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CAUSES AND COUNTERMEASURES FOR CHAOHU LAKESHORE COLLAPSE

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ABSTRACT: By interpreting the remote sensing data of aerial photos and satellite images in different time, combining with field investigation, landform and water level observation, collecting data of weather, hydrology in Chaohu Lake, Anhui Province from 1957 to 2003, the reasons for collapse of Chaohu lakeshore were analyzed. The results are as follows: 1) The collapse of the Chaohu lakeshore is controlled macroscopically by two sets of north-east and the north-west faults, and the degree of collapse is determined microcosmically by lithology. 2) The constant change of water level, resulting from precipitation, wind speed and its direction, is one of the main reasons for intermittence collapse. 3) The soil and water loss or mud and sand filling up, resulting from artificial factors, such as inconsequence control of Chaohu sluice or irrational agricultural and industrial activities, etc., can uplift the lake′s bed and drive water level up. The high water level also results in the collapse. Judging from the above mentioned reasons for the collapse, we have proposed some countermeasures: 1) Putting the lakeshore slope protection project such as stone and cement mortar into practice, and upstream slope should be 1∶2.5 or 1∶3, some parts of them should be 1∶4, if they were not stable. The back slope, which is from Gui Mountain to Zhongmiao Temple, should be 1∶1.5–1∶3. 2) Constructing a greenbelt for the lakeshore, planting some vegetation such as osier, bulrush and poplar, to resist waves between the high and the low water level. 3) Controlling Chaohu Lake water level scientifically. Corrosion of lakeshore that contains gravel clay and ferruginous-manganese concretionary structures, can decrease at low water level. 4) Renovating Chaohu Lake drainage area, strengthening the administration and supervision, breaking regionalism and establishing special administration organization.

KEY WORDS: lakeshore collapse; countermeasures; multi-phase remote sensing; Chaohu Lake

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1 INTRODUCTION

Chaohu Lake (30°25′28"–31°43′28"N, 117°16′54"–117°51′46"E) is located in the center of Anhui Province, and is one of the five biggest freshwater lakes in China. The lakeshore′s collapse is one of the main environmental hazards of the lake. The collapse has destroyed many fields and affected the industries so much that it harmed demotic lives and wealth. For example, the rocky lakeshore has backed off 12m during the last 50 years at Lijiawa (31°31′53"N, 117°43′50"E). As concerns the collapse issue, more is done on riverbank collapse than the lakeshore′s (BAO and LI, 2003; SUSAN *et al*., 1999; HU and WU, 2000; LU and SU, 2002; JACKSON, 2002; YANG and LU, 1998). The researches on Chaohu lakeshore′s collapse are also very limited, and only a few scholars made qualitative analysis on the causes and evolution of the collapse (SUN, 2000; YANG *et al*., 1999). It was still at the moment of sensibility or experience for the research on collapse. There are filling up or collapse at the different parts of Chaohu lakeshore. In this paper, by interpreting the remote sensing data of aerial photos in the 1960s, 1970s, 1990s and TM satellite images in different times, combining with field investigation, landform and water level observation, collecting data of weather, hydrology in Chaohu Lake from 1957 to 2003, the causes of collapse of Chaohu lakeshore were analyzed from tectonism, fracturation, stratum′s lithology, weather factors and artificial factors, etc. And then countermea-

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sures for the collapse were put forward.

2 CLASSIFICATION OF LAKESHORE AND DISTRIBUTION OF COLLAPSE

Yanshan Movement in the Mesozoic and the Himalayan Movement in the Cenozoic contributed greatly to the establishment of Chaohu Lake drainage area. North of the drainage area is denudation upland, which is from the west of the Zhegao River to Cu Town, belonging to the Zhangbaling exfoliation dome; structural denudation low-mountain relief in east, which is east of Zhegao-huaili, belonging to the Xiayangzi syneclise; denudation hillslope in west, which is west of Cuzhe-Huailin, between the Jianghuai elevated plain and Beihuaiyang geosynclinal drape belt. The famous Tan-Lu fault belt goes through the Chaohu Lake basin. And there are also many faults around the basin (Fig. 1).

