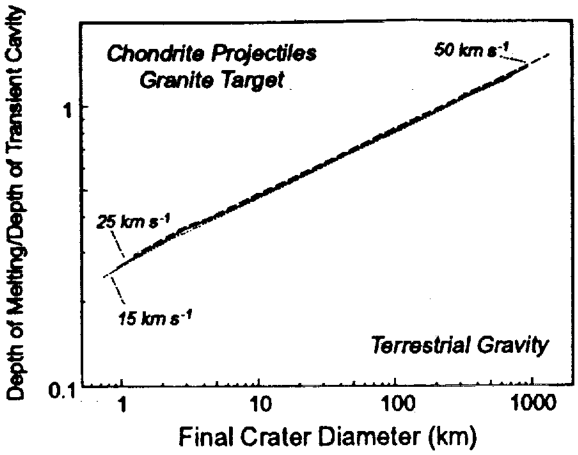

Fig. 2. Depth of melting along the axis of penetration relative to the depth of the transient cavity, plotted as a function of final crater diamater. Note that, regardless of the impact velocity, melting will approach the "base" of the cavity even at relatively small diameters.

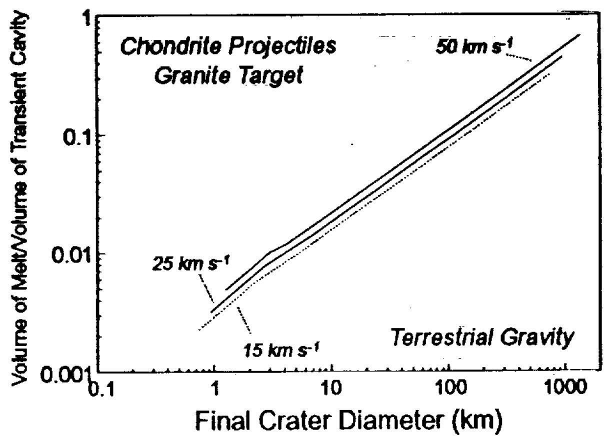

Fig. 3. Volume of melt relative to the volume of the transient cavity as a function of final crater diameter. The melt volume approaches that of the cavity at crater diameters above about 1000 km.

A second implication is that, as the limit of melting intersects the base of the cavity (Fig. 2), central topographic peaks will be modified in appearance and ultimately will not occur. That is, the peak will first develop a central depression, due to the flow of low-strength melted materials, when the melt volume begins to intersect the transient-cavity base. As the melt volume intersects an increasing portion of the transient cavity base, the peak will be replaced upon uplift by a ring. Some of the implications of this mechanism for ring formation and observations on other terrestrial planets is given elsewhere in this volume [9]. The morphology of central structures at complex terrestrial craters was also compiled from the literature [6]; again, erosion is a complicating factor as it can both destroy and create topography. Nevertheless, the general trend is what would be expected with central depressions at values of $D_R \geq$ 40 km, and finally rings appearing at $D_R \geq 100$ km. The latter is equivalent to d_m/d_{tc} values of 0.8–0.9 (Fig. 2), and the diameter at which rings consistently appear in the terrestrial record is also where shock pressures in central-uplift structures record partial melting at $D_R \geq 80$ km (Table 1).

As crater size increases, the volume of impact melt occupies a greater percentage of the volume of the transient cavity (Fig. 3). This implies that less clastic debris is available for incorporation into impact-melt sheets at larger craters. This argument has been used to explain, in part, the general lack of clasts in the bulk of the impact-melt sheet (the Igneous Complex) at Sudbury [10]. There are few detailed studies of clast-content variation in impact-melt rocks. The preserved melt sheets at Mistastin ($D_R = 28$ km) and W. Clearwater ($D_R = 32$ km) are ~100 m thick and have clasts throughout [11,12]. At Manicouagan ($D_R = 100$ km), however, the melt sheet is essentially free of clasts ~30 m above its base [13]. While this is consistent with the implications of the model, it could result from complete resorption of clasts in the thicker (~200 m preserved thickness) melt sheet at Manicouagan. Ultimately, the volume of melt could equal or exceed the volume of the transient cavity (Fig. 3). In this case ($D_R \sim 1000$ km) and at larger diameters, the resulting final landform would not resemble a classic crater. We venture that terrestrial basins in the 1000-km size range might have resembled palimpsests, a suggestion made for very large basins on the Moon and Mercury by Croft [1]. Thus, even if preserved, very large and ancient impact structures, such as those suggested to explain meter-thick, areally large spherule beds in the Archean [14] may be unrecognizable in the context of a classic crater form and its impact deposits. At these sizes, terrestrial impact structures might have appeared as low-relief pools of impact melt rocks (10^7 km^3; Fig. 1) with little clastic debris and no obvious associated crater structure. Accompanying subsolidus shock effects would be buried beneath a massive melt sheet and would also tend to anneal out. It would seem, therefore, that such ancient, large structures might not be recognizable as impact features according to common criteria.

