Explosion craters and penetration funnels in the Campo del Cielo, Argentina crater field

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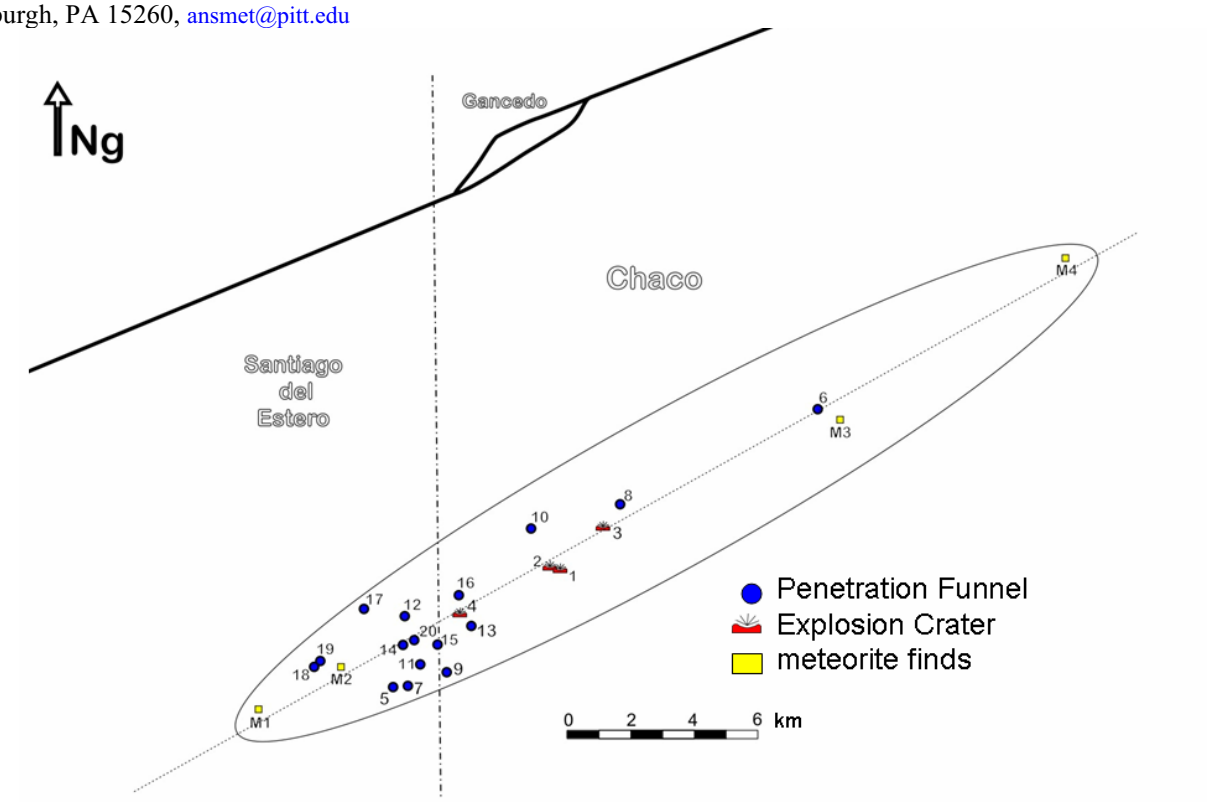

Figure 1. Schematic diagram of the Campo del Cielo crater and meteorite field. Meteorite finds represent large (>700 kg) surficial finds for which the locations are known.

Introduction The Campo del Cielo, Argentina crater field (CdCcf) consists of at least 20 depressions and countless meteorite fragments localized in an ellipse (Figure 1) in the Chaco and Santiago del Estero Provinces of northern Argentina [1]. C^{14} age dating puts the impact event at ~4 ka [1]. Because they resulted from the same fall, we expect the major parameters of each impact crater, such as the velocity, impact angle, azimuth, and composition of the projectile, to be similar. The loess target is also uniform over a wide area, leaving the mass of the impactor as the only significant variable between each crater [1-3]. For each elongated penetration funnel, we can recover and weigh the projectile as well as estimate the azimuth and angle of impact. Thus, the CdCcf is an excellent laboratory in which to reach general conclusions about natural craters in the range of impact parameters represented here. The field occurrence is also interesting because it represents a mixture of both penetration funnels and explosion craters. Fortuitously, these impact sites can help to bridge gaps that may exist in comparisons between impact experiments and much larger natural impacts which are an order of magnitude smaller and larger, respectively [3,4].

From recent field work, we can report magnetic surveys over 2 explosion craters as well as 2 penetration funnels. A portion of these data is presented here.

Explosion Craters Craters 1 through 4 (Figure 1) are apparent explosion craters based on their physical characteristics such as raised rims and distribution of meteorite fragments around them. Also, when investigated by Nágera in 1926 [5], they appeared to be much deeper, which is in agreement with an interpretation as explosion craters. These four craters differ from the other ~16 in that they: (1) are deeper and/or have greater original depth/diameter ratios, (2) are more circular as opposed to the elongate nature of the other 16, (3) do not have large magnetic anomalies caused by the still-preserved impactor, and (4) have meteorite fragments of the disrupted impactor that are angular and dispersed within and on top of the "ejecta" blanket (Figure 2).

