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Impact of Conjugated Shear Joint of “X” Type on Macroscopic Karstification on the Basis of the Analysis of Google Earth Images

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Abstract: As viewed from space remote-sensing images (e.g. Google Earth images) of South Guizhou and North Guangxi, the authors found that macroscopic karst landscape on the Earth’s surface is strongly controlled by the Conjugated shear joint of “X” type. Joints of this kind constitute a huge infiltration network and act as channel-ways for the permeation of meteoric waters from the surface, thus, leading to the dissolution of carbonate rocks nearby. As a result, the karst landscape is formed, which is dominated by linear karst valleys. An “X” karst valley network structure appears in the area where horizontal strata are distributed, and a feather-like network structure appears in the area where vertical strata are distributed, respectively. When the water permeates downwards to the underground-water level, it will flow horizontally along the strike of “X” joints toward the local base level of erosion to form an “X” network system of underground conduits in the area where horizontal strata are distributed, but it is relatively complex, because of the joining of other joints. This is the first time we have made use of Google Earth images to study the karst environment. Therefore, it has been successful in research on the Earth’s geomorphology, which could only rely on aerial photos and satellite photos in the past. Google Earth images provide low-cost and applicable imaging materials for the study of Earth’s geomorphology and karst rocky desertification and its control.

Key words: karstification, Google Earth image, conjugated shear joint of “X” type

1 Introduction

Karst rocky desertification in Southwest China is one of the important environmental problems (Yuan, 1996; Wang et al., 2003). Many researchers studied the main causes responsible for karst environmental rocky desertification from different perspectives (Gao et al., 1983; Yang, 1985; Gao, 1996; Wang et al., 1999; Zhou et al., 2003; Jiang et al., 2004; Ju et al., 2006; Wang et al., 2007; Xu et al., 2007; Yang et al., 2007, 2008; Yang, 2008; Yan et al., 2008; Martin and Tadej, 2010; Zhang et al., 2011; Francisco et al., 2012). In order to fully understand the occurrence and evolution of karst rocky desertification, it is necessary to get information about the distribution of rocky desertification both in space in time and its relations to the geological background, and understand the factors controlling karst rocky desertification so as to provide the scientific basis for the control of karst rocky desertification. Due to less availability of aerial and satellite photos, many scholars’ research in this aspect has been restricted (Xie et al., 2011). Fortunately, the Google Earth images on the international internet provide the necessary conditions for the study of karst rocky desertification on a large scale.

In recent years the Google Earth images on the international internet have significantly expanded the outlook of scientific workers. One can not only view any corner of the globe, but also can get it enlarged (the maximum scale may reach up to 1: 1000) so as to observe its details. Surveying of the regions of South Guizhou and

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Northwest Guangxi by making use of the Google Earth images on the international internet revealed that the karst geomorphic landscape there is obviously controlled by structures, especially by Conjugated shear joint of “X” types. In terms of the Google Earth images the authors analyzed how the Conjugated shear joint of “X” types control the karst landscape. Meanwhile, they proposed to make use of low-cost and applicable Google Earth image resources on the international internet to carry out geomorphic study and provide a new approach to studying karst rocky desertification and its control. Thereby, the bottleneck researching on karst geomorphology by relying merely on the high-cost aerial and satellite photos is broken.

2 Geological Background

“The mountain looks like a range or a cluster of peaks when viewed in two different directions, the mountain peaks vary in height over different distance. One can’t get a true picture of Mt. Lushan, because he is confused in this mountain.” This is a piece of well-known poem written by Su Shi, an outstanding great poet of the Song Dynasty in ancient China. This poem not only is of deep philosophical sense, but also points out a scientific way for the broad masses of scientific and technological workers to conduct all-around observation and acquire natural information so as to get a correct understanding of the objective world. Geological workers stand on the ground and have only a limited vision, so it is usually difficult for them to directly and quickly get an overall and objective awareness of a variety of regionally geological and geomorphological phenomena. Today’s highly developed space technologies make it possible for geologists to get rid of the limitations of ground vision and achieve a great large-field view of the Earth, observe Earth’s surface geological and geomorphic features in an all-round way in order to quickly acquire abundant, integrated and comprehensive and objective information. In this way one can get a correct understanding of the true picture of the “Lushan Mountain” at one glance.

Distributed in the western part of Guizhou Province are either Cambrian or Triassic carbonate rock strata, particularly the Devonian, Carboniferous, Permian and Triassic carbonate rock strata are most widely exposed. Rocky desertification is most developed in the Permian and Triassic strata. Karstification is so widely spread as to account for 61.92% of the total area of Guizhou Province, where the exposed carbonate rocks cover an area of 150000 km^2.

In research on karstification in southern Guizhou in the 1990s, one of the authors conducted a systematic observation and interpretation of the false-color composite satellite photos (scale: 1: 500000) and aerial photos (scale: 1: 50000) taken over a vast area of 40000 km^2 in southern Guizhou (Gao et al., 1986). From these photos it was surprisingly found that the karstification phenomena, which seemed to be unpredictable and chaotic as viewed on the Earth’s surface would actually appear in perfect order when viewed from high altitudes, either the arrangement of karst peaks or the development of karst valleys maintain a certain orientation, obviously controlled by commonly existing conjugated shear joint of “X” types, showing a strong regularity (Fig. 1). This regularity was proved by subsequent on-the-spot field examinations.

