Airburst event in Taihu Lake area of China ~7000 years ago: evidence from iron-rich concretions in a distinctive silty layer. Zhidong Xie[1], Shuhao Zuo[2], David T. King, Jr.[3], Yan Yu[4], Qiyou Zhou[1], Hongxi Pang[5], Jiani Chen[1], Yu Deng[6], [1]School of Earth Sciences and Engineering, Nanjing University, Nanjing, China, zhidongx@nju.edu.cn. [2]Beijing GridWorld Software Technology Co., Ltd. Beijing 100088, China， [3]Geosciences, Auburn University, Auburn, Alabama 36849, USA, [4] Wujiang Dinglong Metal Products Co.,Ltd. Suzhou, Jiangsu Prov. China, [5] School of Geography and Ocean Science, Nanjing University, Nanjing, China, [6] College of Engineering and Applied Sciences, Nanjing University, Nanjing, China,

Introduction: Here we propose that an airburst event likely happened ~ 7000 years ago in Taihu Lake area, China, mainly based on the iron-rich concretions found in one distinctive silty layer, which might be the fallout particles from airburst impact plumes.

The origin and evolution of the Taihu Lake basin has attracted the attention of Chinese geologists since the beginning of modern geological studies in China almost 100 years ago. Taihu Lake is the third largest freshwater lake, with a 65-km diameter, in the southeast of China and is located in the center of the triangle of three big cities: Shanghai, Hangzhou and Nanjing, an economic and cultural center of China. Several hypotheses of the Taihu Lake formation were proposed, which include the lagoon hypothesis [1], tec-tonic hypothesis [2], and dammed lake hypothesis [3], and others. However, no hypothesis was seriously studied in detail and in depth. The southwest arc of Taihu Lake leads scholars to doubt that it was formed by a meteorite impact [4,5,6,7]. However, the origin of the Taihu Lake basin has still not been confirmed yet.

In the early 1990s, an impact origin was proposed on the basis of fractured quartz and a wavy extinction of quartz grains in the sandstone of the Devonian Wutong Formation, which crops out in the islands of Taihu Lake [4, 5]. However, deformation of quartz and the circular structure can have multiple interpretations [8]. The impact origin hypothesis is inconsistent with the very shallow depth (3 m) of Taihu Lake. If the Taihu Lake basin was formed by a meteorite impact, this young Holocene basin should be much deeper and there should be many pieces of classic evidence of impact such as shocked quartz and high-pressure polymorphs of quartz.

The discovery of unique siderite concretions combined with previously claimed impact evidence revived the impact hypothesis in 2009 [7]. In the dredging project of Shihu Lake in Suzhou, many iron-rich concretions including rod-shaped, spherical and irregular-shaped concretions were found in a distinctive silty layer [7]. The irregularly shaped ferruginous concretions were regarded as ejecta materials of impact, launched into the air that then fell back into the impact crater and onto the surrounding area [7]. The claim of the confirmation of impact cratering [7] was not confirmed by additional evidence such as a discernable crater rim, a clear central uplift and an Ir anomaly. Additionally, many additional questions remain, which are not addressed in the study of [7], such as what kind of impact mechanism was involved and how these concretions may have formed.

However, the impact hypothesis is still viable because of a substantial amount of inter-connected evidence, such as deformation features within quartz grains from the sandstone outcrop of the Taihu Lake area, and the abundance of Fe-rich concretions within one distinctive silty layer within Taihu Lake. All these observed clues, plus the shape and shallow bathymetry of the lake, suggest an airburst impact hypothesis, rather than a typical hypervelocity direct contact impact event. Fe-rich concretions may formed in the ejecta plumes resulting from airburst impacts, which could produce a huge, shallow Holocene basin without major crustal disruption under a relatively low but widely distributed shock pressure [9, 10]. Standard contact impact cratering is not applicable in the formation of the Taihu Lake basin, due to the lack of a crater rim, lack of breccias and molten materials, and the contradictory nature of the basic characteristics of Taihu Lake (a large, flat, shallow, young basin [9, 10]).