2.1 Classification of Chaohu Lakeshore

When the water level is about 8m, the length of Chaohu lakeshore is almost 184.66km. The lakeshore can be divided into three types by the different lithology.

2.1.1 Rocky lakeshore

The bedrock lake shore is approximately 24.5km, with points stretching into the lakeshore, but the quay of points is short in lake. In the east lakeshore, there are some points such as Guishan point, Dayuanzi point, Lijiawa point, Yuanjiashan point, etc. In the north shore, there are also some points from Liujiafan to Zhongmiao. For bedrocks are cavitations damaged by lake breeze and waves, there are many caves at points. Rocky lakeshore′s lithology is mainly gray gritstone in the Jurassic and red gritstone in the Cretaceous. The landform of bedrock lakeshore is denudation low-mountain or sub-mountain foothill.

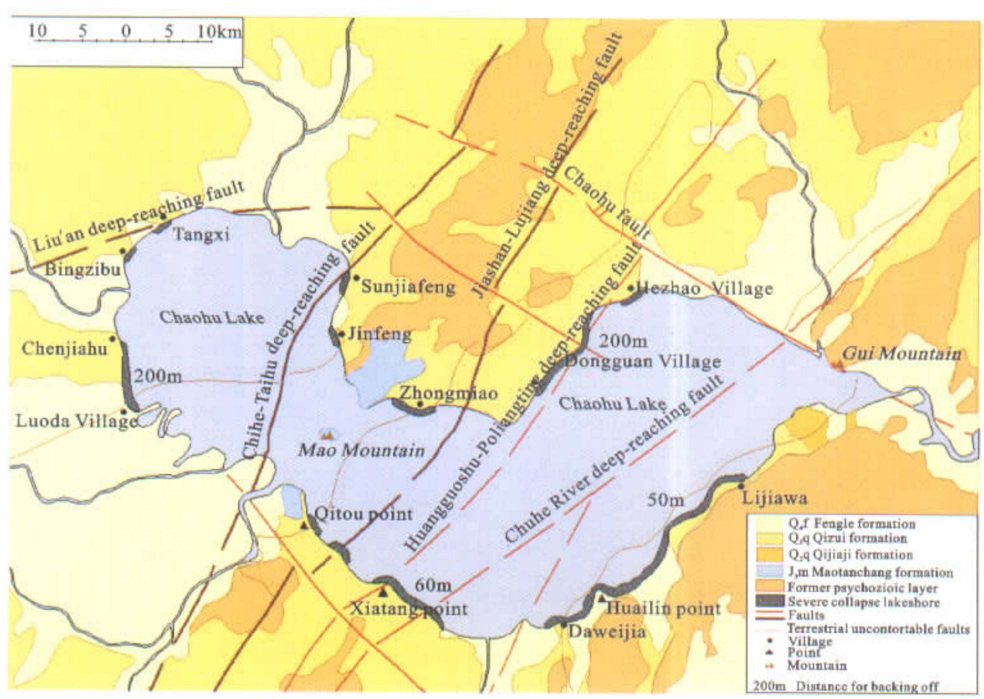

Fig. 1 The distribution map of collapse, faults and strata in Chaohu Lake (BI, 1987)

2.1.2 Sandy lakeshore

The loam sandy lakeshore is about 95.76km long, and can be shaped into wide shallows by the current and waves, because of its loosening structure and strong osmosis. It is distributed at the river mouth around the lake, such as the Hangpu River, the Pai River, the Nanfei River and the Zhegao River. The lakeshore′s lithology is mainly gray loam sand in the Holocene. The landform of sandy lakeshore is shallow.

