1977]. There is as yet, however, no consensus on the process or the mechanism, which is generally considered to be related to gravity collapse and/or rebound [see papers in *Roddy et al.*, 1977; *Schultz and Merrill*, 1981; *Melosh*, 1977, 1982].

Insight into the formation of complex structures has been gained from structural information at terrestrial structures [*Dence et al.*, 1977; *Grieve et al.*, 1981]. A more comprehensive model, however, requires the full integration of the morphological data obtained from lunar structures [e.g., *Howard et al.*, 1974; *Hodges and Wilhelms*, 1978]. It has been shown, however, that the nature of the target exerts an influence on complex crater morphology [*Carr et al.*, 1977; *Cintala et al.*, 1977; *Grieve and Robertson*, 1979]. The few relatively fresh complex terrestrial structures that are available for morphological comparison, such as Ries, Haughton, and Popigai, were formed in mixed targets of sediments overlying crystalline basement and thus may not be direct analogs to large lunar craters. The ideal terrestrial complex structure for comparison would be formed in a crystalline target, and would have identifiable original morphological elements and abundant information on the geology of the crater floor. Unfortunately, the same erosive forces which expose the floor of a terrestrial structure and make it accessible to intensive study also modify the original morphologic elements.

The Manicouagan impact structure (51°23'N; 68°42'W) in central Quebec, Canada is the best studied complex impact structure in a predominantly crystalline target in North America, if not the world [*Phinney et al.*, 1978 and references therein]. Numerous geological and geophysical studies have been undertaken at Manicouagan, and it has been variously interpreted as an analog to multi-ring basins several hundred kilometers in diameter [*Floran and Dence*, 1976], and to smaller endogenically modified floor-fractured complex craters on the moon [*Orphal and Schultz*, 1978]. *Floran and Dence* [1976] estimate the original rim diameter and transient cavity diameter at Manicouagan to be ~75 km and 30–45 km, respectively, whereas *Orphal and Schultz* [1978] consider ~100 km and ~80 km to be better estimates for the same features. Although the concept of a transient cavity at large complex structures has little physical significance, with cavity formation and modification possibly occurring simultaneously in different areas of the evolving structure [*Grieve et al.*, 1981], the term has been retained here for comparison with previous work. The diameter of the transient cavity in large structures is best equated with the diameter within which relatively deep-seated material is removed by ballistic ejection [*Grieve et al.*, 1981].

A reanalysis of the Manicouagan impact structure has thus been undertaken. Manicouagan is of particular significance because of the wide variety of information available, its crystalline substrate, and its well-exposed crater floor. Manicouagan is also similar in size to fresh lunar structures such as Tycho and Copernicus, and thus provides a test of the influence of planetary gravity on the morphological equivalence of complex structures in a specific diameter range [*Dence*, 1977; *Grieve et al.*, 1981; *Pike*, 1980]. This contribution attempts to reconstruct the preerosional geology of Manicouagan in order to derive original dimensions that are consistent with all available data. The observations available for Manicouagan are discussed under the general categories of topographic, geologic, and geophysical data. Where possible, interpretations of original crater dimensions and form are made under each data set and then combined to derive an internally consistent interpretation of the Manicouagan structure.

TOPOGRAPHY

Erosion, in particular, glaciation, and its relative effects on the various rock types and structural elements of the original impact structure has been a major factor in shaping the present morphology of the Manicouagan structure. Unlike fresh lunar complex structures, most of the outstanding morphologic elements of Manicouagan are negative topographic features. *Floran and Dence* [1976] subdivided the present structure into five morphologic elements. *Orphal and Schultz* [1978] recognize a sixth additional element and their convention is followed. These morphologic elements are based largely on topographic expression (Figure 1) and are: (i) An outer circumferential depression, diameter ~150 km; (ii) An outer disturbed zone, outer diameter ~150 km; (iii) An inner fractured zone, outer diameter ~100 km; (iv) An annular moat, outer diameter ~65 km; (v) An inner plateau, outer diameter ~55 km; and (vi) A central region, outer diameter ~25 km.

These features are well described in *Floran and Dence* [1976] and *Orphal and Schultz* [1978]. Their salient characteristics are noted here, with some amplification over these previous studies where necessary.

The outer circumferential depression is best defined in the west, where the basement geology is restricted to essentially a single lithology, the ubiquitous grey gneisses of the Grenville Province of the Canadian Shield [*Murtaugh*, 1976]. It is visible on satellite images as an annular pattern of rivers and lakes and represents the limit of visible effects associated with Manicouagan. *Floran and Dence* [1976] suggest the outer circumferential depression is a fracture zone separating disturbed from essentially undisturbed basement rocks and equate it with the faint outermost ring observed in some lunar multi-ring impact basins. It is, however, a negative topographic element and shows no clear evidence of being a ring fault [*Floran and Dence*, 1976].

The outer disturbed zone and inner fractured zone lie between the outer circumferential depression and the annular moat (Figure 1). They are also best delineated in the west, where the division between inner and outer zones is marked by

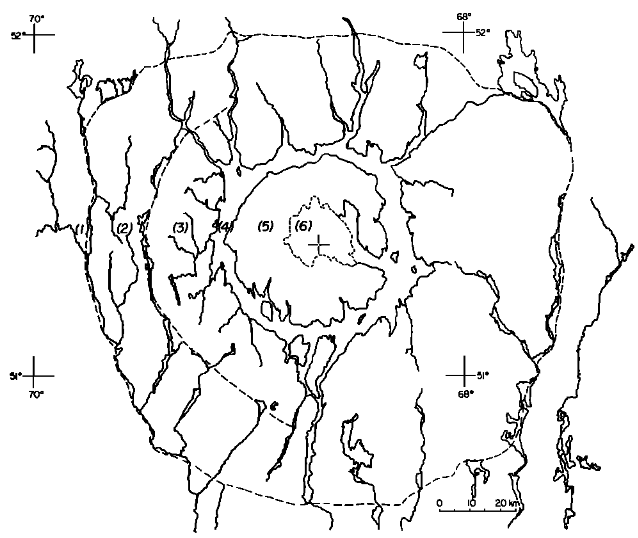

Fig. 1. Principal morphologic elements of the Manicouagan structure: (1) outer circumferential depression, (2) outer disturbed zone, (3) inner fracture zone, (4) annular moat, (5) inner plateau, and (6) central region. See text for details. Geometric center of structure is indicated by the cross.