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STRUCTURAL AND GEOMORPHOLOGICAL EVOLUTION OF HUANGSHAN (YELLOW MOUNTAIN), ANHUI PROVINCE, CHINA

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ABSTRACT

Huangshan (Yellow Mountain) is an 1864-m granite massif situated at 30 10 N and 118 11 E, south of the lower reaches of the Yangtze River. The granite formed during the Early Cretaceous and was subsequently uplifted several times along faults. After the initial uplift, about 54 Ma, erosion proceeded to wear away the mountain for the next 30 Ma. By 24 Ma the Bright Summit Peneplain had formed. Renewed uplift in the Miocene along the same fault systems produced a mountain in the same place as the original one. This mountain was eroded to produce a second mature denudational in the Pliocene. Subsequent uplift has again elevated the massif and erosion is continuing. Three sets of joints and numerous faults cut the rocks of Huangshan. The joint sets are oriented E-W, N-S, and NE-SW. Faults are similarly oriented, but include some with N60W strikes.

It has been proposed that Huangshan was a site of Quaternary glaciation. However, no erosional topography or deposits on or adjacent to Huangshan appear to be glacial in origin. The granite surface of the mountain is exfoliated, spheroidally weathered, and has sheeting in places. Weathering and fluvial erosion have produced the geomorphologic features of Huangshan.

INTRODUCTION

Huangshan (Yellow Mountain) is the middle mountain of a granitic massif situated at 30 10 north latitude and 118 11 east longitude south of the lower reaches of the Changjiang (Yangtze) River in southern Anhui Province, China (Fig. 1). The mountain is about 340 km southwest of Shanghai and has a maximum altitude of about 1864 m above mean sea level. Huangshan lies in a humid subtropical area with warm summers (Espenshade and Morrison, 1978). During winter months snow falls and accumulates on the mountain. The Huangshan region is about 154 square kilometers in area and was included in the World Natural and Cultural Heritage List by UNESCO in 1990.

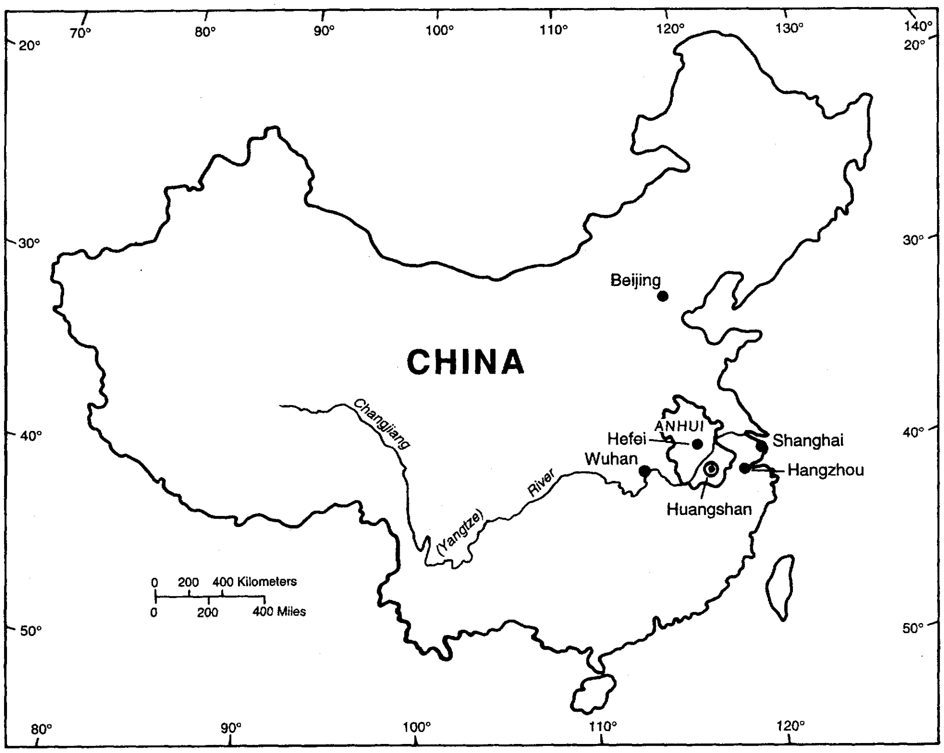

Figure 1.
Map showing the location of Huangshan in China.

The geomorphological evolution of this famous mountain has not been studied systematically before, although Lee (1936) proposedthat it had been erosionally modified by glaciers during the middle Pleistocene. The existence of these hypothetical glaciers has been debated considerably. The senior author of this paper first questioned the glacial hypothesis in 1963 (Huang, 1963a, b).

Basic research in recent years principally by Huang, and to a lesser extent by Diffendal, Yang and their colleague, P.E. Helland at the University of Nebraska Geology Department, has led to new interpretations of the geology, Cenozoic geomorphic development, and the age of the Huangshan Granitic Massif. The purposes of this report are to outline the structural development of the Huangshan region, to document structures on the mountain that may have controlled later geomorphic development, to outline the evolutionary processes of mountain geomorphology, and to resolve the questions regarding the occurrence of Quaternary glaciations at Huangshan.

SURVEY OF TECTONICS AND STRUCTURE

The Huangshan region was located at the northern margin of a peninsula of the Yangtze Block during the Precambrian (Fig. 2). Whole rock Samarium-Neodymium (Sm-Nd) isochron ages for rocks in this block range from 1.03 to 0.93 Ga (Chen *et al.*, 1991). The shallow trough of the Yangtze Block lay to the north of the peninsula, while a remnant sea basin and the South China Block lay to the south.