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VENUSIAN IMPACT BASINS AND CRATERED TERRAINS.

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The consensus regarding interpretation of Magellan radar imagery assigns Venus a young volcanic surface subjected in many areas to moderate crustal shortening [1–3]. I infer that, on the contrary, ancient densely cratered terrain and large impact basins may be preserved over more than half the planet and that crustal shortening has been much overestimated. I see wind erosion and deposition as far more effective than do others in modifying old structures. Integration with lunar chronology suggests that most of the surface of Venus may be older than 3.0 Ga and much may be older than 3.8 Ga.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

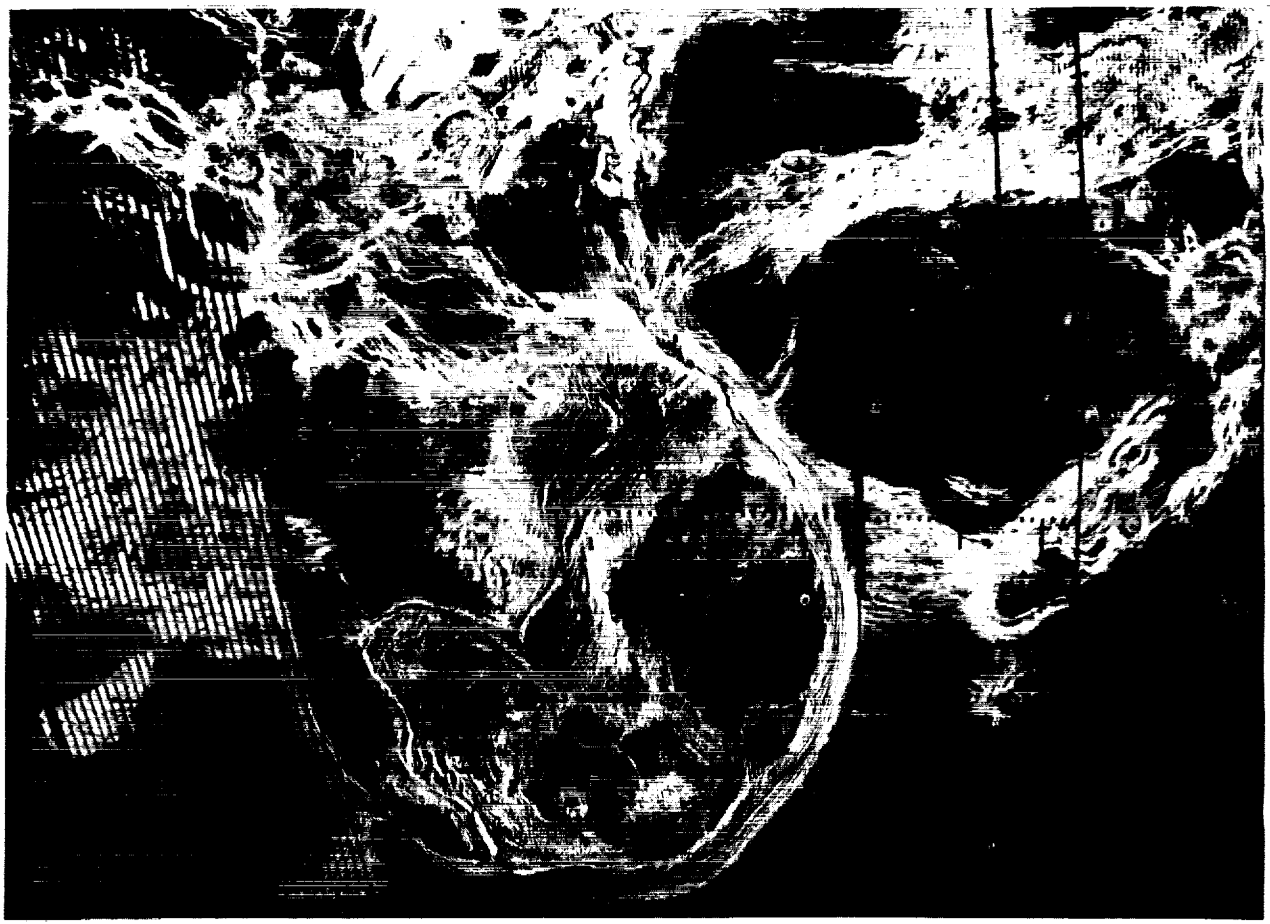

Fig. 1. The nearly circular Artemis structure, 2000 km in diameter and centered at 133°E, 35°S, may be the largest impact structure on Venus. The scoured-bedrock ring consists of an inner rim, steepest on the inside, and an outer basin inside a broad, dark outer rim. Other large and small subcircular structures may be the eroded and partly deformed roots of other impact structures. C2-MIDRP.30S129;1, by JPL.

Broad volcanos, huge volcanic domes, plains preserving lobate flow patterns, and numerous lesser volcanic features, pocked sparsely by impact craters, are indeed obvious on Magellan imagery [4]. Some of these postvolcanic impact craters have been slightly extended, but only a small proportion has been flooded by still younger lavas [5]. Relative ages of the young craters are indicated by the varying eolian removal of their forms and ejecta blankets and flow lobes, and the oldest are much subdued [6]. If these young impact craters, maximum diameter 275 km, include all preserved impact structures, then their quantity and distribution indicate that Venus was largely resurfaced by volcanism ~0.5 Ga, subsequent eruptions having been at a much reduced rate [5].

Away from the ~0.5-Ga volcanic features, much of Venus is, however, dominated by circular and subcircular features, 50–2000 km in diameter, many of them multiring, that may be mostly older impact and impact-melt structures substantially modified by wind action. Eolian erosion scoured to bedrock old ridges and uplands, including those that may be cratered terrains and the rims and outer-ring depressions of large impact basins, and removed all surficial deposits to the limits of resolution of the imagery. The complementary eolian deposits form not only dunes, wind streaks, and small plains [6,7] but also broad radar-dark plains, commonly assumed to be volcanic although lacking flow