Itokawa – a mid-ocean ridge asteroid

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Introduction

Itokawa is a peanut-shaped near-Earth asteroid, c. 535 m long and c. 200 m thick (Fig. 4). Itokawa orbits the Sun between Earth and Mars, and was generally explained to have formed by the accretion of two smaller asteroids that gravitated toward each other and stuck together. Fujiwara et al. (2006) suggested an early collisional breakup of a preexisting parent asteroid followed by a re-agglomeration into a rubble-pile object.

Itokawa was selected as the target for Japan's unmanned sampling mission. The Hayabusa probe arrived in the vicinity of Itokawa in 2005 and touched down, but failed to operate the soil sample collecting device. Despite technical difficulties, minor quantities of dust were recovered, and Hayabusa left the asteroid.

In 2010, the Hayabusa craft dramatically fireballed in Earth's atmosphere; however, the sample return capsule made a safe parachute landing in Australia. The Japan Aerospace Exploration Agency (JAXA) confirmed that most of the 1,500 rocky particles found inside the capsule originate from Itokawa. Concentrations of olivine and pyroxene were identified.

The sampling sites of Itokawa material in JAXA's possession are unknown at the time of this writing. Detailed analyses are pending.

JAXA obtained a number of orbital and landing site images of Itokawa. Some of the images, published on JAXA's internet pages, were copied, processed and interpreted by the writer. In the following, the geological evolution of mid-ocean ridge (MOR) environment will be reviewed and exemplified, Itokawa images will be presented and discussed, and conclusions will be drawn on findings.

Figs. 1–3, taken by the writer, are presented as an introduction to MOR basalts. Figs. 4–8, credited to JAXA, make the case.

The mid-ocean ridge concept

Terrestrial seafloor spreads at MOR. A deep underwater rift typically runs along the spine of MOR. Plates of oceanic crust are conveyed away, and new lithosphere is created as basaltic magma rises from the Earth's mantle (Condie 1985, Salters and Stracke 2004, Wilkinson 1985). Magma fills the spreading zone with feeder dykes that in a cross section appear as a parallel dyke swarm (Kurewitz and Karson 1998).

Dykes feed >1000 ° C basaltic magma to the ocean floor where pulses of pillow-making lava pile on previous, solidified layers. Widths of individual feeder dykes vary from c. 30 cm up to meters. Pillow diameters in basaltic lava range from tens of centimeters up to a meter. The Troodos ophiolite complex on Cyprus is often referred to as type example of MOR sequences; there pillowed flow units average 100 to 200 m in thickness (Schmincke et al. 1983).

Pillow skins cool fast in seawater: glass rims are formed. Pillow interiors cool relatively slowly and develop cooling cracks. As pressure is released, gases dissolved in magma expand and form vesicles (Jones 1969).

▲ *Fig. 1. Basaltic dyke in a sheeted feeder dyke complex, Løkken Mine region, Norway. Colours were enhanced to highlight primary structures in chemically homogeneous material. Despite metamorphism, friction banding in viscous melt at the relatively chill margin area, and cubical cooling fractures in the central region, are clearly discernible.*

The images

Løkken, Norway

The Løkken basalts are of MOR type, Lower Ordovigian (c. 450 million years) in age and originate from a shallow depth of magma reservoirs (Grenne 1989a). At Løkken, the c. 2 km thick volcanic sequence is tectonized (overturned) and metamorphosed; however, structures characteristic of MOR basalts remain detectable. The Løkken volcanogenic massive sulphide deposit exemplifies ore forming processes that operate in MOR environments (Grenne 1989b). Figs. 1–3 represent a feeder dyke complex and related metabasalts in the Løkken Mine region, Norway.