As can be seen from Fig. 1, there is developed NE-SW conjugated shear joint of “X” types, as well as a group of N-W-extending faults. In addition, as can be seen clearly in the figure, the NE-SW conjugated shear joint of “X” types cut through the N-W-extending faults. The karst topographic features formed under the action of the conjugated shear joint of “X” types are represented by cluster-peaks or peak-forests, which are distributed in the chessboard grid or diamond-shaped grid forms. These regular grids, which are connected with each other at a certain angle and possess a certain geometric form, are an outstanding topographical manifestation of karstification proceeding along the “X” conjugate joints. The topographical features formed under the action of large joints are presented as linear karst ditches, karst valleys or equiaxed or long strip-shaped karst depressions, which are arranged in the form of beads. At the intersection of two groups of large joints karstification is well developed, with karst funnels and sink holes commonly seen in the karst depressions.

It is a common geological knowledge that karstification is controlled by the ruptured plane in soluble rocks. However, on the basis of the direct information provided by aerial and satellite photos and karstification phenomena on the Earth’s surface observed in the vast field, in conjunction with many on-the-spot field observations, it can be said with certainty that karstification and related macroscopic features are controlled mainly by conjugated shear joint of “X” types. Since the Neogene, under the influence of continuous uplifting of the Qinhai-Tibet Plateau, the unique karst topographical features in Guizhou Province have been created, as represented by crisscrossed peak-forest basins, peak-forest valleys, peak-forest depressions and cluster-peak valleys, which show great differences in height and gradient. Such a great cutting depth and gradient determines the ecological environmental vulnerability. During the Neogene to the Early Pleistocene Guizhou Province had experienced vast-area uplifting, and the uplift movement at the end of Early

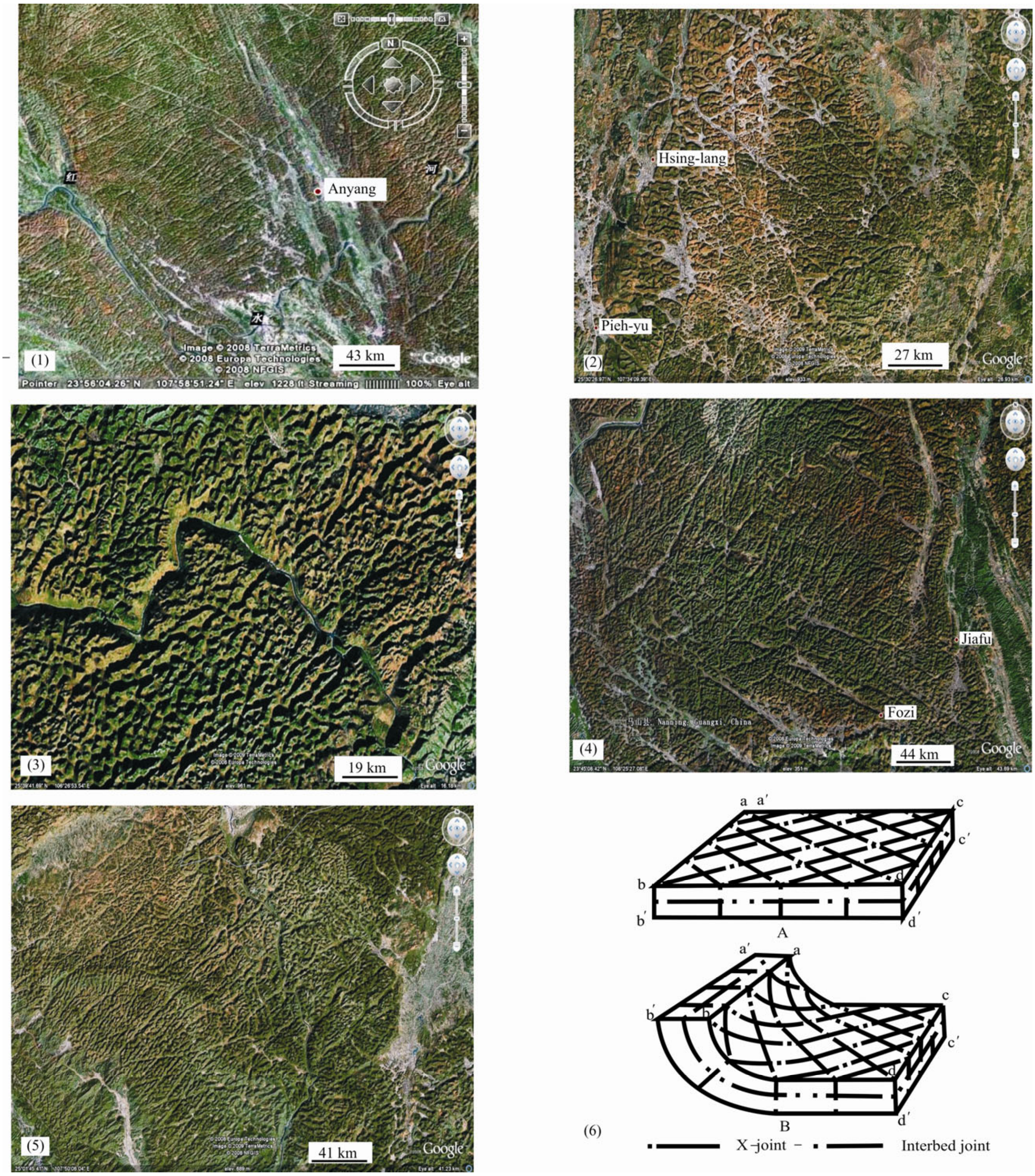

Fig. 1. The karst landscape controlled by conjugated shear joint of "X" types in karst areas (Images from Google Earth images of 2008 TerraMetrics, 2008 Europa Technologies and 2008 NFGIS).