2.1.3 Clayish lakeshore

The clayish lakeshore is about 64.4km long, and does not develop into a lake beach. For lakeshores′ collapse and eddy erosion, the clayish lakeshore develops into irregular serrations. The lakeshore′s lithology is clay, which is a filemot or palm ferruginous-manganese concretionary structure in the Late Pleistocene. And the concretion has a diameter of 0.5cm approximately. The landform of clayish lakeshore is hummocky upland, which is also the secondary denudation terrace and steep shore.

2.2 Distribution of Lakeshore Collapse

There are different situations of filling up or collapsing at the different parts of the lakeshore of Chaohu Lake. The collapses take place at the clayish lakeshore, which is secondary denudation terrace. The rocky lakeshore is distributed at low-mountain relief and it is collapsed lightly. Sediment, which are from rivers around the lake, fill up the loam sandy shallows. It does not collapse when its wide lakeside is at normal water level. So we can divide the collapse lakeshore into three parts: severe collapse lakeshore, hypo-severe collapse lakeshore and light collapse lakeshore (Table 1).

3 CAUSES OF LAKESHORE′S COLLAPSE IN CHAOHU LAKE

3.1 Geologic Structure of Chaohu Lakeshore

3.1.1 Fault factors

Eight faults, which develop around the basin, control the shape of Chaohu Lake. Firstly, the Chaohu fault is from Changfeng County to Dongguan Town of Hanshan County. It extends to the northeast of the lake and is by way of Gang Town, Hefei City and Chaohu City. Its length is about 95km (Fig. 1). The second fault parallels with the Chaohu fault, it is from Jiongyang Town to Fuxing Town and its length is about 43km. The third fault extends to the southwest of the lake and parallels with the Chaohu fault. It is from Shengqiao Town to Beishan Town and the length is about 60km. Chihe-Taihu deep reaching fault, Jiashan-Lujiang deep-reaching fault, Huangguoshu-Poliangting deep-reaching fault and Chuhe River deep-reaching fault extend to southwest. The Chuhe River deep-reachingfault is from Tingzi Mountain to Dajian Mountain. All these faults walk through the lake. The last fault is Liu′an deep-reaching fault that is from Liu′an to Feixi County and its length is about 140km.

Table 1 Three types of collapse lakeshore in Chaohu Lake

Lakeshore type	Length (km)	Proportion in gross lakeshore (%)	Lithology of lakeshore	Landform of lakeshore	Character of collapse	Distribution
Light collapse lakeshore	24.50	13.27	Gray gritstone in the Jurassic and redness gritstone in Cretaceous	Denudation low-mountain relief or sub-mountain region	Cape, steep shore, caving bank	Gui Mountain, from Dayuanzi to Lijiawa, from Sunjiafeng to Zhongmiao
Hypo-severe collapse lakeshore	20.02	10.84	Netlike clay and gravelly clay in the Mid Pleistocene (includes quartz and chert)	Sub-mountain denudation region, thirdly terrace	Cape, steep shore, caving bank, serration lakeshore	From Lijiawa to Daweijia and east of lakeshore
Severe collapse lakeshore	44.38	24.03	Filemot or palm ferruginous-manganese concretionary structures in the Late Pleistocene (± 0.5cm)	Thirdly denudation terrace, steep shore	Cape, caving bank, steep shore	Qitou point, Xiatang point, from Luoda Village to Chenjiahu

Linear characteristics of those faults are clear in TM satellite images, and we can conclude that all of faults control the shape of the basin. For example, the Chuhe River deep-reaching fault controls the lakeshore of about 43.2km in southeast. This results in collapse paralleling to the fault. The newest developed Chaohu fault, which split the Chuhe River deep-reaching fault and Tan-Lu fault belt, controls the straight northeast lakeshore of about 22.8km; Huangguoshu-Poliangting deep-reaching fault controls the north lakeshore of about 15.9km; Chihe-Taihu deep-reaching fault controls the lakeshore whose length is about 8.8km; The fault, which is from Jiongyang Town to Fuxing Town, controls a lakeshore of about 14.1km; the fault, which is from Shengqiao Town to Beishan Town, controls the southwest lakeshore of about 27.5km; Liu′an deep-reaching fault controls the northwest lakeshore of about 19.8km. The total length that is controlled by faults is over 152.1km, namely 82.4% of the whole-length of lakeshore.

