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, amphitheatere-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 multiringing 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 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.

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 [6]. 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 Sharpn et 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 v2 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.


PROPOSED LAW OF NATURE LINKING IMPACTS, PLUME VOLCANISM, AND MILANKOVITCH CYCLES TO TERRESTRIAL VERTEBRATE MASS EXTINCTIONS VIA GREENHOUSE-EMBRYO DEATH COUPLING. D. M. McLean, Department of Geological Sciences, Virginia Polytechnic Institute, Blacksburg VA 24061, USA.

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 affects 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 CO2 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 CO2 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