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Structural elements of Western Carpathians and their Foredeep on the basis of satellite interpretation

The satelite images present the features of the Earth's surface in synthesized form. It has enabled to join many local geological structures into the regional lineament zones. There are many indicatiors that the lineaments are surficial expression of the regional tectonic systems. Most of the mentioned zones were unknown from the geological data. Some of the lineament zones extend 400 km e.g. Myjava, Hron, the distances of the other lineaments are very close to it: Muraň, Przemyśl, Northern Tatra.

INTRODUCTION

Geological investigations of the Carpathians have been carried on by Czechoslovakian and Polish geologists for a long time. As a result of this investigations stratigraphy and lithology of this area have been elaborated quite well. However, determination of structural units has proved to be not so simple because of inaccessibility of the area and its heavy vegetation cover. A lot of information has been afforded by geophysical investigation. Also satellite images and other remote sensing techniques may reveal a new light on solving the problems of surface structural discontinuities even deep-seated ones.

This paper is an attempt to compare the results of geological and geophysical investigation in the Carpathian area with the materials obtained from remote sensing. Photogeological elaboration of the Carpathians comprising the whole of Polish and Slovakian Carpathians Photogeological Map of the Western Carpathians and surrounding areas has been compiled on the scale of 1:500,000 (S. Doktór, et al., 1984).