Lakeshore′s collapse is also affected by faults during the evolution of Chaohu lakeshore. From Fig. 1, we can find out that Tangxi and Bingzibu is the crossing of Liu′an deep-reaching fault and lakeshore, Sunjiafeng is the crossing of Chihe-Taihu deep-reaching fault and lakeshore, Qitou point is the crossing of Jiashan-Lujiang deep-reaching fault and lakeshore, Xiatang point and Dongguan Village are the crossings of Huangguoshu-poliangting deep-reaching fault and lakeshore. Those are all severe collapsed areas. Faults develop at all the crossings, so the geologic structures are instable. All these factors influence condition of lakeshore′s collapse.

From Fig. 1, we can also find out that there are three terrestrial facies and depression unconformable faults cutting through the basin. The unconformable faults cross the lakeshore at Jinfen, Luoda Village, Qitou point, Lijiawa, Daweijia, etc., and all the crossings are severely collapsed areas. To sum up, faults are the most important factors that affect the Chaohu lakeshore′s collapse during its evolvement.

3.1.2 Lithology of lakeshore's collapse

From these research and previous study (SUN, 2000), we can draw profile map of three types of lakeshore′s collapse with the aid of field investigation (Fig. 2). Field investigation indicates: lithology of severe collapsed lakeshore is clay of Qizui formation in the Late Pleistocene (Q_3q). The soil horizon has ferruginous-manganese concretionary structures; the clayish minerals are mainly vermiculite, chlorite and little montmorillonitic clay, quartz, etc. So the soil horizon has the characteristic of dilating when it is mixed in water, or contracting when it becomes dry. Some perpendicular cleftiness has developed, there are many clefts in steep lakeshore, and the lakeshores will collapse severely when they are eroded by waves, or soaked by rainwater. Caverned banks develop when lakeshores are eroded by waves, then collapse due to the effect of gravitation (Fig. 2A). Hypo-severe collapse lakeshore can be divided into two layers: the upper layer, which has ferruginous-manganese concretionary structures, is clay of Qizui geological group in the Late Pleistocene (Q_3q); the nether layer, which is made from quartz and firestone, is gravelly clay of Qijiaji geological group in the Mid Pleistocene (Q_2q). In general, the lake water can not arrive the upper layer at low water level, and the nether layer is not eroded seriously for it is concretionary and close gravelly clay. But it is a different case when the rain is centralized, the water level will be high enough to arrive the clay of upper layer, and then collapse occurs rapidly and violently (Fig. 2B). In effect, collapse of this type is lighter than the first one; Light collapse lakeshore can also be divided into two layers: the upper layer is clay of Qizui geological group in the Late Pleistocene (Q_3q) and the nether layer is gray gritstone of the Jurassic and red gritstone of the Cretaceous. The top of gritstone is 8m above high water level, so waves can not erode the upper layer, and only cavities develop (Fig. 2C). The upper layer is only eroded by rain and gravitation. Due to the difference in their ability to resist erosion, lakeshores, which have high ability to resist erosion, develop projections into the lake, while other lakeshores develop into gulfs in the lake, resulting to the scragginess of the Chaohu lakeshores (Fig. 1). For this reason, Chaohu lakeshore is called "7 gulfs and 15 points".

