Modeling Simple Craters Using Gravity Mesurements

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Abstract: A study was carried out for two early Paleozoic impact structures in Sweden. These two impact structures (Granby and Tvären) are located in the southern part of Sweden. Common features can be identified of these two structures as similar diameter of ca 2 km and a substantial post impact fill with Paleozoic sedimentary rocks. The Granby structure represents an almost completely preserved impact crater within a Paleozoic sedimentary rock sequence — only the uppermost part of the raised crater rim might be eroded and was subsequently covered by Quaternary sediments. The Tvären structure is eroded below the surrounding pre-impact Paleozoic cover rocks into the underlying crystalline basement and has a Quaternary sediment fill. Gravity measurements were carried out on land and sea ice. The inverse gravity modeling shows a gradual change of density and the equivalent porosity with radial distance from the explosion center within the damage zone around and below simple craters.

1. Introduction

The study of impact structures are important in the field of geothermal energy as impact structures may represent a potential source for geothermal energy, provided sufficient water flow can be established at depth, where temperatures are higher (Henkel et al., 2005). The impact induced damage zone results from the passage of the shock- and rarefraction waves extending radially outwards from the explosion centre. In an isotropic medium it will form a half-spherical space with outward reduced accumulated strain, as seen in numerical models (Collins et al., 2004) The damaged rock volume is brecciated and the reative displacement of clasts leaves the rock with an increased porosity, some of which remains for geological time. This remainig porosity reduces the density of the target rocks and the damaged rock volume can cause a negative gravity anomaly. This effect was studied for two early Paleozoic simple craters, Tvären and Granby, in southern Sweden. The Granby crater is totally concealed under Quaternary cover while the Tvären crater is totally submersed in a deep bay of the Baltic Sea. The Granby structure provides an example of a simple crater and is almost completely preserved

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The Tvären structure is significantly eroded as the Paleozoic cover rocks are completely removed from its surroundings as evident from the geological map provided by the Geological Survey of Sweden (Lundström, 1976).

2. Data and constraints

Gravity measurements were made on sea ice (Tvären) and on frozen ground (Granby) and displayed a negative gravity anomaly of -45 and -20 μms^{-2}, respectively. In both structures drill holes were sunk (Wickman et al.,1980, Ormö & Blomqvist 1996) and for Tvären, marine seismic measurements and their interpretation were available (Flodén,1986).

Figure 1 Gravity anomaly of the Granby structure. © Geological Survey of Sweden.

Density data were estimated for crystalline target rocks and extracted from the national database for sedimentary cover rocks.

The gravity anomaly *G* of a structure depends on the density contrast *C*, a function *f(V)* of the volume of anomalous rock, and the distance *d* to the structure:

$$G = d^{-2}\, C\, f(V). \tag{1}$$

In the case of eroded structures, the distance to upper surface is known. An important constraint is the assumption of a hemispherical damage zone (the isotropic case), and knowledge of the crater shape from simple scaling rules for simple craters (Melosh, 1989)

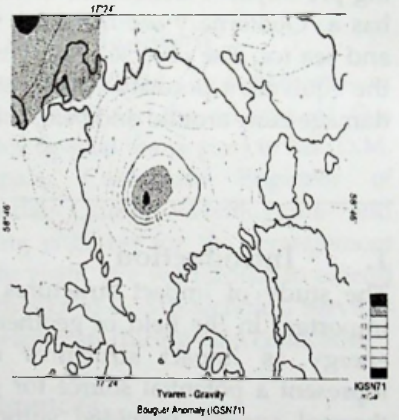

Figure 2. Gravity anomlay of the Tvären structure. © Geological Survey of Sweden.

The erosion level for the two structures is quite different. At Granby, almost the entire crater is preserved within Paleozoic cover rocks and just the top of the ejecta ring is eroded. (Wickman et al., 1989). At Tvären, the erosion level has cut ca 300 m into the crater and the Paleozoic cover sequence is totally eroded.

(Lundström, 1976). The remaining unknowns for the subsequent modeling are thus the ***radial distances*** to shells representing the damage zone and their, outward decreasing ***density***.