1, Regional conjugated shear joint of "X" type in karst area; 2, Image of karst in horizontal stratum area (Shangsi, Dushan county, Guizhon); 3, Image of karst in peak cluster-depression area (Getu valley, Ziyun county, Guizhou); 4, Image of karst in horizontal stratum area (Mashan, Guanxi); 5, Image of karst in horizontal stratum area (Nandan, Guanxi); 6–7, Landscape and space status of large X conjugate joints in folding; 8, Before folding and deformation; 9, After folding and deformation.

Pleistocene is a tectonic movement of transforming significance in the geological history. It is this tectonic movement that gave rise to the oblique uplift of the Yunnan-Guizhou Plateau, thus establishing the modern landscape pattern of the region of Southwest China. Since the Middle Pleistocene the crust movement has been dominated by intermittent oblique uplift over a vast area, accompanied by local differentiated uplift. The intermittence of neo-tectonic movement resulted in planation surfaces of different ages, leading to a cascadelike decline of landscape from the watershed to the valley within the various drainage basins, and in the karst valleys are commonly developed 4–5-level terraces (Guizhou Provincial Bureau of Geology and Mineral Resources, 1987). Intensive neo-tectonic activities speeded up the evolution of the karst landscape, increased the cutting depth on the Earth's surface, and accelerated water erosion, thus providing the dynamic conditions for the development of karst rocky desertification.

Rocky desertification in Guizhou Province is affected by the tectonic system. In the areas where the strata are strongly cut the fault systems are well developed, thus making surface water permeate to depth. As a result, rocky desertification is rather developed there. In the karst planes or karst basins where the terrains are relatively flat (or low in relief) the development of fault systems is favorable to the cycling of underground water and surface water. In addition, it is favorable to intensive pedogenesis. As a result, soil layers are relatively thick and rocky desertification is less developed there. The forms of folds are closely related to the development of rocky desertification. In the inseparably folded areas rocky desertification is seldom recognized, while in the widely and gently folded areas rocky desertification is rather developed.

The rocky desertified strata developed in Guizhou Province are mainly Devonian, Carboniferous, Permian and Triassic strata. As the late-stage structures in Guizhou are controlled by earlier structures, the tectonic lines are consistent with each other (Guizhou Provincial Bureau of Geology and Mineral Resources, 1987). Since the Late Paleozoic, Guizhou has experienced the Guangxi movement, thus giving rise to a N-W tectonic line for the Devonian and Carboniferous systems; the Duyun movement is responsible for a S-N tectonic line; the Yanshanian movement resulted in a tectonic line that is superimposed on both tectonic lines resultant from the Guangxi and Duyun movements. The nearly E-W tectonic line was formed as a result of the Guangxi, Duyun and Yanshanian movements (Guizhou Provincial Bureau of Geology and Mineral Resources, 1987).

3 Large Joints

The large joints refer to those magnificent (several to more than ten kilometers in length) and widespread joint systems, which are hard to observe due to limited vision on the Earth's surface. Only when viewed at high altitudes, one can get the true pictures of those large joints. They are expressed as large orientational linear images and the dynamic mechanisms of their formation are of no difference from those of the tectonic joints in a common sense, though the large joints are larger in scale. According to their forming mechanisms, three categories can be distinguished.

3.1 Regional-first-order "X" conjugated shear joints

This category of joints is a most ubiquitous joint system and it is also a category stressed in this study. These joints resulted from a first-order conjugate shear stress prior to folding-induced deformation of strongly fragile strata in certain tectonic stress fields i.e., the so-called "Luder Line" ruptured plane in the field of material mechanics, particularly in carbonate strata. That is because the rocks are easily eroded by carbonic water along such joint planes, thereafter showing an intensive karst landscape-creating process. The large joints usually occur in groups on a large scale and are equally spaced to some extent. The large joints exhibit "X" conjugate structure and diamond-shaped network pattern, with its acute angle bisector representing the direction of compressive stress. That is why it is always vertical to the local regional tectonic line. Earth's surface observations showed that there is no remarkable dislocation between the hanging and foot-wall strata and the linear ditches and valleys that extend over long distances and isodirectional knife-cutting -like upright cliffs or close-spaced joints are commonly seen along the line. Such joints are widespread in Guizhou Province (Fig. 2), particularly in the region of Northwest Guangxi (Fig. 1-1).

The "X" conjugate joints are usually developed in the flat fold zones, generally several to ten kilometers long, with the maximum length up to 30 km. They look almost like straight lines in appearance and extend nearly linearly, as if they are knife-cut, because they are not affected by surface undulation on a large scale. Usually there are two or more than two groups of joints intersecting at a certain angle, and also are connected with a certain tectonic system. The joints are of equidistant spacing. Joints of the same category are almost similar in spacing intervals while those of different categories show differences in spacing interval. The joints that are more than 20 km in length have a spacing interval range of 5–8 km; the joints that are 5–20 km in length have a spacing interval range of 2–3 km; the joints that are less than 5 km in length have a spacing interval of 1 km. In the inseparably folded zones, it is hard to see any "X" conjugate joints.