▲ *Fig. 2. Metabasaltic pillow, Løkken, Norway. Hammer points towards stratigraphic bottom, gross flow direction runs from right to left. The glassy rim, and glass in cooling cracks, stand out. Vesicles no longer are voids but are filled with metamorphic mineral assemblages.*

◄ *Fig. 3. Matabasaltic flow breccia, Løkken, Norway. Fragments of broken pillows are mixed with hyaloclastic rubble.*

Asteroid Itokawa

A magmatic complex of asteroid size cannot form by rubble accretion in space. Instead, a planet-size parent body is a necessity – one with voluminous basaltic magma reservoirs and plate tectonic phenomena in operation. To the writer's knowledge, terrestrial seafloor spreading and related volcanic processes are the only mechanism that produce MOR sequences. Figs. 4–8 represent the sequence of sheeted feeder dykes and overlying pillow lavas in asteroid Itokawa.

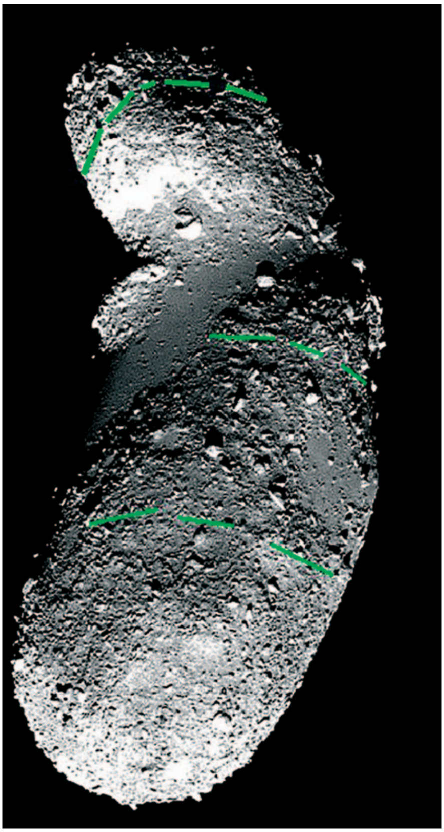

Fig. 4. Asteroid Itokawa. Green lines indicate the general strike of volcanic layering. Shadows emphasize a feeder dyke swarm at the lowest quarter of the image, over the length of c. 200 m. Depositional bottom is down, layer tops are up.

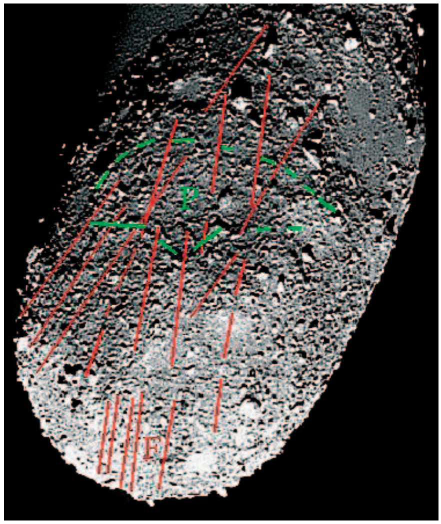

Fig. 5. Asteroid Itokawa. A mushroom-shaped pillow lava unit (P), composed of c. 50 separate flow pulses, is schematically outlined in green. Some of the feeder dykes (F) are marked in red. The youngest of dykes penetrated flows. Such dykes may have reached seafloor and fed another unit of pillowed lavas from a magma reservoir located at shallow depth. The relatively thick (10–20 m) feeder dykes suggest a fast spreading rate for Hadean oceanic crust (Kurewitz and Karson 1998).

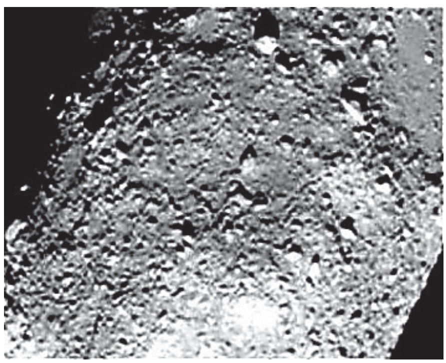

Fig. 6. Asteroid Itokawa. This image displays in more detail the area lined with green in Fig. 5. The flow unit stands c. 70 m high and 180 m wide. Flow pulses average a few meters in thickness. Attention should be paid to fluidal structures in individual lava flows and rift-like structures at the base of the mushrooming flow unit.

