NUMERICAL SIMULATIONS OF SILVERPIT CRATER COLLAPSE.

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Introduction: The Silverpit crater is a recently discovered, 60-65 Myr old complex crater, which lies buried beneath the North Sea, about 150 km east of Britain [3]. High-resolution images of Silverpit's subsurface structure, provided by three-dimensional seismic reflection data, reveal an inner-crater morphology similar to that expected for a 5-8 km diameter terrestrial crater. The crater walls show evidence of terrace-style slumping and there is a distinct central uplift, which may have produced a central peak in the pristine crater morphology. However, Silverpit is not a typical 5-km diameter terrestrial crater, because it exhibits multiple, concentric rings outside the main cavity. External concentric rings are normally associated with much larger impact structures, for example Chicxulub on Earth, or Orientale on the Moon. Furthermore, external rings associated with large impacts on the terrestrial planets and moons are widely-spaced, predominantly inwardly-facing, asymmetric scarps. However, the seismic data show that the external rings at Silverpit represent closely-spaced, concentric fault-bound graben, with both inwardly and outwardly facing fault-scarps [3]. This type of multi-ring structure is directly analogous to the Valhalla-type multi-ring basins found on the icy satellites. Thus, the presence and style of the multiple rings at Silverpit is surprising given both the size of the crater and its planetary setting.

The mechanics of Valhalla-type multi-ring basin formation: Theoretical and numerical modeling of multi-ring craters [2,4] suggests that external ring formation is a consequence of the basal drag exerted on a brittle, elastic surface layer by a more mobile substrate as it flows inwards to compensate for the absence of mass in the excavated crater. This model has been further constrained for Valhalla-type multi-ring basins. The formation of closely-spaced, concentric fault-bound graben, appears to require that the elastic upper layer be thin and that the mobile substrate be confined to a relatively thin layer [5,6,7]. This rheologic situation is easily explained in the context of the icy satellites; however, the presence of a thin highly mobile layer just below the surface is not a common occurrence on rocky bodies in the Solar System. In the case of the apparently unique Silverpit structure, it has been suggested that the mobile subsurface layer was caused by the presence of overpressured chalk layers at depth that acted as detachments and expedited inward flow of a thin subsurface layer [3].

Numerical Simulations: We have begun to test the proposed model for the formation of the Silverpit crater using two contrasting yet complementary numerical tools: SALES 2 and Tekton. SALES 2 is a hydrocode capable of modeling the dynamic collapse of large impact craters. It has been successfully applied to the problem of central peak and peak-ring formation [1]. Tekton is a finite-element code designed to be applied to a wide range of tectonic problems, where displacements are relatively small and the dynamics are less important. It has been used extensively to simulate the relaxation of large craters and the formation of exterior rings in multi-ring basins [2].

Using both modeling techniques, we simulate the gravity-driven collapse of a bowl-shaped transient crater, 1-km deep and ~3-km in diameter. We model the target to a radial distance of >10 km and a vertical depth of 10 km to avoid boundary effects. Our models consist of three, originally-horizontal layers, deformed using the Z-model approximation of the excavation flow. The top two layers are assigned appropriate rheologic parameters to represent the brittle upper layer and the lower mobile layer at Silverpit. The bottom layer occupies the remainder of the mesh. We simulate the inner-crater collapse using the acoustic fluidization model for complex crater collapse, where a fluidized region surrounding the transient crater facilitates slumping of the crater wall and uplift of the crater floor [for example 1,2]. We define a low viscosity (~10^5—10^7 Pa secs) for the acoustically fluidized region and the mobile layer (Figure 1).

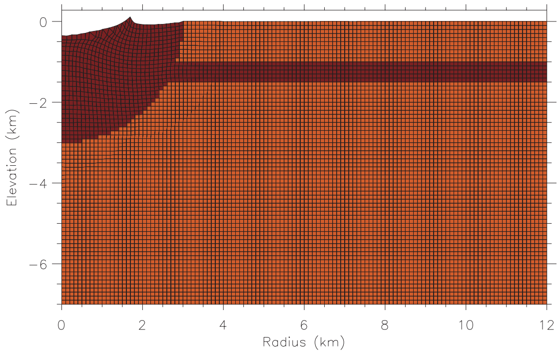

Figure 1: Cross-section of an axisymmetric finite-element model of a partially collapsed 3 km diameter transient crater in a 1-km thick layer of limestone (rheologic parameters for dolomite) over a 500 m thick weak layer represented by a Newtonian material with a viscosity of 10^7 Pa s. Dark red shading indicates the mobile layer and acoustically fluidized material.

Results: Figure 2 shows the stresses in the upper, brittle layer in an example simulation, after 2 seconds of the collapse. The brittle layer can be seen to be in compression at its base, immediately above the inwardly flowing mobile layer, and in extension nearer the surface. Thus, results from our preliminary simulations suggest that the brittle upper layer must be ~1-km thick in order to produce normal faulting to a depth of 500 m. This suggests that, contrary to the initial idea of the weak, mobile layer being over-pressured chalk, ~0.5-1 km below the pre-impact target surface, the mobile layer was probably part of the Jurassic shale unit beneath the Tertiary chalk. We will present the results of our models and the implications for both Silverpit and the two modeling methods.

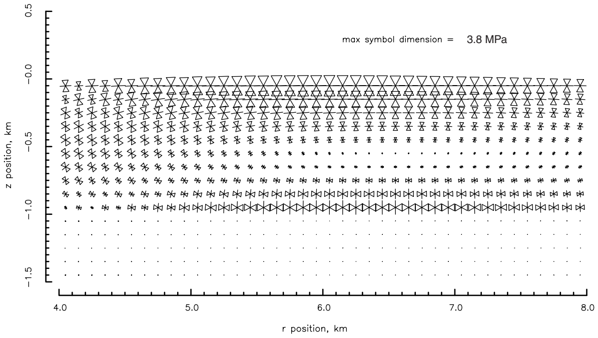

Figure 2: Close-up of the same simulation as shown in Fig. 1, at the same time, illustrating the principal stresses in the brittle upper layer. Pairs of triangles represent compression and lines represent extension. The size of the symbol scales with the magnitude of the stress, the largest symbol here is 3.8 MPa.

Comparison between SALES 2 and Tekton: SALES 2 and Tekton are two numerical tools that have been used to simulate complex crater collapse [1,2]. Here we apply both techniques to the collapse of the Silverpit crater, to compare and contrast their capabilities. We find consistency between their predictions of stress and likely style of faulting. SALES 2 has the advantage of being able to simulate the collapse of the central crater region; where as Tekton has the advantage of being able to simulate displacements along predefined fault-scarps.

Conclusions: Silverpit is a fascinating and unique terrestrial impact structure. The proposed model for the formation of the external rings at Silverpit is supported by our modeling results. Results from our preliminary simulations suggest that the brittle upper layer must be ~1-km thick in order to reproduce observed fault patterns and the central uplift.

SALES 2 and Tekton offer a powerful means of verification while providing complementary information regarding the details of complex crater collapse.

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