An aquifer is the control of magma eruption

Yi Ding (chinakimberlite@126.com)
Hebei GEO University

Yunxia Wu
Hebei GEO University

Zheng Hou
Hebei GEO University

Wensheng Wu
Hebei GEO University

Zongyuan Tang
Hebei GEO University

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Abstract

The location of a large group of maars in a basin of 200 km2 in Huitengxile, Inner Mongolia Autonomous Region of China, was probably the center of a magmatic plume in the past. The cross section of maars looks like saucers, with diameters ranging from the largest 900 to the smallest 10 m. Crashed rocks in strata exposed by the drill core and magnetic survey indicate explosions underground by insupportableness of steam accumulation from interaction of magma and water. In Huitengxile and other parts of Inner Mongolia, maars with the same shape and caprock age characteristics exist in an area of 30,000 km2, which indicates that they formed by substantial magmatic activity at the same time and in the same phreatic style. The aquifer layer in the crust constrained the eruption of the magma to overbear via phreatic shooting and releasing its energy. What has been happening at Yellowstone has similar phenomena to what had in Huitengxile and surroundings. The magmatic activities under Yellowstone may have been reined by an aquifer so that magma could not threaten the world.

Introduction

Maars in Huitengxile (HT) have different natures of much more in numbers, in high density, no margins and dryness from maars in Germany well recognized. They were products of phreatic explosions underground with a general census. However, no research has been carried out on the relationship between large maars and smalls. Are their formations by the same reason? Although concentrated at HT, maars are distributed in a large area in the Inner Mongolia Autonomous Region. What underground magma chamber look like, a plume? Are what these geological phenomena telling us?

Geological Settings Of The Study Area

The study area is in a basin (Fig. 1(a)) at the northern edge of the North China Craton (Fig. 1(b)). Archean metamorphic rocks, Permian granites and Miocene basalt are distributed as the caprock (Fig. 1 (c)). Zhang and Han (2010) divided Miocene basalts into three eruption cycles, which formed at 33 Ma, 22.8-22.1 Ma and 12.2-9.4 Ma. Bai et al. (2008) investigated five volcanoes sixty kilometers away in the northeastern direction of the HT, in which volcanoes formed in the late Pleistocene.

Maars In Ht

Maar is the name for small lakes in West Eiffel, Germany (Lorenz, 1973) and formed by phreatic shooting produced from magma with underground water. There are 180 maars with rainwater or dryness in a 200-km2 basin of HT (Fig. 1 (a)), a region 300 kilometers away in the west of Beijing. In the field, maars are systematically numbered, measured (the diameter, height and slope), and zoned. Three maars were surveyed with the magnetic method (on the maars marked by 26, 55 and 93 in Fig. 1). Drill by an XY-4 machine with a diamond bit and a core diameter of 75 mm was carried out to 186 m at the center of Baijian (67 in Fig. 1), and the borehole histogram is shown in Fig. 3.

Their Natures

The cross-sections of these maars look like saucer with flat bottom and wide edge, circular or elliptical overlooked. No magma overflow or eruptive bedding deposits in or out of maars are found (Fig. 2 (a)(c)(e)). Rock fragments (Fig. 2 (f)) stacked on the sides are olivine basalt, the caprock in the area (Ding et al. 2019). The Maar distribution is dense around the Miocene volcano (Fig. 1 (a) and Fig. 2 (d)), 35 maars in area A and 37 maars in area B. Based on 116 craters (maars with diameters greater than 50 m), the average diameter (from edge to edge on the top of maars) is 268 m. The largest maar, Dajiajiazi ("51" in Fig. 1 (a)), is 962 m (an ellipse with a longer axis of the north-south). Maars in diameter are more in from 100 to 400, 35 are between 100-199 m, 33 between 200-299 m, and 21 from 300 to 399 m. The slope between the crater side and the horizontal plane is 4-12 degrees. The height (depth) from the crater bottom to the top plane is 10-25 m. The slope angle and the depth are proportional to the maar diameter. The maar bottom is flat with black gray soil (Fig. 2(c) (e)). Most maars are dry except for the rain season and have lake lines on the side of maars (Fig. 2(c)).