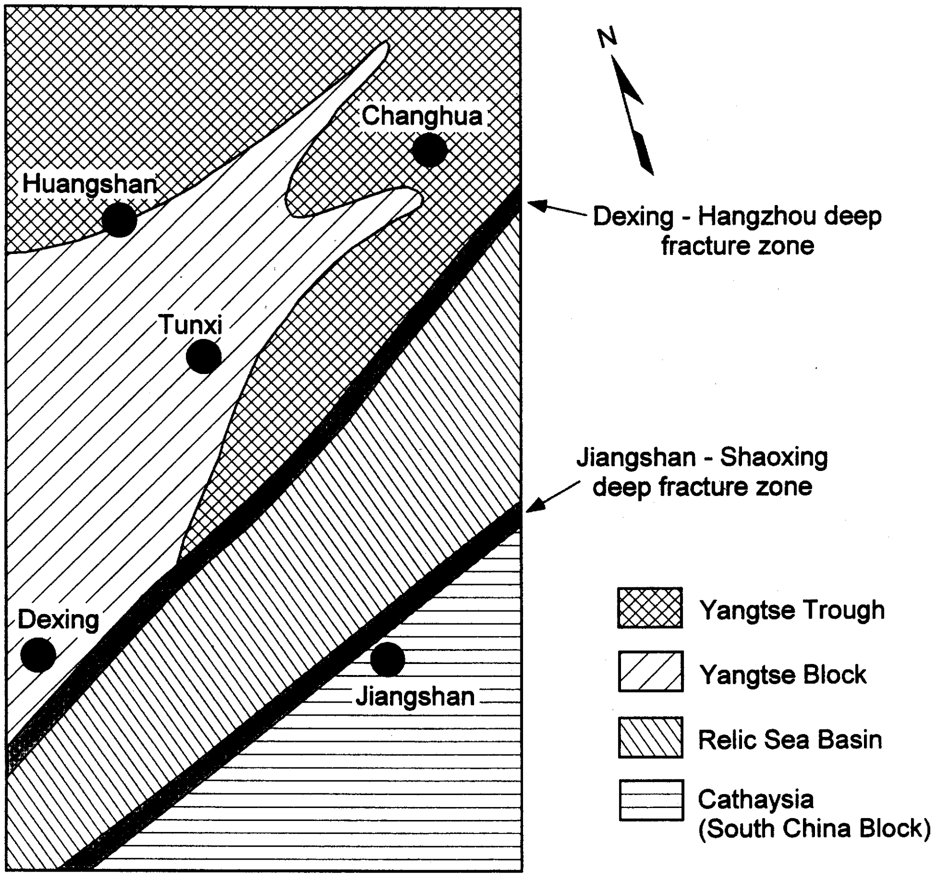

Figure 2.
Generalized diagram of paleogeography of the Huangshan region about 1.0 Ga ago.

The South China Block was subsequently subducted toward the Yangtze Block. The two blocks collided with the loss of the remnant sea basin about 0.8 Ga ago. The former site of the paleo-peninsula of the Yangtze Block was submerged to become a sea basin about 0.7 Ga. Cambrian, Ordovician, Silurian, Carboniferous, Permian, and Triassic deposits accumulated in the basin until about 0.2 Ga. Regional uplift in the Late Triassic formed land. Later in the Mesozoic this region was strongly compressed due to subduction of the Pacific Plate under the eastern margin of the Asian continental lithosphere. Parallel folds with NE-SW doubly plunging axes were generated and granitic magmas were intruded during parts of the Cretaceous Period (Wang, 1989). Newly obtained 40Ar/39Ar isochron ages show that the Taiping Granitic Batholith is about 137 Ma old and the Huangshan Granitic batholith is about 125 Ma old (Zhou *et al.*, 1988). A granitic stock located at the top of Huangshan is called the Shizilin Granite (Fig. 3).

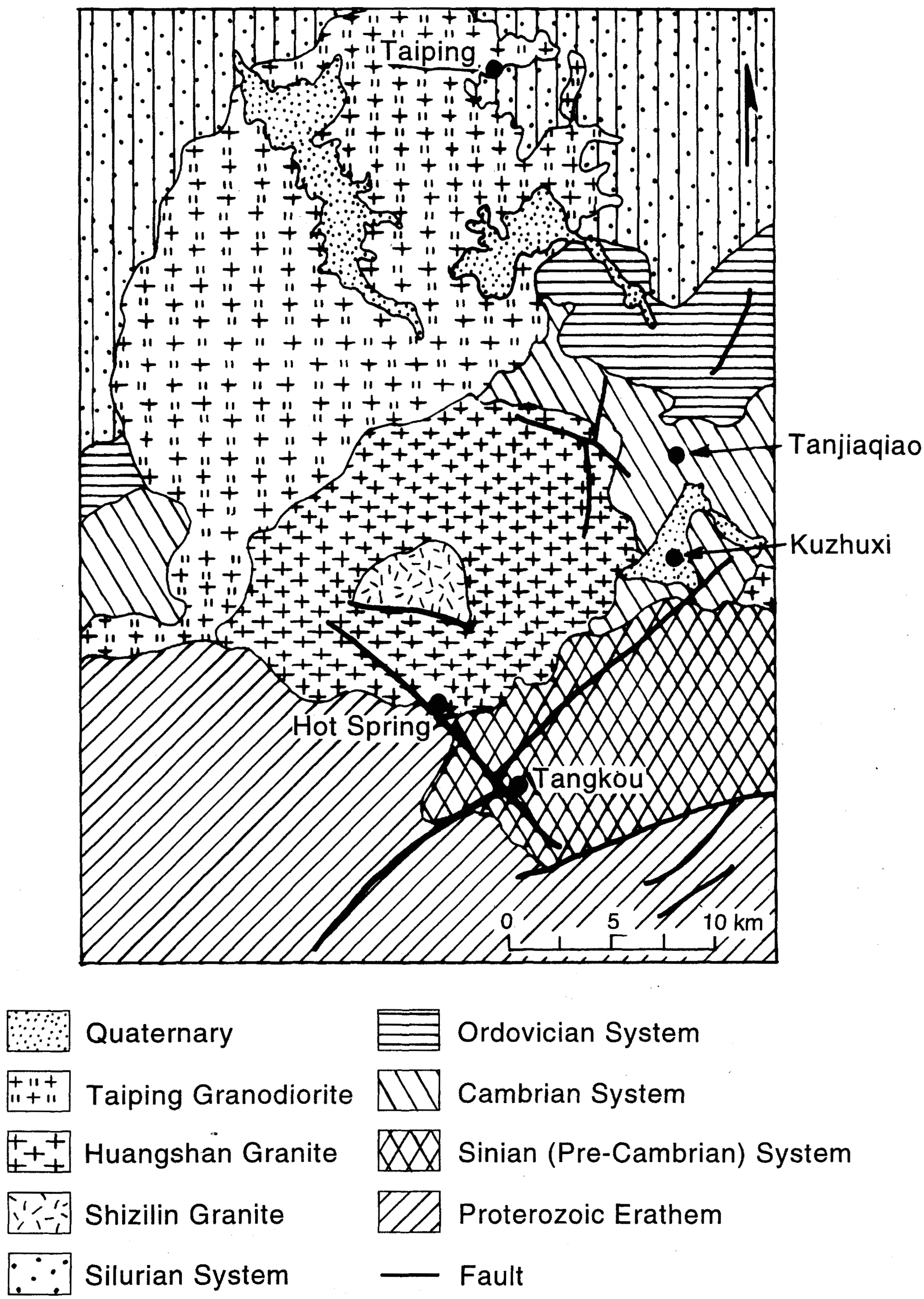

Figure 3.
Enlarged geologic map of Huangshan and adjacent piedmont areas (modified after Wang, 1989).

