**iSALE NUMERICAL MODELING OF THE MANIITSOQ STRUCTURE, WEST GREENLAND: A CRUSTAL-SCALE COLUMN OF MECHANICAL MIXING REACHING THE MOHO.** Alex Trowbridge[1*], Adam A. Garde[2], H. Jay Melosh[1], and Christopher Andronicos[1]. [1]Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, Indiana, USA, 47907, *atrowbr@purdue.edu, [2]Geological Survey of Denmark and Greenland, aag@geus.dk.

**Introduction:** It has been recently proposed that the giant (100 x 100 km) Maniitsoq structure in West Greenland (see Fig. 1) had an impact origin [1–4]. Hydrothermally altered zircon grains place the potential impact at 3.0 Ga [2]. If this structure were the result of an Archean impact, it would be the largest and oldest confirmed impact basin on Earth.

Key observations behind the proposal of a deeply exhumed impact structure at Maniitsoq include the identification of a 35 x 50 km central domain, of mechanically mixed crustal rocks (the Finnefjeld domain, [2]), a surrounding 'melt zone' with direct melting of K-feldspar and biotite [3, 4], widespread micro-cataclastic, pseudotachylyte-like zones [1], intense and widespread hydrothermal alteration, and a curvilinear belt of noritic intrusions apparently sourced from mixed crustal and depleted mantle material [5]. A large central zone of thorough mixing and cataclasis had not previously been described from terrestrial impact structures, and some researchers have been reluctant to accept that the above-mentioned features were created by a giant impact.

The numerical modeling presented here was designed to investigate the development of the potential Maniitsoq impact structure, with emphasis on the distribution of impact-induced strain, material movement, and temperature rise deep below the crater floor. The results of the modeling are compared to field observations [1-4] to evaluate the validity of the impact origin hypothesis.

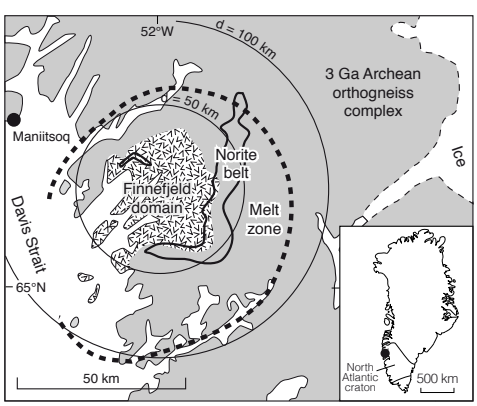


**Fig. 1**. Simplified map of the Maniitsoq structure with location in Greenland.

**Modeling parameters:** In this study, we use the shock physics code iSALE-Dellen 2D [6-8] to model an impact event that would generate a basin the size of the Maniitsoq structure. The impact was simulated using a 30 km in diameter dunite projectile impacting vertically with a velocity of 17 km/s. We used the dunite ANEOS equation of state to model the impactor.

The Earth was modeled as a rectangular target with a 40 km thick crust. We used the granite ANEOS equation of state to model the Archean continental crust, while the mantle was modeled using the dunite ANEOS equation of state. We used an Archean geotherm of 30 K/km based on P-T conditions for Archean granulite metamorphism in the Godthab-Fiskenaesset region [9].

Granite and dunite's inherent strength and their strength's dependence on temperature, pressure, and damage were modeled based on [8,10]. We incorporated dilatancy within our modeling using values in [11]. Additional frictional weakening, i.e. acoustic fluidization, was incorporated into our model using the "block-model" [12]. Porosity was ignored within our simulation.

**Results:** Our impact simulation generated a basin approximately 280 km in diameter (see Fig. 2). As the basin was excavated, the crust folded back upon itself, thickening the crust 60-120 km from the basin center. As the transient crater collapsed, crustal material flowed inward, covering the exposed mantle plug and leaving a substantially thinned crust (~25 km thick) within a 100 km diameter of the basin center.

Tracer particles (see Fig. 2a) show extensive mixing of crustal and mantle material within a diameter of 50 km from the basin center. The central mantle plug was shocked to peak pressures of 90 GPa (see Fig. 2b) and temperatures up to 2000 K (see Fig. 2c). The incorporation of acoustic fluidization and dilatancy had negligible effect on the final basin structure.