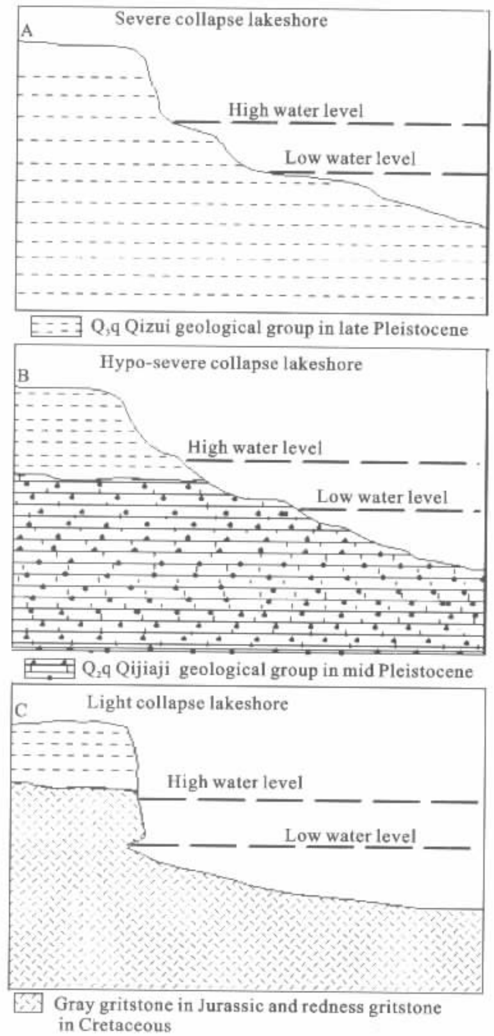

Fig. 2 Profile map of three types of lakeshore′s collapse and the corresponding lithologies

3.2 Weather Factors

The amount of precipitation in Chaohu Lake drainage area is different each year. For example, the average precipitation from 1957 to 2003 was about 1034.9mm; the average precipitation from September to next February is 41–52mm during those years; March to May is 77–144mm; June to August is 147–206mm, and the precipitation is about 642mm in July, 1991. The precipitation is centralized in summer, so floodwaters are formed in Chaohu Lake. For the effect of the Changjiang River water level, Chaohu Lake often has higher water level in the rainy season; the alteration of water level is between 3–4m in the rainy season from June to August and drought season from September to the next February. So the alteration is great in a year. And annual alteration of water level is also great. For example, the highest water level in 1954 was over 12.93m, but the average water level is about 8.03m. The seasonal or annual alteration of water level is very important for lakeshore′s collapse, because the alteration affects water-content in the rocky lakeshore, and the water-content enables the mineral expand or shrink, which in turn influences the collapse of lakeshore. That is to say, the clay or gritstone in the cranny of lakeshore hardens under dryness, but when it was mixed with water, it softens or muds. Then collapses happened, as it cannot uphold itself gravitation, especially the lakeshore that contains high hydrophilic mineral, such as montmorillonitic clay, etc. In conclusion, collapse often happens when the lake is at high water level, especially in rainy season.

At the same time, wind speed and its direction also affect collapse greatly. Wind is the root cause of comber. Wind speed and its direction affect the comber′s intensity and direction, which are important factors for undercutting, and undercutting may develop into collapse. Chaohu Lake drainage area is in monsoon climate zone, the wind direction is east in February and March, southeast from April to July, northeast from August to October, northwest from November to next January, and the wind speed is greater from April to July and from November to the next January. For example, the average wind speed was 2.9m/s from 1957–2003; the greatest wind speed was 13.8m/s in land and 18m/s on the lake surface. Owing to the perennial aeolian erosion, clefts develop, especially due to the northwest and southeast wind. From Fig. 1, we discover that severe collapse areas are in the southeast and the northwest of the lakeshores, which are from Lijiawa to Daweijia and from Dongguan Village to Hezhao Village.

3.3 Artificial Factors

Chaohu Lake drainage area is very famous for its pleasant weather and abundant products, and it is also one of the earliest human habitats in history. For new tilths, the lake′s marshy environment has been destroyed from the 1950s, especially after the Chaohu sluice was build. Since the sluice has cut the free change of water between Chaohu Lake and the Changjiang River, Chaohu Lake has become a half artificial lake. The water level is high enough to touch the soil horizon, and collapse happened frequently. For this reason, plenty of deposits have filled up the basin, especially since the 1980s (LI, 2002). At the same time, industrial and living wastewaters heavily enter the basin. Besides, it also keeps high water level in winter for development of fishery. All of those can prevent the growth of aquatic plants, which are essential for the scattering of waves. The absence of these plants account for farther collapse. In addition, some illogical project would also accelerate collapse. For example, the bank slope used to establish balance after collapse, evolvement of the collapse was limited, but now we chucked stones on the bank slope, balance was distorted, and then collapse happened again.