According to the conjugate acute angle bisector direction, three assemblages can be distinguished: (1) The joints whose acute angle bisector extends nearly east-westwards and which are distributed within the S-N box-like large anticline and the complex zone where some S-N structures are connected with other structures extending in other directions, for example, in the complex zone of S-N

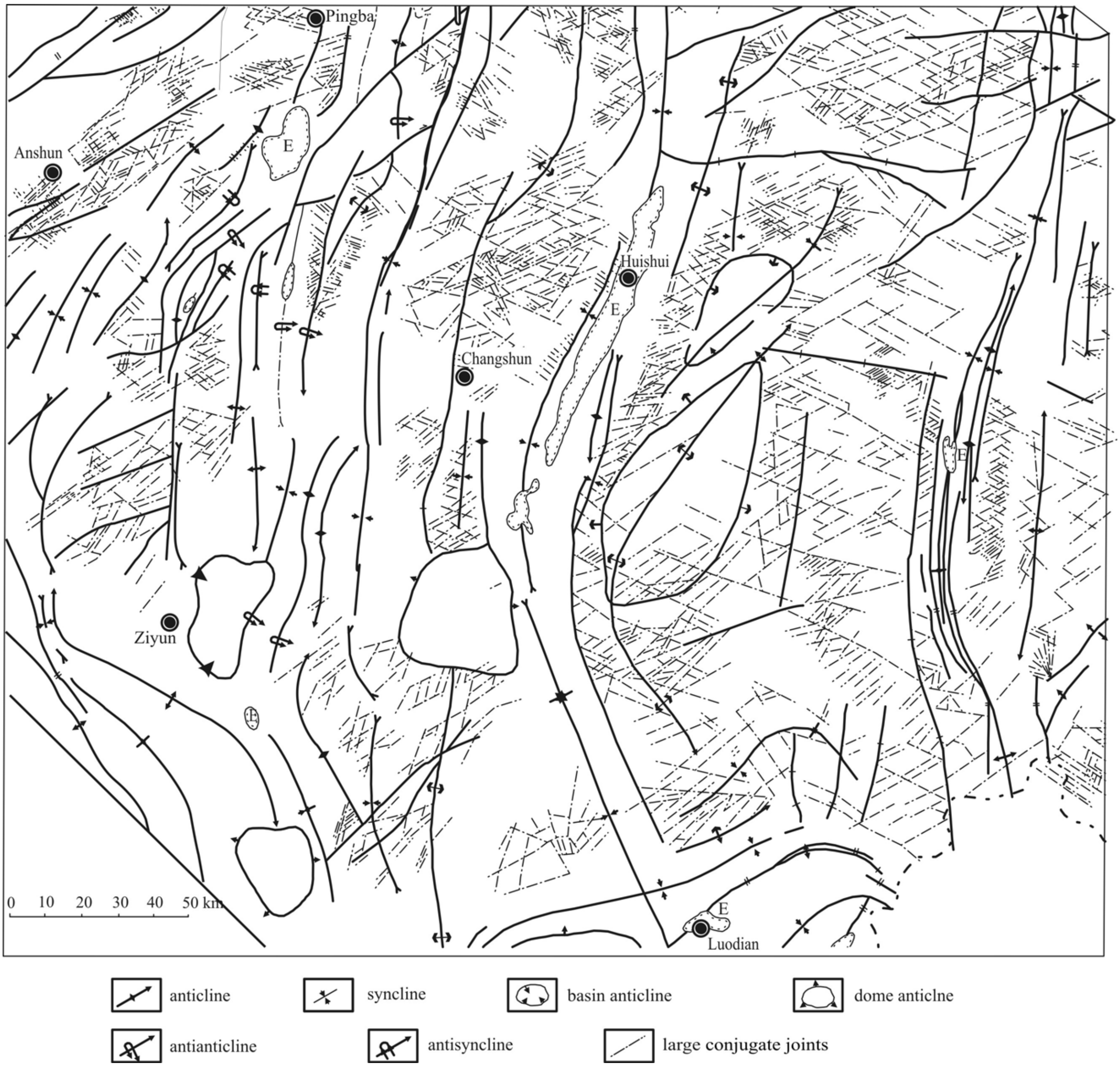

Fig. 2. The distribution of large "X" conjugate joints in the S-N box-shaped folded zones of southern Guizhou (from Gao et al., 1986).

and N-E structures from Anshun to Guiyang, Guizhou Province, and the complex zone of S-N structures around the region of Moyang–Luodian, Guizhou Province. (2) The joints whose acute angle bisector extends north-eastwards and south-westwards and which are distributed mainly on the northeastern sides of the N-W structures developed in the areas of Zhenning and Ziyun, as well as in the Gebi River Valley, Guizhou Province. (3) The joints whose acute angle bisector extends north-westwards and south-eastwards and which are distributed within the N-E tectonic zones. The above joint assemblages in combination with the S-N structures, N-W structures and N-E structures constitute a conjugate joint system. Therefore, the conjugate joints developed in Guizhou Province are consistent with the three major tectonic zones there.

3.2 Interlayer joints

This kind of joint represents a first-order tensile ruptured plane formed along different stratagraphic interfaces due to differences in strata materials. Joints of this kind are usually concealed underground in the flat folded zones, and only in the folded zones can they be exposed on the Earth's surface, though they have been converted to compressive joints.

