Magnetic susceptibility, magnetization, magnetic moment and characterization of Carancas meteorite

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Resumen

El 15 de septiembre del 2007, en la comunidad de Carancas (Puno, Perú) un meteorito rocoso formó un cráter de tipo explosivo con un diámetro promedio de 13.5m varias muestras de fragmentos de meteorito fueron coleccionados. El análisis petrológico realizado indica que corresponde a un meteorito del tipo condrito ordinario H 4-5.

En el presente trabajo analizamos las propiedades magnéticas de un fragmento del meteorito con un magnetómetro de protones.

Con la finalidad de tener una completa caracterización del meteorito de Carancas y su cráter, a partir de diversas publicaciones, artículos y reportes, realizamos una compilación de las más importantes características y propiedades de este meteorito.

Palabras clave*: meteorito de Carancas, magnetización remanente, susceptibilidad magnética.*

Abstract

On September, 15th, 2007, in the community of Carancas (Puno, Peru) a stony meteorite formed a crater explosive type with a mean diameter of 13.5m some samples meteorite fragments were collected. The petrologic analysis performed corresponds to a meteorite ordinary chondrite H 4-5.

In this paper we have analyzed the magnetic properties of a meteorite fragment with a proton magnetometer.

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Also in order to have a complete characterization of the Carancas meteorite and its crater, from several papers, articles and reports, we have made a compilation of the most important characteristics and properties of this meteorite.

Key words: *Carancas meteorite, remanent magnetization, magnetic susceptibility.*

Introduction

On September, 15th, 2007, 11:40:14.4 Local Time, close to noon, (16:40:14.4 UT) , the impact of a stony meteorite took place in the community of Carancas, Desaguadero town, Chucuito city, Region of Puno, Peru, on the south, near to lake Titicaca on the border with Bolivia, forming a crater explosive type with a mean diameter of 13.5m. The geodesic coordinates of the center of the crater measured with GPS are: latitude 16° 39' 52.2'' South, longitude 69° 02' 38.8'' West, altitude 3,824m. Meteorite fragments were sent to laboratories for petrologic analysis; results correspond to a meteorite type Ordinary Chondrite and of group H 4-5 by their iron content.

In this paper we have analyzed the magnetic properties (remanent magnetization, remanent magnetic moment, magnetic susceptibility and induced magnetic moment) of a meteorite fragment with a Overhauser proton magnetometer POS-1.

On the other hand, spectrographic, chemical and others analyses were performed. Several papers, articles and reports were published in different journals, each work showing different characteristics and properties such as the fireball and its trajectory, the meteorite, the crater and the ejecta. In order to have a complete characterization, we have made a compilation of all these works of the most important characteristics of the Carancas meteorite and its crater.

Magnetic susceptibility, magnetization and magnetic moment measurements

Magnetic susceptibility and magnetization of rocks and the permanent and induced moment of objects such as a meteorite can be measured using a proton magnetometer. The procedure involves rotating a sample about a point close to the magnetometer sensor on a line which is in the direction of the earth's total field F and passes through the center of the sensor. Measurements of the maximum anomaly T_{max} and minimum anomaly T_{min} observed and the value of the field without the sample present T_0 is sufficient to allow calculation of magnetic susceptibility and induced and remanent magnetization. Next, measure the diame-

ter of the sample which should be spherical as possible, measure the average diameter D, of the specimen and the distance *r*, between the center of the specimen when rotated and the center of the sensor. These five parameters, T_0, $T_{\max}$, $T_{\min}$, *D*, and *r*, are all that is needed in the following formulae to calculate both magnetic susceptibility and magnetization or the induced and permanent magnetic moments of a small object (Breiner, 1973).

Mathematical formulations

For the remanent magnetization:
The remanent anomaly T_r is given by:

$$T_r = \frac{T_{\max} - T_{\min}}{2} = \frac{2M_r}{r^3} = \frac{2I_r \frac{4}{3}\pi\left(\frac{D}{2}\right)^3}{r^3} \qquad (1)$$

Therefore

$$I_r = \frac{3}{2\pi}\left(\frac{r}{D}\right)^3 \left(T_{\max} - T_{\min}\right) \qquad (2)$$

and

$$M_r = \frac{r^3}{4}\left(T_{\max} - T_{\min}\right) \qquad (3)$$

where I_r is the remanent magnetization per unit volume expressed in nT $\left(1 \cdot nT = 10^{-5} G\right)$[1] and M_r is the remanent magnetic moment expressed in "*electromagnetic unit (emu)*" $\left(1 \cdot emu = 1 \cdot G \cdot cm^3\right)$.
For the induced magnetization:
The induced anomaly T_i is given by:

$$T_i = \frac{T_{\max} + T_{\min}}{2} - T_0 = \frac{2M_i}{r^3} = \frac{2I_i \frac{4}{3}\pi\left(\frac{D}{2}\right)^3}{r^3} \qquad (4)$$

