Arabia Terra contain Interior Layered Deposits (ILD) in sediment mounds of uncertain origin. Becquerel Crater (22°N, 353°E) has one of the best sedimentary sequences of these craters. We are using HiRISE, HRSC-DTM and MOLA data to characterise the ILD within Becquerel and compare them to those of other craters. This combined imagery has provided 1 m DTM and high resolution stereo coverage (>25 cm/pixel). With it we are able to extract accurate dip-strike, layer thickness and structural information. The aim is to enable an accurate description of martian environmental conditions during their deposition by characterising the origin of the sediments. Various formation models have been proposed for Crater ILD including hydrothermal mounds and lacustrine [1, 2]. Becquerel is a -2.6 to -4.4 km deep, 167 km diameter crater containing an approximately 600 km² massif of ILD (at -3.1 to -3.7 km elevation) in its southern part. This is some of the best exposed and most complete stratigraphic record of sediments imaged on Mars.

The Becquerel Sediments: There are 2 photo-geological units within the Becquerel layered deposits: a light coloured, blocky deposit which has undergone extensive cryogenic jointing and breakup. The second unit is darker and does not clearly show this intense cryogenic activity. One possibility is that the dark colour simply represents an accumulation of basaltic sand on shallower terrace slopes. However, discrete depositional aeolian landforms can be clearly identified and they are not present over most of the darker areas. These represent limited remobilisation of recently eroded material from the ILD. In some cases the light-dark bedding planes are displaced by faults suggesting that the dark unit represents an original sedimentary lithology.

The undisturbed bedding planes have a dip of ~5° towards the SE (Fig. 1). Individual layers are 1-2 m thick. Some thicker layers of the light coloured lithology form prominent terraces and their presence implies cyclic sediment deposition. Figure 1 shows a 40 m thick cycle of 10 light and dark layers. In total the Becquerel ILD have preserved about 15 such cycles in the vertical succession. Layers can be traced for 10s of km across the massif.

The central part of the ILD mound has been tectonically disturbed as a result of gravity sliding. Here the shallow-dipping succession has been rotated into a tectonic melange and beds dipping at 30-35° towards the SSW (Fig. 1).

Origin of the Becquerel Interior Layered Deposits: Carr [3] catalogued 8 ILD sediment mounds, within craters of Arabia Terra near Schiaparelli Crater (2°S, 17°E). Malin and Edgett [4] noted that the elevation of such sediment mounds sometimes exceeded the surrounding plain, which they took to mean that a more extensive formation had previously been present over this part of Arabia Terra before erosion had reduced it to the remnants now present within craters. The present day surface of the Becquerel sediments is clearly recent, reflecting the intense aeolian erosion and absence of superimposing craters. However, the formation age of Becquerel ILD and similar sediments, whether Noachian as suggested by [4], or more recent remains uncertain. The ILD sediment mounds, although of uncertain age, can be distinguished from other sedimentary sequences in Terra Meridiani such as the Opportunity site sediments which are clearly part of the Noachian underlying terrain predating the formation of large impact craters [2].

The metre-scale bedding and cyclicity of the Becquerel sediments could be consistent with a lacustrine origin or deposition as dust from the atmosphere. However, neither OMEGA nor CRISM have identified any sulphate or phyllosilicate associated with the deposits [5,6]. This contrasts with ILD within Valles Marineris where sulphate has been identified [7,8]. The absence of this likely evaporite-like signature argues against a lacustrine or hydrothermal origin. The cyclicity identified at Becquerel also argues against an origin as hydrothermal deposits or volcanoclastic sediments.

Orbital Controls and Polar Layered Deposits. The regularity of the light-dark layer alteration in the Becquerel sediments suggests that their deposition was controlled by regular variations in the climate. This in turn indicates an orbital control. Within the last 1 million years the short, warm season on Mars switches between the southern and northern hemispheres every 25 000 years as a result of the combination of eccentricity cycles and variation of the precession of Mars'

spin axis controlling the timing of perihelion [3,9]. However, changes in obliquity will have more intense climatic effects. Laskar et al. [9] modelled the variations in obliquity over the history of Mars and found that during the last 10 million years it had varied with a period of 1.2×10^5 years between 15° and 35° with an average of 24° . Larger variations in obliquity e.g. $>40^\circ$ cause the solar flux at the poles to increase to a point when the ice at the poles is lost through sublimation and instead ice accumulates in equatorial regions. Beyond 10 Myr the obliquity cycles are not well understood but Laskar et al. calculated a 63% probability that obliquity reached 60° over the last 1 Gyr. Thus glaciation in equatorial regions has been an important geological process throughout much of Mars' history [10].