3.3 Serrated (vertical and laterial) tensional joints

Serrated tensional joints are developed in different segments of the “X” conjugate joint systems along different directions, belonging to second-order structural features. They usually appear in individual cases, with no regional characteristics.

Interlayer joints and serrated tensional joints are not the subject to be discussed in this paper. In the following the focus is put on the “X” conjugate joints (simply called “X” joints below).

Along with the continuity of tectonic deformation the strata experienced folding, and the “X” joints would change in a three-dimensional state. Meanwhile, the “X” joints also changed in surface patterns (Figs. 1-6, 1-7).

Gently folded zone: The Conjugated shear joint of “X” types are fully developed in the plane, and they are diamond-shaped network-like in shape (Figs. 1-2–5, and Fig. 2), but usually one of the groups is of predominance. Interlayer joints are concealed, for example, the case is true for several box-shaped anticline regions in the south-central parts of Guizhou.

Tightly folded zone: The conjugated shear joint of “X” types occur as short parallel lines vertical to the strike of the strata at plane, and the interlayer joints extend along the strike of the strata, both of them jointly constituting a feathered-like structure (Fig. 1-2), for example, as seen in the close-spaced compressive zones in the N-E structures in the western part of Guizhou and the S-N structures in the central parts of Guizhou (Figs. 3-3, 3-4).

Transitional zone: It is intermediate between the above two, i.e., converting from “X”-shaped to furthered-shaped. The patterns seem to be disordered.

4 Karst Regional Images

As viewed from aerial photos (scale: 1: 50000) and amplifying Google Earth images on the international network, the karst landscape images from the regions where the degrees of folding and deformation are different have different characteristics and show significant differences, though they are consistent with the regional large “X” joint system network, the former being strictly controlled by the latter.

Gently folded zone (the dip angle of the strata <15°):

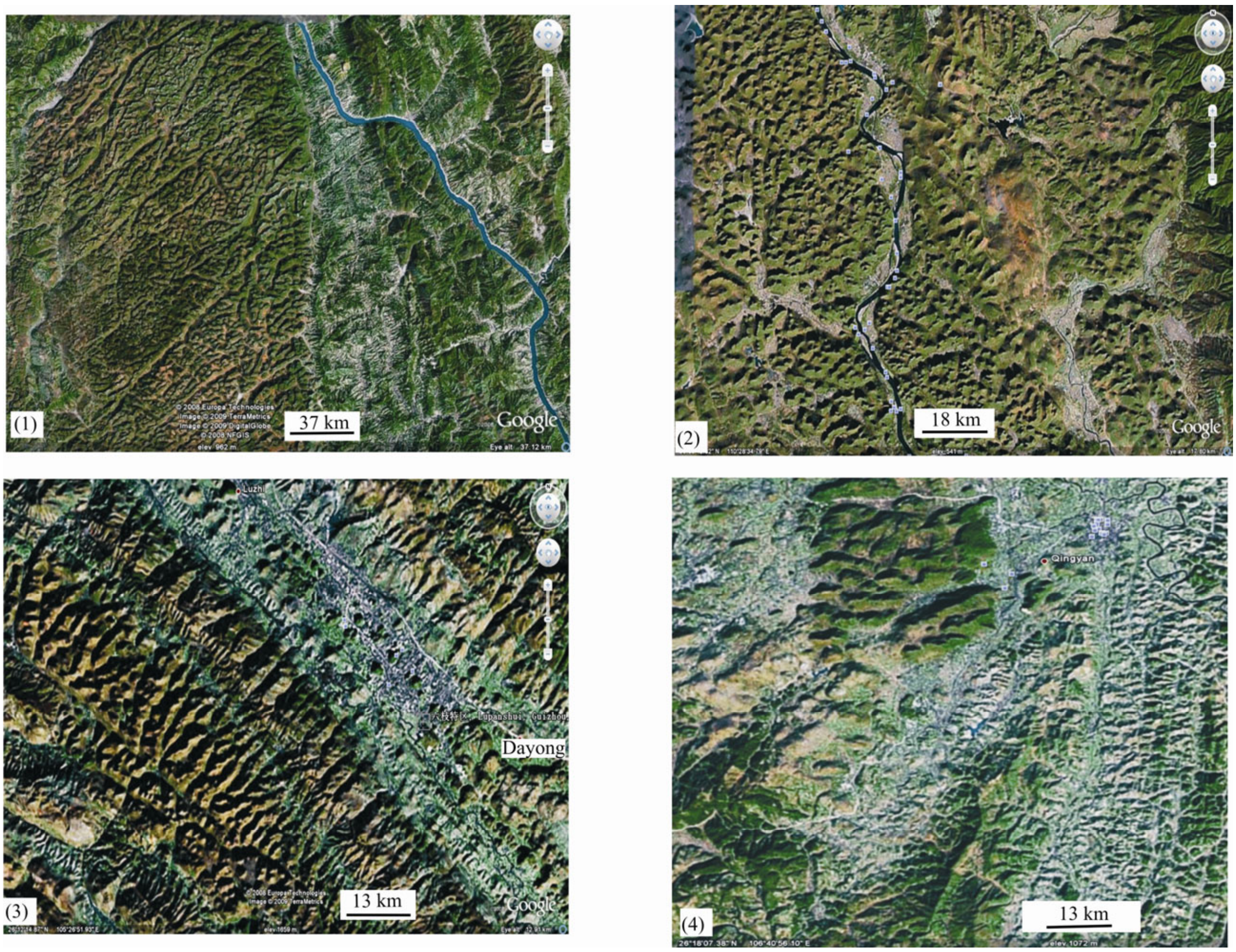

Fig. 3. The remote-sensing image of karst in vertical stratum area, peak cluster-depression and Fenglin-valley area (Images from Google Earth images of 2008 TerraMetrics, 2008 Europa Technologies and 2008 NFGIS).
1, Tian’e county, Guangxi; 2. Lijiang, Guilin county, Guangxi; 3, Liuzhi, Guizhou; 4, Huaxi, Guiyang.