We hypothesize that multiple meteorite or comet airburst impacts may have disturbed the shallow layer of the Taihu Lake area and formed impact plumes with aerosol environments which contained lots of fine debris including fine soil dust which came from the topsoil layer of the hard loess rich in Fe^{2+} and Fe^{3+}, and fine quartz grains coming from the bedrock of sandstone or the topsoil layer. The impact plume could be the reaction chamber of the aerosol, which synthesize the goethite and form spherules similar to the accretionary lapilli with a colloidal texture for the interior, whereas a dense shell and semi-plastic morphological features can form in the falling processes from higher altitudes in the plume. The fallout of impact plumes may include a distinctive silty layer and iron-rich concretions [10]. The apparent aerodynamic shapes and internal characteristics of the iron-rich concretions of Taihu Lake may have formed during the initial formation of concretions and the later falling processes from the plumes.

Iron-rich concretions occurring in a marker silty layer: Our study shows that there is one marker silty layer formed around ~7 ka B.P. [10,11] which has very different sedimentary characteristics compared with the upper and lower layers. The marker silty layer has uniform silty sizes, higher total organic carbon (TOC) contents, higher magnetic susceptibilities and different XRF element content profiles. The lower layer represents the hard loess layer with an aeolian origin after the last ice age at ~11.7 ka B.P. when the Taihu Lake basin had not formed yet. The upper layer represents the modern Taihu Lake deposit layer after ~5 ka B.P. [11]. The marker silty layers widely occur in the Taihu Lake area, containing abundant iron-rich concretions. These iron-rich concretions can be divided into three categories based on morphology: spheroid concretions (here referred to as spherules), elongated concretions and irregular-shaped or massive concretions. All concretions have a typical colloidal structure with abundant angular quartz grains and minor fragments of clay and feldspar embedded in the fine matrix of siderite crystalline aggregations in elongated and massive concretions or goethite crystalline aggregations in spherules. Three types of iron-rich concretions occur together and have intergrowth relationship. Sometimes, they are interconnected with each other, such as through inter-wrapping, inter-including, inter-winding or inter-crossing, which suggests they formed at nearly the same time in one event [10, 12].

The occurrence of spherules in the marker silty layer and the unique upright occurrence of rod-shaped concretions indicate that they are not erosional lag deposits from the underlying hard loess layer, which was suggested by other scholars [3]. Previous studies also found there are abundant spherules occurring at the bottom of the Taihu Lake basin [3, 13]. The iron-sand belts near PingTaiShan Island were reported [3] and are thought to be accumulating belts of iron-manganese nodules which were washed out from the underlying hard loess layer, and later accumulating as iron-sand belts by storm flows in the center of the lake.

Our studies do not agree with these previous explanations. We think they are accumulating products of seasonal storm flow, but from the iron-rich marker silty layer, not from the underlying hard loess layer. Our previous works discovered that the original layers in Shihu Lake and East Taihu Lake possess relatively little later perturbation after deposition [9, 11]. There are primitive marker silty layers with rod-shaped concretions vertically occurring within the silty layer. No similar iron-rich concretions, except some calcareous ginger stone nodules, are found in the underlying hard loess layer and the upper modern mud layer. The vertical occurrences indicate that the iron-rich concretions formed later than the marker silty layer or at the same time. The spherules and the rod-shaped concretions bond with each other and occur together, even with some elongated concretions consisting of many small spherules, and in some instances, spherules attached to the surface of the rod-shaped concretions [7, 9].

Discussion the formation of concretions: The origin of iron-rich concretions in the marker silty layer of ~7000 B.P. in Taihu Lake provides a clue concerning the formation of the basin of Taihu Lake and may hold a record of the geological event at that time. The origins of iron-rich concretions can be sedimentation formed in hydrosols and during volcanic eruptions, both of which are not favored here, or an impact-related event. Hydrosol concretions have horizontal laminae of silt, which is lacking at Taihu. Volcanism and impact plume can provide an aerosol environment [14,15,16]. The morphology of the spherules of Taihu Lake is similar to the volcanic lapilli with an aerodynamic shape. However, volcanic lapilli generally contain volcanic components, which are lacking in the spherules of Taihu Lake. In addition, no volcanic eruption during the Holocene has been recorded in the Taihu Lake area, suggesting they are not volcanic lapilli. That leaves the impact hypothesis as the most viable.

The iron-rich concretions of Taihu Lake are similar to impact-formed accretionary lapilli, which are best explained as fallout particles from an impact plume. This supports our hypothesis of the origin of the Taihu Lake basin being an airburst impact, which noted above. The main mass of data so far show that the airburst-impact hypothesis is an entirely reasonable explanation for the observation of the iron-rich concretions in the distinctive silty layer [12, 13]. Thus, it is worth to carry on more work to test the airburst-impact hypothesis. Here we report our progress to date.

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