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PLATE TECTONICS IN THE SOLAR SYSTEM

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It was realized about 30 years ago that a mechanism of large scale geological activity called "plate tectonics" is continuously in action on the Earth since at least several hundred million years. Its main characteristics can be summarized as follows: the solid crust is broken into several rigid plates that are carried by the circulating molten material of the mantle. Over the upwelling places the plates are moving away from each other, and the upwelling molten material arriving to the surface after cooling forms a new crust that is welded to the edge of the receding plates. As the surface of a spherical body is finite, if the mechanism is working for a long time, the plates on other places must converge and collide to each other either piling up as folded mountain chains or subducting one under the other. In this latter case the subducting plate reaching the molten mantle will also be melted and annihilated as a piece of the rigid crust, at the same time, however, the other plate becomes thicker partly because of the banding and lift off by the subduction, partly because of the volcanic activity caused by the subducted and melted crust rich in volatile material.

Generally at least two conditions are needed to develop these characteristic features on a crusty planetary body. First the crust should not be too thick or too plastic for braeking and for subducting. If a celestial body is too cold and has a thick crust, it can not split anymore into plates. If it is too hot then its crust is thin and plastic. Such a crust can not be broken into pieces and can not subduct because it is not rigid enough. Very probably every celestial body goes through such a phase during the cooling process when its crust is thick and rigid enough for braeking and subducting. The other condition needed is that the rate of cooling should not be too quick giving time for more than one cycle of circulation before the crust gets too thick to stop the process. At the present state of our knowledge we can claim that this mechanism is working only on the Earth. All other crusty planetary bodies in the Solar System are either too cold or too hot for this mechanism.

All other crusty planetary bodies in the Solar System are smaller than the Earth, the only one which is comparable is Venus. As regards the smaller planetary bodies, very probably the cooling was too quick compared with the time scale of plate tectonics, and their crust became thick so quickly that there was no time for even one cycle of plate tectonic movement to be completed. In the case of four of these bodies (Mars with a diameter of 6787 km, Fig. 1; Ganymede with a diameter of 5276 km, Fig. 2; Enceladus with a diameter of 502 km, Fig. 3 and Triton with a diameter of 2705 km, Fig.4) one can observe some traces of splitting started in some period in their history. Moreover in two cases (Ganymede of 5276 km and Enceladus of 502 km) or perhaps in a third one (Triton of 2705 km) there are transform faults so characteristic on plate tectonics — hundreds or thousands of them are present on Earth (Fig.5) — demonstrating that not only splitting but relative movement of plates occured on them.

As regards Venus, with a diameter of 12104 km, its surface is almost totally governed by volcanism suggesting that the crust is very thin. Along the equator, however, there are some deep large valleys of asymmetric cross section (Dali and Diana Chasmas, Fig. 6) considered earlier as deep oceanic trenches. Furthermore, there is a region around Lakshmi Planum with folded mountain chains (Freya, Akna, Danu, Maxwell Montes; Fig.7) that could be considered as compression zones. On the basis of these two surface features some scientists suggested that Venus had plate tectonics. But after the high resolution Magellan mission this idea was dropped. Anyway, Venus is the only place in the Solar System outside the Earth, where mountain chains were formed. Moreover, Freya Mons shows no trace of relaxation, that means, that compressional forces are still in action, that is, Venus is still an active planet not only because of its volcanism. The existence of these mountain chains and the tessera regions (Fig. 7.c) suggest that some region of the crust are moving relative to each other, but we can not even guess whether they are spreading or converging. It is, however, more probable that Lakshmi Planum is a convergence zone. In the case of Venus the very massive atmosphere prevents heat loss, moreover, the runaway greenhouse effect keeps the surface temperature very high (about 500 K). Even, if there were separated plates moving in such a high temperature, the rocks were too plastic for subduction. Instead of subduction the very thin crust becomes crinckly at collision. Very probably Venus represents a former stage of evolution of our Earth, but it is not certain, whether it will follow later its sister-planet, as regards plate tectonics. If Venus will cool slowly enough, perhaps it can happen.

There is another very interesting planetary body in the Solar System, namely Io, the innermost Galilean moon of Jupiter with a diameter of 3632 km. It is not larger than the other small crusty planetary bodies, but in spite of this, it shows up an extra strong volcanic activity even today. There is no trace of separated surface pieces or relative movement of such pieces. In this case the ongoing tidal heating prevents the cooling of the interior. If the tidal heating would switch off, Io would cool very probably as quickly as the other smaller planetary bodies did, i.e. too fast for developing plate tectonics.