The borehole core shows two groups of strata with age gaps: Archean rocks mainly composed of gneiss and amphibolite and Cenozoic strata represented by olivine basalt and mudstone. The basalts have three forming stages, at 103.8-115.2 m, 55.5-58.4 m and 9.6-42.4 m (Fig. 3), in which layers formed with the lava at the bottom and pored basalt at the top. Five broken layers were found with no-splicing rock fragments, and the cracks were obviously different from those due to the possible drilling process (Fig. 3).

Phreatic Activities Only

In HT, there are no stacks of fragments different from the cover rock higher than the surface, and no erupted pyroclastic rocks found on the surface in and out of maar craters tell no new fragments erupted by magmatic activities. The drill core proves that no new magma participated in forming these maars. These individual and separated broken fragments indicate that the impact agent is only steam (phreatic), and no magmatic liquid, as shown in the phreatomagmatic agent, would have cemented crushed agglomerates or breccia together after steam impact, as found in the upper part of kimberlite pipes (Ding, 2019). Six rock fracture layers in the core (Fig. 3), rock fragment arrangement of caprock-olivine basalts in rings (Fig. 2 (b) (f)), broken fragment alignments in cycle under soils detected by magnetic measurement (Fig. 2 (b)) indicate steam shooting-up execution from the beginning to the end, even after forming maars.

A Model: The Surface Rock Collapsed From The Center To The Edge

Most maars with diameters of more than 300 meters and a depth of more than 15 meters have small cliffs at edges, as shown on Landa (Fig. 2 (g)). From the point of viewing the maar landform and crushed rocks exposed in the drill core, this study infers that maars collapsed down at the beginning from the maar center continuously to the edges, as shown in the model in Fig. 3. Undoubtedly, no magma participated, which might have stopped in some layers that had abundant water – an aquifer. The water consumed the magma energy by producing steam that went up continuously until met a barrier and stopped. The basalts in this case had no cracks, but boreholes temporarily held some volume of steam. However, when steam accumulated and pressured, explosions were evitable (Fig. 3).

The landforms of maar volcanoes found in the world are different from positive to negative terrain (Kereszturi et al. 2018), which are all the reason for the water amount joined in magmatic activities. The smaller the volume of water joined in volcanic activities is, the larger the amount of debris ejected out by magma (Kurszlaukis and Lorenz, 2017; Lorenz, et al. 2017). Kurszlaukis and Lorenz (2017) have the same conclusion that volcanic craters with negative topography are graben collapses near surface strata caused by underground water vapor explosions. This study testifies to the magma that created these maar craters encountering an aquifer with abundant water, and the pressured steam made explosions more than once for those large maars and less explosion for small maars located besides large maars and small maars along the fracture (Fig. 2 (h)).

Other Maars In A Large Area

Maars that occur densely in the HT suggest that the new magma upward channel was probably along the channel of the Miocene volcano (Fig. 1 (a)). In hilly areas, including the Miocene volcano itself, there is no maar, which indicates that shoot-up steam would have more difficulty penetrating through "thicker" areas. Nearby basins in the larger area of 1750 km2 reside maars (Fig. 4 (a)), 81 in an area of 115 km2 of "Qile", 12 maars in 17 km2 in Suji, and 13 in 24 km2 in Houfang. From their same appearance (caused by weathering degree) and same caprock as the one in the HT, they formed, at the most possibly, by the same magmatic activity as in HT. The same judgments for an even wider area are shown in Fig. 4(b)-(e). The steam shooting-up area is up to 30,000 km2. These maars are all the same as those in HT with the same weathering degree and in the same simple basin with similar caprock. The magmatic activities that created those maars are giant and could have become a supervolcano if erupted.