Gently folded zones are typically developed in the vast areas of southern Guizhou and northwestern Guangxi. The surface strata there are mainly post-Late Paleozoic strata, and carbonate rock series are widely developed, characterized by relatively simple tectonic deformation history. With the exception of a few narrow, close-spaced compressive zones, more than 70% of the strata are gentle in undulation (Guizhou Bureau of Geology and Mineral Resource, 1987). In such gently folded zones are extensively developed large "X" conjugate cross-cut stockwork karst ditch and valley systems, among which are arranged karst peak cones in the form of beads, exhibiting a wonderful karst landscape composed of peak-clusters, karst depressions, karst peak forests and karst valleys, as described in the poem mentioned above (Figs. 3-1, 3-2). Karst valleys are usually free from the influence of topographic undulation and thus extend linearly. They look like knife-cut features, similar to those observed on the surface of dolomite outcrops. Moreover, they are developed more regularly. The karst valley courses developed in the same direction are parallel to one another and appear in groups and possess equidistance. Those developed in different directions are cross-cut at a certain angle and their acute bisector direction is vertical to the local tectonic line. Inter-valley peak cones are mostly arranged in the form of beads in one direction, and the long edges of strip-like peak cones usually maintain unchanged along the same line over several or even several tens of kilometers, and just look as if they are knife -cuts. The Google Earth images exhibit "peanut crust-like structure" or "psoriasiform structure", or "cansellate structure" (Fig. 2-5). The images occur in groups and extend along the direction of a constant tendency. The images in the same direction are parallel to each other and also occur in groups, whereas those in different directions are usually cross-cut at a certain angle, making up regular geometrical patterns. Linear precors usually do not shift to other images.

In the peak-cluster and depression stage of karst development (Fig. 1-3, Fig. 3-1), karst valleys were relatively narrow, and karst depressions extended along the valley courses and were arranged in the form of beads. The karst depressions are usually rounded or elliptical in shape, with the long axis consistent with the extending direction of the valley courses. Karst depressions at the intersection of karst valleys developed in different directions are relatively large in scale and are very complicated in form. Funnels and sink holes developed in the karst depressions may evolve into karst depressions measured at more than one hundred meters, or even become underground-river karst "windows" or blind valleys, thus making subterranean streams exposed on the surface, with the decline of the erosion base-level, depending on differences in the burial depth of the water table. Brain stria-like structures are observed on the Google Earth images and those linear structures (or linear massifs) have some curvature. The linear structures extend only over a short distance and possess a large curvature.

At the time when karstification evolved into the peak forest-karst gorge stage (Fig. 1-2, Fig. 3-2), tightly cansellate structure, and short linear massifs and curve linear massifs are observed on the Google Earth images of karst.

At the time when karstification evolved into the peak hill-karst plateau stage, the karst valleys were connected mutually and the previously described landscape features disappeared, for example in the peak hill-karst plateau areas of Dushan, Anshun and Pingba. In the regions with a complicated tectonic movement history the conjugated shear joint of "X" types were relocated mutually owing to multi-time compression and deformation, and changes also took place in their spatial distribution patterns. As a result, the textures have been destroyed, karst valleys and peaks interstitial to the valleys are randomly distributed, the previously described landscape features are faintly seen, for example, in the region of North Guizhou where Lower Paleozoic strata are spread. No linear mass is observed on the Google Earth images of karst valleys and inter-valley peak massifs, "peanut crust-shaped structure" or "psoriasiform structure" or "cansellate structure" all disappeared.

Tightly folded zone: The strata are nearly vertical in attitude and their karst landscape is quite different from the former. Karst topographic features are distributed as a narrow belt along the strike of the strata. Karst valleys are mostly vertical to the strike of the strata, but occur as short and small karst valley groups parallel to each other, exhibiting feathered-like structure, for example in the N-W and S-N close-spaced compressive belts in Guizhou Province (Figs. 3-3, 3-4). Short and small linear massifs are seen on the Google Earth images, the linear massifs are thick and strong, extending rather gently. The images have a highlight contrast and show strong three-dimensional effects.

Transitional zone: It is intermediate between the two zones described above. The macroscopic karst features are of no regularity.

Obviously, differences in the karst images described above are related to the spatial dislocation of conjugated shear joint of "X" types due to differences in folding intensity of the strata in the study region (Figs. 1-6, 1-7), and are all controlled by these kinds of joints.

Later folds, faults, low-order joints all have some influence on karstification. Due to the influence of later tectonic activities, karst features, which are characterized by “multi-layer”, “superimposition” and “zonation” would generally be formed. Planation surfaces formed as a result of uplifting during different periods have different elevations. Thereby, joints of different ages can be distinguished.

