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Search for meteorites around Kamil crater and preliminary radiometric measurements

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Abstract. About 1600 kg of iron meteorite fragments were found in and around the Kamil impact crater by an Italian-Egyptian geophysical team in February 2009 and February 2010. Two samples of the Gebel Kamil meteorite (one shrapnel and a piece of the only one individual that has been found) were measured at Monte dei Cappuccini Laboratory (INAF) in Torino, using a selective gamma spectrometer and ^{26}Al cosmogenic activity was detected in both fragments.

Key words. Meteoroids - Cosmic rays - Sun: magnetic fields - Techniques:gamma spectroscopy

1. Introduction

The Kamil Crater (Figs. 1 and 2) was identified by V. De Michele (former curator of the Natural History Museum in Milan, Italy) through a Google Earth search for prehistoric villages in the southwestern Egyptian desert. QuickBird satellite images revealed a decametric-sized crater in a rocky desert plain ca. 600 m a.s.l., with a number of ejecta rays highlighting the exceptional freshness of the structure. The thousands of iron meteorite specimens found scattered within the crater and in the surrounding area during a preliminary survey in February 2009 confirmed the meteoritic impact origin of the crater.

In order to deeply investigate this newly discovered crater, in February 2010 we carried out a joint Italian-Egyptian geophysical expedition, within the framework of the 2009 Egypt-Italy Science Year, under the auspices of the Academy of Scientific Research and Technology of Egypt (ASRT) and the Italian Embassy in Cairo. Data confirmed the already assessed meteoritic origin of the crater and documented its pristine conditions (Folco et al. 2010, 2011). Note that similar well-preserved craters with ejecta ray structures have been previously observed only on extraterrestrial rocky or icy planetary bodies. This unique crater feature and the association with an iron meteorite impactor, shock metamorphism and rock melt provides a unique impression of aspects of small-scale hypervelocity impacts on the Earth surface. Data also allowed us to tackle the delicate issue of impact hazard posed by small meteoroids on decadal to secular time scales (Brown et al. 2002; Bland & Artemieva 2006). In particular, we concluded that, contrary to current models, ground data indicate

Fig. 1. The Kamil crater.

that iron meteorites with masses of tens of tons may be able to penetrate the atmosphere without substantial fragmentation. During the geophysical expedition, we observed that a prehistoric trail ~ 100 m due north of the crater was overlain by rock sandstones ejected from the crater and meteorites. Literature data suggests that the human occupation of this region ended in the middle Holocene, about 5000 years ago, with the onset of hyperarid conditions (Kuper & Kröpelin 2006). We thus infer that the impact occurred not later than 5000 years ago (Folco et al. 2010).

2. The Gebel Kamil meteorite

A total of about 1,600 kg of iron meteorite shrapnels (thousands of pieces), ranging in mass from < 1 to 34,000 g, plus a single 83 kg individual (see Fig. 3), completely covered with well developed regmaglypts, was found in and around the Kamil impact crater by the Italian-Egyptian geophysical team. The iron meteorite was classified by M. D'Orazio and L. Folco as an iron meteorite (ungrouped), Ni-rich ataxite, showing extensive shear deformation and low weathering, and named "Gebel Kamil" (Weisberg et al. 2010). More than 800 kg of the total mass observed in the field (the regmaglypted individual included) was recovered. The meteorites show a rough, dark-brown external surface.

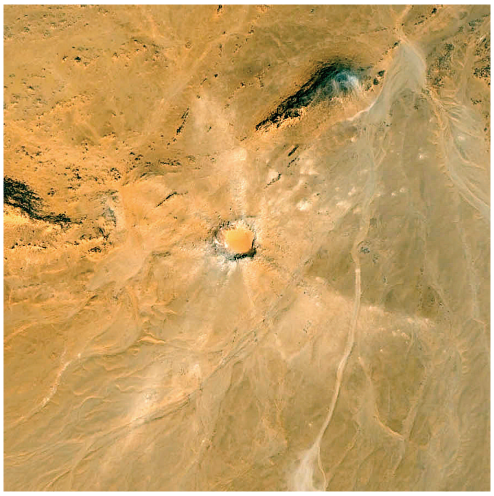

Fig. 2. The Kamil crater as seen by the Quick Bird EO satellite on 2005 October 22.

Fig. 3. The only *individual* meteorite found nearby the Kamil crater. It weighs 83 kg and is completely covered by remaglypts.