Rock Layers In Upper Crust Determine Magma Fate

In addition to the depth of magma origin, composition of magma and tectonic factors, this study implies that magma fate also depends on an aquifer layer near the surface in the upper crust. In particular, rock properties (composition, thickness, water amount, etc.) in a layer of 100-1000 m near the surface are important factors. If magma intrudes into a layer containing abundant water, an aquifer layer could have governed magma eruption by generating steam. The case of an iron ore in Ningwu is another typical example of how important a sedimentary layer was. The magma intruded in a layer of gypsum and salt limestone in the upper crust and assimilated its compositions to form hydrothermal liquid, which leached iron composition out of cooling porphyritic magma to form iron deposits (Ding, 1992).

The Magma Underground At The Yellowstone Might Not Erupt

A possible giant volcanic eruption at the Yellowstone has been threatening the world. The area had past volcanic activity and had formed maars by steam shooting (geyser) now, covering an area of 9,000 km2. The earthquake in the area is over 1,700 times a year (Yellowstone Volcano Observatory, 2021). Although the area is smaller than the area of HT and its surroundings, steam shootings and the formation of maars are quite similar to what happened to the case of this study. Those earthquakes that occurred in Yellowstone might be steam explosions underground when pressure steamed in its temporary storage reached a tolerance limit. The geysers apparently originate from the interaction between magma and an aquifer. Steam shooting in a way of releasing magma energy actually consumes the magma energy in the way of avoiding damaging humankind by possible magma eruption. The aquifer layer is a good resistance consuming magma energy or better to say it is a determiner for the fate of magma. The magma, while intrusing upward, may rest to produce geysers and further form a sill after cooling. If such an aquifer was so important to control magmatic activities, humans might consider injecting more water into the layer above the magma chamber at Yellowstone to rein possible magma eruption by water supplementation.