**Discussion:** P-T conditions for Archean granulite metamorphism place the exposed Maniitsoq structure at depths of 20–25 km during formation [9]. Therefore, the crustal material within our modeling down to this depth should be ignored, as it would have been eroded by processes that post-date the impact. With this in mind, the portions of our simulation that would form

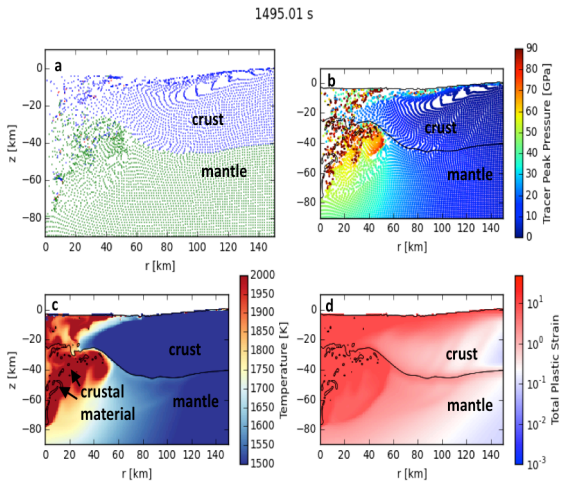


**Fig. 2.** iSALE results 1495 seconds after impact. (a) Tracer particle result. Blue tracers are crust. Green tracers are mantle. Red tracers are remnant projectile. (b) Peak pressure in GPa. Black line marks the moho. (c) Temperature plot in K. Irregular shaped objects within the high temperature zone of the mantle are crustal material. (d) Total plastic strain result.

the present-day surface geology consist of a 50 km diameter zone of mixed mantle and crustal rocks. Xenoliths in younger kimberlite dikes show that the Archean mantle in this part of the Archean craton is highly depleted, even for Archean cratons, and likely composed largely of dunite [13]. The simulated melting in the upper mantle, aided by the mechanical addition of crustal material, could possibly produce the observed noritic intrusions [1, 5], and would likewise explain the anomalous, boninitic composition that has been documented within the Maniitsoq structure in the otherwise tholeiitic to mildly alkaline Paleoproterozoic rift-related mafic dyke swarm of SW Greenland [14]

The surrounding annulus, ~10 km in width, consists of crustal material that experienced temperatures of ~1750 K and peak pressures of 75-85 GPa. The modelled temperature is at least 100 degrees higher than required for direct melting of K-feldspar and biotite, but not high enough to melt quartz [4]; this matches the observed melt zone around the Finnefjeld domain [4].

The extensive plastic strain seen within our numerical simulations occurs within the mixed mantle-crustal plug and within a 100 km diameter of the basin center. This highly strained zone matches with the observed 100 km diameter, widespread micro-cataclastic, pseudotachylyte-like zones [1].

Recent drilling of the Chicxulub structure unexpectedly intersected intensely microfractured crystalline rocks of mid-crustal origin only 750 m below surface [15], corroborating our iSALE modelling of intense, crustal-scale mechanical mixing in the core of large impact structures as well as the older field observations at Maniitsoq [3].

**Conclusions:** The new iSALE simulation reproduces many of the major crustal-scale features originally described in the Maniitsoq structure. These include a central column of mechanically mixed rocks, a surrounding zone containing shock-melted rock-forming minerals, and melting of refractory upper mantle mixed with crustal material (the Norite belt). Similar effects of giant impacts are likely to have resurfaced the earliest crust of the Earth and may have effectively limited preservation of crustal structures and lithologies older than the LHB [16].

Future work will explore effects of varying impact velocity as well as crustal thickness. Additionally, we will build Finite Element Models (using the Abaqus code) to simulate conductive cooling of the high temperature central crustal column and mixed mantle-crustal plug. This will allow us to determine the time scale of the high temperature thermal anomaly following the initial impact. This is a crucial test of the impact hypothesis for Maniitsoq structure.

Determining an impact origin for Maniitsoq could result in the development of new tools for identifying impact generated structures within deep-seated crustal material.

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