3. Modeling

The gravity data were extracted along a profile SW-NE parallell to the regional field (Granby) and perpendicular to the trend of geological structures (Tvären). An interactive 2½-d modeling sofware was used to calculate the gravity effect of the different sub-structures. Three shells for the sub-crater damage zone were included with porosities ranging from 14.5 over 5.5 to 2.5 %. The highest values correspond to those reported for Siljan (Juhlin,1991) and Puchez Katunki (Masaitis, & Pevzner, 1999). Outside the damage zone, a normal crystalline porosity of 0.5 % was assumed. The crater proper with its diameter, shape and fill material is considered as known and is based on the drilling results. The obtained models were tested for robustnes by changing the shell densities with 10 %.

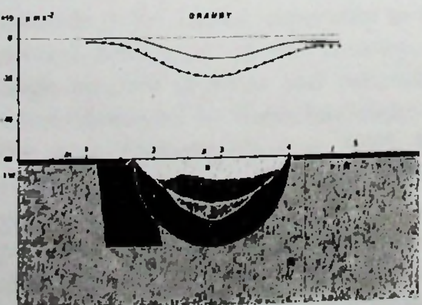

Figure 3. Gravity model of the Granby structure. From Henkel et al. (2010). The upper curve represents the crater fill. The thin layer to the side of the impact structure represents the Paleozoic cover rocks.

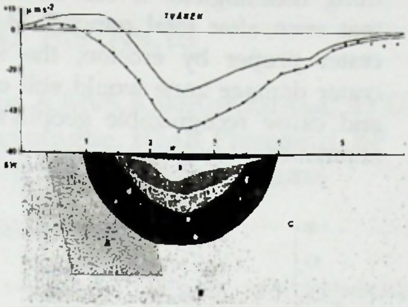

Figure 4. Gravity model of the Tvären structure. From Henkel et al., (2010). The upper curve represents the crater fill.

Out of the gravity models the following relation between remaining porosity P and the radial distance R, normalised with the transient crater radius, was derived:

$$P = 0.05\, R^{-4.1} \qquad (2)$$

The data for Puchez Katunki follow a smilar relation as seen in Figure 5. A simple relation beteween remaining porosity P and the accumulated strain S could aslo be derived: $S \sim 1.2\ 10^2\ P^{\ 2}$.

4. Conclusions

As the model for the radial density - porosity structure of the sub-cater damage zone was derived from two simple impact structures with different erosion depth and diameter, and this relation also fits the density - porosity structure of a larger complex crater (with compensation for its structural uplift), it is considered generally applicable. The modeling strategy included a separate treatment of the crater proper and its sub-crater structure which is essential, as a single model structure would mix up the involved features to something meaningless. It can be noted that even after total removal of the crater proper by erosion, the sub-crater damage zone would still exist and cause recognizable geophysical anomalies.

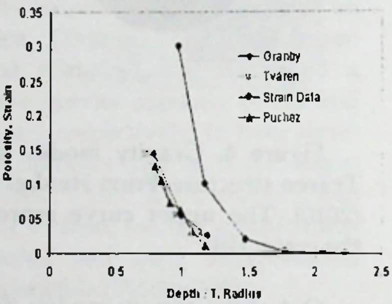

Figure 5. The relation of porosity - radial distrance in the sub-crater damage zone. From Henkel et al., (2010).

Table 1. Applied densities. Units are in Mgm-3

Impact structure	*Granby*		*Tvären*	
Geology	body nr., density		body nr., density	
Quaternary water			w	2.670
peat	p	1.100		
sediments			s	2.200
Paleozoic impact fill	o	2.630		
basal breccia	n	2.540	n	2.580
Proterozoic, highly frac.	d	2.410	h	2.385
			g	2.411
moderately frac.	c	2.559	d	2.559
			e	2.530
			f	2.493
weakly fractured	b	2.609	c	2.541
	a	2.619	b	2.580
			a	2.608
Paleozoic target rocks	i	2.670		
	k	2.450		
	m	2.610		
Proterozoic target rocks	B	2.650	C	2.580
	A	2.660	B	2.620
			A	2.648

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