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Geologia. — *Structural lineaments of the Central Asian Orogenic Syntaxis from Landsat imageries* (*). Nota I di ROBERTO BARTOLE (**), presentata (***) dal Socio A. MARUSSI.

RIASSUNTO. — Viene presentata una carta dei lineamenti strutturali della *Sintassi Orogenetica Centro-Asiatica*, carta basata sullo studio sistematico di 98 immagini LANDSAT.

Sono stati distinti 3 tipi di lineamenti sulla base della loro evidenza sulle immagini. Sulla stessa carta (scala 1 : 4.000.000), sono state riportate le aree di più recente ringiovanimento, quelle di più recente invecchiamento ed i conoidi alluvionali di maggior evidenza.

1. The aim of this article is to present the annexed map on a scale of 1 to 4 million of the structural lineaments of the *Central Asian Syntaxis* derived from the analysis of 98 LANDSAT imageries. The analysis has been carried out in an objective manner, avoiding subjective interpretations as much as possible.

The imageries that have been analyzed cover an area comprised between longitudes 66° to 82 °E and latitudes 30° to 42° N. It includes the western Tien Shan, the western part of Kun Lun, the Pamirs, the north-eastern part of the Hindu Kush, the Great Karakorum, the Kashmir Himalaya and the Salt and Sulaiman ranges. The imageries which have been used cover only those areas which include relief.

The present map thus extends the previous work of C. Ebblin (1976) to a more comprehensive area.

The lineaments and their appearance are represented in the map by symbols which proved particularly suitable. The map further includes data referring to morphological peculiarities relevant in the detection of recent crustal movements: thus, areas of most recent rejuvenation, of most recent fluvial deposition and the most striking alluvial fans are also represented.

The work has been based on black and white LANDSAT imageries furnished by the EROS Data Center. The imageries were obtained from the two space observatories Landsat I (1972) and Landsat II (1975). These satellites were designed to provide earth surface images of quadrilaterals of 185×185 km from a polar orbit at an altitude of about 900 km. Each satellite carries 3 data acquisition systems and a multi-spectral scanner which acts as the primary sensor system. This scanner makes it possible to obtain imageries

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of the same quadrilateral in four spectral bands in the visible and near-infrared portion of the electromagnetic spectrum. These four bands are:

– band 4 (green band, 0.5–0.6 micrometers): emphasizes areas of shallow water;

– band 5 (red band, 0.6–0.7 micrometers): emphasizes agricultural features;

– band 6 (near-infrared band, 0.7–0.8 micrometers): emphasizes vegetation, the boundary between land and water and landforms;

– band 7 (second near-infrared band, 0.8–1.1 micrometers): provides the best penetration of atmospheric haze and also emphasizes vegetation, the boundary between land and water and landforms.

2. Landsat imageries are available in various scales ranging from the largest 1 : 250.000 (size 90×90 cm) to the smallest 1 : 3.369.000 (size 5.5×5.5 cm). The scale 1 : 500.000 (size 45×45 cm) has been chosen since it permits a better synoptic view. Nevertheless, some additional imageries on a scale of 1 : 250.000 have been used for detailed observations. Altogether 98 imageries with an overlapping zone of approximately 10 % have been examined. The imageries used were those in the lowest frequency band compatible with their quality and the percentage of cloud cover. Thus almost all the imageries have been ordered in band 7 or 6, the two near-infrared bands which permit better detection of the hydrographic network, of the landforms and of the differences due to ground peculiarities such as lithologic composition of the rocks, water content and weathering.

The visible lineaments, the morphological features and the hydrographic network were traced onto separate sheets of transparent paper with the aid of a light table. These sheets were then photographed and printed on transparencies on a scale of 1 : 2.000.000.

The transparencies were then assembled on a grid in the polyconical projection with reference to the hydrographic network taken from USAF Pilotage charts on a scale of 1 : 500.000. Then mosaics were retraced on four larger transparent sheets corresponding to the colors used for the printing. Finally the map was printed on a scale of 1 : 4.000.000.

On LANDSAT imageries major valleys, rivers, ridges, watersheds, escarpments, lakes, glaciers, plains, highlands are easily discerned; in addition distinct boundaries between areas of different tonalities of grey can be identified.

3. All the above-mentioned peculiarities emerge on the imageries with a great variety of shapes, sizes and order. Some stand out either because they are greatly elongated or because they seem to lie over imaginary straight lines. Such features have been termed lineaments. From a strictly analytical point of view each lineament is characterized by four factors; the

combined factors produce a visual effect which may be called the *appearance* of the lineament. The four factors are:

1) *Length*: the linear extension of the lineament.

2) *Linearity*: the property of the lineament to approximate a straight line. If the lineament can be approximated by a curved line, the curvature may be expressed in terms of the bending radius. According to this, the greater the bending radius, the smaller the curvature.