What could be the reason that not the largest crusty planetary body has the thinest crust but Venus and Io? The explanation in the case of Io is clear: the tidal heating is added to the radiogenic heating. But what can we say about Venus? Very probably we have to say something about the Earth instead of Venus as the moonless Venus may represent the normal way of evolution. I wonder whether this explanation could be in connection with our Moon. It is highly probable that during the giant impact that initiated the birth of the Moon, all the ancient atmosphere of the Earth was blown off — as in the case of the Argyrae-impact on Mars. With a thin atmosphere the crust of the Earth started to cool quickly in accordance with the first condition of plate tectonics, but after that the tidal heating originating from the Moon slowed the cooling down making plate tectonic circulation possible for at least several cycles. Pluto and Charon may be another example for such a tidal heating during the synchronization process if they have captured each other. Titan, on the other hand, with its massive atmosphere can be a similar case to Venus where the thich atmosphere can slow the cooling. Therefore, it can not be ruled out that traces of plate tectonics are present on Pluto/Charon and also on Titan.

Summing up we can be almost certain that 1./ by now only the Earth has plate tectonic mechanism as a heat loss process, and 2./ not only the size and age of a planetary body determine what happens on its surface but the atmosphere and the presence of additional heat source (e.g. tidal heating) may play an important role slowing down the cooling or even heating up the interior.

Size of the Crusty Planetary Bodies

Name	Diameter (km)
Earth	12756
Venus	12104
Mars	6787
Ganymede	5276
Titan	5150
Mercury	4878
Callisto	4820
Io	3632
Moon	3476
Europa	3126
Triton	2705
Pluto	2302
Titania	1610
Oberon	1550
Rhea	1530
Japetus	1460
Umbriel	1190
Charon	1186
Ariel	1160
Dione	1120
Tethys	1060
Enceladus	502
Miranda	484
Proteus	416
Hyperion	410
Mimas	394

Fig.1
Mars with Valles Marineris in the middle

Fig.2
A transform fault on Ganymede

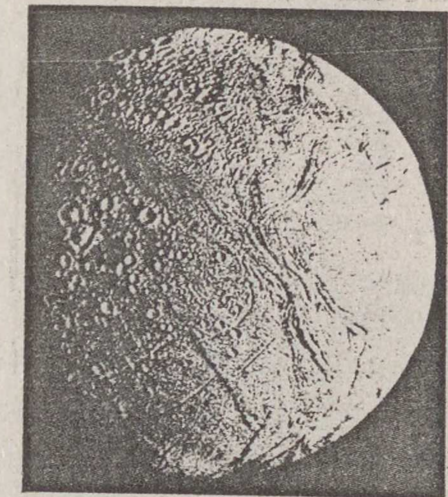


Fig.3
Transform faults on Enceladus

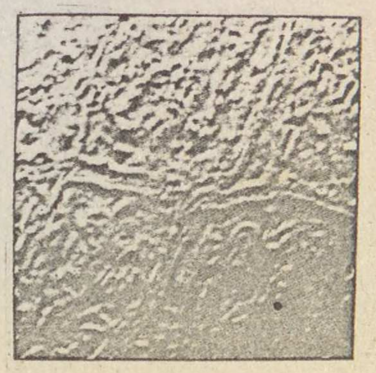


Fig.4
A part of the surface of Triton

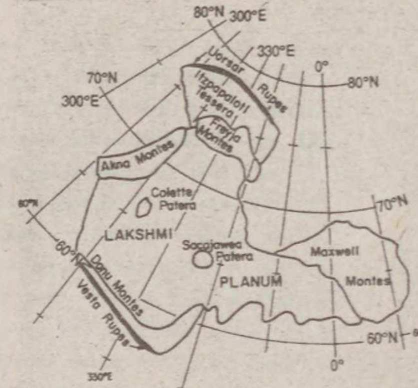
Fig. 5

Transform faults on Earth.

Fig. 6

Enormous valleys on Venus.

a



b

c

Fig. 7

Region of folded mountains on Venus

a: Magellan radar (lower part, middle)

b: map

c: Freya Mons (lower part) and Itzpapalotl Tessera (upper part).