MANICOUAGAN AND POPIGAY STRUCTURES: COMPARATIVE MORPHOLOGY AND SPATIAL DISTRIBUTION OF IMPACT MELT ROCKS. R. J. Floran, NASA Johnson Space Center, Houston, TX 77058

The 65 km-diameter Manicouagan ring-structure of central Quebec (51°30'N, 68°30'W) and the 100 km-diameter Popigay basin of northern Siberia (71°30'N, 111°30'W) are two of the largest well-preserved and least tectonically deformed impact structures on Earth. They are complementary in that each contains ejecta deposits which are no longer present or readily accessible at the other structure and each is exposed at a substantially different level of erosion. Although imperfectly known, the three-dimensional structural-stratigraphic relations at Manicouagan and Popigay can be used to model the formation of multiringed basins on the terrestrial planets.

This paper draws on several recent Russian publications (1-4) which present detailed descriptions of the morphological characteristics and impact deposits of the Popigay basin. These studies represent the first in-depth analysis of a relatively fresh terrestrial impact structure substantially larger than the Ries basin.

Prior to erosion the Triassic-age Manicouagan structure was either a triple-ringed basin, a double-ringed basin or a double-ringed basin transitional to a crater with a central uplift (5). Choosing from among these alternatives depends on whether an outer circumferential depression, ∿150 km in diameter, represents the base of a former ring-structure and whether a massif near the geometric center is a remnant of an uplift that protruded above the basin floor. Assuming similar rock properties and gravitational scaling, Manicouagan should be a structural analog of 400-500 km double-ringed basins on the moon such as the Moscoviense basin (5). A problem in reconstructing the preerosional morphology of Manicouagan is the large uncertainty associated with the radius of the transient cavity rim, estimated at 19±4 km. The probable location of the subsided outer slope of the transient cavity is marked by a 5-10 km wide peripheral trough at a distance of 30-35 km from the center of the structure. Exposures of deformed Lower Paleozoic limestone and shale within the trough suggest that a thin sedimentary veneer, probably less than 100 m thick, overlay the crystalline basement at the time of impact. Their structural position further suggests that downward, inward slumping of the rim took place during the post-cratering modification stage. Moderate to deep erosion at Manicouagan has considerably modified the original basin morphology. A thick surficial layer of ejecta has been stripped away, exposing a 100-200 m thick sheet of clast-laden melt rocks that lie directly on fractured Precambrian basement.

The ambiguities associated with Manicouagan are less severe at Popigay where detailed field mapping combined with geophysical studies reveal a complex basin morphology that is somewhat similar to the Ries basin (1-3; Fig. 1). Responsible for the complexity is the heterogeneity of the target material which consists primarily of Archean crystalline rocks (ρ = 2.8 - 2.9 g/cm^3) overlain by northward dipping terriginous and carbonate formations of Proterozoic,Cambrian and Permian age (ρ = 2.2 - 2.7 g/cm^3). Minor erosion, sedimentation and tilting in Pliocene-Quaternary time, shortly after the impact, led to uplift and exposure of the SW and W sectors and partial burial of the structure in the NE and E sectors. The basin consists of an inner "crater" in crystalline basement (D = 72 km) and a discontinuous outer "crater" (D = 100 km) confined to the 1 km thick sedimentary cover. The outer crater is characterized by the presence of concentric thrust faults which dip toward the center of the structure at various angles. The multilayered nature of the target is responsible for the disappearance of the outer crater in the north and southwest. Variations in the strength of the substrate have produced concentric craters in the laboratory (6) and have undoubtedly influenced final crater geometry at Popigay.

Within the inner crater lie sinuous and arcuate ridges composed of clast-laden melt rocks (tagamites). These form discontinuous sheets 10's of meters thick overlying fragmental breccias and suevite; they also occur as dikes, necks and irregular bodies within the other impact deposits. The arcuate ridges, which have been termed pseudovolcanic structures because of their resemblance to volcanic flows, are thought to be the surface expression of basement ring-structures (1). Fragmental breccias, suevites and rarely, tagamites form tongues that extend outward into the outer crater. Similar deposits interpreted as impact melts have been described in and around lunar craters (7). Deposits equivalent to tagamite are present at several localities within the Ries basin (8; Hörz, p.c.) but are extremely rare. In contrast, the distribution of suevite and fragmental breccias at Popigay is very similar to that at the Ries (1).

A continuous melt layer is not exposed within the Popigay basin, as at Manicouagan, but is likely to be present at shallow depth. Petrographically, the tagamites resemble melt rocks from the basal melt unit at Manicouagan. Thus within fresh, large impact structures very fine-grained, clast-rich melt rocks overlie a topographically irregular basement at depth and at the surface. Between local elevations of basement or buried ring-structures, thick accumulations of clast-poor melt led to crystallization of coarser-grained, igneous-textured rocks such as the micromonzonite that forms the upper melt unit at Manicouagan (9).