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Figures

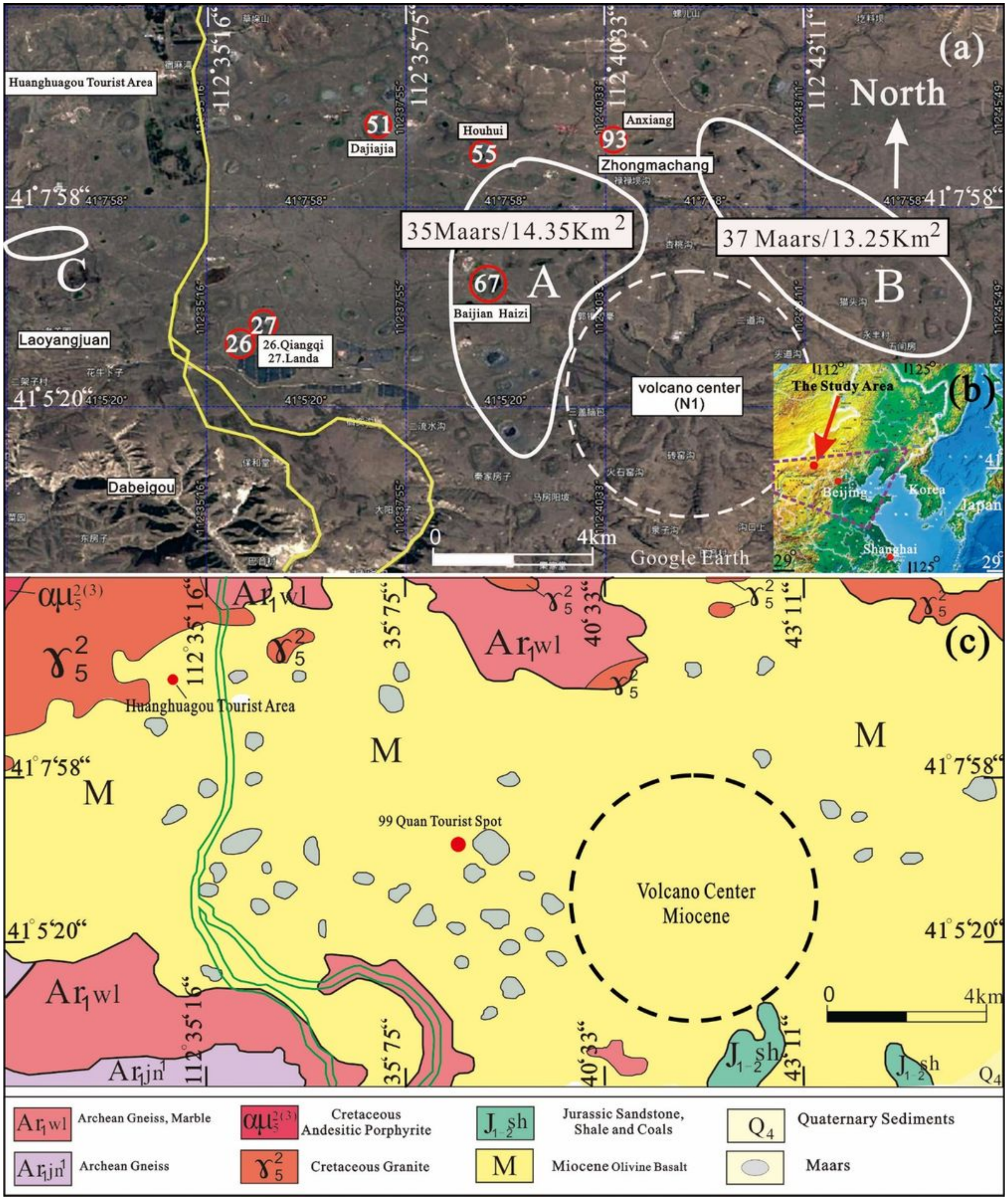

Figure 1

(a) the interpreted satellite image of HT. Maars densely distributed ((A) and (B)) around Miocene volcano (the circle by the dotted line). The circles with numbers are the maars mentioned in the paper. (b) The location map of the study area and the dotted line circles of the North China Craton; (c) the geological map (based on Li et al. (1996)).