4 COUNTERMEASURES FOR COLLAPSE

4.1 Reducing Gradient of Slope for Protecting Bank

It is a project, which is based on the geologic structure of the Chaohu lakeshore. Firstly, the gradient of slope should be reduced, for example the steep lakeshore from Lijiawa to Daweijia. Combined with the analysis of landform of the lakeshore, in order to ensure stability of soil body of lakeshore, upstream slope should adopt the gradient of 1∶2.5 or1∶3, some parts of them should be 1∶4. The back slope, which is from Gui Mountain to Zhongmiao, should be 1∶1.5–1∶3. For the need of traffic, the top of slope should be 7–10m high and 6–8m wide.

The primary materials of protective bank in Chaohu Lake are desiccated bondstones, but it is not ideal for the strong winds and waves. Water Conservancy Department has ameliorated the measure. For example, we poured concrete directly into desiccated bondstones, but found that the superstratum of concretes can not combine perfectly with substrates. And the substrates were also eroded by water, then collapse happened due to gravitation or undercutting. We could have the unitary sash of desiccated bondstones to increase the effect, but it′s too expensive to be popularized. The following measures, which have been proved effective on the Hefei Section of Chaohu Lake should be adopted, firstly we eliminate the tiny stone from desiccated bondstones, then irrigate the 10cm thick concrete on the desiccated bondstones, fully shake and equally mixed, thirdly set up 2 banks for eliminating waves. This kind of bank protection method made a good result in practice (LI and XING, 2002).

4.2 Building Greenbelt of Lakeshore

When putting the countermeasure against collapse in place, we must consider how to reduce erosion from precipitation, wind speed and so on. We could build a greenbelt on lakeshore, especially plant some plants (such as osier, bulrush, etc.) on the bottomland, which is between the high and low water level. During the experiment of the Hefei section of Chaohu Lake, we planted poplars and osiers on the bottomland. Planting of economy crops (such as cole, etc.) should be sternly forbidden in winter when the bottomlands are revealed, or it would bring on new ecological problem and cause further collapse.

4.3 Controlling Water Level Scientifically

In the Chaohu Lake, water level rises in summer and falls in winter. And its warning line is 10.5m in flood season. To fight against a flood or drought, water level must be controlled scientifically. For example, we can reduce water level when agricultural irrigation need little water in winter. The measure not only can reveal a large number of bottomlands to help greenbelt grow but also reduces water that is in contact with the clay, which contains ferruginous-manganese concretionary. In the investigation of Hezhao Village and other places in November 2003, the water level was about 8.5m that arrived at the upper layer (which is easy collapse) fitly, and collapse was accelerated. If water level was controlled at about 7.5–8m, the lake wave could only touched the nether layer that is gravelly clay, then the speed of collapse would have been reduced greatly, and there would also be about 28.56km^2 bottomland revealed for planting greenbelt (ZHANG and PAN, 1990) In addition, it is necessary to rebuild Chaohu sluice, set up ecological lock and improve the ability of exchange with the water body in the Changjiang River and reform the ecological environment in Chaohu Lake drainage area.

4.4 Carrying out Ecological Comprehensive Administration

The erosion of soil and water should be controlled. First, we can build ecology forest in the drainage area (about 9258km^2) to improve the forest coverage rate (WANG, 1994). Administrative supervision and management should be strengthened, such as herd, excavating turf; destroying forest arbitrarily should be prohibited heavily. Since Chaohu Lake drainage area extends across Feidong County, Feixi County, Hefei City, Chaohu City and Lujiang County, it is difficult for a certain city or county to manage the whole lake. Regionalism should be broken and set up a special managing organization, similar to Comprehensive Administration of Huaihe River.

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