Scientific Research Publishing

Open Journal of Geology, 2024, 14, 117-125
https://www.scirp.org/journal/ojg
ISSN Online: 2161-7589
ISSN Print: 2161-7570

The Origins of the Arc-Shaped Langshan Uplift and Linhe Trench

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How to cite this paper: Ding, Y., Wu, Y.X. and Hou, Z. (2024) The Origins of the Arc-Shaped Langshan Uplift and Linhe Trench. *Open Journal of Geology*, **14**, 117-125.
https://doi.org/10.4236/ojg.2024.141007

Received: December 19, 2023
Accepted: January 26, 2024
Published: January 29, 2024

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Abstract

In the northern part of the Ordos Basin, there is a 325 km long arc-shaped Langshan uplift and a 15 km-deep Linhe Trench in front of Langshan, which are rare geological phenomena for which origins no one has explained. This article comprehensively analyzes the research achievements over the past 40 years of geology, geomorphology, seismic exploration, paleogeography, and oil and gas exploration in the Ordos Basin and Langshan. It recognizes that the northern part of the Ordos Basin experienced a meteorite impact in the Late Cretaceous period. The impact pushed the block northwest ward, subducting after colliding with igneous rocks in the north. This sudden event formed a clear arc-shaped mountain zone in the north and a wedge-shaped trench in front of the mountain. The chaotic layers, prolonged and continuous faults, and numerous thrust layers in the Langshan, a negative anomaly area in the center of the northern Ordos, abnormal orientation of crystalline basement structures in the north of Ordos, Moho uplift, and distribution of meteorite fragments in the northwest of Langshan, all of these geological phenomena support the occurrence of the meteorite impact event, forming the arc-shaped Langshan and the Trench.

Keywords

Meteorite Craters, Linhe, Ordos, Arc-Shaped Langshan, Trench

1. Introduction

The Ordos Basin (OB, Figure 1(a)), located in the western part of the North China Craton, is a stable continental block from the Middle Paleozoic to the Cretaceous periods. The Langshan Mountains (LS) in the north are arc-shaped, with a length of 325 km. Before the Cenozoic era, the Linhe Basin was a trench with a depth of 15 km in front of LS, gradually shallower towards the north of