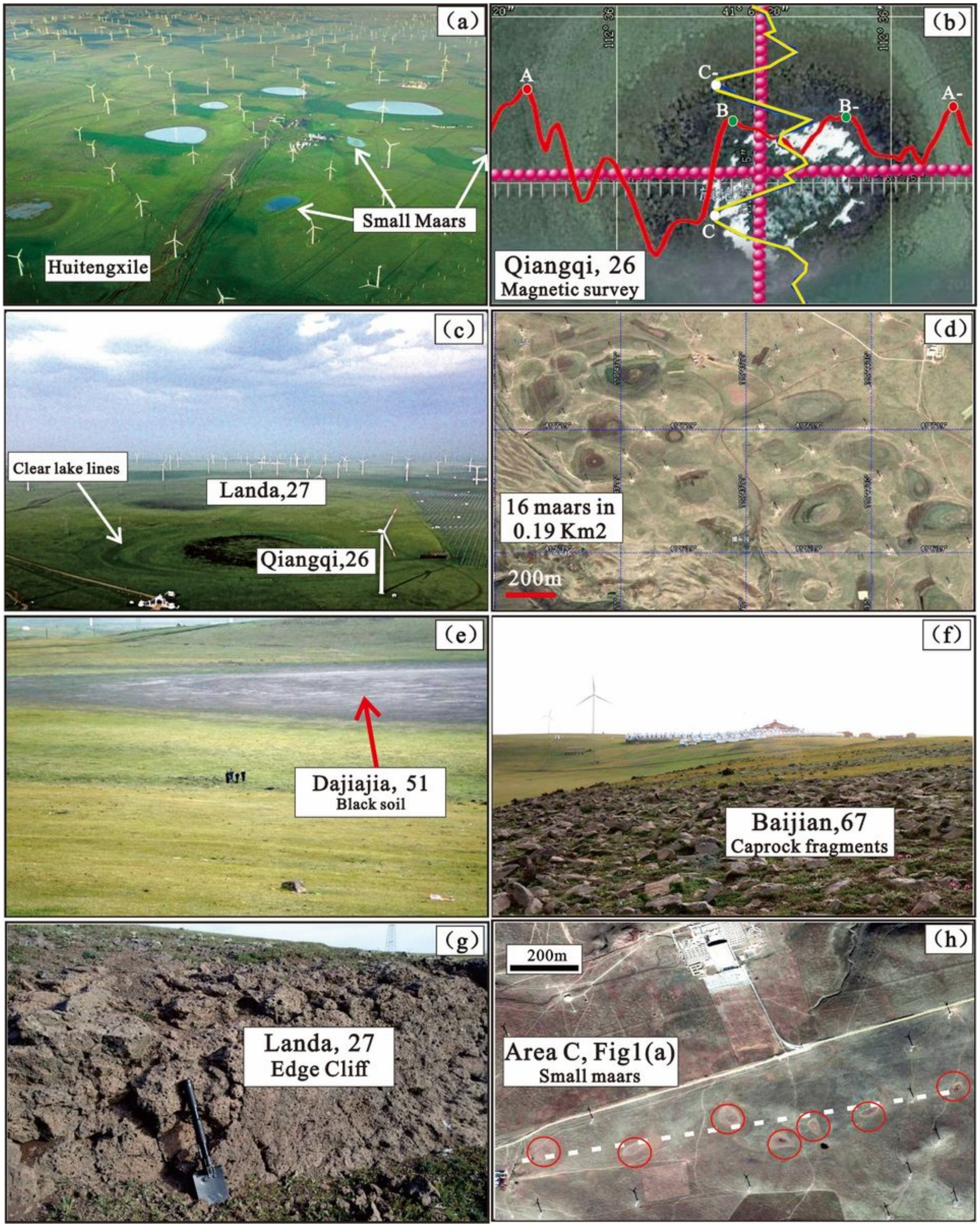

Figure 2

(a) UAV photo of some maars in HT. (b) Magnetic survey chart on Qiangqi ("26" in Fig. 1), displaying the cycle distribution of basalt blocks under soil. (c) UAV photo of Qiangqi ("26" in Fig. 1) and Landa ("27" in Fig. 1), showing clear lake lines and black soils. (d) Satellite image in area B (Fig. 1 (a)), showing that maars were distributed densely. (e) Field photo of the largest maar in HT, Dajiajia ("51" in Fig. 1), the bottom with grayish black soil. (f) Field photo displaying the stack of caprock fragments on the inside of the maar (“67” in Fig. 1 (a)). (g) Field photo displaying a small cliff at the margin of Landa (“27” in Fig. 1). (h) Satellite image in the western part of the HT (away from the Miocene volcano), showing small maar alignment along a fracture.