The surface originally sitting in the desert soil shows some oxy-hydroxides due to terrestrial weathering. Etched sections show an ataxitic structure interrupted on a centimetric scale by crystals of schreibersite, troilite and daubreelite enveloped in swathing kamacite. Kamacite spindles (20 ± 5 mm wide) nucleated on tiny schreibersite crystals. The spindles form small aligned clusters and are rimmed by taenite. The matrix is a duplex plessite made of approximately the same proportion of kamacite and taenite lamellae (1-5 mm in thickness) arranged in a micro-Widmanstätten pattern. Many sections show, particularly close to the external surface, shear dislocations offsetting the plessitic matrix and the crystals of the accessory phases by several millimeters. Composition of the metal is Ni = 19.8, Co = 0.75 (both in wt%), Cu = 464, Ga = 49, Ge = 121, As = 15.6, Mo = 9.1, Ru = 2.11, Rh = 0.75, Pd = 4.8, Sn = 2.49, Sb = 0.26, W = 0.66, Re = 0.04, Ir = 0.39, Pt = 3.5, Au = 1.57 (all in ppm). With the exception of a single 83 kg regmaglypted individual, all specimens of Gebel Kamil (the iron meteorite that formed the Kamil crater) are explosion fragments weighing from $<$ 1 g to 34 kg. Gebel Kamil is an ungrouped Ni-rich (about 20 wt% Ni) ataxite characterized by high Ge and Ga contents (approximately 120 μg g^{-1}and approximately 50 μg g^{-1}, respectively), low Ir content (0.55 μg g^{-1}), and by a very fine-grained duplex plessite metal matrix. Accessory mineral phases in Gebel Kamil are schreibersite, troilite, daubreelite, and native copper. Meteorite fragments are cross-cut by curvilinear shear bands formed during the explosive terrestrial impact.

Two fragments of this meteorite were measured at Monte dei Cappuccini Laboratory (INAF, Torino), using the selective gamma spectrometer described in the next paragraph. The first fragment that we measured, here named GK1, has a mass of 672 g and was found nearby the crater; the second fragment, here named GK2, has a mass of 450 g and is a sample taken from the 83 kg individual shown in Fig. 3, which was found about 200 m North of the crater.

3. Experimental system

The γ-ray spectrometer is a large volume high-efficiency HPGe-NaI(Tl) detector system located in the underground Laboratory of Monte dei Cappuccini (INAF, Torino, Italy) at 70 m of water equivalent depth. This system consists of a hyperpure Ge detector (3 kg, 147% relative efficiency), operating within an umbrella of NaI(Tl) scintillator (90 kg) and is housed in a thick Pb-Cd-Cu passive shield. Both detector signals are digitized by the multiparametric acquisition system allowing coincidence and anti-Compton spectroscopic analyses. Details of the apparatus can be found in Taricco et al. (2006) and Colombetti et al. (2008, 2013).

4. Results and discussion

Fig. 4 shows the γ-spectra of the two fragments GK1 (*upper panel*) and GK2 (*lower panel*) of Gebel Kamil meteorite in *normal* and *coincidence* modes in the 400–2000 keV spectral region. The main peaks of the detected radioisotopes are marked.

^{26}Al (half life 0.717 My) is mainly produced by cosmic ray interactions with Mg, Al and Si present in the meteorite. In Fig. 5, the ^{26}Al main peaks at 1,808.65 keV (in *normal* mode) are shown for fragment GK1 (*upper panel*) and GK2 (*lower panel*). The ^{26}Al peak