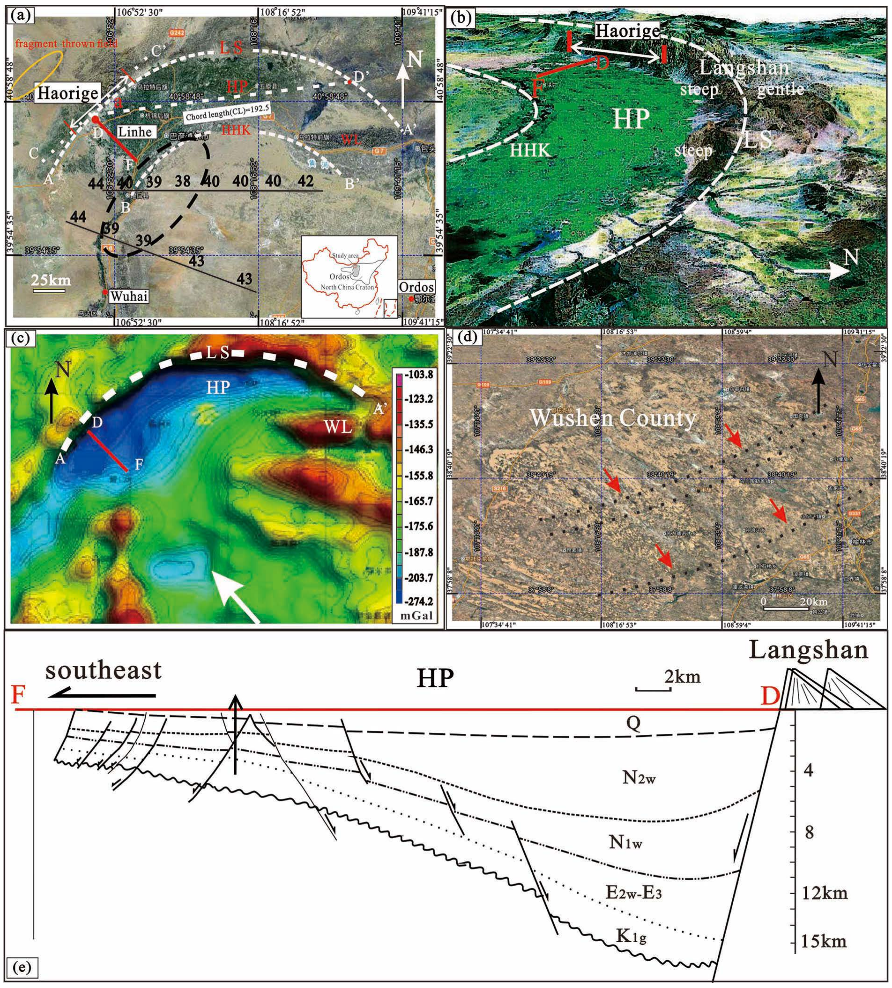

Figure 1. (a) The satellite image of Ordos impact structure (based on the data of Tencent Co., Ltd.). The A-A' arc is the LS, 325 km long and 25 km wide, displaying as the outer edge of the arc concentric structure. The arc of B-B' is the Huanghekan (HHK), the inner edge. LS, HP, and HHK together form a concentric arc nest. Wula Mountain (WL) cut off the southeast wing of LS in the east-west direction. The small insert illustration shows the OB location in the North China Craton (Gray Square). With the tangent (C-C'), chord length (D-D', 192.5 km), and tangent angle (a = 35), the calculated radius is 167 km. The two black lines are the deep seismic-sounding profiles of the North China Craton (based on [5]), with the number of the depth of Moho interface. The orange-color circle in the upper left corner is the scattered area of meteorite fragments. The black and short-line oval represents the raised Moho area, ranging from 38 to 40 kilometers and gradually deepening outside with over 41 kilometers. (b) A 3D image of the concentric construction in the northern OB, showing locations of LS, HP, and HHK and displaying LS with a steep slope in the south and gentle in the north. (c) Is the superimposed Bouguer gravity anomaly map and current terrain (based on [6]). The blue area in front of LS Mountain is the trench with an average depth of 14,000 meters. The white dot lines indicate the arc-shaped LS. The arrow points to the movement direction of the block pushed by the meteorite. (d) The Satellite image of Wushen country, in the southern part of the Ordos Basin. According to the radius, an arc-shaped landform is traced (pointed by red arrows). (e) D-F Profile (see the lines in (a) (b)). Directly in front of Haorige, this wedge-shaped deep trench underwent uneven sedimentary deposition in thickness after K1 (based on [2] [3] [4]).

OB, forming a wedge-shaped Linhe Trench (LT, **Figure 1(a)**, **Figure 1(b)**). On LS and LT, there have been 40 years of research in geology, geomorphology, seismic exploration, paleogeography, and oil and gas exploration ([1] [2] [3] [4]), but no one could discuss the causes of LS and LT. This article comprehensively studies the numerous publications of the different geological sciences mentioned above and conducts logical deductions to explain the origin of LS and LT based on these research results.

2. Geological Setting of OB

The OB lies in the western part of the North China Craton. The basin has an area of 250,000 km^2, with longitude ranging from 106˚ to 114˚E and latitude between 34˚N and 41˚N. Its crystalline basement is similar to other parts of the North China Craton, consisting of amphibolite granulite quartzite, marble, and granite gneiss from the Ar to Pt1 strata. A relatively stable and sizeable geological block has been submerged in the sea or exposed in geological periods. The basin has sediment strata of the Great Wall (Pt2), Jixian (Pt3), and Sinian (Pt3) formations and the ones during Cambrian, Ordovician, Carboniferous, Permian, Triassic, Jurassic, Early Cretaceous, and Quaternary periods, with a total thickness of 5000 to 10,000 meters. The central part of OB lacks O2 to C1 and K2 strata ([7] [8] [9] [10]).