While the structural development of the Huangshan area has been worked out in detail by Wang (1989), other studies covering wider areas can be used to put the more local picture of geologic development of southern Anhui province into the larger regional geologic framework. Among these are those by Terman (1974), Lu *et al.* (1983), Zhang (1983), Bureau of Geology and Mineral Resources, Jiangxi Province (1987), Chen (1989), and Meyerhoff *et al.* (1991). The latter publication shows maps indicating that parts of the region have undergone shearing, tension, and/or compression at times in the Cenozoic and that earthquakes and hot springs indicate that these tectonic effects continue there. Major fault trends near and in the Huangshan area are mostly NE and NW, but some trend nearly E- W. Lu *et al.* (1983) report that lineaments observed on Landsat images of eastern China mostly strike NE, NNE, and NNW, although there are some that have directions that are nearly E-W and N-S.

FEATURES ON LANDSAT IMAGES OF HUANGSHAN

A 100% cloud-free Landsat image of an area in China that includes Huangshan taken on 10 March 1989 (Fig. 4), shows a remarkable correspondence of features with those tectonic elements mapped by Wang (1983). The areas underlain by igneous intrusives, the fold belts, and many of the faults match or very closely match features on the image. An enlarged part of the image, showing the higher parts of Huangshan in lighter tones, reveals a series of linear features (Fig. 5). The traces of many of the most prominent of these linear features are shown on Figure 6. Some lineaments pass near Huangshan, some pass through the mountain, but most appear to be restricted to the granite massif. Most lineaments are nearly straight, a few are curved, and two appear to be circular (Figs. 5, 6). Most of the faults passing very close to or cutting parts of Huangshan (Fig. 3) appear to correspond to lineaments (Fig. 6) and one of the circular features (Fig. 6) matches the location of the Shizhilin Granite Stock. A Rose Diagram (Fig. 7) of the Huangshan lineaments shows NNW, NNE, NE, and E-W trends. Of these the generally E-W striking lineaments appear to be most abundant. General study of lineament distributions crossing Huangshan (Figs. 5, 6) seems to show that the E-W trending lineaments occur across most of the massif, NNW ones are most common in the northwest part, NE and NNE are dominant elsewhere on the mountain.

JOINT SETS AND FAULTS CUTTING HUANGSHAN

Extension jointing on Huangshan is common, especially in granites exposed along and near the steep sides of the mountain. Joint sets trending generally NNW, NNE, NE and E-W are present. Most of these joints are vertical or nearly vertical and intersect to form parallelogram, triangular, and other multiple- sided outlines on exposed surfaces (Fig. 8).

Weathering and subsequent removal of decomposed rock by running water has enlarged the joint traces in many areas along the mountain's sides to form pinnacles of granite (Fig. 9). Sheeting, a form of flat-lying extension jointing, is also common in these areas, where it forms a fifth set. The sheeting combined with two or more of the other joint sets has broken the granite into blocks and large tabular pieces that can and do move downslope in rockslides, rockfalls, and other types of mass movement.

Major joints and faults have produced zones of weakness that running water has followed to erode valleys down the sides of Huangshan. Some faults are very obvious (Fig. 10), while others are inferred. Overall, many faults and high angle joints cutting across the rocks of Huangshan conform well to lineaments noted on the Landsat image (Fig. 5) of the mountain.