morphology, whose materials appear to be thick because they are smoothly compacted into buried craters. Plains and erosional features are displayed on Magellan stereo-image pairs. For example, a blowout, longitude 073° to 076°E, latitude 2°N to 2°S, stripped deep into the bedrock of large superimposed craters, is surrounded by a vast swirl of connecting erosional canyons, wind streaks, and linear dunes atop an eolian plain.

Numerous possible large magma-flooded impact basins are also preserved. These include many coronae and have nearly circular rims, 300–2000 km in diameter, steeper on the inside than the outside. Many are multiring, the inner rims encircled by peripheral basins (some chasmata), outer broad, subdued rims, and concentric and radial fracture systems [8–10]. The interior volcanic plains are commonly higher than plains beyond the rings but lower than the inner rims. Some large circular basins are superimposed on older ones. Scaling considerations require that impacts on Venus produce larger craters and much more melt than on the Moon [11], and venusian basins, like some lunar maria, may be found to have positive gravity anomalies because they are underlain by thick lopoliths fractionated from impact-melt lakes. The large basins have mostly been regarded as formed by magma welling upward and outward atop giant plumes but they lack the lobate or irregular forms to be expected of such origins and their abrupt circular or subcircular rims have yet to be explained in terms of plumes.

The inferred heavily cratered terrains consist of arrays of separate or overlapping circular to subcircular rims and multiring complexes 50–1000 km in diameter. Many rims form radar-bright stripped-bedrock ridges enclosing radar-dark eolian(?) plains. Other tracts are now eroded to almost continuous bedrock distinguished by numerous much-subdued, large, subcircular rims and basins. The prevailing interpretation of these diverse ring complexes as produced by crustal shortening and magma upwelling cannot account for their superimposed circular patterns.

Misunderstanding of visual illusions in radar imagery detracts from some interpretations. The scale of imagery in the sidelook direction is not horizontal distance but rather is proportional to slant distance. Slopes facing the spacecraft are foreshortened because their tops and bottoms plot close together, whereas slopes facing away are lengthened, an effect opposite to that of optical imagery. Symmetrical ridges appear to be hogbacks dipping gently in the direction of radar look, and such illusions have been misinterpreted to be thrust-imbricated sheets [2,12]; straight ridges of varying heights can mimic contorted and faulted structures.