3. Geology, Structure, and Topography in LS

The LS, a 25 km in width of the mountain belt, is located in the northern and northwestern parts of the Hetao Plain (HP). The Haorage section, 175 km long on the southwest wing of LS (**Figure 1(a)**, **Figure 1(b)**), is a large and complex anticline composed of rocks from the Proterozoic to Mesozoic eras. LS has a steep slope on its southeast side and a gentle slope on its northwestern side (**Figure 1(b)**). The isotopic ages of the Pt2 group range between 2300 and 1380 ma. The Pt2 group is the primary strata of Haoridge, consisting of schist, slate, limestone, and quartz layers ([5]). The Permian and Carboniferous granites and the lower Pt2, schist, and slate are in the center. In contrast, the upper Pt2, limestone, and quartzite are on both wings of the anticline. Many thrust structures in LS have arranged Pt2 over the Cretaceous Guyang Formation (K1G). On the Cretaceous Lisangou Formation (K1L), there are several Proterozoic and Paleozoic thrust rocks ([11]) (**Figure 2**). The extension length of faults is from 10 km up to 100 km ([1]). The fault zone is distributed in front of LS and extends 160 km northeast ([12]).

4. LT in Front of the Mountain

In the past 35 years, oil and gas surveys have been conducted in the HP, including 28 deep wells, 870 km of electromagnetic profiles, and 6514 km of two-dimensional seismic lines. Researchers ([1] [2] [3] [4]) found that the Linhe Basin towards the center of the Northern Block of Ordos Basin is a wedge-shaped deep

