WERE MORB-LIKE MARE BASALTS GENERATED IN ABSENCE OF ANY PLATE-TECTONICS LIKE SET UP IN EARLY ARCHAEAN? T. Ruj[1], N. Dasgupta[1], D. Ray[2] and S. Misra[3], [1]Department of Geology, Presidency University, Kolkata- 700073, India (trishitruj@gmail.com), [2]PLANEX, Physical Research Laboratory, Ahmedabad- 380009, India (dwijesh@prl.res.in), [3]SAEES, University of KwaZulu-Natal, Durban-4000, South Africa (misras@ukzn.ac.za).

Introduction: Although Phanerozoic plate tectonics is thought to be a prime mechanism for the formation of the Archaean crusts on our planet Earth [1-4], the process is presently suggested to be in operation only from the Ordovician onward [5], and the existence of modern plate tectonic set up in the Archaean is now questionable [6, 7]. One of the major problems in proper understanding the mechanism of growth of the terrestrial crusts in the Archaean is perhaps the wide application of geochemical discrimination diagrams in literature, which have their basis on the Phanerozoic tectonic settings [8], although suggestions were there that siliceous liquids of similar compositions could have been generated by diverse magma-tectonic processes [9].

One of the easiest ways to look into the problems on early crustal growth on the Earth (and other planetary bodies) is perhaps an investigation on the magma-tectonics of our closest neighbor Moon that has been magmatically and tectonically fossilized ~3.6 Ga ago [10]. In our present abstract, we have made a preliminary attempt to correlate the trace element geochemistry of high (H)-Ti and low (L)-Ti mare basalts with the megatectonics on the Moon. Our study shows that the mare basalts, which are similar to the terrestrial mid-ocean ridge basalts (MORBs), were perhaps generated in absence of any terrestrial-like mid-ocean ridge system of the Phanerozoic age.

Lunar tectonics: The Earth-like tectonic fabrics ranging from extensional to compressional domain like graben, reverse fault, wrinkle ridge, shearing, folds on basaltic layers etc. are reported from the lunar crust [11]. It is believed that the tectonic activity within the lunar crust, which was essentially extensional, ceased ~3.6 Ga ago, and the satellite is considered as a one-plate planet with an immobile lithosphere [12]. The ratio z_c/z_l (z_c and z_l are the thickness of the crust and tectonic lithosphere respectively) of the Moon was also found to be too high (> 0.25) to sustain plate tectonics [13, 14].

Our studies show that the Lunar mega-fractures could be classified into two principal types: (a) cracks emerging from large craters and run for several hundreds of kilometres, and (b) cracks within the mare regions as well as on the floor of the large craters. The type 'a' fractures are believed to act as channel ways for the outpouring of basaltic lava flows [11]. In order to comment on the possible origin of these mega-fractures, we carried out fracture pattern analyses from two well-known terrains on the Moon, viz. (i) Kopff crater, Mare Orientale basin far side, and (ii) Rima Hyginus, near side of the moon (Fig. 1).

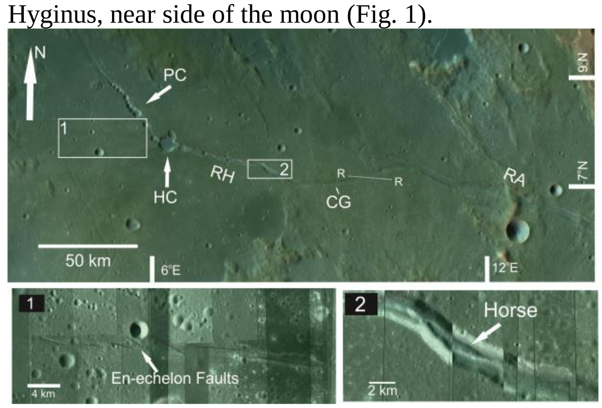

Fig. 1. Rima Hyginus crater and associated area. RH- Rima Hyginus, RA- Rima ariadeus, HC- Hyginus crater, CG- cross graben, PC- pit chains, RR- reverse fault. Areas labelled 1 and 2 are shown separately. Within area 1 En-echelon faults are seen. Within area 2 tectonic horse is noticeable within the graben walls.