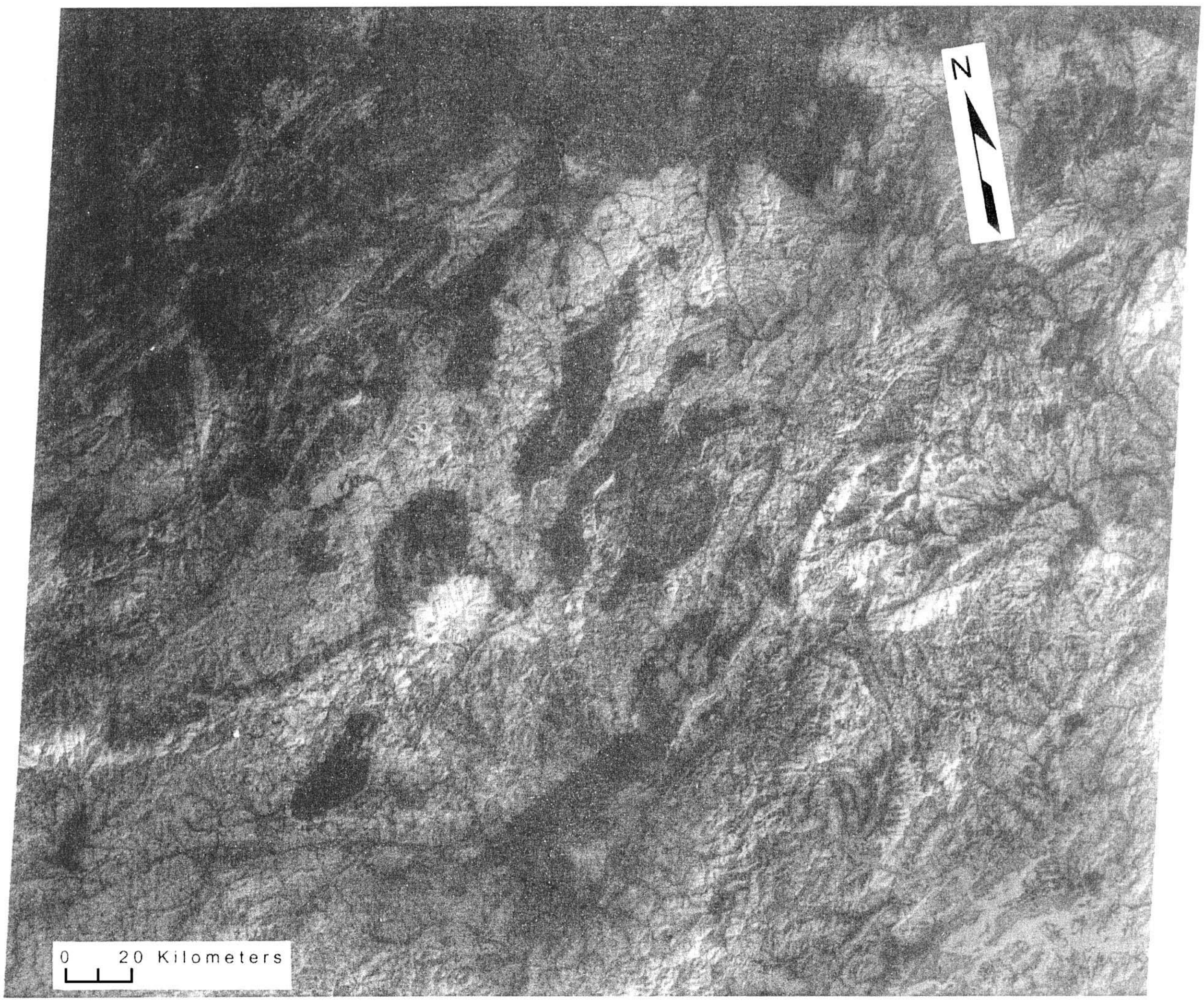

Figure 4.
Landsat image of the Huangshan region. Huangshan is light colored area near center of image.

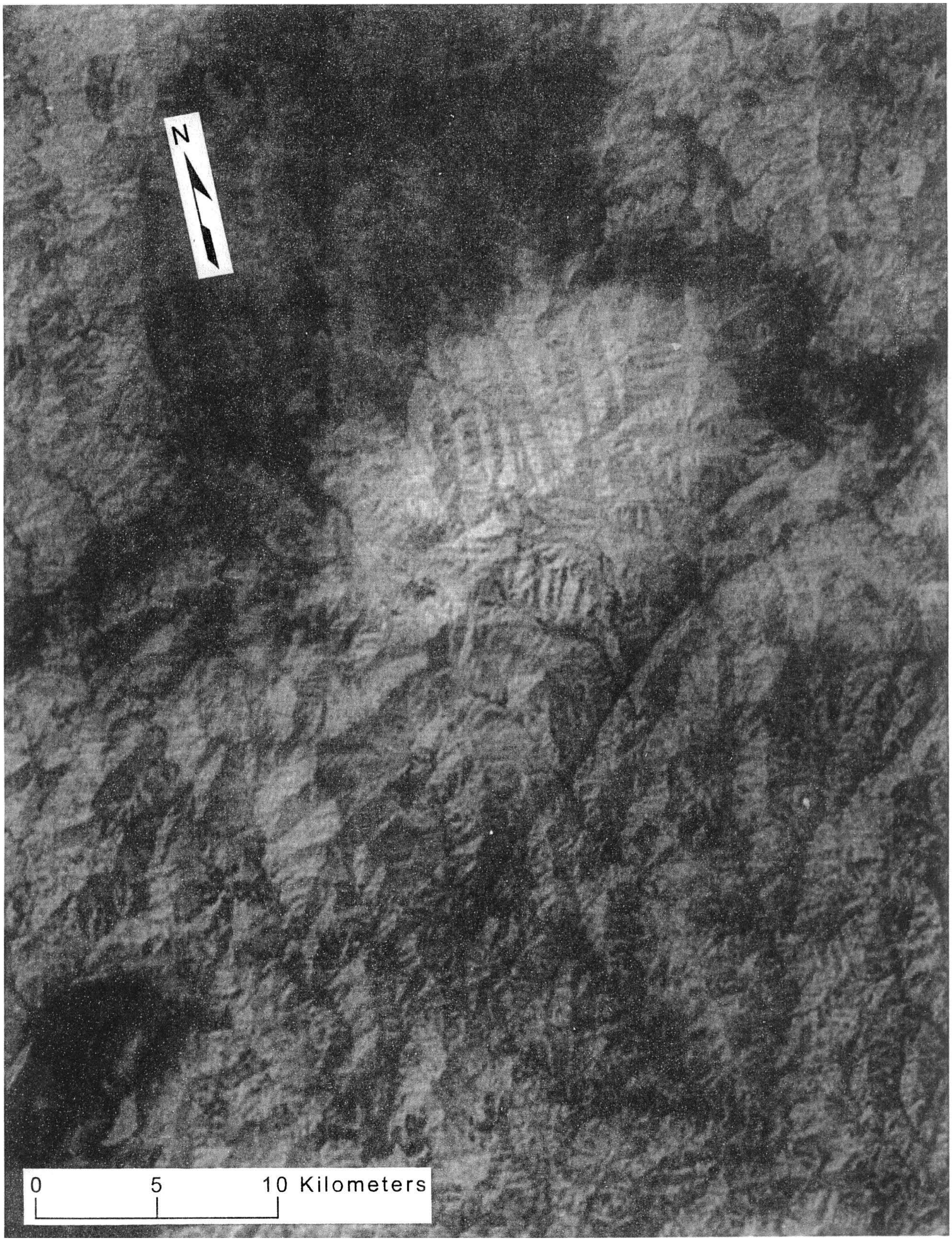

Figure 5.
Enlarged section of Fig. 4 showing the lineaments on and around Huangshan in detail.