3) *Evidence*: taken to indicate the clearness by which a lineament can be recognized without considering its length. It can also be defined as the degree of detection. It depends upon:

a) The quality of the image. Casual overexposures or underexposures, atmospheric hazes or cloud covers considerably decrease the evidence of the lineaments to the point of obliterating them.

b) The illumination. When the lineaments are made up of orographic and hydrographic features, the evidence depends upon the azimuth and the elevation of the sun. Since the mean value of such azimuth for the LANDSAT imageries of this zone is about 140°, the lineaments having a NE-SW orientation are enhanced with respect to those perpendicular to them. Two imageries of the same area taken in different periods with different values of elevation and azimuth of the sun, may therefore present conspicuous differences. Areas in which the landscape is rough are particularly subject to limitations in evidence.

c) The roughness of the landscape. This may be defined as the ratio between the wave amplitude and the wave length of the topographic relief. A high ratio enhances the evidence of the lineaments.

d) The differences between the areas at the opposite sides of the lineament. Casual differences in the patterns of the hydrographic networks, the orientation of the shortest lineaments, the depth of the valleys or the intensity of the reflected light increase the evidence of the lineaments.

4) *Continuity*: this is the property of a lineament of appearing without solution of continuity. The features which make up the lineaments may appear either in one single stretch or in many separate stretches of different lengths. If a lineament is made up of more than one stretch it may be thought that its continuity is dependent on the relative length of the stretches. If the total length of the stretches is greater than the total length of the intervals separating them, more than one lineament is considered.

It is essential to remember that the four factors described above depend upon the scale in which the study is carried out. The smaller the scale the better the recognition of major lineaments; but on the other hand the recognition of minor lineaments is good for larger scales. For example short lineaments and weak evidence in the scale 1 : 500.000 could no longer

be detected on a smaller scale, e.g. 1 : 1.000.000. If such scale had been used, nearly all the lineaments having short length and weak evidence would have been lost. Furthermore, elongated features characterized by a multitude of lineaments would have been represented as one single lineament. A significant example is given by the large elongated feature located at the south eastern edge of the Sulaiman range facing the Indus Valley between latitude 30° and 31° N. Careful examination of the imageries indicates that the feature is an antiform which has been mapped by means of lineaments traced along its otucropping layers. The structural significance of this feature would probably have been lost and its mapping effected as one single lineament traced along its axis if the study had been carried out on a smaller scale. Once the scale is established, the recognition of the lineaments on the imageries is determined exclusively by the four factors described.

4. In connection with the present work, it seems sufficient to quantify the global appearance of the lineaments in three classes: major, intermediate and minor lineaments, each corresponding to a different degree of appearance.

Major lineaments, traced with continuous heavy red lines, represent the longest hydrographic and morphological features of marked evidence and continuity and of high linearity. Generally they follow the main tectonic trends and appear uncorrelated with the other lineaments of the same class. In some cases they are associated in « Y » shaped patterns

Intermediate lineaments, traced with continuous thin red lines, represent hydrographic and orographic features on intermediate or short length with a marked evidence and continuity. They may also represent features of greater length but weak evidence and continuity. The same symbol has been used to represent linear boundaries between areas on the imageries of different gray tonalities.

Minor lineaments, traced with continuous thin ochre lines, represent hydrographic and orographic features of short length, weak evidence, high linearity and sufficient continuity.

The same symbol has also been used to represent features of probable stratigraphic nature that appear on the imageries as lineaments of various length, marked evidence and continuity but generally of low linearity.

Usually minor lineaments appear associated in groups. It is often possible to easily distinguish lineaments having preferential orientations in the same group.

5. In addition to the recognition of lineaments, the analysis of LANDSAT imageries permits identification of the areas of most recent rejuvenation marked by the deep carving of the valleys, and the areas of most recent deposition marked by alluvial fans and sedimentary fillings. The recognition of the rejuvenated areas is based on the carvings caused by the action of the streams. The carvings are easier to recognize if they occur on levelled zones such as peneplains or alluvial fillings.

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STRUCTURAL LINEAMENTS FROM LANDSAT IMAGERIES IN THE CENTRAL ASIAN OROGENIC SYNTAXIS

compiled by R. Bartole

major lineaments

medium lineaments

minor lineaments

alluvial fans

areas of most recent fluvial deposition

areas of most recent rejuvenation

drawn by G. Cavicchi

Aging has been recognized where hydrographic networks or single streams show their course or a part of it filled by alluvial sediments. More generally speaking aging is recognized where the morphology of the bottom of the valleys is smooth with respect to the slopes.

Aging has also been recognized in the alluvial plains and in the peneplains located within the orogenic area, while plains and peneplains on the outside of the orogen such as the Indus plain or the Takla Makan desert were not taken into consideration.

It has been possible to recognize zones in which rejuvenation and aging followed one after the other e.g. zones which were once filled with alluvial sediments and which are now characterized by carvings caused by present rejuvenation. In these cases only the last action of deposition or excavation has been considered.

Areas of probable aeolian deposition have also been recognized but not mapped.

Last, but certainly not less important, are the alluvial fans which for the most part have been recognized at the edges of the orogenic belts. They show a great variety of size and evidence and only the most prominent ones have been reported on the map.

The above-mentioned morphological features have been represented using the following symbols:

- light blue areas: areas of most recent fluvial deposition;
- light red areas: areas of most recent rejuvenation;
- ochre fan-shaped symbols: alluvial fans.

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