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Hailar crater – A possible impact structure in Inner Mongolia, China

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ABSTRACT

Hailar crater, a probable impact structure, is a circular depression about 300 m diameter in Inner Mongolia, northeast China. With broad elevated rims, the present rim-to-floor depth is 8–20 m. Regional geological background and geomorphological comparison suggest that this feature is likely not formed by surface processes such as salt diapir, karst, aeolian, glacial, or volcanic activity. Its unique occurrence in this region and well-preserved morphology are most consistent with it being a Cenozoic impact crater. Two field expeditions in 2016 and 2017 investigated the origin of this structure, recognizing that (1) no additional craters were identified around Hailar crater in the centimeter-scale digital topography models that were constructed using a drone imaging system and stereo photogrammetry; (2) no bedrock exposures are visible within or adjacent to the crater because of thick regolith coverage, and only small pieces of angular unconsolidated rocks are present on the crater wall and the gently-sloped crater rim, suggesting recent energetic formation of the crater; (3) most samples collected from the crater have identical lithology and petrographic characteristics with the background terrain, but some crater samples contain more abundant clasts and silicate hydrothermal veins, indicating that rocks from depths have been exposed by the crater; (4) no shock metamorphic features were found in the samples after thin section examinations; and (5) a systematic sample survey and iron detector scan within and outside of the crater found no iron-rich meteorites larger than ~2 cm in size in a depth of ~30 cm. Although no conclusive evidence for an impact origin is found yet, Hailar crater was most likely formed by an impact based on its unique occurrence and comparative geomorphologic study. We suggest that drilling in the crater center is required to verify the impact origin, where hypothesized melt-bearing impactites may be encountered.

1. Introduction

Impact craters are common landscapes on planetary bodies that have solid surfaces, such as Earth's moon, Mercury, and Mars. Inner solar system bodies, including Earth, have the same cratering history (e.g., Strom et al., 2015); but active surface geological processes have removed or buried most of the crater record on Earth (e.g., French, 1998). So far, only 191 impact craters have been confirmed on Earth, and 126 of them are exposed on the surface (http://www.passc.net/EarthImpactDatabase/). Theoretical estimates suggest that numerous craters, especially those <~6 km in diameter are awaited to be confirmed on Earth's surface (Hergarten and Kenkmann, 2015). Considering that buried and partly destroyed impact craters are more difficult to discover, the number of unconfirmed impact craters on Earth is much larger (Stewart, 2011). The significance of impact cratering to Earth's evolution has been well recognized (e.g., French, 1998), and each newly confirmed impact crater has significantly promoted our understanding of the impact history on Earth, cratering mechanics, and the profound effect of impact cratering on Earth' system (e.g., Collins et al., 2012).

China has great potential for finding new impact craters. For example, the source crater of the Australasian tektites might be located in China (Kenkmann et al., 2014; Mizera et al., 2016). The spatial and stratigraphic positions of confirmed Earth impact craters show an uneven distribution, as most impact craters are discovered at tectonically stable regions (Stewart, 2011). China is an anomalous area on the world map of confirmed Earth impact craters (Fig. 1), because so far only one crater (Xiuyan, 1.8 km diameter) has been confirmed in China (Chen, 2008). The paucity of impact craters in China cannot be solely ascribed to its complicated tectonic evolution, as large areas of cratonic regions exist in China (Ren, 1996) and ~115 of the 191 confirmed Earth impact craters were formed in the Mesozoic or later (http://www.passc.net/EarthImpactDatabase/). Rather, a major reason is that the concept of impact cratering as an important geological process on Earth's surface has not been well advocated or popularized among the Chinese geology community, as only a handful of possible impact craters in China have been proposed since the 1970s (Xu et al., 2017).

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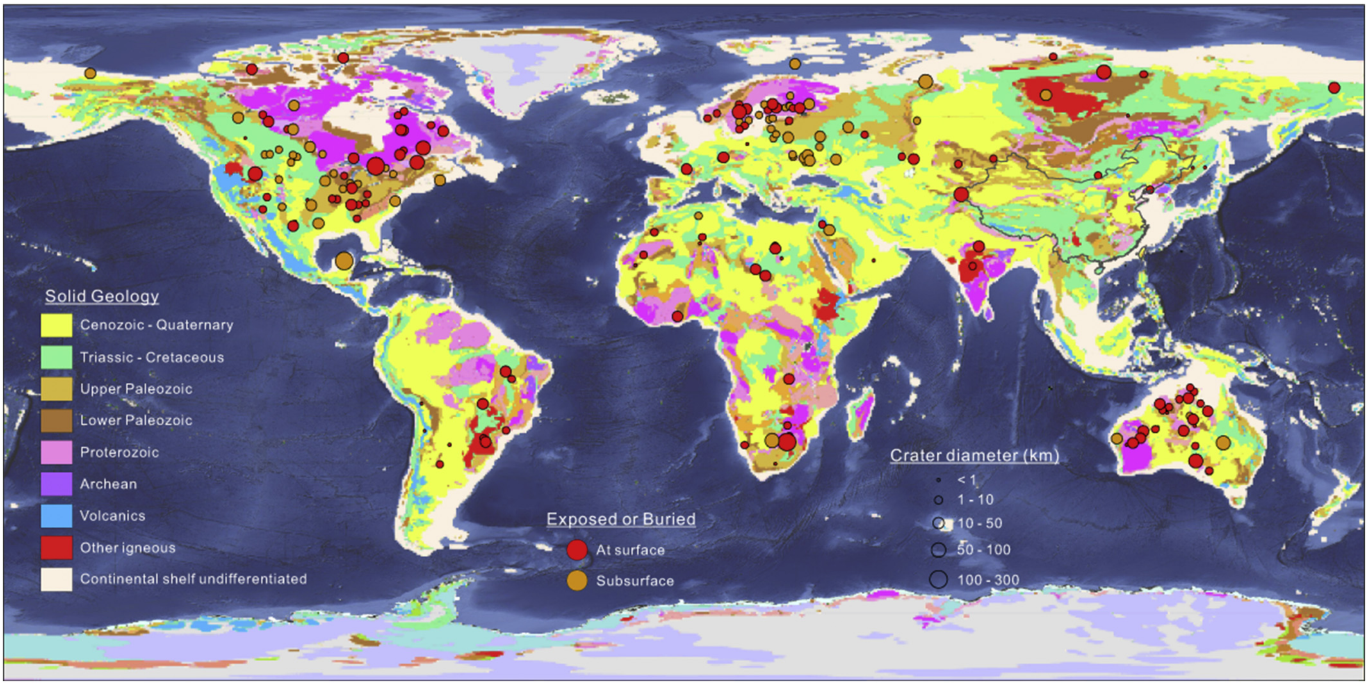