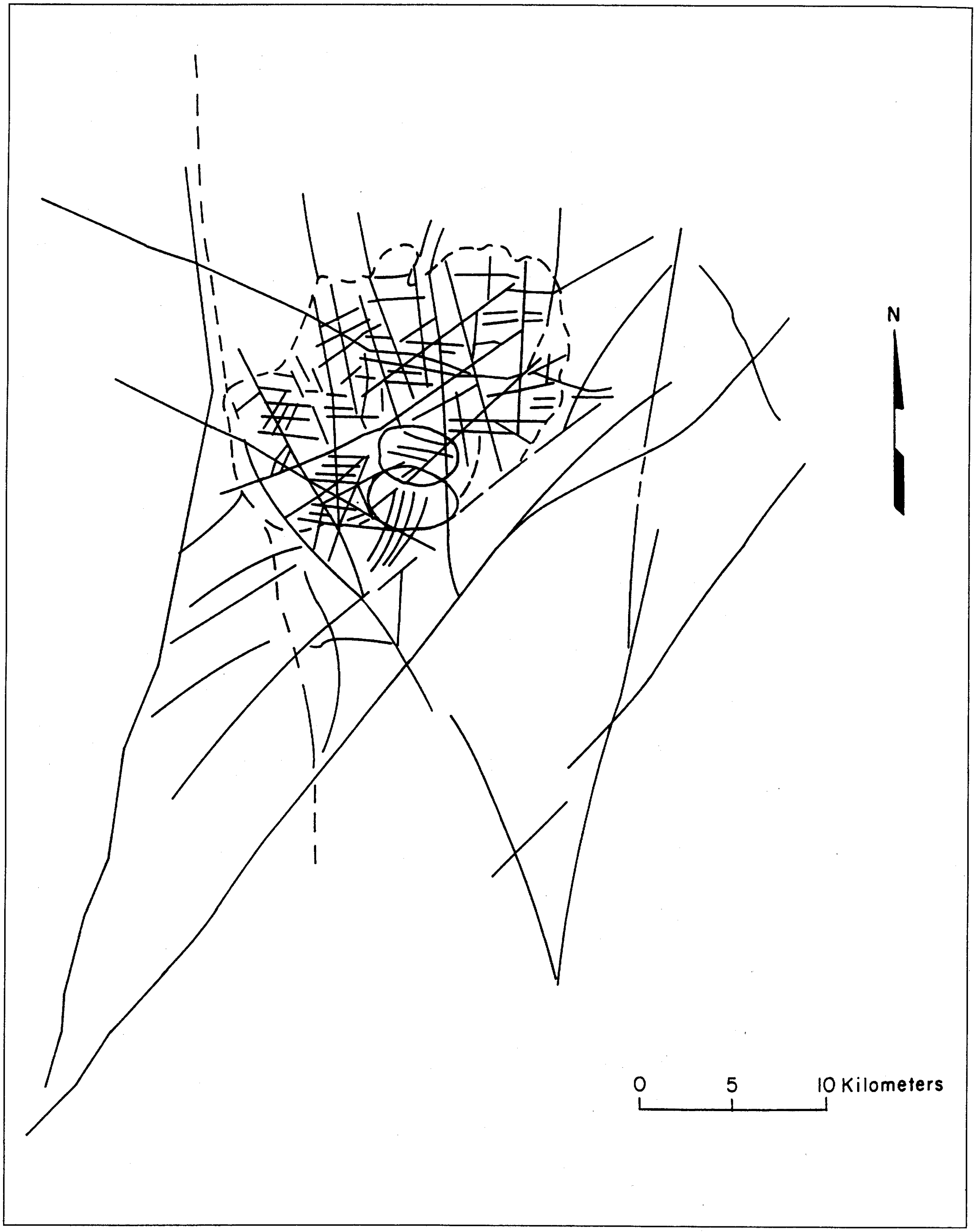

Figure 6.
Lineament map of Huangshan and adjacent areas derived from analysis of Fig. 5.

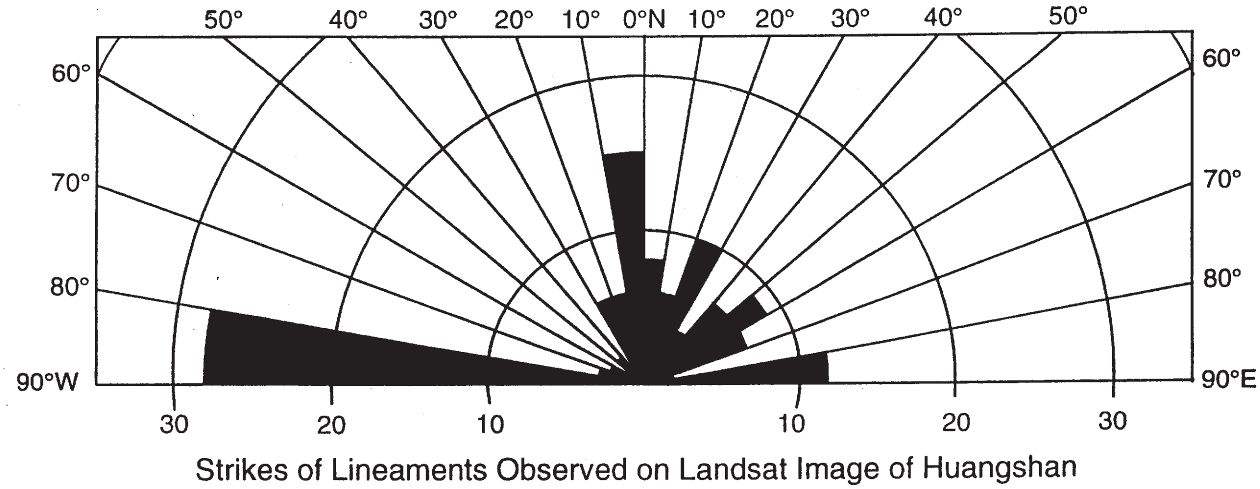

Figure 7.
Rose diagram of strikes of Huangshan lineaments.