Direct deposition from glaciers would produce a large amount of coarse, poorly sorted debris, but this is not present. Instead the Becquerel ILD layering shows a marked similarity to that of the current Polar Layered Deposits. The latter are laterally continuous for 10s of km, consist of light-dark layers of metre-scale thickness. Some layers in Polar Layered Deposits form steeper slopes and prominent layers, again similar to the Becquerel ILD.

The thickness of the current Polar Layered Deposits at 3 km also indicates that the relatively rapid accumulation of thick sedimentary sequences such as the Becquerel ILD is possible through deposition of dust from air. A combination of obliquity and eccentricity variations has produced variations in the intensity of dust storms leading to the light-dark layering seen in the current Polar Layered Deposits. During Spring frost is sublimed leaving an annual layer of dust.

The extensive erosion of the Becquerel ILD to a level below that of the Becquerel Crater rim has meant that firmly determining the age of the deposits is not possible. However the apparently rapid erosion of the ILD may indicate that the remnants seen today were deposited during a recent geological epoch.

Conclusion: Our study of the Becquerel ILD layering suggests that they formed through cyclic deposition of dust from air during an epoch of higher obliquity. Thus their origin is analogous to that of the current Polar Layered Deposits. The similarity of the Becquerel ILD layering to that in other Arabia Terra craters suggests that such deposition occurred over a large part of equatorial to mid-latitude Mars.

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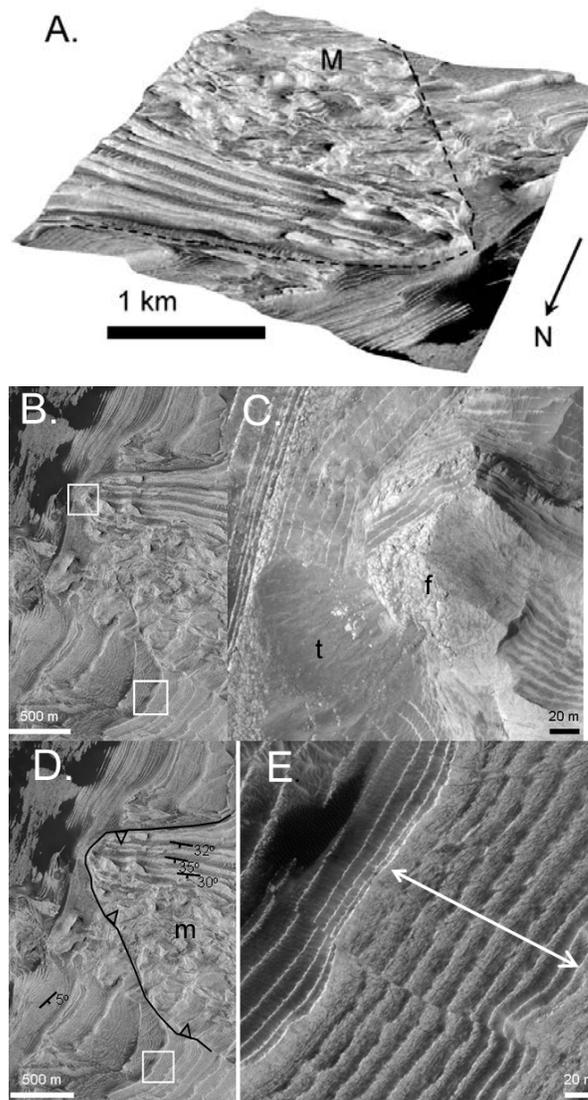


Fig.1. (A). 1m DTM of Becquerel ILD, with M tectonic melange, dashed line fault between tectonic melange and underlying undisturbed sediments. A-E based on HiRISE stereo pair PSP001955-2015. (B) Eastern part of Becquerel ILD, top inset is area of C. (C) t talus slope, f cryogenically fractured terrain and light-dark layers. (D) m tectonic melange at top of ILD. Dip strike data and fault layer shown. Inset is E. (E) Cyclic unit of 10 dark and 10 light layers arrowed. Each layer is 1-2 m thick and sediment cycle is 40m thick.