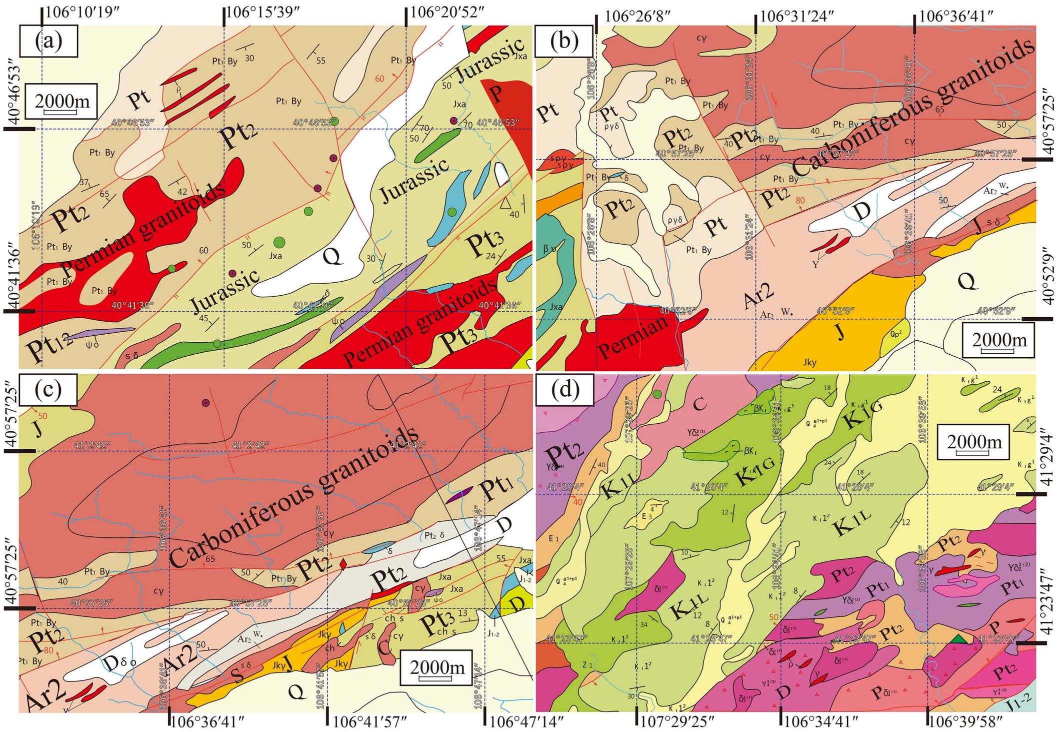

Figure 2. The stratum distribution in Haorige (see the location in **Figure 1(a) Figure 1(b)**), from the southwest (a) to the northeast (d) [7] and the geological map of the scale 1:200,000 compiled by the Geological Bureau of Inner Mongolia).

trench (the deepest just in front of the mountain). The sediments gradually become thinner towards the southeast (**Figure 1(e)**). Guo and Yu (1990) ([2]) pointed out a fault in front of the Haorige section of LS. The fault extends 5000 to 7600 meters east and 5000 to 8000 meters to the west. The work of wide-angle reflection and refraction seismic sounding ([13]) and Bouguer gravity anomaly (**Figure 1(c)**) confirm the existence of the trench and draw the same conclusion. This trench has been receiving lacustrine sediments, with a width of 20 km, a length of 300 km, and an area of 6000 km^2 ([3]). The maximum depth of the LT is 15 km ([3] [4]), and the area is 2.43 × 104 km^2. The drilling and well profiles indicate that the sedimentary thickness of K_1 in the LT is uniform, with K_2 sediment missing. However, the thickness of the Cenozoic strata is uneven ([3] [4]), and the front of the mountain is shown by the thickest sediments that become thinner away from LS. HHK serves as the inner edge of the arc-shaped Hetao Plain (HP). In contrast, LS serves as the outer edge to enclose HP, with an area of approximately 60,000 km^2 (**Figure 1(b)**). Seismic exploration revealed that the northern and southern parts of LS have the same Precambrian basement ([7]).

5. Discussions

Can one explain the arc-shaped formation of LS using two-step shear structure movements? There is no evidence, let alone persuasiveness. It is too difficult to infer its origin from general thinking; No wonder many scientific papers never discuss this issue([3] [4] [9] [10])! The curved LS is most likely to be impacted by a meteorite on the North Block of Ordos, forming a block bullet with a curved shape at the front. All meteorite craters on other plants and the confirmed large craters on Earth have the topography of arc-shaped mountains. LS and HHK form a double arc structure with concentric circles, characteristic of large meteorite craters ([14]).

The faults simultaneously extend the same curvature as LS formed with anticlines and thrust structures. Under the collision of two blocks, the southeastern strata became downwards. In contrast, the northwestern strata under force were upwards, causing strata of different ages to have overturned and presented upright, forming LS in a curved shape. The LS's steep slope is in its southeast direction, which is the force surface of the collided party. In contrast, its northwest direction has a gentle slope, which is the direction behind the collided party (**Figure 1(b)**) and consistent with the geomorphic morphology of the Mariana Trench formed by sea plate collision on the continental side ([15]). LS has thrust structures in an upright posture in many places, and the sedimentary strata are disorderly (**Figure 2**). The thrust fault parallel to the axis tilts southeast or northwest, and the direction and other deformation phenomena displayed in the strata indicate that the strata have experienced compressive stresses between southeast and northwest. A sudden impact could create all of these geological phenomena.