It is interesting to note that the ring-structures within the Popigay basin appear to have approximately $\sqrt{2}$ spacing (Table 1). However, evidence for the existence of the innermost ring is weak, being based entirely on arc-shaped tagamite ridges on the surface. The second ring is well-defined by a circular positive gravity anomaly and discontinuous surface outcroppings of brecciated gneisses (Fig. 1). These data suggest that the second, most prominent ring is the likely location of the transient cavity rim. The inner and outer "craters" are also ring-structures, representing the collapsed margin of the transient cavity in crystalline and sedimentary rocks respectively.

The continuous ejecta deposits at Popigay rarely extend beyond the outer crater rim. Although modified by erosion, this restricted distribution appears to be responsible in large part for the subdued topography of the Popigay basin and burial of ring-structures. As shown by Gault et al. (10),the radial extent of continuous deposits for a given rim diameter decreases systematically in accordance with increases in gravity among the terrestrial planets. Atmospheric drag will further reduce the width of ejecta deposits on Earth. Thus rim and fallback ejecta should be several times thicker at Popigay than at similar-sized lunar craters. Supportive evidence is provided by observations at the Ries basin and Meteor Crater (10) which have narrow ejecta blankets compared with lunar and Mercurian counterparts. Because of their low surface relief, ancient "multiringed" terrestrial basins may have been relatively featureless, with only slight outward resemblance to lunar basins.

The depth of erosion at Manicouagan precludes a rigorous morphological comparison with Popigay. It is instructive to note, however, that the pre-erosional diameter of the two structures in crystalline basement rocks is nearly identical (Table 1). Although the position of the transient cavity at Manicouagan is uncertain, field mapping has revealed the presence of 50-150 m high basement blocks in two areas 13 and 16 km from the center of the structure which lie at stratigraphic levels normally occupied by the melt sheet. Whether these are analogous to the innermost ring(?) at Popigay or whether they represent local "ripples" formed in the basement is uncertain and can only be resolved by further field studies.

Although morphological comparisons have been made between the eroded Manicouagan structure and relatively fresh lunar basins (11) a more appropriate comparison is possible with the Popigay structure, which at 100 km in diameter, should be a better morphological analog of lunar basins ≥600 km across such as the Orientale basin. In this comparison, the hypothetical innermost ring at Popigay would be analogous to the subdued, 320 km ring at Orientale and the prominent second ring, representing the transient cavity rim, would be equivalent to the Inner Rook Mountains (Table 1). The inner and outer craters at Popigay would thus correspond to the Outer Rook and Cordillera Mountains respectively. If correct, this implies that the Orientale basin has a crater-within-crater morphology in which the outer "crater" is developed primarily in the less dense, surface fragmental layer.

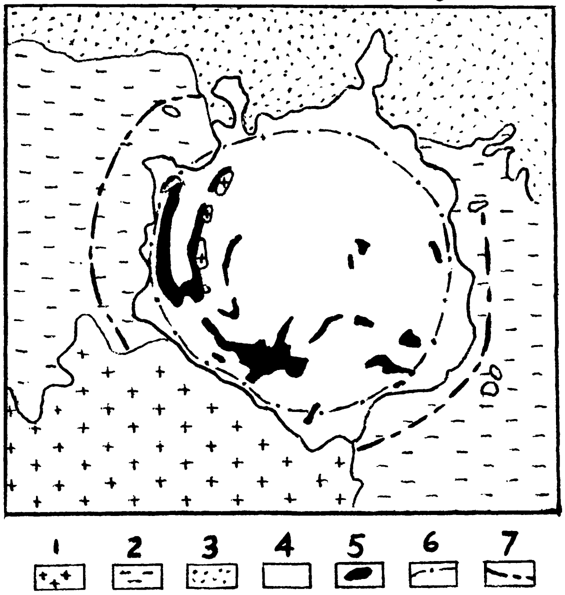

Figure 1: Structure of the Popigay basin (modified from Masaytis et al., 1971).

1. Archean rocks
2. Proterozoic and Cambrian rocks
3. Upper Paleozoic rocks
4. Fragmental breccias and suevites
5. Tagamites
6. Inner crater within Archean rocks
7. Outer crater within Proterozoic and Cambrian rocks

Table 1: Concentric Rings (in km) and Ring-Spacing of Manicouagan, Popigay and Orientale Basins

Manicouagan		Popigay		Orientale	
		32?		320	
			1.5		1.5
30 - 45		45 - 52		480	
	~2		1.5		1.3
75		72		620	
	~2		1.4		1.45
145 - 160		100		900	

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