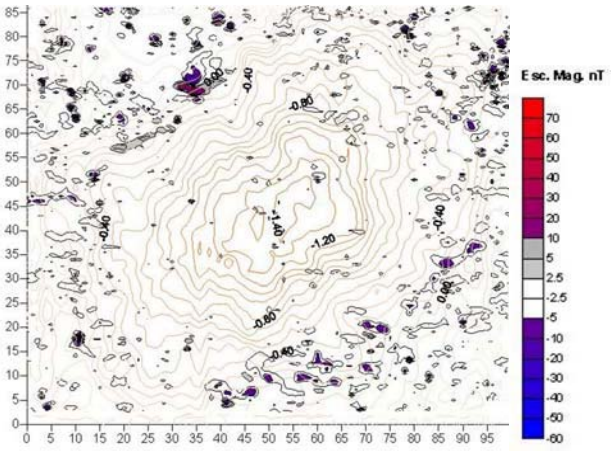

Figure 2. Topographic map and variable magnetic signals of Crater 3 ("Laguna Negra"). The greater density of magnetic signals are outside the central bowl and there is no large fragment under the NE rim. This and the large size of the crater (compare to Crater 17 in Figure 3) suggest that this is an explosion crater. Scale in meters.

Penetration Funnels Sixteen craters have been identified as penetration funnels by their elongate shapes and magnetic anomalies associated with them. There are also three new features that we identify as probable penetration funnels. All of these craters have a different morphology from the explosion craters, with distinct SW-NE elongations and smaller diameters, depths, and depth:diameter ratios. All 19 have large magnetic anomalies below the NE rim. In each of three of these (Table 1), a large mass of 1A iron octahedrite has been excavated at depths of meters beyond the NE edge of the crater. These 19 craters are believed to have been created by the impact of NiFe meteorites with low impact velocities and impact angles. During the 2006 field season, we constructed magnetic maps of explosion craters 1 and 3 and investigated a penetration funnel (Crater 17) in detail (Figures 2 and 3). We note that major magnetic anomalies are located at the NE ends of Craters 12 and 17, but not in Craters 1 and 3, which are explosion craters.

Table 1:

	Crater 10	Crater 13	Crater 17
Year excavated	1972	2005	2006
Penetration Length	30 m	>50 m ?	24 m
Penetration Depth	6 m	7.6 m	4.6 m
Mass of Projectile	36000 kg	14850 kg	7850 kg
Impact Angle	8°	8°	11°
Azimuth of infall	N75°E	N64°E	N56°E

Crater 17 Excavation Excavation at the site of Crater 17 produced a 7850 kg meteorite, as well as 1000 kg of smaller fragments (Figure 3). The depths of present-day soil, silt, and breccia layers were measured for constraints on the dimensions of the original crater, which we associate with the top of the breccia lens [4]. The energy of formation is calculated from these measurements [4].

Discussion It is probable that the angles of impact and impact velocities of all impactors were approximately equal. Our preliminary interpretation is that larger masses with greater associated kinetic energy produced an explosion crater in four cases. All four are located near the center azimuth of impact in the elliptical crater field with the majority of penetration funnels found uprange (Figure 1).

Future Work The methodology followed for Craters 13 [2] and 17 will be duplicated for more craters. Crater 12 will be excavated in 2007. Field data will be applied to hypervelocity impact experiments and theoretical modeling in efforts to duplicate the observed crater parameters. Aerial and satellite remote sensing is currently being used in conjunction with ground truth data in an effort to locate more craters in the CdCcf.

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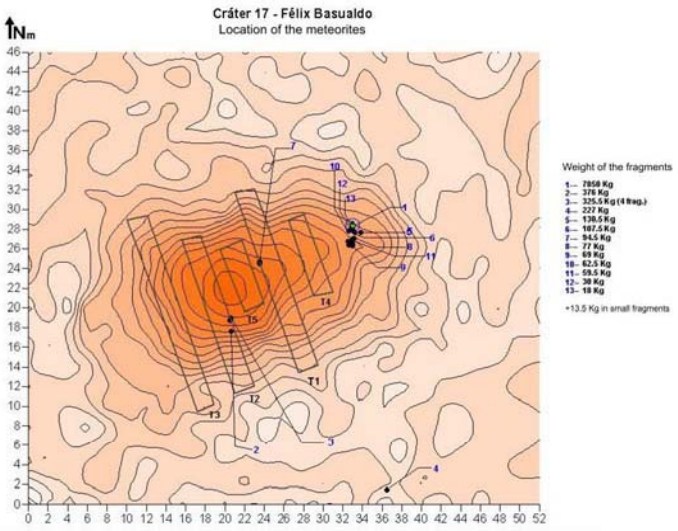

Figure 3. Topographic Map of Crater 17 as it exists today, with outlines of trenches dug to determine structure and locations of meteorites found by magnetic measurements [4] and later recovered. Presence of meteorites suggests this is a penetration funnel. Scale in meters.