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slightly elevated western margin of the depression. Field work in 1989 showed sandstone outcropping on this western margin. Unconsolidated sediments in the center of the structure seem to be lake deposits.

Site 2: We list this site immediately after site 1 because it is geographically near, but the available evidence for impact origin is ambiguous. The center is only 4 km east of site 1; a small airport, Sua Phra Camp, and the villages of Ban Nan Noi and Ban Nong Saena occupy elevated ground surrounding three sides of the 0.8 radius, amphitheater-like depression that opens westward into a small reservoir. The satellite image of the area is dominated by bleached ground indicating bare soil due possibly to grading or agriculture.

Site 3: This site is located ~17 km southeast of Amphoe Det Udom. The village of Ban Lup Lao is centered within a 3-km-radius partial bull's-eye pattern prominent on both the SPOT image and the topographic map. Outcrops along the annular streams would be suitable initial targets for investigation.

Site 4: This site is geographically near site 3 and also seems to be a multiring structure. About 9 km east-northeast of Ban Lup Lao, the village of Ban Bua Ngain is situated on a small area of higher ground that may represent the center of a bull's-eye feature nearly 3 km in radius. Trails radiate from the village several kilometers in all directions indicating generally gentle relief but the drainage pattern weakly suggests possible concentric ring troughs at radial distances of 0.8 km and 3 km.

Site 5: This 1-km-radius circular feature is centered some 3 km north of Ban Pa Tia village and 2 km southeast of Ban Nonk Kop. This area is at the southeast end of the big Lam Dom Noi Reservoir in a region of intense road building east and northeast of Buntharik. The structure is within several kilometers of tektite recovery sites near the village of Huai Sai.

Sites 6a–6e: Scattered in low-lying regions throughout the area are numerous elliptical or subcircular features having radii smaller than ~0.3 km. Most appear to be basins with subdued rims, especially along southern margins. Many are elongated with longer axes running north-northwest to south-southeast. Several are located along a 3-km stretch north of the road between Wat Ban Mak Mai and Highway 2182. This is the area between the Ban Lup Lao bull's-eye structure and Amphoe Det Udom. Because these structures are quite small, it would be remarkable if they are craters that have been preserved for 770 ka.

A field trip to northeastern Thailand by North American and Thai scientists is planned for January 1994. The prime targets for investigation are the first five listed in Table 1. In addition we will survey the occurrence of layered tektites in the region. A preliminary survey in 1989 indicated that all fragments in the tektite-bearing-laterite marker horizon in this region are layered.

If time permits, we will also survey some circular sites about 200 km to the north where layered tektites have been found northwest of the city of Mukdahan. SPOT images of this region have been requested.

We expect to receive SIR-C shuttle radar images of these regions in mid 1994; these will allow additional sites to be defined for investigation in subsequent field work.

References: [1] De Gasparis A. A. et al. (1975) *Geology, 3,* 605–607. [2] Barnes V. E. and Pitakpaivan K. (1962) *Proc. Natl. Acad. Sci., 48,* 947–955. [3] Wasson J. T. (1991) *EPSL, 102,* 95–109. [4] Izett G. A. and Obradovich J. D. (1992) *LPS XXIII,* 593–594.

SOME IMPLICATIONS OF LARGE IMPACT CRATERS AND BASINS ON VENUS FOR TERRESTRIAL RINGED CRATERS AND PLANETARY EVOLUTION.

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Approximately 950 impact craters have been identified on the surface of Venus [e.g., 1], mainly in Magellan radar images. From a combination of Earth-based Arecibo, Venera 15/16, and Magellan radar images, we have interpreted 72 as unequivocal peak-ring craters and four as multiringed basins [2,3]. The morphological and structural preservation of these craters is high, owing to the low level of geologic activity on the venusian surface (which is in some ways similar to the terrestrial benthic environment). Thus these craters should prove crucial to understanding the mechanics of ringed crater formation. They are also the most direct analogs for craters formed on the Earth in Phanerozoic time, such as Chicxulub. Below we summarize our findings to date [2,3] concerning these structures.