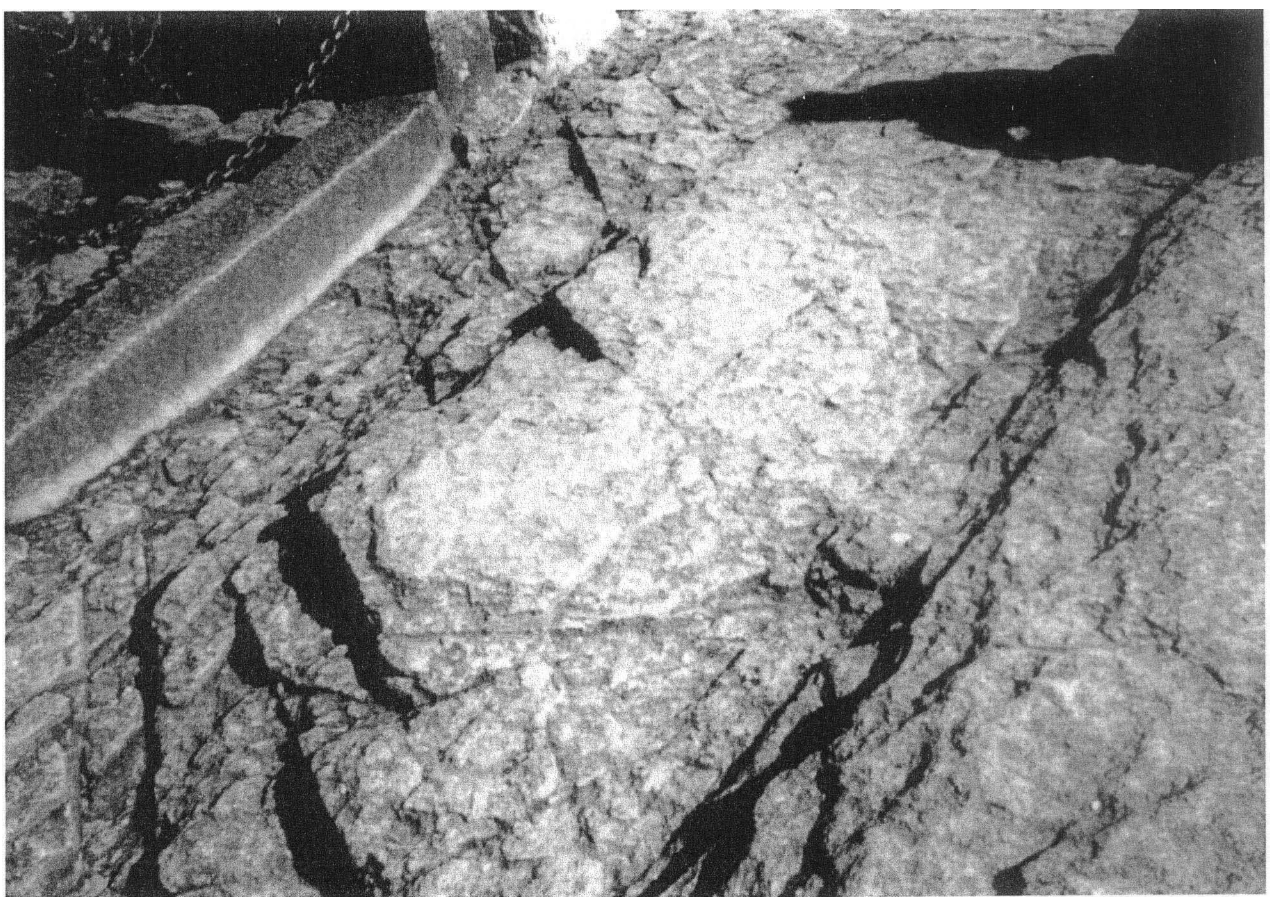

Figure 8.
Three sets of nearly vertical joints in Huangshan granite.

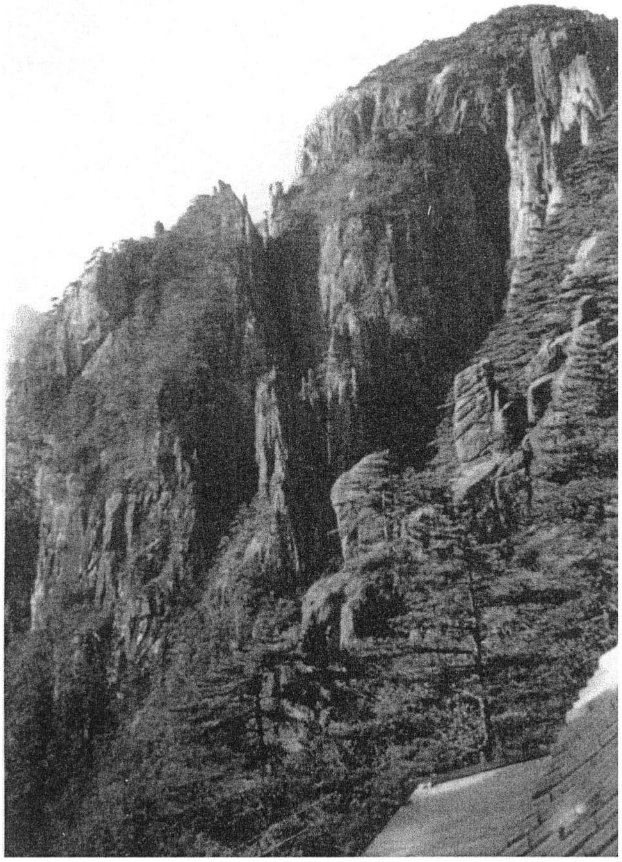

Figure 9.
Tabular weathering Huangshan granite showing vertical joints and sheeting.

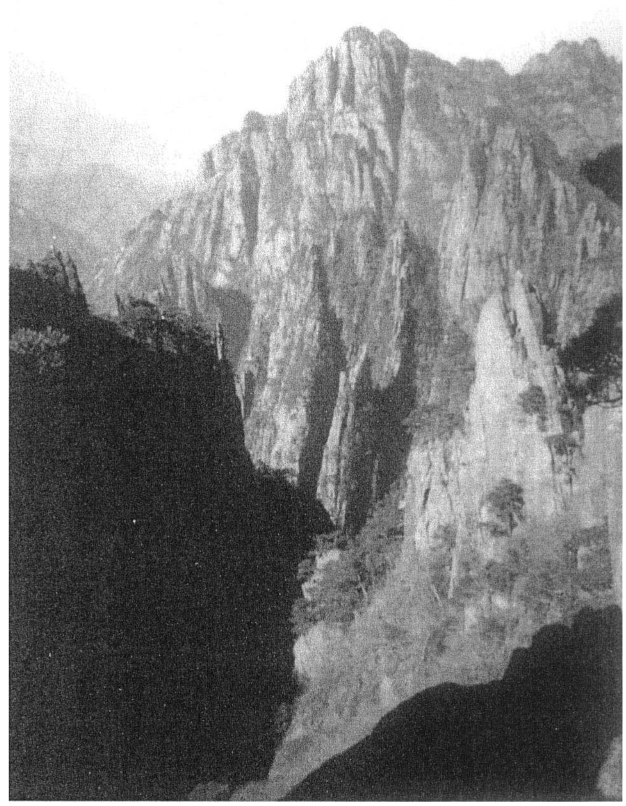

Figure 10.
Fault (top center) and jointing in the Huangshan granite.