According to the arc-shaped LS (**Figure 1(a)**), using the chord length CL is 192.5 km in length, the chord tangent "angle a" is 35, and the radius of the crater R = 0.5CL/Sin (**Figure 1(a)**), resulting in a radius R = 167 km. Most of the crater circle is under the jurisdiction of Ordos City, so this crater with a diameter of 340 km is called the Ordos Crater. Based on the radius, in the opposite direction to the LS, the crater margins are in the "Wushen County." Satellite image analysis shows that there is indeed a concentric circular arc structure in the center of the North of Ordos (**Figure 1(a)**, **Figure 1(d)**), where structural traces are the result of the asymmetric uplift of the crater caused by the meteorite's angled attack on OB. There are craters with a diameter greater than 200 km in the world, including Sudbury in Canada ([16]), Vredefort in South Africa ([17]), and Chicxulub on the border between the United States and Mexico ([18] [19]). They all have features of asymmetric arc-shaped margins resulting from meteorites hitting the ground at vector angles in one direction.

Starting with settling sediments in the Cenozoic era, LT underwent uneven deposition with varying thicknesses, much thicker in the Piedmont, indicating that LT was a deep wedge-shaped trench in front of the mountain before the Cenozoic era. Could uneven geological subsidence result in the wedge-shaped deep trench? Of course, it is impossible. Just like wedge-shaped trenches on the edge of oceanic convergent plates, the LT resulted from the collision of southeastern plates from OB with the northwestern granite. Then, the moving and weak plate from OB with compositions of sedimentary rocks was down, as the plate was undershooting. The C~P granite at the location of LS played a role as a "rooted stone pillar," its strength causes the southeastern plate to continuously subduct until the impact energy is exhausted, forming a wedge-shaped deep trench (**Figure 3**).

The impact of a meteorite on the northern part of OB forms a rare large arc-shaped mountain belt and a 15 km wedge-shaped deep trench in the world, which is also supported by the following evidence:

a) The Bayingobi 001 meteorite, an L5-type ordinary chondrite meteorite, was discovered in 2015 (35 kg, 41˚19.03'N, 105˚20.57'E) and has been certified and registered in the international meteorite database (https://www.lpi.usra.edu/meteor/metbull.php?nwas=&strewn=&code=65061). The team of meteorite enthusiasts has collected up to 200 kg of meteorites, which have formed a distribution belt covering an area of up to 30 km^2. This scattered field is in the northwest direction outside LS, approximately 90 km from the tangent point of the crater edge (**Figure 1(a)**), which coincides with the predicted and thrown direction of the break-up meteorite (**Figure 3(c)**).

b) The study of the crystalline basement and deep magnetic field distribution of the northern part of Ordos found a difference with the 39-latitude line as the boundary between the south and north. In the north, magnetic anomalies on crystalline substrates are mainly east-west oriented, while in the deep, they are primarily north-to-south. In the south, the magnetic anomaly of the crystalline basement is consistent with the NE direction of the deep magnetic anomaly ([13] [20]).

c) The deep seismic detection profile in North China ([5]) indicates that the depth of Moho varies in the northern part of OB. Near the inner edge of the northwest impact crater (**Figure 1(a)**), there is an anomaly in the Moho interface uplift area (38 - 40 km). Outside the uplift area, the depth of the Moho interface gradually deepens to 49 km. The Chicxulub is a recognized meteorite crater located on the border between the United States and Mexico, and there is an anomaly of 1 - 2 km above the Moho surface ([18]). Meteorites significantly impact the Earth's surface, causing the central part of large craters to descend and then rebound, forming a central negative anomaly zone. There is a clear negative in the gravity area in the central part of the northern OB (**Figure 1(a)**).