The clustered peak-forests exhibit “binary structure”, i.e., peak-forests is superimposed on peak-clusters. In addition, the development of depressions and funnels in the karst depressions is the result of superimposition of later structures. Linear massifs are obviously developed, and the three-dimensional images with strong sense are indicative of the karst landscape formed from the superimposition of later faults and joints, or network-like structures are randomly developed. The absence of regular karst images is also attributed to the superimposition of later structures. So the karst images with typical “peanut crust-like structure” or “psoriasis-like structure” or “cansellate structure” refer to the karst topographic features formed by the large “X” joints, which were not transformed by later structures.

5 The Impact of Faults and Joints on Karst Underground Waters

5.1 The impact of faults on karst underground waters

The faults can serve as the channelways for the vertical permeation and lateral movement of underground waters. As a result, underground conduit systems are produced along the faults. Compressive faults can disconnect underground waters, thus forming underground water obstacles. Lateral tensional faults are usually developed into underground water channelways, and linear karst valleys, within-valley karst depressions, and karst funnels are formed along the faults, of which the karst funnels are distributed in the form of beads and the karst depressions are long and strip-like. Semi-cut-off underground rivers can be seen occasionally, indicating there exists underground rivers.

In the faults with different kinetic characteristics are all developed underground rivers. So it is not wise to judge the control of faults on underground rivers merely based on the fault kinetic properties. An actual analysis of the factors controlling karst development in the southern part of Guizhou indicates that faults as a controlling factor are far less important than regional large joints (Gao, 1986).

5.2 The impact of joints on karst underground waters

Karstification shows strong preference to the “X”-type ruptured planes in soluble rocks. In the gently folded zones are widely developed regional conjugated shear joint of “X” types with perfect permeability. The joint planes are almost perpendicular in space and can connect with the underlying under groundwater level over the shortest distance. There is no doubt that meteoric waters will preferentially select this kind of ruptured planes as permeating channelways. That is why karstification in a gently folded zone is closely controlled by the regional conjugated shear joint of “X” types.

In the almost linearly extending karst valleys there exist karst funnels, karst depressions and sink holes, which are distributed in the form of beads, and the underground channels in the early stage of development mostly have developed fault planes (the fault planes of maturely developed channels were greatly transformed with respect to their form because of the influence of later lateral erosion, collapse and deposition), in the position of “Pear’s Grip” is always developed a large shear joint. All this is the evidence suggesting why conjugated shear joint of “X” types are preferentially chosen as the permeating channelways by meteoric waters.

Actually, the clustered parallel short karst valleys observed in the feather-shaped karst images taken over close-spaced folded zones are also controlled by regional conjugated shear joint of “X” types, though these joints are dislocated along with tectonic changes and never in the upright state (Figs. 1-6, 1-7). In spite of this, their dip angles are still large (>45^{o}), only coming next to those of interlayer joints; these joints can penetrate through the soluble carbonate strata and can serve as ideal channelways for the downward permeating of meteoric waters in carbonate rocks toward the underground water level. Of course, in such regions, the joints with the maximum dip angles are interlayer joints. The distance from the surface to underground water level is shortest, so the joints are the best channelways for the permeating of meteoric waters downwards, though they are usually the interface between soluble and insoluble strata. So, in addition that they can serve as the channelways for the downward permeating of meteoric waters, they can also constrain the development of karstification in space. Moreover, in these kinds of regions interlayer joints are compressive in nature and can’t serve as the good channelways for the permeating of running water.

After meteoric waters permeate downwards along the faults and large joints to the underground water level, they will discharge along this kind of ruptured plane toward the local erosion base level to form underground conduits. Practical investigations have shown that under many large -scale linear karst valleys lie underground rivers.

However, the underground conduits in the network of a large joint system are not developed in balance, and they would strictly select their scale, azimuth and dip angle. Their development shows certain regularity. The authors refer this as to be the *"Rule of Best Path"*.

5.2.1 Tendency of selecting large joints as permeating channels

When meteoric waters permeate downwards, all the joint fractures connecting with the surface and groundwater level will serve as the permeating channels. However, larger-scale channels are relatively good in permeability, thus a larger volume of meteoric water can pass through the channels and thereafter the rocks will be more strongly eroded, leading to intensive development of karstification. The regional conjugated shear joint of "X" types are huge in scale and have perfect permeability, therefore, beneficial to the permeation and movement of fluids. That is why such conjugated shear joint of "X" types are preferentially chosen by meteoric waters. In the large-scale, well continuous karst valleys are developed bead-like karst depressions and funnels, as evidenced by the existence of underground rivers bellow them. The scale and permeability of ordinary joints are far less than those of the conjugated shear joint of "X" types, and meteoric waters can only flow along such micro-features as karst ditches and fractures.

5.2.2 Tendency of selecting the shortest flow path

Karst water, just like other sorts of fluids, always shows a tendency of selecting the shortest flow path to flow to its destination – local regional erosion base level. Thereafter, there are derived the tendencies of selecting joints with steep dip angles and of selecting the orientation.