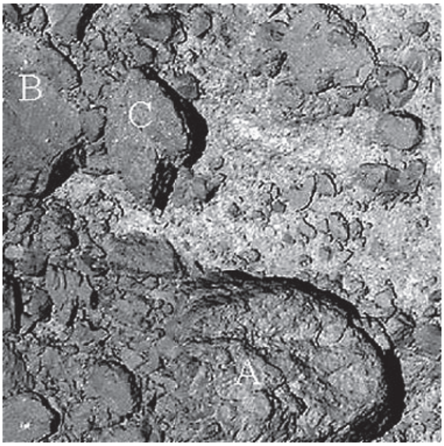

Fig 7. Asteroid Itokawa. A beautiful lava pillow is marked with A (compare with Fig. 2). The pillow is rimmed with black glass, while cooling cracks and vesicle pocks characterize interior. It is unclear whether the pillow (A) lies in situ or is torn apart; however, in the image, bottom is down and gross flow direction runs from left to right. B and C are identified as pillow fragments due to chill rims, arcuate outlines, and vesicles. Dry land probably did not exist at this part of the MOR: the relatively small size of vesicles refers to deep water conditions (Jones 1969).

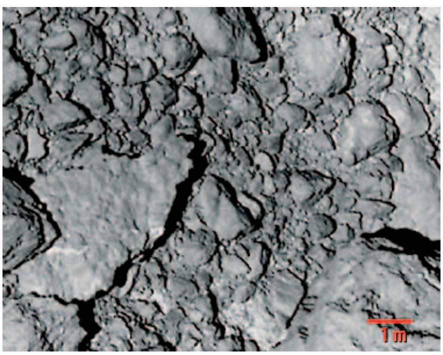

Fig. 8. Asteroid Itokawa. Flow breccia. Some of the rubble may be loose; however, there is a great resemblance to the schistosed and regionally metamorphosed flow breccia in Fig. 3.

Conclusions

- Asteroid Itokawa displays features diagnostic of terrestrial mid-ocean ridges: There is a feeder dyke swarm (Fig. 5), a mushrooming flow unit (Fig. 6), and pillow lava (Fig. 7). Seldom, if ever, can a complete MOR sequence be observed in a cross section on Earth.

- The specific gravity of basalt ranges from 1.72 to 2.76 g/cm^3, depending on vesicularity in the sample (Gates 2008). The bulk specific gravity of asteroid Itokawa (1.9 g/cm^3, Abe et al. 2006) falls within the terrestrial range.

- The MOR origin of asteroid Itokawa proves that plate tectonic processes operated on Earth already in the Hadean era. The writer suggests that early plate movements were a continuum to convections in proto-Earth. Deep-rooted convections may have carried from great depths high-pressure minerals and rare isotopes (Anders and Zinner 1993). Locally, shallow-depth basaltic magma reservoirs may have caused sanidine facies burial-thermal metamorphism (low pressure, high temperature) – features explained shock-thermal in a basaltic micrometeorite of presumed asteroid origin (Gounelle et al. 2009).

- Primitive organisms were identified in meteorites by Hoover (2011). Since meteorites are considered broken-up asteroids (http://www.meteorites.fr), and as asteroids originate from the Earth (Mäkelä 2011, and this article), it is concluded that life sparked in Hadean oceans as soon as hydrosphere precipitated from idigenous vapors. On Itokawa, signatures of life may exist on top of the mushrooming flow unit (Figs. 5 and 6) or higher in stratigraphy.

- Points to ponder: Detailed analysis of Itokawa feeder dykes would reveal the composition of the Earth's early, undepleted mantle.

Paleomagnetic surveys on Itokawa feeder dykes would provide information on the provenance of asteroids in general (terrestrial polar vs. equatorial regions), and on the magnetic polarity of Hadean Earth.

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