The Late Heavy Bombardment of the Moon – an Evolving Problem. G.Arrhenius [1] and J. R. Hill[2], [1] Scripps Institution of Oceanography, UCSD, La Jolla CA 92093-0218, arrhenius@ucsd.edu, [2]2728 Nansen Ave, San Diego, CA 92122-3122, hillrodjay@alumni.ucsd.edu

The impact record on the Moon has been suggested to show either the tail end of extended accretion or to represent a discrete impact interval extending from about 4 Ga to about 3.45 Ga, the age of the last major dated impact event [1]. Discussion in the literature has largely focused on the interval theory. An early assumption about the nature of the projectiles has suggested them as a swarm of marauding asteroids invading the inner solar system, turning the crusts of the planets into oceans of molten rock.

Observational difficulties with this scenario led to the suggestion [2] that the bombardment of the Moon would be a localized phenomenon within the Earth – Moon system – a series of impacts by a number of small primordial Earth satellites with the Moon, receding toward its present expanding orbit from its initial formation- or capture orbit close to the Earth. Recapture of ejecta by the Moon would add to the number of cratering events. With impact velocities rarely exceeding the escape velocity of the Moon, only a small fraction of ejecta would be expected to reach the Earth, explaining the lack of a physical impact record in the Archean sedimentary rocks in the age range 3.5 – 3.8 GA overlapping in age with the last major impacts on the Moon.

Besides the lack of physical impact features in the 3.8 Ga old Isua Supracrustal Belt (ISB) in SW. Greenland or in the ~3.5 Ga sedimentary rocks in S. Africa and W. Australia, we sought impact evidence in the finely laminated banded iron deposits (BIF) in the Isua supracrustals. The sedimentary sequences, overlapping in time with the tail end of the lunar bombardment period contain structural disturbances that may or may not be impact related. One of the most notable features of this kind that we investigated [3] is found at the NE. end of the formation with strongly disturbed 0.1 – 1 m thick strata sandwiched between layers of finely laminated BIF. Some of the thicker disturbed strata show graded bedding of the component rock fragments, possibly from suspension of surge deposits sorted during resettling.

17 samples were analyzed for Ir by neutron activation using the Luis W.Alvarez Iridium Coincidence Spectrometer at LRL, UCB with a 5 ppt detection limit for Ir at the highest interfering iron concentrations. The measured values range from below detection limit to 12 ppt, well below average crustal abundance (~50 ppt). No meaningful concentration trends were found in the graded beds nor any systematic contrast between Ir in disturbed and undisturbed layers including sediment strata immediately overlying the graded beds. These findings would suggest a minimal deposition of undifferentiated extraterrestrial materials either in the undisturbed sedimentation process or in the violent surge possibly caused by a minor impact.

Evidence from Mars of unmelted crust from 4.6 Ga, although represented by a single sample, would also seem to support the notion of the late heavy lunar bombardment (LHLB) limited to the Earth-Moon system. Extensive cratering seen on the surfaces of Mars and Mercury has in the literature been associated with LHLB but this assumption is not supported by radiometric age measurements and conflict with the albeit sparse evidence for a lack of a late, impact generated magma ocean on Mars. Crustal melting on a global scale could however be prevented if major impacts were sufficiently separated in time to permit intermittent cooling [4]

A new contribution to the problem has been given by [4] who with extensive support from dynamic and geochemical evidence point to the likelihood that comets rather than asteroids would be the source of the lunar projectiles if thought to come from outside of the Earth-Moon system. The basis for the cometary suggestion includes a set, twice as large as ours but with lesser sensitivity of analyses of iridium in metasedimetary rocks from the ISB, expanding the range of concentrations beyond that found in our previous work and including two other rock types in addition to banded iron sediments (BIF) exclusively used in our study.

The results of [4] suggest a generally low iridium content in the BIF samples but several times higher in mica schists and detrital turbidites – in one case with evidence for a single particle consisting of platinum group elements

Seen in the light of the internal Earth – Moon system proposition these results provide a basis for estimating the amount of impact debris brought into capture by the Earth. In view of the continuing lack of evidence for accompanying major impact craters this component could be thought of as largely consisting of small particles brought in from Earth orbit by Poynting – Robertson drag.

Orbital dynamic calculations, currently carried out, will further test the probability of natural, small satellites of the Earth, destroyed by collision with our present abnormal, receding Moon as the source of the late heavy lunar bombardment [2,3], and the limitations of its effects on Earth

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