Within the Kopff crater, the existing fracture patterns show dissimilarity in disposition to the fracture systems encountered in the East African Rift valley on the Earth (Fig. 2), which is a newly opening continental scale fracture system outpouring voluminous mantle-derived ultra-alkaline to theoliitic lavas and is thought to evolve as a mid-oceanic rift in future [15]. The fracture density pattern and fracture frequency rose of the East African Rift valley have distinct fracture trends with two modes (NNW-SSE and NE-SW) (Fig. 2c). The fracture frequency azimuthal rose diagram for the Kopff crater does not show any preferred fracture density pattern and orientation similar to those in the East African Rift valley (Fig 2a), however, the fracture pattern within the Kopff crater is very similar to the fracture rose pattern of desiccation cracks on dry lake beds observed on the Mars (Fig. 2b) [16].

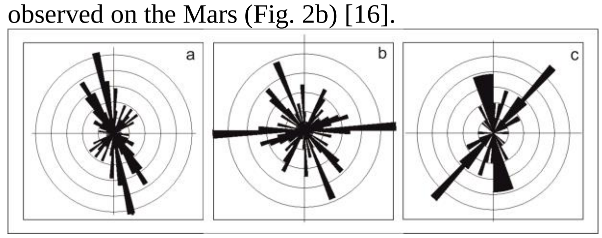

Fig.2. Frequency-azimuth rose diagram of fracture systematics in (a) Kopff crater (Moon), (b) dessicated mud (on Mars), and (c) East African Rift valley (Earth).

Fracture systems were analysed, within an area enclosed by the Rima Hyginus to the west and the Rima Ariadaeus to the east [17] (Fig. 1). There is an ENE-WSW oriented cross graben, detached at its north central region. The Rima Hyginus is itself a graben system with a width of 500m. Our studies indicate the presence of en-echelon faults within the southern margin, which has several tectonic horses bounded by faults. Deploying Anderson's hypothesis on fracture formation, we show a sequence of stress regime, which varies in orientation through time as the fractures evolve (Fig. 3). Switching of principal tectonic stress directions with time over a small area (<50 km^2) suggest the absence of any time-consistent large scale tectonic stresses within the lunar crust. The situation is in contrast to the plate-tectonic set up driven by self-regulating internal thermal convection [18] within Earth.

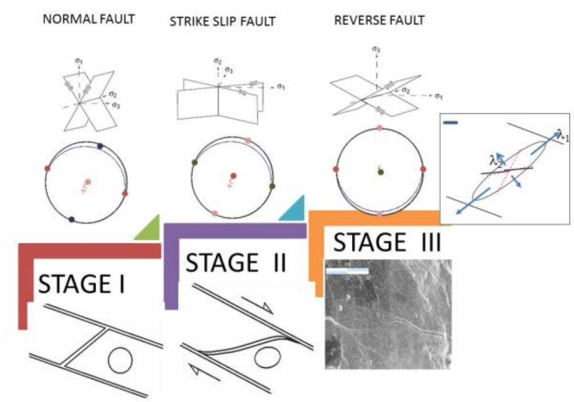

Fig. 3 Model of development of the fracture system within the Rima hyginus. Note the changing orientation of the principal stress direction with time.

Lunar basalts geochemistry: Our synthesis on incompatible trace element geochemistry showed that the L-Ti mare basalts (from Apollo 12 and 15 sites) are similar in composition to that of the terrestrial enriched (E)-MORB, whereas H-Ti mare basalts (from Apollo 11 and 17 sites) have chemistry between terrestrial E-MORB and Ocean Island Basalt (OIB), although the H-Ti mare basalt is moderately enriched in Nb and Ta and also significantly enriched in HREEs [19, 20]. We have further re-examined our findings using more sensitive incompatible trace element ratios Nb/Yb versus Th/Yb plot [21]. In this diagram, L-Ti mare basalts well correspond to the array defined by global terrestrial MORBs, however, the H-Ti mare basalts are relatively depleted in Th/Yb ratios (Fig. 4).