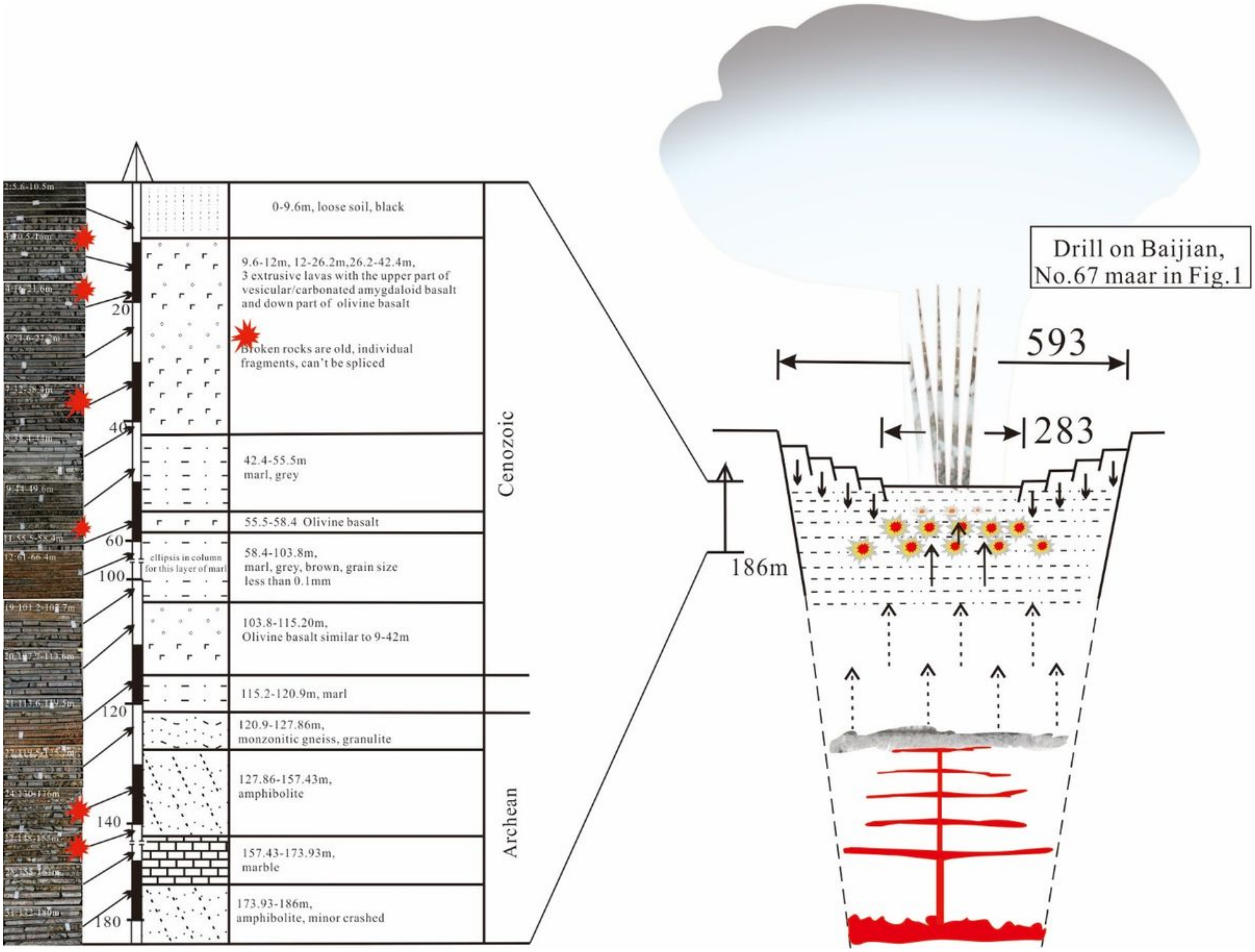

Figure 3

Left: Core diagram of Baijian (“67” in Fig. 1). With the core photo on the left, the broken rocks of the core are marked with the explosion symbol, and the arrow points to the corresponding position in the column. Right: Genetic model of HT maar formation. The diameter of the crater (margin to margin) is 593 m, the diameter of the crater bottom is 283 m, and the depth is 22 m.