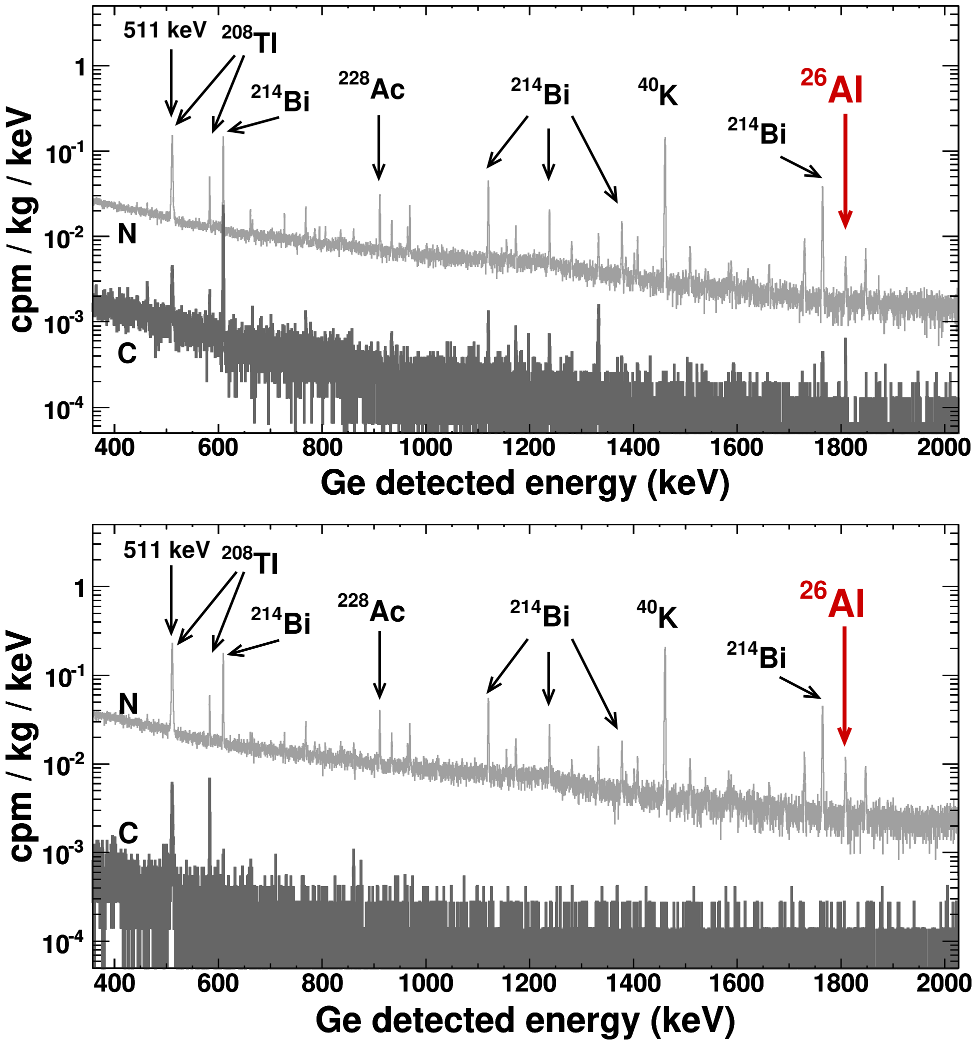

Fig. 4. Ge-NaI spectrum in normal mode (*light grey*) and in coincidence mode (*dark grey*) for the two Gebel Kamil fragments, GK1 (*upper panel*) and GK2 (*lower panel*). Cosmogenic ^{26}Al peak and a few peaks from the background of naturally occurring potassium, uranium and thorium are marked: ^{214}Bi come from ^{238}U, ^{208}Tl and ^{228}Ac from ^{232}Th.

count rates for the two fragments are respectively $C_1 = (0.0055 \pm 0.0003)$ cpm and $C_2 = (0.0095 \pm 0.0004)$ cpm. We notice that the two values are appreciably different, with a C_2/C_1 ratio of about 1.72; after the mass normalization, we obtain $C'_1 = (0.0082 \pm 0.0005)$ cpm/kg and $C'_2 = (0.0211 \pm 0.0010)$ cpm/kg and therefore the ratio further increases to 2.57. The most probable cause of this difference seems to be the different shielding depth of the two fragments in the parent meteoroid and not the different efficiency related to the shape of the fragments.

The ^{26}Al measurements we present here, together with the production ^{26}Al curves, are

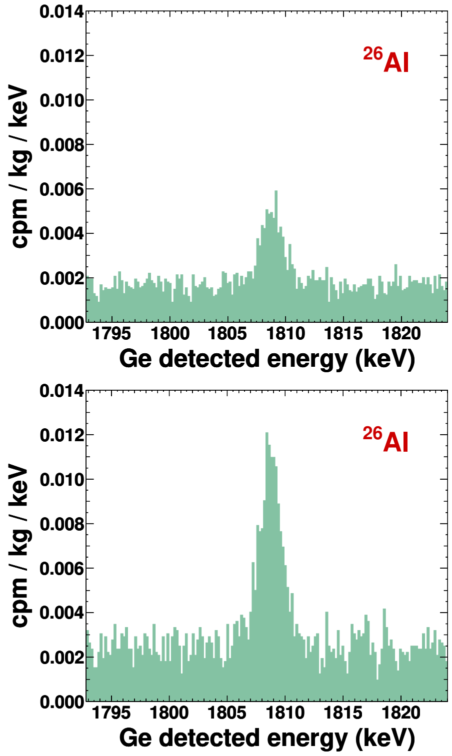

Fig. 5. Cosmogenic ^{26}Al peak at 1808.65 keV *normal* mode detected in GK1 (*upper panel*) and in GK2 (*lower panel*).

useful to estimate the pre-atmospheric radius of the parent meteoroid; moreover, the absence of the ^{44}Ti peak in the spectrum allows to deduce a constrain to the age of the crater (paper in preparation).

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