SUB-LITHOSPHERIC ‘SUBDUCTION’ ON MARS: CONVECTIVE REMOVAL OF A LITHOSPHERIC ROOT. II: ALBA PATERA. Evelyn D. Scott. Planetary Science Research Group, I. E. N. S., Lancaster University, Lancaster LA1 4YQ, U. K. E.Scott@Lancaster.ac.uk

Abstract: A thickened lithospheric root anchoring the volcano Alba Patera in buoyant equilibrium is detached by convective eddies within the asthenosphere, which then upwells and occupies the space left by the root, inducing new volcanic activity by remelting the underplated material at the base of the edifice [1]. The crustal block, no longer anchored, rebounds buoyantly until it reaches a topographic high point where boundary stresses can no longer hold it in equilibrium and it begins to subside. At the same time, it spreads horizontally generating an extensional stress regime within itself and a compressional one in the region buttressing it. The detached lithospheric root subducts to the base of the mantle where it produces the chemical and thermal homogeneities which trigger new plume formation. This model can explain how the Martian mantle remains sufficiently mixed to be able to generate prolonged volcanism within the Tharsis Province for extended periods of the planet's history. It can also explain two of the morphological peculiarities of Alba Patera, namely the extremely low angle of its flank slopes and the system of annular graben around the edifice, and the fact that the nature of its volcanic activity apparently changed from volatile rich to volatile poor, previously interpreted as a consequence of the evolution of the mantle. In this model, end stage activity at Alba Patera is different because it is sourced from re-melted underplated igneous material rather than juvenile melt from the mantle.

Alba Patera: Alba Patera is an extremely large volcanic edifice, with a diameter of 2700 km and a volume of up to \(4 \times 10^9\) km\(^3\) [2]. Eruptive activity lasted between 1.5 and 2.8 Ga, building an edifice which stands 6.5 km above the northern lowlands to the north and 3.5 km above Tharsis to the south [3]. The flanks of the volcano have a slope of less than 0.5\(^o\), interpreted in the past to indicate that the lavas must have had an extremely low viscosity, although there is evidence for cones of very viscous material on the floor of the outer caldera, extruded before formation of the inner caldera [2].

Alba Patera is surrounded by graben which are tangential in the east and west, but radial to the north and south. These graben were previously thought to have formed as a response to the loading of this edifice on the lithosphere [4]. However, it is now argued that the location of these graben within the edifice flank indicates that this view is untenable and that they must have formed as the result of uplift following a sub-lithospheric load e.g. underplated magma or formation of a low density residuum, late in the volcano’s lifespan [5].

It is proposed in this abstract that the Alba Patera edifice built a substantial lithospheric root, commensurate with its large mass. This root held the volcano in buoyant equilibrium until it was detached by convective eddies within the asthenosphere [1], causing the edifice to rebound to a topographic high-point. Asthenosphere upwelled into the region previously occupied by the root, and heated the base of the volcano, generating remelted magmas which had a different rheology and volatile content from the earlier products of the volcano, because they were sourced from different materials. Alba Patera has two identified episodes of volcanism, the first volatile rich and the second volatile poor, previously interpreted to indicate that the Martian mantle became depleted of volatiles during the building of this edifice [6]. However, if the second episode of volcanism at Alba Patera was related to isostatic rebound it would be expected to be volatile poor, especially if the magmas were remelted underplated material that had previously degassed. The waning stages of eruptive activity at Alba Patera produced relatively viscous flows that erupted from a plethora of NNE-SSW fissures to produce en-echelon spatter ridges. If the inner caldera formed as a consequence of reactivation of underplated magmas, this would be consistent with its good state of preservation and the presence of cones built from more viscous lavas on the floor of the outer caldera.

The edifice continued to rebound until it reached a height where it could not be supported by the boundary stresses of the adjacent regions and it began to subside [1]. As it subsided, it also spread horizontally, generating a horizontal extensional stress regime and therefore the graben which surround the edifice. Extensional faulting is only likely to occur when convective removal of the lithospheric root is essentially complete [7], consistent with the fact that the graben are dated at the end of the active lifespan of Alba Patera [4].

In Tibet, a terrestrial situation where detachment of a lithospheric root is thought to have occurred, the extensional faulting occurs at the centre of the plateau [7]. However, a greater degree of exten-
sional stress may be expected on Mars because the adjacent region would not be buttressed by the compressional tectonics of a plate tectonic collision zone, explaining why the lithosphere fails preferentially at the periphery of the uplifted zone, although the offset nature of the extension may simply be an artefact of the size of the region affected. If a terrestrial rift zone is wider than the lithosphere is thick, the maximum lithospheric stretching is offset and vigorous convection eddies occur where the lateral temperature gradients are the greatest, i.e. at the edges of a rift zone [9]. The initial graben at Alba Patera are at a radial distance of 250 km from the centre of the edifice. Hence the width of the Alba Patera ‘rift’ is about 500 km, several times the postulated thickness of the lithosphere at this location.

At some critical distance, there should be a change from extensional tectonics to compressional ones, producing wrinkle ridge type folding [7]. No wrinkle ridges are known in the vicinity of Alba Patera but this could be either because the stresses did not reach a critical level to initiate their formation [7] or they did form but were buried beneath the eruptive products of Olympus Mons and the three Tharsis Montes volcanoes.

Summary: It is proposed that convective removal of a lithospheric root and its ‘subduction’ to a region analogous to the terrestrial D’ layer at the Core Mantle Boundary on Mars acts as the initiator of a subsequent mantle plume. In this way the Martian mantle is mixed and this explains its ability to generate volcanic activity at static locations throughout the lifespan of the planet. This model has implications for the thermal and geochemical profile of the mantle, because previous modelling has assumed that the absence of subduction means there has been no recycling of crustal material back into the mantle [10].

It is unlikely that this process has only happened at Alba Patera; it is further proposed that it explains the geomorphology of the Syria Planum region. The extremely large sizes of other Martian volcanic shields indicate that they should also develop comparably massive lithospheric roots and the detachment process should start as soon as a root reaches a critical size. However, there will be no visible indication of this until the shields have undergone topographic uplift to the point where they are unsupported and therefore unstable, initiating subsidence under the influence of gravity and the extensional tectonics which produce visible evidence of the process. The volcanic shields of Tharsis have great topographic height, about 27 km relative to the mean datum, which must be compared critically with the 7 km height of Alba Patera at its maximum topography. It is argued that the extreme difference is because Alba Patera has subsided, whereas the other shields are still uplifted. Could it be possible that the cliffs at the edge of the Olympus Mons edifice are normal faults generated by topographic rebound?