Peak-ring craters are relatively large complex craters whose central structure is a ring of peaks rather than a single central peak or central-peak complex. Otherwise they possess the usual features of complex craters: flat, usually melt-covered floors and a collapsed, terraced rim. For peak-ring craters on Venus, crater-rim to inner-peak-ring diameter, or ring, ratios decrease with increasing crater diameter; the ratios do not follow $\sqrt{2}$ spacing [4]. The onset to the peak-ring form is in the ~30–40-km-diameter interval [3]. The morphology of peak-ring craters, the decrease in ring ratios with increasing crater size, and the general size-morphology progression from complex central-peak to peak-ring crater, including some with both an inner ring and a central peak or peaks, on Venus and the other terrestrial planets suggest a similar process of peak-ring formation: hydrodynamic downward and outward collapse of an unstable central peak to form a ring. The overall phenomenology of the peak-to-peak-ring crater transition on the terrestrial planets (morphology, ring ratios, etc.) is also consistent in character with the differential melt/crater volume scaling hypothesis of Grieve and Cintala [5], in which the core of the central uplift is shock melted and weakened so that the final, stable, emergent form of the uplift is a ring.

The four largest ringed structures on Venus—Klenova, Lise Meitner, Isabella, and Mead—are structurally and morphologically more similar to the Orientale Basin on the Moon, and are probably true multiringed basins. Here we refer to multiringed basins as those that have one or more outer rings that are (usually) asymmetric in radial topographic profile and structurally appear to have formed by circumferential normal faulting. While the four venusian structures (≈145-, 150-, 170-, and 270-km diameter) are smaller than Orientale (≈930-km diameter), we suggest that based on the megaterrace/ring tectonic model of Melosh and McKinnon [6], the higher gravity and temperature gradients on Venus, compared with that of the Moon when its basins formed, compensate and allow a crustal or mantle asthenosphere to form and inward viscous flow to create sufficient radial extensional stress in the overlying lithosphere. It is this stress that initiates the circumferential normal faulting and outer ring formation.

Turning our attention to the Earth, given that the geology and surface gravity of the Earth and Venus are similar, we expect that fresh terrestrial impacts greater than ~30–40-km diameter should have interior rings. In the tabulation of large terrestrial impacts in, or dominantly in, crystalline rocks [5], the majority above 40 km diameter have central depressions, offset peaks, or rings, despite the interpretational difficulties posed by erosion. We also expect that terrestrial craters ≥150 km diameter have the potential to be true multiringed basins. The formation of outer, asymmetric-in-profile rings in the megaterrace/ring tectonic model depends on subsurface rheology, which is determined by composition and especially by temperature. Large asteroids striking present-day oceanic lithosphere could create rings by this mechanism, but probably would not within continental cratons because of the low heat flows there [7]. There the peak-ring form should persist to much higher diameters. As an example, we address one of the largest and most significant structures in the terrestrial record, Chicxulub.

Suspected from magnetic data, corroborated by gravity, and finally confirmed as an impact by petrology [8, cf. 9], Chicxulub is probably the KT crater (or the major one). Chicxulub is definitely in the size class to be multiringed. The gravity and magnetic anomalies define a bull's-eye pattern ~180 km across [8]. Unfortunately it is buried by younger carbonate platform rocks, so structural information on the crater itself is lacking. Reprocessed gravity data over the northern Yucatan by Sharpton and others [10] clearly show a main rim with a diameter of 199 ± 12 km and a central ring with a diameter of 105 ± 10 km. The gravity signature hints at an additional ring between the two others, but it is not nearly as prominent, if it exists. Chicxulub may thus be a very large peak-ring crater. On the other hand, Chicxulub apparently formed within a few hundred kilometers of several active plate margins [8], albeit excavating into early Paleozoic crystalline basement [10], so it is not inconceivable that the heat flow was high enough to, for example, define a crustal asthenosphere during transient crater collapse, leading to outer ring formation and thus to three (or four) rings. We are not claiming that Chicxulub is a true multiringed basin, only that it is a possibility.