SPHEROIDAL WEATHERING AND EXFOLIATION

Granites exposed to the climate typical of Huangshan decompose to grus. This is true on Huangshan. The blocks noted previously weather spheroidally and form rather rounded forms upon long exposure. Exfoliation is common on larger exposed granite surfaces, particularly at or near the top of the mountain. The exfoliated surface resembles such surfaces at Stone Mountain, Georgia, U.S.A., and other large mountainous granites around the world formed under similar weathering conditions. Spheroidal weathering, exfoliation, and weakness zones in the granite formed by jointing and faulting have combined with frost action at higher altitudes and the erosive action of running water on Huangshan through the Cenozoic to produce the features seen on the mountain today.

FORMATION OF PALEOGEOMORPHIC SURFACES

The Huangshan Granitic Pluton was formed about 125 Ma in the Middle Stage of the Yenshan Movement (or in the Middle Alpine Orogeny). It was uplifted by the Early Himalayan Movement in the Middle Eocene (Huang *et al.,* 1980). Its covering strata were degraded and eroded. The exposed Huanshan Granitic Pluton formed an ancestral Huangshan about 54 Ma ago (Table 1). Over the next 30 Ma the granite was eroded to a late mature stage of geomorphic development. By 24 Ma ago, near the beginning of the Early Miocene (as determined at present), the mountain had been eroded down to a landscape with about 200 m of relief consisting of relict hills (such as Bright Summit and Celestial Capital Peak) and shallow depressions (such as North Sea and Heavenly Sea) on the paleo-gradational surface (near- peneplain). The period of formation of the paleo-gradational surface has been called the Bright Summit Stage by Huang (1993a, 1995a). The height of the remnant of this surface at present is 1600-1864 m above sea level (Fig. 11).

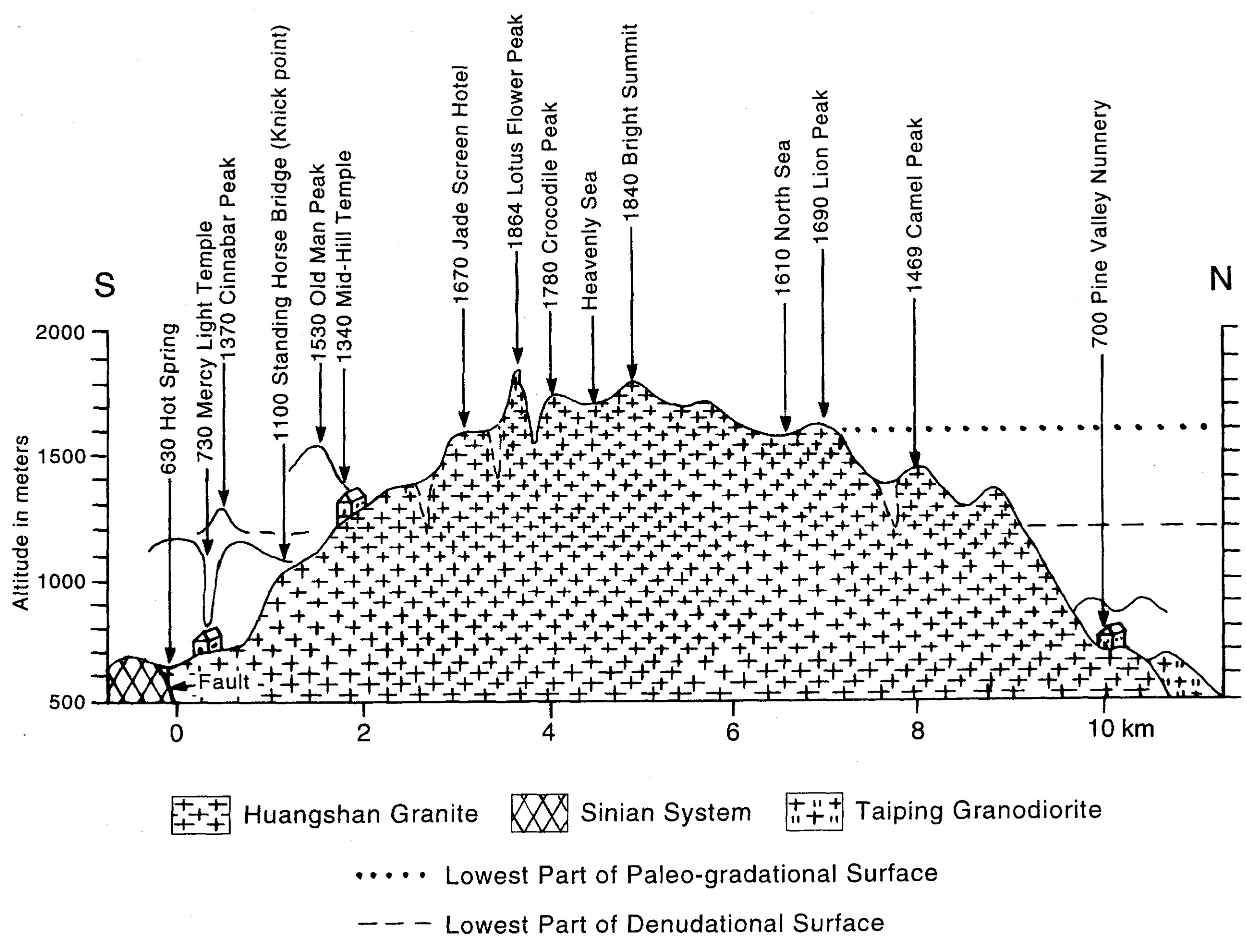

Figure 11.
S-N geomorphologic cross section across Huangshan showing the locations of topographic features and the paleo-gradational and denudational surfaces.

The Huangshan paleo-gradational surface was uplifted during the Second Episode of Himalayan Movement in the Miocene (Huang *et al.*, 1980) and subsequently partially dissected by streams flowing off the uplift to modify the central high paleo-gradational surface and to form middle-lower mountains. These lower mountains were eroded by streams to full maturity during the Pliocene and resulted in formation of a denudational surface of lower mountains and wide valleys with reliefs of

200-500 m flanking and encircling the central higher part of ancestral Huangshan. The period of formation of this denudational surface has been called the Old Man Peak Stage by Huang (1995a). The altitude of this second and lower denudation surface at present is from 1200-1500 m above sea level (Fig. 11). Remnants of the first and oldest paleo-gradational surface today form the central highest parts of Huangshan and are surrounded by remnants of the second and lower surface (Fig. 11).

