TABLE 1. Craters with Shock Effects and Melt Rocks

Crater Diameter	Classification by Relative Erosion Depth 1	2	3	4	5	6	7
100 meters	Wabar Henbury Aouelloul Monteraqui	(Wolf Creek)					
1 km	Barringer						
		Tenoumer Köfels	(Lonar L.) New Quebec*	Holleford† W. Hawk L.† Brent†			
5 km							
		Bosumtwi				Pilot L.* L. Mien*†	
					L. Wanapitei*	Lac Couture*	
			Deep Bay†				
10 km							
			Steen River† Manson†	E. Clearwater† Strangway		Nicholson L. L. Dellen Rochechouart Lappajärvi (Jänisjärvi) L. Mistastin Gosses Bluff	
20 km							
		Ries					
30 km							
				L. St. Martin†	W. Clearwater		Carswell Siljan Charlevoix
50 km							
					Manicouagan		
100 km						Sudbury	Vredefort

Parentheses indicate craters at which shock effects have yet to be identified.
* Melt rocks known mainly or only from glacial float.
† Melt rocks known mainly or only from diamond drilling.

et al., 1969] forms surficial deposits up to tens of meters thick and is distributed both inside and outside the crater rim. There is abundant evidence that the glassy masses ('bombs' or 'Fladen') in the great majority of Ries melt deposits were aerodynamically shaped and chilled before deposition in the ejecta blanket [*Hörz*, 1965].

Mixed breccias in which glasses are associated with shocked fragments are also developed in the interior of craters among the rocks underlying the crater floor, and so are only exposed in more deeply eroded craters, such as West Clearwater Lake [*von Engelhardt and Dence*, 1971]. In these breccias the fresh or recrystallized glasses show intricate intrusive relationships with the enclosing fragmental rocks, indicating that the masses of melt were incorporated into the breccia while still hot and mobile. In some cases breccia fragments are entrained between layers of glass to give a banded fabric. Such breccias have also been called 'suevites,' but the term is more properly applied only to rocks like the Ries material, in which the glassy masses are of the Fladen type. In craters of small to intermediate size (up to 10 km), the relationships of breccias within the crater rims are generally complicated by slumping.

3. *Subhorizontal sheets of igneous rock*. In large craters the melt occurs predominantly as large sheets of igneous rock. The sheets are distributed within the craters as an annulus around one or more peaks of the central uplift, as seen at the West Clearwater Lake and Manicouagan occurrences. Mappable variations in the igneous rocks in both structures are mainly based on differences in grain size and in the content of inclusions that produce differences in patterns of jointing.

At West Clearwater Lake, for example, the following succession has been recognized on the ring of islands [*Dence*, 1964; *Bostock*, 1969]: (a) fractured and weakly shocked basement gneisses overlain by (b) up to 40 meters of mixed breccias with glassy fragments, overlain in turn, generally with sharp contact, by (c) a unit, averaging 30 meters in thickness, of fine-grained igneous rock with abundant shocked inclusions (coherent breccia of Bostock). The latter unit has a well-developed vertical jointing similar to jointing developed in welded ignimbrites, with which the Clearwater rocks have been compared [*Kranck and Sinclair*, 1963]. The fine-grained rocks grade upward into (d) a coarser-grained, massive, weakly jointed phase in which inclusions are generally inconspicuous (quartz latite of Bostock).

Similar variations on a larger scale have been mapped at Manicouagan [*Murtaugh and Currie*, 1969], where, nonetheless, paleomagnetic measurements show that the igneous rocks behaved as a single cooling unit after their formation in the Triassic [*Robertson*, 1967; *Larochelle and Currie*, 1967]. The preserved igneous section at West Clearwater is as much as 130 meters thick; at Manicouagan it is twice as thick. At both craters an estimated 50 meters or more of section has been removed by erosion, the missing material probably being similar to the fine-grained, vesicular, inclusion-rich igneous rocks recovered by drilling below sedimentary fill in East Clearwater Lake [*Dence et al.*, 1965].

The full lateral extent of the igneous rock sheets can only be surmised from the preserved record. A comparison of the more completely preserved craters suggests that with increasing crater size, the thick igneous sheets are more extensively spread over the crater floor and in the largest craters may even overlap the rim of the primary crater [as defined in *Dence*, 1968]. Thus at West Clearwater [*Dence*, 1965] and Lake St. Martin [*McCabe and Bannatyne*, 1970] craters the thick igneous sheets are concentrated on the inner side of a ring uplift of crystalline basement rocks 20 km in diameter. At Manicouagan, on the other hand, the ring structure has a diameter of about 45 km and is completely covered by the 200-meter-thick sheet of igneous rocks. They extend radially for a further 5 to 10 km well into the peripheral trough that marks the down-dropped crater rim.

Massive igneous rocks have not been recorded at the Ries, where the ring uplift is 12 km in diameter, but strong magnetic anomalies within the crystalline ring [*Pohl and Angenheister*, 1969] may indicate concentrations of melt comparable to those at the Canadian craters. The exposures of crystalline vesicular igneous rocks at Polsingen and Amerbach on the east side of the crater [*von Engelhardt et al.*, 1969] are probably outlying tongues of the inferred igneous sheet.

4. *Dikes of melt and breccia in basement rocks*. The fourth form in which igneous rocks occur at shocked structures is also observed at Manicouagan in deep gullies that dissect the crater rim. There small dikes of glass and breccia cut the fractured basement rocks. The dikes are similar in composition, texture, and age to the overlying sheets of igneous rocks and breccias and are apparently derived from them as fracture fillings during the later stages of crater formation. At the most deeply eroded structures, such as those listed in column 7 of Table 1, minor intrusions of this type are the only manifestations of the more extreme conditions of strain and temperature that were attendant on their formation. Representative occurrences include the melt rocks and breccias from Charlevoix [*Rondot*, 1968] and Carswell [*Currie*, 1969] craters and the enstatite granophyre dikes at Vredefort [*Willemse*, 1937]. Pseudotachylite veins found at a number of these craters are not considered to be a form of the melt rocks but are interpreted as resulting from frictional melting of mobilized basement rocks, particularly those involved in the central uplift.

TEXTURES

The considerable textural variety exhibited by the igneous rocks of shock-metamorphosed structures is attributable to two factors: (1