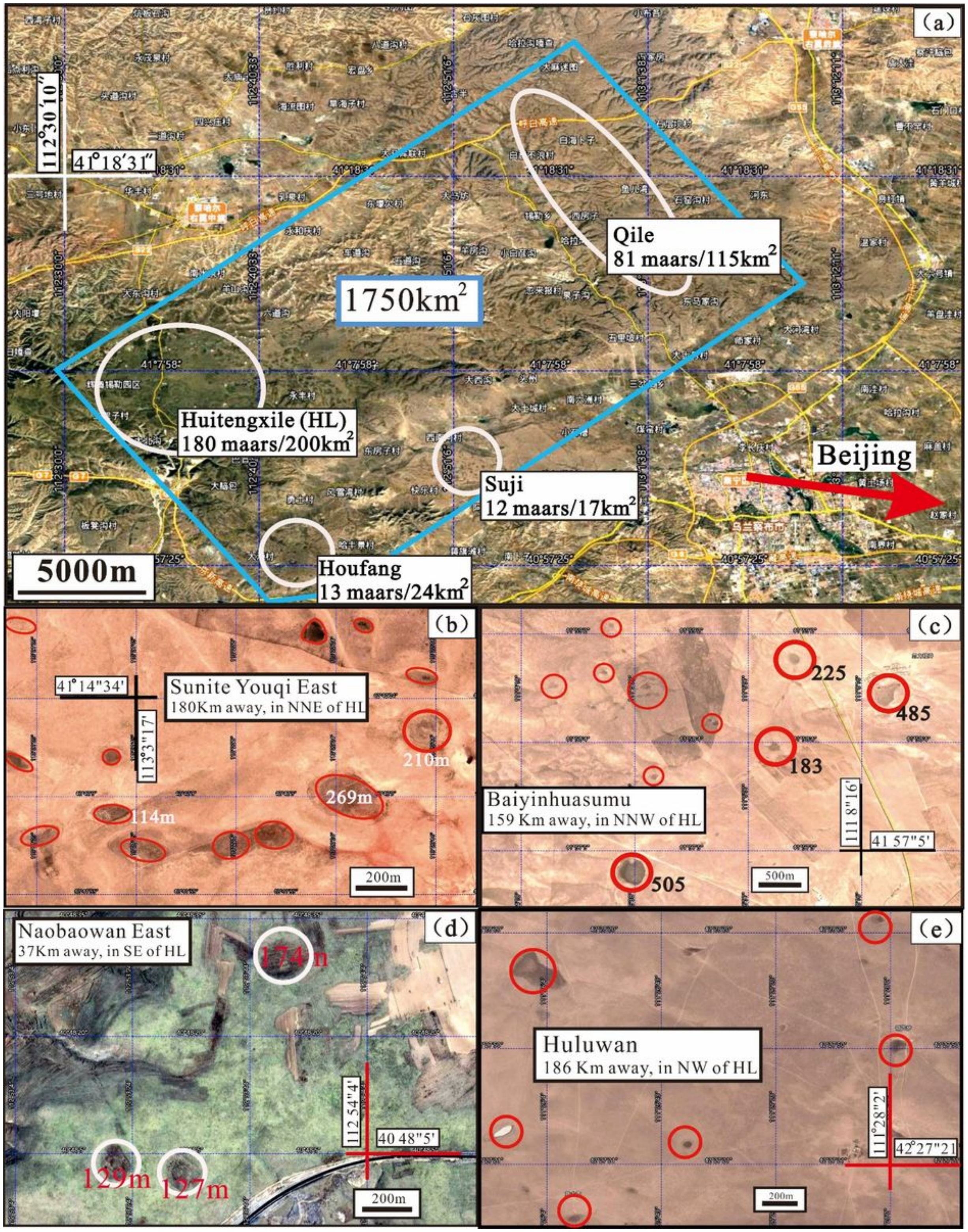

Figure 4

(a) Satellite image of nearby basins of HT with an area of 1750 km2 residing maars, 81 in an area of 115 km2 of “Qile”, 12 maars in 17 km2 in Suji, and 13 in 24 km2 in Houfang. As a center of HT, more maars exist in “Sunite Youqi East” (b), “Baiyinhuasumu” (c), “Naobaowan East” (d), and “Huluwan” (d), which form a large area of 38,000 km2. Numbers in or besides the circles in (b) - (d) are diameters in meters.