[1] *G*: Gauss.

and

$$I_i = kF = \frac{3}{2\pi}\left(\frac{r}{D}\right)^3 \left(T_{\max} + T_{\min} - 2T_0\right) \tag{5}$$

Hence

$$k = \frac{3}{2\pi F}\left(\frac{r}{D}\right)^3 \left(T_{\max} + T_{\min} - 2T_0\right) \tag{6}$$

and

$$M_i = \frac{r^3}{4}\left(T_{\max} + T_{\min} - 2T_0\right) \tag{7}$$

where I_i is the magnetic susceptibility per unit volume expressed in nT, and M_i is the induced magnetic moment expressed in emu. k is the magnetic susceptibility, is a dimensionless proportionally constant that indicates the degree of magnetization of a material in response to an applied magnetic field. The total magnetization per unit volume is $I_t = I_r + I_i$.

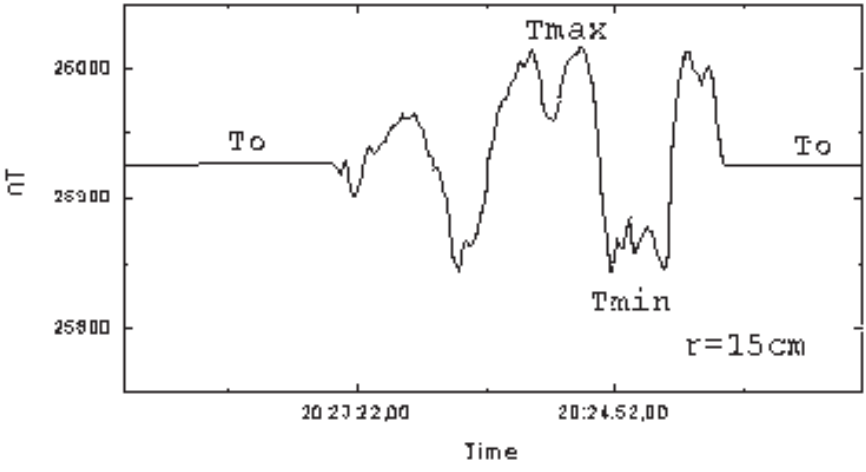

Figure 1. Readigns during rotation of meterorite fragment to 15cm away from the proton sensor.

The meteorite fragment analysed have 28.777gr, an average diameter D=2.460cm, with density 3.629gr/cm³. The readings obtained during rotation of specimen to 15cm away from the proton sensor are shown in Figure 1.

Eight sets of measurements were performed at 10, 15, 20, 25, 30 40, 50 and 75 cm away from the proton sensor, the set at 10cm was removed due to the signal of proton magnetometer was degraded.

The determination of magnetic properties of Carancas meterorite is given in the Table 1. For I_i and M_i has not been possible to determine with greater precision so these values are only referentially.

Table 1
Magnetic susceptibility and induced and remanent magnetization

r(cm)	T_r (nT)	T_i (nT)	I_r (G)	M_r (emu)	I_i (G)	M_i (emu)
15	93.132	9.094	0.2016	1.5720	0.0197	0.1530
20	39.710	6.393	0.2038	1.5890	0.0328	0.2560
25	20.245	0.514	0.2029	1.5820	0.0052	0.0400
30	11.569	0.863	0.2004	1.5620	0.0149	0.1170
40	4.871	0.658	0.2000	1.5590	0.0157	0.1220
50	2.671	0.658	0.2142	1.6690	0.0528	0.411
75	0.795	0.402	0.2151	1.6770	—	—
Mean			0.2054±0.0064	1.6014±0.0500	0.0235±0.0169	0.1832±0.1317

Characterization of Carancas meteorite and its crater

Some samples meteorite fragments were collected. Magnetic, spectrographic, chemical and others analysis were performed. Several papers and articles about Carancas meteorite were published, each work showing different characteristics and properties. The compilation of all these works with the most im portant characterizations of Carancas meteorite and its crater are:

The place impact:

Latitude	16° 39’ 52.2’’ South	
Longitude	69° 02’ 38.8’’ West	
Altitude	3,824m	(Rosales *et al.*, 2008)
Impact date	September 15th, 2007	
Impact time UT	16:40:14.4 universal time	(Tancredi *et al.*, 2009)
Impact time LT	11:40:14.4 local time	

Community	Carancas	(Rosales *et al.*, 2008)
City	Chucuito	
Region	Puno	
Country	Peru	