Fig. 1. Global map of confirmed Earth impact craters. The base image is the 1:50 million onshore geological map of the world (http://www.onegeology.org/). The Xiuyan crater is so far the only confirmed impact crater in China.

We launched a program to search for possible Earth impact craters in China in 2014. Those proposed by earlier researchers, which were primarily based on their circular morphology, are our first-stage targets. Six high-priority examples have been studied via field investigation and sample analyses, and five of them are disapproved to have an impact origin, e.g., the Duolun basin (Xu et al., 2017) and the Baisha crater (Pu et al., 2018). The Hailar crater in Inner Mongolia, northeast of China is so far the only one that has a high possibility of being an impact crater. This crater possesses significant scientific value for understanding the regional paleoclimate as it has been a stable depositional center since formation, and it may also serve as a useful benchmark for impact cratering mechanics that occur on volcanic breccia. Here we report the results of a remote sensing study and two field expeditions, in September 2016 and October 2017, to verify the origin of the Hailar crater.

2. Geological background

The Hailar crater, with a rim-to-rim diameter of ~300 m and central coordinates of 49.630°N, 119.186°E, is within the Hulun Buir grasslands of Inner Mongolia (Fig. 2). The apparent crater diameter is ~200 m (Fig. 2B). This feature was first noticed by Xiao et al. (2012) during a regional geological survey. A possible impact origin was proposed based on its unique occurrence in this region, but the flat crater floor was mistakenly regarded as a morphological indicator of impact cratering (Xiao et al., 2012). Referring to well-accepted criteria used in identifying Earth impact craters (e.g., French and Koeberl, 2010), no diagnostic evidence (e.g., remnants of impactor and shock metamorphic features) for the impact hypothesis has been established for this crater.

This region is part of a Mesozoic fault basin, the Labudalin basin (about 57 × 210 km) that is developed on top of the Xing'an–Mongolian orogenic belt (Fig. 3). The orogenic belt was formed during the accretionary orogenesis of the North China plate and the Siberia plate since the Paleozoic (Pan et al., 2009). Compression dominated regional tectonic activity until the early Cretaceous, when the source of tectonic stresses shifted from the Paleo-Asian Ocean tectonic regime to the circum-Pacific tectonic regime (Liu et al., 2008). Since the early Cretaceous, extension has been the dominate deformation pattern in the basin, mainly driven by the subduction of the Pacific plate under the Eurasian plate. Faults that trend northeast, north–northeast, and east–west were formed in the Early Cretaceous, which also set the boundary of the Labudalin basin (Fig. 3). Massive center- and fissure-type volcanism occurred in the basin from the Middle Jurassic and ceased at the end of the Early Cretaceous as the eruption center migrated eastward (Wang et al., 2006). Vertical movements dominated the regional tectonic activity after the Early Cretaceous, and Paleogene rocks are weakly developed within the basin because of crustal uplift (Fig. 3). The Labudalin basin was occupied largely by lakes during the Pleistocene and early Holocene owing to periodic warming and downfaulting (Yan and Zhang, 2008). The Pleistocene sediments in the basin are mainly lake deposits such as clays and loess, and the Holocene sediments are mainly gravels, silts, and sands formed by a combination of fluvial deposition, lake evolution, and aeolian processes (Zhou et al., 2000). The present topography of the Labudalin basin consists of low-relief hills, which are mainly composed by the Upper Jurassic and Lower Cretaceous volcanic rocks (Fig. 3).

In summary, geological evolution has formed a two-layer stratigraphy in the Labudalin basin (Fig. 3): (i) a basement that is mainly composed by Paleozoic and upper Mesozoic granites and metamorphic rocks that outcrop at limited locations (Fig. 3), and (ii) a younger cover that is dominated by Upper Jurassic and Lower Cretaceous intermediate–felsic volcanic rocks and Quaternary sediments. The Hailar crater is formed in the Lower Cretaceous volcanic rocks that belong to the Shangkuli Formation (Fig. 3), which can be divided into three segments based on the lithology. From bottom to top, these are (Meng et al., 2011): (i) dacite that is interbedded with rhyolite and shale; (ii) rhyolitic quartz trachyte and tuff; (iii) ignimbrite and rhyolitic breccia.

3. Methodology

Except for the location and regional geological background, little else is known about the Hailar crater that might be helpful to determine its