After studying the Haoridge section, Feng (2017) ([11]) pointed out that LS may have uplifted after the formation of K1L and K1G. Liu *et al.* (2006) ([8]) analyzed the fission tracks of 125 apatite samples and 50 zircon samples and concluded that LS formed after the end of the Early Cretaceous period. Lv *et al.* (2018) ([21]) studied the zircon ages in the serpentinite intrusion into Haoridge and had similar results, indicating that the LS formed at least after the Early Cretaceous period. In summary, all studies point to the earliest age of the LS uplift being in the Late Cretaceous. Wula Mountain (WL, **Figure 1(a)**) is a mountain range that extends 220 km from east to west, cutting off the southeast LS wing, which indicates that the formation of LS was earlier than that of WL Mountain and sets an upper limit on the LS uplift age. Fan (2019) ([22]) studied the

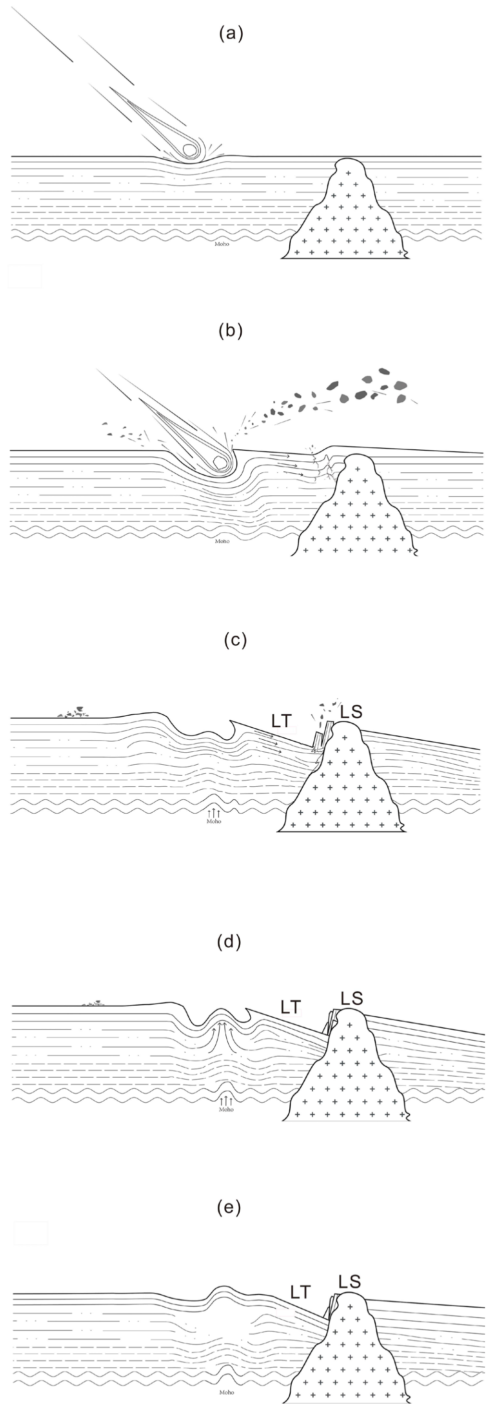

Figure 3. Schematic diagram of the process of meteorite colliding with the northern part of the Ordos Basin to form the trench.

geomorphological parameters of the lateral water system around WL and concluded that WL formed in the early Pliocene. The data from the apatite (30 samples) fission track method and zircon age (14 samples) method indicate that large-scale uplift and erosion (24.3 m/ma) occurred in the early Cenozoic era ([12]).

6. Conclusion

The paper describes the arc-shaped LS, the chaotic strata in this mountain belt with faults and thrust structures distributed along it, scattered areas of meteorite fragments, changes in the direction of the crustal structure in the OB center, and the uplift of the Moho surface. All these phenomena are rare in the other parts of the world but occur in the North of OB. Based on all the information, we have deducted and concluded: just before the Cenozoic era, a meteorite impacted the north part of OB from the southeastern direction, pushed the block northwestward, and collided with the igneous rocks in the northwest. The sudden impact created the curved LS with a length of 325 km, and the block subducted, forming a trench with a depth of 15 km in front of the LS.

Acknowledgements

The first author thanks the president of Hebei GEO University for giving him support working in China and for discussion with Professor Wu Siben.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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