Discussion: It was suggested that the Earth-like plate tectonics was absent on the Moon [12, 13]. Our present observation also suggests that the continental scale fractures present on the lunar surface, which could be the channel ways for the outpouring of lunar basalts [11], are dissimilar to the terrestrial fracture system found in the East African Rift. These fractures on the lunar crust could have originated by mega-impact [22] followed by out pouring of basaltic magma in the later part of lunar crustal evolution, or desiccation cracks developed on the surface of cooling basaltic melts (Fig. 2). So it can be concluded that the terrestrial MORB-like L-Ti mare basalt [19, 20] could also be generated in the absence of any modern plate tectonic-like set up present on the Earth, although it is believed that the terrestrial MORBs of the Phanerozoic age are generated only in the Mid Oceanic Ridge system [23].

The H-Ti mare basalts are although follow in part the terrestrial MORB trend in figure 4, these basalts have relatively low Th/Yb ratios. These H-Ti basalts also have extremely high Nb/U (> 100) and low Pb/Nb ratios (≥0.02), which are uncommon for the terrestrial analogs [20]. It appears that the source mantle of the H-Ti mare basalts perhaps experienced a previous history of hydrothermal activity that depleted it in Pb, Th and U. Further studies in this regard are in progress.

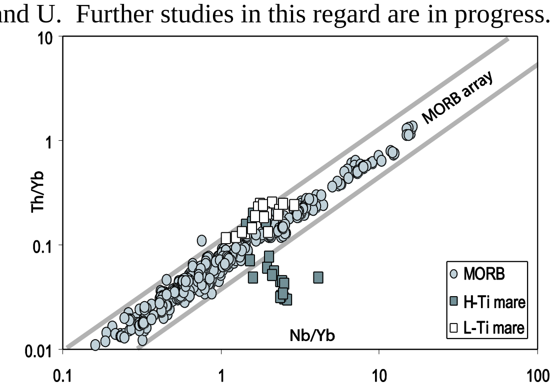

Fig. 4. Plots of the mare basalts in Nb/Yb versus Th/Yb space for the terrestrial MORBs.

References: [1] Condie K. C. (1976) *Plate Tectonics and Crustal Evolution*, Pergamon press, New York, 288 p. [2] Kröner A. (ed.) (1981) *Precambrian Plate Tectonics*, Elsevier, 781 p. [3] Nisbet E. G. and Fowler C. M. R. (1983) *Geology, 11*, 376-379. [4] Condie K. C. (2008) *Geology, 36*, 611-614. [5] Hamilton W. B. (2011) *Lithos, 123*, 1-20. [6] Moyen J-F and Hunen J. v. (2012) *Geology, 40*, 451-454. [7] Moyen J-F and Hunen J. v. (2012) *Annu. Rev. Earth Planet. Sci. 40*, 195-219. [8] Rollinson, H. R. (1993) *Using Geochemical Data: evaluation, presentation, interpretation,* Longman, Essex, 352p. [9] Brown G. C. et al. (1984) *J. Geol. Soc. London, 141*, 413-426. [10] Watters T. R. et al. (2012) *Nature Geosciences*, *5*, 181-185. [11] Melosh H. J. (2010) *Planetary Surface Processes,* Cambridge University Press, 500p. [12] Solomon S. C. and Head J. W. (1979) *JGR (Solid Earth), 84,* 1667 -1682. [13] Solomon, S. C. (1978) *GRL, 5,* 461–464. [14] Warren P. H. (1993) *JGR (Planets), 98,* 5335 – 5445. [15] Winter J. D. (2001) *An introduction to Igneous and Metamorphic Petrology*, Prentice-Hall, New Jersey, 697p. [16] http://spacefellowship .com/news /art13072/ evidence-of-dry-lake-beds-on-mars. html. [17] Ruj T. et al (2013) *Lunar and Mars Geoscience (Abstract volume), SAC, ISRO,* 7**.** [18] Tozer, D. C. *Phil Tran R. Soc. London, 258, 252 - 271*(1965). [19] Ray, D. and Misra, S. (2012) *EPSC, 7,* Abstract no. EPSC 2012-73-1. [20] Ray D. and Misra S. (2014) LPSC (this volume). [21] Jenner F. E. (2013) *Geology, 41*, 327-330. [22] Greeley R. (2013) *Introduction to Planetary Geomorphology*, Cambridge University Press, 90p. [23] Wilson M. (2007) *Igneous Petrogenesis*, Chapman & Hall, 457p.