5.2.3 Tendency of selecting the shortest flow path in the vertical plane

This is a tendency of selecting the shortest flow path in the vertical plane. It is not hard to imagine that the joints with steeper dip angles are favorable to the arrival of meteoric waters at the underlying base level at the highest speed and over the shortest distance, and then meteoric waters will continue flowing toward the eroded base level. In the gently folded zone: the first-order regional "X" joints basically maintain their primary upright state, providing the shortest flow path for the downward permeation of meteoric waters to the underground level. This may explain why the surface karst valleys and depressions and karst funnels are commonly developed along these large joints in such regions as described above, and it also explains why peak-forests and stone forests mostly occur in flat-lying strata and why they have the characteristics of karst cliffs. In the tightly folded zone: Interlayer joints are the joints whose dip angles are most steep. It is why there are developed bead-like karst depressions or sink holes at the contact interface between soluble and insoluble strata. Within such regions, although the special location of large "X" joints has already changed, making their extension in the direction of the strike of vertical strata constrained, their dip angles are generally still higher than 45^{o} and the "X" joints can penetrate through the whole soluble carbonate rock strata and are still beneficial to the downward permeation of meteoric waters, thus still playing an important role in the development of local karstification. As a result, the karst landscape commonly exhibits feathered-like (karst valley) texture (Figs. 3-3, 3-4).

5.2.4 Tendency of selecting the shortest flow path in the horizontal plane

This is a tendency of selecting the shortest flow path in the horizontal plane. In many regions there usually exist more than two groups of large joints extending in different directions. The main streams and main tributaries in the underground conduit system show a preferential tendency to intersect at an acute angle with surface runoff at the discharge base level and are developed in a group (Nicola et al., 2012). As running water, which flows only along the ruptured plane in one direction would possess the highest kinetic energy, and could discharge toward the base level at the highest spread and over the shortest distance. This rule has been evidenced by underground river tracing experiments (Fig. 4).

6 Conclusions

(1) The development of regional karstification on a macroscopic scale is controlled by the regional first-order conjugated shear joint of "X" types extensively developed in carbonate strata. The existence of large "X" joints provide the best channelways for the downward permeating of surface water, thus bringing the development and evolution of surface and underground large-sized karst features under control.

(2) The existence of regional large "X" joint systems provides a huge infiltrating network for the distribution areas of carbonate strata, thus a factor leading to serious surface water erosion and soil loss and ecological environmental deterioration – rocky desertification.

(3) To grasp the rules of large "X" joint systems controlling the development of karstification will be certainly beneficial to the improvement of ecological environment and search of underground water resources.

(4) The Google Earth images on the international internet can be used to investigate karst environments so as to supply a new method in the study of Earth's topography merely relying on aerial and satellite photos. This provides low-cost and convenient photographic

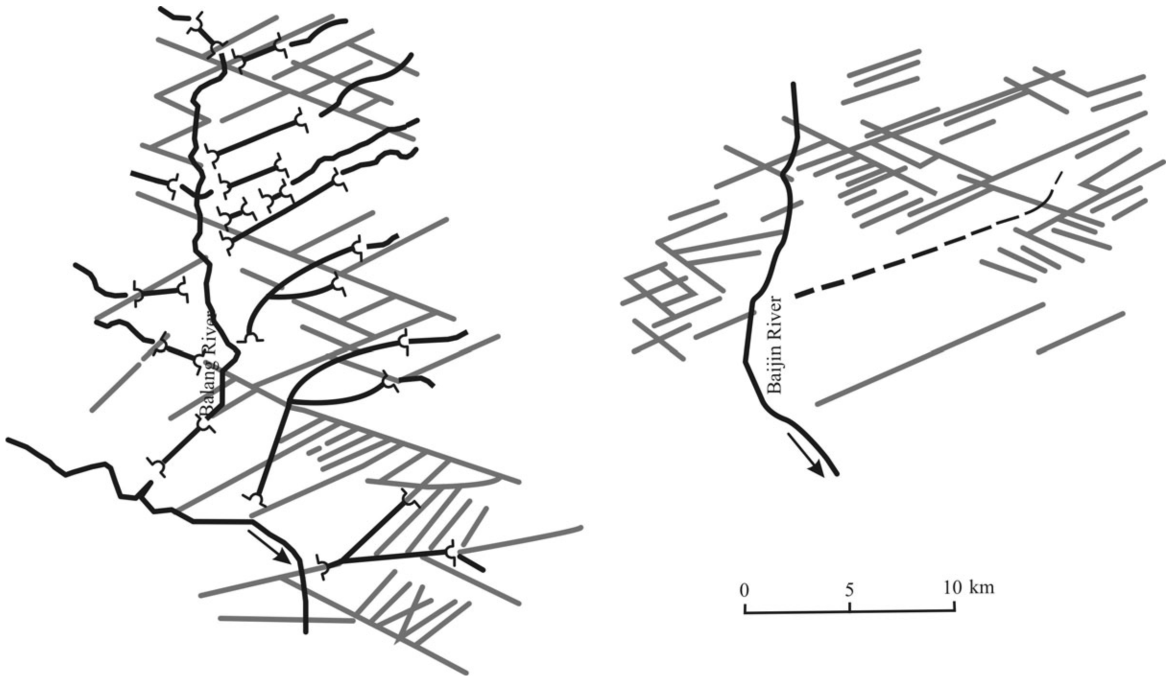

Fig. 4. The map showing the selection of underground rivers toward the direction of conjugated shear joint of "X" types (from trace test) in Guizhou Province.

materials for the study of landscape and the study and control of karst rocky desertification.

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