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WHERE'S THE BEAVERHEAD BEEF?

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Only rare quartz grains with single-set planar $(10\bar{1}3)$ deformation features (PDFs) are present in breccia dikes found in association with uniformly oriented shatter cones that occur over an area 8 × 25 km (see Fiske et al., this volume). This suggests that the

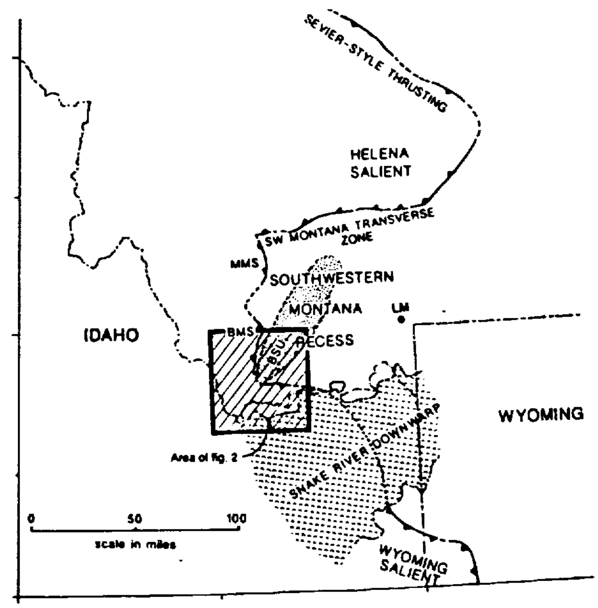

Fig. 2. Southwestern Montana Recess in Sevier Front (from [4]).

Beaverhead shocked rocks come from only the outer part of the central uplift of what must have been a large (>100 km diameter) complex impact structure. These rocks are allochthonous. They are present in the Cabin thrust plate (one of many in the Cordilleran belt), and are considered to have been tectonically transported 50 to 150 km east-northeast from a source in east central Idaho during the Laramide orogeny [1,2].

An impact event of this magnitude on continental crust (thought to have occurred in late Precambrian or early Paleozoic time) could be expected to punctuate local geologic history. Furthermore, although it may now be covered, its scar should remain despite all the considerable subsequent erosion/deposition and tectonism since the impact. The following are three large-scale singularities or anomalies that may reflect the event and mark its source.

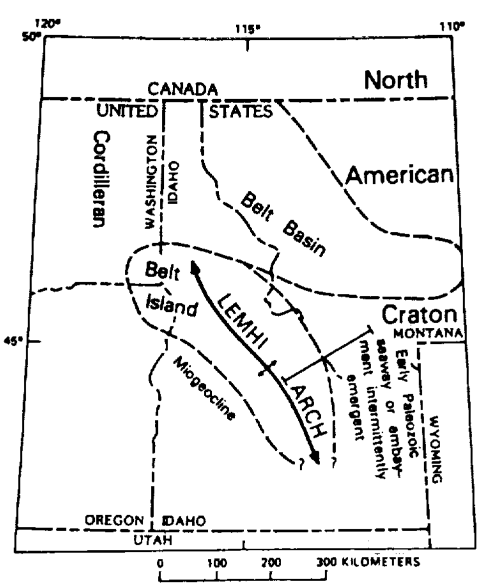

Fig. 1. Location of Lemhi Arch (from [3]).

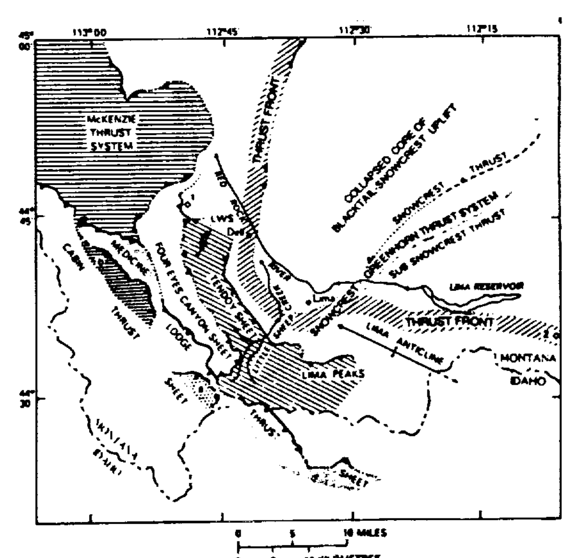

Fig. 3. Detail of apex of Southwestern Montana Recess (from [4]).