The case for Chicxulub being a multiringed basin in the structural sense meant here would be enhanced if it were larger, implying greater driving stresses during collapse and lower deep crustal viscosities. A fourth, outer ring of 278 ± 22 km diameter is advocated in [10] on the basis of some very-low-amplitude, discontinuous gravity highs. It is also apparent that the argument for this ring and the intermediate one mentioned above is enhanced in [10] by belief in an invariant $\sqrt{2}$ spacing for impact rings [4]. Our results for Venus [2,3], as well as those of the Magellan team [1], demonstrate that ring spacing is not invariant and alone is an imperfect guide for understanding impact mechanics. Clearly, direct structural information must take precedence (this is partly why the relatively pristine craters on Venus are so valuable). Thus it is interesting that a less than conspicuous feature of the venusian multiringed structures, the inner "peak ring," should be so prominent in the gravity maps interpreted in [10], while a major structural feature, the outer down-faulted rim, hardly shows up in the Chicxulub gravity field (i.e., the outer ring in [10]). Volcanic burial of venusian peak rings and erosion of the original Chicxulub rim can be invoked, but erosion won't erase the offsets of subsurface layers caused by the outer ring fault. Greater attention to this last point, as well as additional gravity and seismic data, should confirm or deny the existence of the 280-km ring of Chicxulub. Modeling Magellan gravity to constrain the subsurface structure beneath the large venusian craters, and well as theoretical models of their formation, will also be important.

Any discussion of Chicxulub naturally brings up the question of the KT mass extinction. It is sobering to contemplate a map of the venusian surface with its impact craters clearly marked (for example, Plate 2 in [11]). Over the same time period (~500 m.y., or the length of the Phanerozoic) the Earth has accumulated an even greater number of impacts because of the relative thinness of the terrestrial atmospheric shield, but the number of large craters (including those that are ringed) should be very similar. The formation of an Isabella or a Mead on the Earth would surely be a catastrophe for a large portion of our planet.

References: [1] Schaber G. G. et al. (1992) *JGR, 97,* 13257–13301. [2] Alexopoulos J. S. and McKinnon W. B. (1992) *Icarus, 100,* 347–363; Erratum: *Icarus, 103,* 161. [3] Alexopoulos J. S. and McKinnon W. B. (1994) *GSA Spec. Paper,* in press. [4] Pike R. J. and Spudis P. D. (1987) *Earth, Moon, and Planets, 39,* 129–194. [5] Grieve R. A. F. and Cintala M. J. (1992) *Meteoritics, 27,* 526–538. [6] Melosh H. J. and McKinnon W. B. (1978) *GRL, 5,* 985–988. [7] McKinnon W. B. (1981) *Proc. LPS 12A,* 259–273. [8] Hildebrand A. R. et al. (1991) *Geology, 19,* 867–871. [9] McKinnon W. B. (1982) *GSA Spec. Paper 190,* 129–142. [10] Sharpton V. L. et al. (1993) *Science, 261,* 1564–1567. [11] Phillips R. J. et al. (1992) *JGR, 97,* 15923–15948.

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PROPOSED LAW OF NATURE LINKING IMPACTS, PLUME VOLCANISM, AND MILANKOVITCH CYCLES TO TERRESTRIAL VERTEBRATE MASS EXTINCTIONS VIA GREENHOUSE-EMBRYO DEATH COUPLING.

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A greenhouse-physiological coupling killing mechanism active among mammals, birds, and reptiles has been identified. Operating via environmental thermal effects upon maternal core-skin blood flow critical to survival and development of embryos, it reduces the flow of blood to the uterine tract. Today, during hot summers, this phenomena kills embryos on a vast, global scale. Because of sensitivity of many mammals to modern heat, a major modern greenhouse could reduce population numbers on a global scale, and potentially trigger population collapses in the more vulnerable parts of the world. In the geological past, the killing mechanism has likely been triggered into action by greenhouse warming via impact events, plume volcanism, and Earth orbital variations (Milankovitch cycles).

Earth's biosphere is maintained and molded by the flow of energy from the solar energy source to Earth, and on to the space energy sink (SES) [1]. This SES energy flow maintains Earth's biosphere and its living components, as open, intermediate, dissipative, nonequilibrium systems whose states are dependent upon the rate of energy flowing through them. Greenhouse gases such as CO_2 in the atmosphere influence the SES energy flow rate. Steady-state flow is necessary for global ecological stability (autopoiesis).

Natural fluctuations of the C cycle such as rapid releases of CO_2 from the mantle, or oceans, disrupt steady-state SES flow. These fluctuations constantly challenge the biosphere; slowdown of SES energy flow drives it toward thermodynamical equilibrium and stagnation. Fluctuations induced by impact events, mantle plume