Meteoroid before entering the atmosphere:

Initial velocity	Between 12 - 17km/s	(Tancredi *et al.*, 2009)
Initial mass	Between 7 - 12ton	
Initial diameter	Between 1.6 - 2.0m	
Initial kinetic energy	From 0.12 - 0.41kT TNT	
Original orbit meteoroid	Compatible with NEAs*	

The meteoroid before the impact:

Diameter	Between 0.6 - 1.1m	(Tancredi *et al.*, 2009)
Mass	Between 0.3 - 3.0tons	

The meteoroid during the impact:

Impact velocity	Between ~3 - 6km/s	(Tancredi *et al.*, 2009)
Impact angle	Between 45° - 60°	
Trajectory azimuth	Between 80° - 110°	
Impact energy	Between ~1 - 3tons TNT	
Local seismic magnitude	ML = 1.45	(Le Pichon *et al.*, 2008)
Seismic energy generated by impact	Roughly 9.4×10^6 J Equivalent to 2.3kg TNT	(Tancredi *et al.*, 2009)
Seismic efficiency	10^{-3}	

The meteorite:

Type	Ordinary Chondrite H4-5	(Varela and Branztatter, 2007)
Density	$3.629 gr/cm^3$	(Rosales *et al.*, 2008)
Remanent magnetization per volume unit	$I_r = 0.2054$ Gauss	
Ablation coefficient	$0.014 s^2/km^2$	(Kenkmann *et al.*, 2008)

* NEAs: Near-Earth Asteroids.

The crater:

Diameter approximately	13.5m	(Rosales *et al.*, 2008)
Deep of crater	Between 2.4 - 5.0m	(Tancredi *et al.*, 2008)
Type crater	Explosive	(Pereira, 2007)
Shape of the crater	Nearly circular	
Diameter water pond in the crater	Between 7.4 - 7.8m	(Miura, 2008)

The ejecta:

Density of ejecta	1.700gr/cm^3	(Tancredi *et al.*, 2009)
Ejection max. distance and direction	348m SW	(Rosales *et al.*, 2008)

The meteorite mineralogical composition:

Pyroxene 1	40%	(Macedo *et al.*, 2007)
Olivine	20%	
Feldspar	10%	
Pyroxene 2	10%	
Kamacite	15%	
Troilite	5%	
Cromite	traces	
Native Cu	traces	

The meteorite chemical compound:

Compound	Ol (%)	Px (%)	
SiO2	38.30 - 39.7 0	55.4 0 - 56.5 0	(Varela and Brandztatter, 2007)
Al2O3	0.00	0.15 - 1.55	
TiO2	0.00 - 0.06	0.06 - 0.29	
Cr2O3	0.00 - 0.03	0.14 - 0.76	
MnO	0.42 - 0.48	0.47 - 0.48	
FeO	17.1 - 17.2	16.60	
CaO	0.00	0.54 - 1.08	
MgO	43.40 - 43.50	29.10 - 31.40	

The meteorite chemical elements:

Si	18%	
Mg	14%	
Fe	14%	
Al	1.7%	
S	1.6%	
Ca	1.5%	
Na	1.9%	(Nuñez del Prado *et al.*, 2008)
Cr	traces	
P	traces	
K	traces	
Cu	traces	
Re	traces	
Rh	traces	

The oxygen isotope analysis:

$б^{17}O$	Between 3.02 - 2.94 %	
$б^{18}O$	Between 4.52 - 4.32 %	(Nuñez del Prado *et al.*, 2008)
$Δ^{17}O$	Between 0.67 - 0.68 %	

The X-ray diffractometry analysis:

Pyroxene	paramagnetic	
Olivine	paramagnetic	
Troilite(FeS)	magnetic	(Cerrón and Bravo, 2008)
Kamacite (FeNi)	magnetic	

Conclusion

The Carancas meteorite is a ordinary chondrite H 4-5, which produced a crater on Earth's surface, an event like this should have not occurred, normally such meteoroids ablating on the Earth’s atmosphere.

Carancas crater was product of a hypervelocity impact. In spite of significant ablation, the meteoroid did not catastrophically disrupt and/or disperse during its atmospheric entry (Tancredi *et al.*, 2009).

Carancas meteorite has a remanent magnetization of $I_r = 0.2054$ Gauss and remanent magnetic moment $M_r = 1.6014$ emu. Induced magnetization could not be determined with greater precision so this value determinates ($I_i \approx 0.0235$ Gauss, and $M_i \approx 0.1832$ emu) are only referentially.

The characterization of the Carancas meteorite and its crater allows us to have all the necessary information about this event.

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