QUATERNARY REJUVENATED LANDSCAPE OF HUANGSHAN

The Huangshan Granitic Pluton with its remnant Oligocene paleo-gradational surface and Pliocene denudational surface was uplifted greatly along the mountain-front fault zones (Tangkou-Kuzhuxi Fault—NE-SW and Hot Springs Fault—NW-SE) in the Late Pliocene by Late Himalayan Movement (Huang *et al.*, 1980). The granite, the surface of which had been eroded twice before to form the hills and shallow valleys of the paleo-gradational surface and the lower mountains and wider valleys of the denudational surface, was partially eroded once again by streams to form deep canyons and middle mountains (Table 1). The knick points of present headward erosion are migrating back along the bottoms of the wide valleys of the denudational surface. These knick points are at altitudes of 1100-1200 m above sea level. The knick point at Standing Horse Bridge, for example, is 1110 m above sea level. Below the erosional knick point deep V-shaped valleys have been formed by fluvial erosion mostly along faults and joints (Fig. 11).

Several of the geomorphic features described previously were thought by Lee (1936) to be of glacial origin. Lee proposed that the depressions on the paleo-gradational surface, North Sea and Heavenly Sea as they are called, were neve basins. These depressions are much shallower and smaller than neve basins. They are confluence basins of headwaters on the paleo-gradational surface, not neve basins. The wide valleys on the Pliocene denudational surface were called glacial U-shaped valleys by Lee (1936). But the valley heads of these valleys are very narrow, lack cirques, and lack valley shoulders and faceted spurs of glacial valleys. The V-shaped valley below Standing Horse Bridge has a nearly vertical wall with smooth surfaces on its eastern side. Lee (1936) noted that this surface has parallel striae (960 m above sea level) along the lower part of the valley wall and said that this was evidence supporting abrasion by glacial ice. However, the surface with striae is in a V-shaped valley, not U- shaped as would be expected if the valley had been abraded by glaciers. These striae have troughs 3-5 cm deep, 30-50 cm wide, and 1-10 m long. The troughs are irregular in shape and do not have the wide heads and narrow down valley tails typical of glacial striae. Convex coarse porphyritic crystals of potassium feldspar are aligned along the troughs and may have weathered in such a way as to produce the striated surface (Huang, *et al.*, 1985). The smooth valley wall is a result of exfoliation of granite and peeling off of granite slabs along joint planes. At present the origin of the striae is not known.

Deposits of clay, sand, gravel and boulders which accumulated at the mouths of valleys on the piedmont adjacent to Huangshan were interpreted as glacial moraine deposits by Lee (1936). The deposits have been studied since then to see if they have characteristics of glacial deposits. A Landin Discrete Map of grain size analyses showed that these deposits set in a discrete region of alluvial fans. And clay mineral assemblages from the deposits are of kaolinite and illite (Huang, 1994). These characteristics are different from glacial moraine deposits and are like those of alluvial fans and debris flows. Spore-pollen assemblages indicate a mixed evergreen and deciduous forest typical of a subtropical humid climate in the area when these sediments accumulated and not a cold glacial climate (Huang *et al.*, 1987). Helland *et al.* (1996) have also done SEM analyses of surface textures of quartz sand grains from the deposits and have found that the grains are of alluvial/colluvial origin.

Table 1. Crustal movements and geomorphological evolutionary processes affecting the Huangshan region.

Era B.P. (Ma)	**Orogeny**	**Crustal Movement**	**Relief**	**Erosion cycle**
Q 2.5	Neotectonic Movement	Uplifting stage of fault block	Middle mountain and canyon (altitude of the highest peak	(Altitude of knick point (1100–1200m)
N2 5.0		Relatively stable stage	Lower mountain, hill and wide valley (Denudational surface)	Mature stage (Old Man Peak stage)
N1	Second episode	Uplifting stage	Middle mountain	Young stage
24	of Himalayan		and canyon	
	Movement			
E3 37		Relatively stable stage	Lower hill and shallow depression (Gradational surface)	Late mature stage (Bright summit stage)
E2 54	First episode Himalayan	Uplifting stage	Middle mountain and canyon	Young stage
E1 65		Batholithic upheaval of granitic mountains		
K2 96	Late Yensham Movement	Batholith and stock formation of granite	Denudation mountains of relief inversion	
K1 143	Middle Yensham Movement	Magmatic intrusion of granite	Sedimentary covering fold mountain	

Results of studies of Quaternary climate changes in China by Huang (1963 a, b) showed that the coldest climate in eastern China occurred at the end of the Late Pleistocene and not in the Middle Pleistocene as proposed by Lee (1936). Studies of end-stage Late Pleistocene sporo-pollen assemblages from Beijing to south of the Yangtze River (Huang, 1993a, b; Huang, 1995b) revealed that the average temperature in the Huangshan region was 7 C lower than at present. Using these data, the annual temperature at the top of Huangshan in the so-called neve basins would have been about 1.7 C, January average temperatures were about -16.3 C, and July average temperatures were approximately 14.1 C. From these and average figures for the rest of the year, the calculated snowline would have been at an altitude of 2883 m, 1019 m higher than the highest peak, Lotus Flower Peak, on Huangshan. Thus, during the coldest period at the end stage of the Late Pleistocene in China (the coldest period during the Pleistocene in China) valley and piedmont glaciers could not have developed on Huangshan and the adjacent piedmont. Strong frost weathering did take place at the top of the mountain then, accelerating frost heaving, fracture enlargement, and even, perhaps, solifluction and other forms of mass movement. Overall the Quaternary geomorphic development of Huangshan proceeded under subtropical to temperate climates during that period.

CONCLUSIONS

From the foregoing the following conclusions have been reached:

1. Huangshan has a complex tectonic history that has affected the Cenozoic geomorphic history of the mountain.

2. Lineaments on Landsat images of the Huangshan region can be used to locate larger faults, joints, and intrusive bodies. Finer scale joints, joint sets, and faults, and larger comparable features match, in general, lineament trends seen on Landsat images.

3. Joints, faults, exfoliation, and spheroidal weathering combined with downslope movement, the erosional action of running water, and frost action have produced the geomorphic features on Huangshan.

4. Huangshan has been uplifted several times since it formed in the Cretaceous. Each time the mountain geomorphology has been modified significantly.

5. There is no undisputed evidence to support the idea that Huangshan and its adjacent piedmont areas were glaciated during the Quaternary.

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