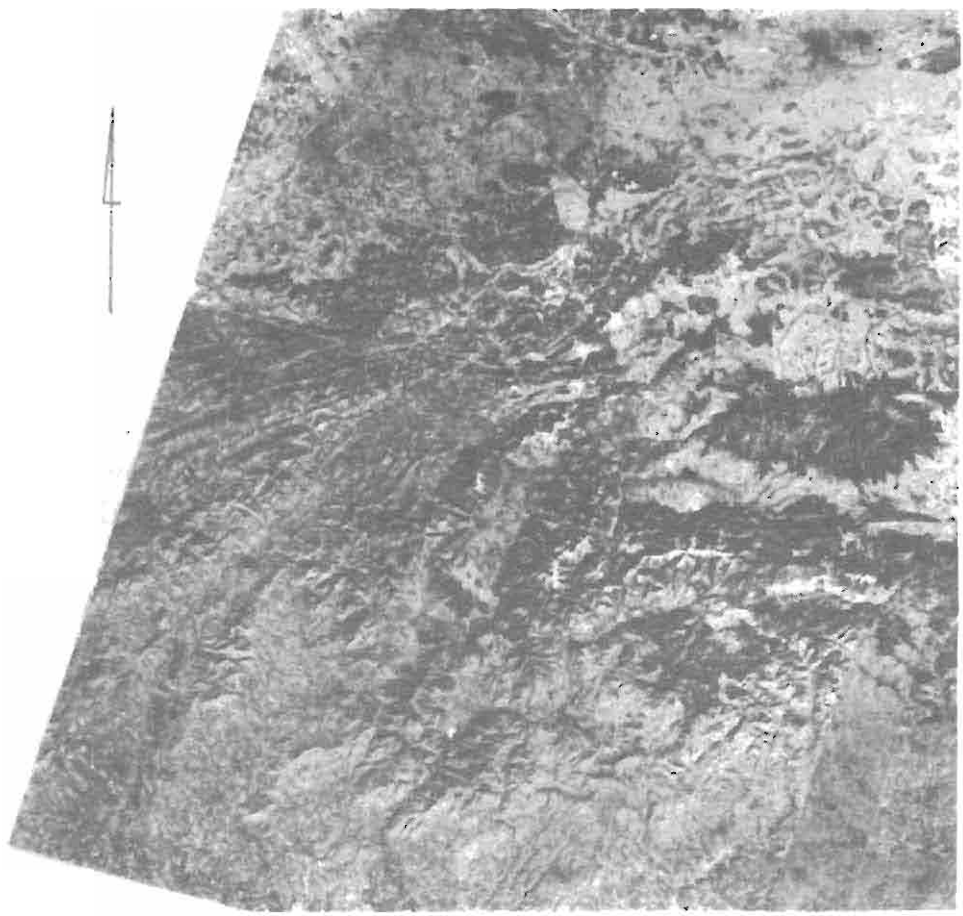


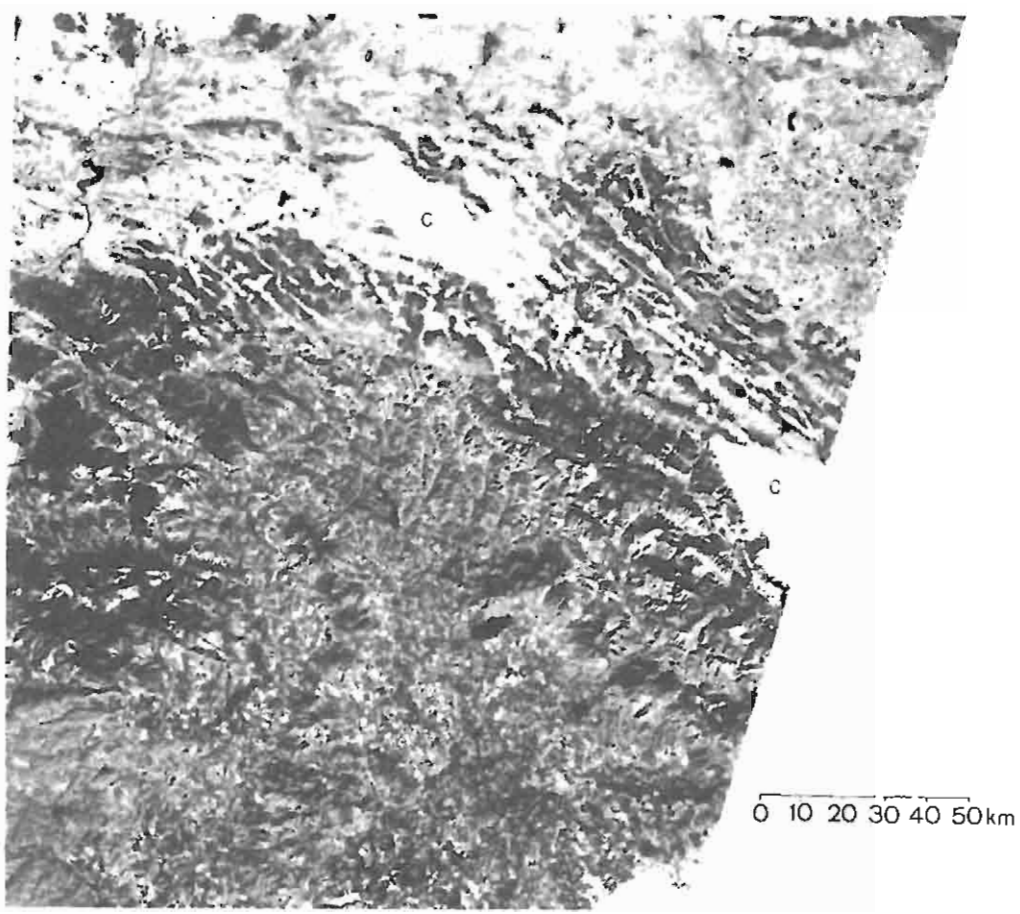
Fig. 1. The Landsat mosaic of the Western Carpathians

C – clouds (chmury)

MATERIALS AND METHODS USED IN PHOTOGEOLOGICAL INTERPRETATION

Different kinds of remotely sensed data were used for the preparation of the photogeological map. All available satellite data of various types were investigated. The following systems were applied: Landsat 1, 2 and 3, Kosmos, Salut 6 and Meteor. The Landsat images have been found most applicable for geological interpretations (fig. 1). There were 25 scenes, acquired by three Landsat satellites between the years 1974 and 1980. The scenes were independently interpreted by four photogeologists. For the interpretation there were used:

1. Positives and negatives of images in MSS bands 4, 5, 6 and 7 (green, red and two near infrared) on the scale of 1:3,369,000, which were used for generalization and analysis of colour composites by means of additive viewer.



Fotoszkic Karpat Zachodnich, zestawiony ze zdjęć satelitarnych Landsat

2. Paper prints of images in MSS bands 4, 5, 6 and 7 on the scale of 1:500,000.

3. False colour composites (FCC) – photographically generated from the bands 4, 5 and 7 on the scale of 1:250,000.

4. Digital processing of the Landsat images was made by the U.S. Geological Survey in Flagstaff, Arizona, and Institute of Geodesy and Cartography in Warsaw.

In this way, an emphasizing of several structural units, invisible on standard images was obtained. For digital processing adequate programmes were applied, including:

- linear stretching,
- sinus stretching,
- mode separation (histogram equalization),
- principal component analysis,
- ratios of different bands,
- "addition" of the third no existing band of MSS scanner for the blue range.

The principal component 1 and 2 analysis plus made separation have been found to be the best variants of digital processing for geological interpretation.

The images acquired in different seasons (May, June, July, September, October, November) have been interpreted. The interpretation of repeatable images from different seasons with variable sun's elevation from 24 to 56° was of great importance for legibility of structural units. The value of the sun's elevation determines the length of shadows cast by different relief of the Earth's surface and it influences the "plasticity" effect of an image. The whole group of lineaments connected with rectilinear elements of the Earth's surface is much more legible on the images taken in autumn. It is of great importance especially for an interpretation of mountain and submountain regions. Also the presence of a snow cover helps to distinguish some rectilinear structural elements in mountain regions.

The material intepreted in different scales was combined on a topographic map on the scale of 1:500,000.

RESULTS OF INTERPRETATION

The legibility of geological structures on satellite images depends on fulfilment of the following conditions:

1. Geological units should be relatively big in relation to image resolution (e.g. the Landsat satellites from 60 to 80 metres).
2. Different geological units should have different spectral characteristics.
3. Different geological units should be characterized by dissimilarity of morphological expression.
4. The relation should be maintained between the pattern and texture of an image and elements of a geological structure.

Thus the recognition of regional structures and certain lithologic boundaries on satellite images is possible.

On the satellite images of the Carpathians two main types of linear elements may be distinguished. The first type is connected with fold structures and lithological differencies.

In consideration of a regular configuration and an accumulation of folds two areas may be distinguished in the Outer Carpathians: the east and the west one. In both areas mountain ranges and narrow valleys corresponding to the course of the folds, make up long and regular alternate forms, especially well visible on satellite images. However, the folds of the middle part of the Carpathians are irregular and discontinuous. All known directions of folds: Carpathians (NW–SE), Tatra (W–E) and Silesian (NE–SW). K. Tołwiński (1922) are confirmed by the satellite images. The Pieniny Klippen Belt is visible on the images only in fragmentary form, probably because of the lack of folds continued at longer distance in this area. However, the Inner Carpathians are well distinguished from the outer ones. This is connected with a different relief of the Earth's surface. Because of a high degree of tectonic complication of the Inner Carpathians and because of a diversity and irregularity, the fold structures are not well legible. Only some parts of overthrusts and the lines limiting the igneous rock areas from intermountain basins are visible. In Hinterland the fold elements are not very good visible, but the areas of igneous rocks stand out in relief.

The second group of lineaments is connected with different discontinuous

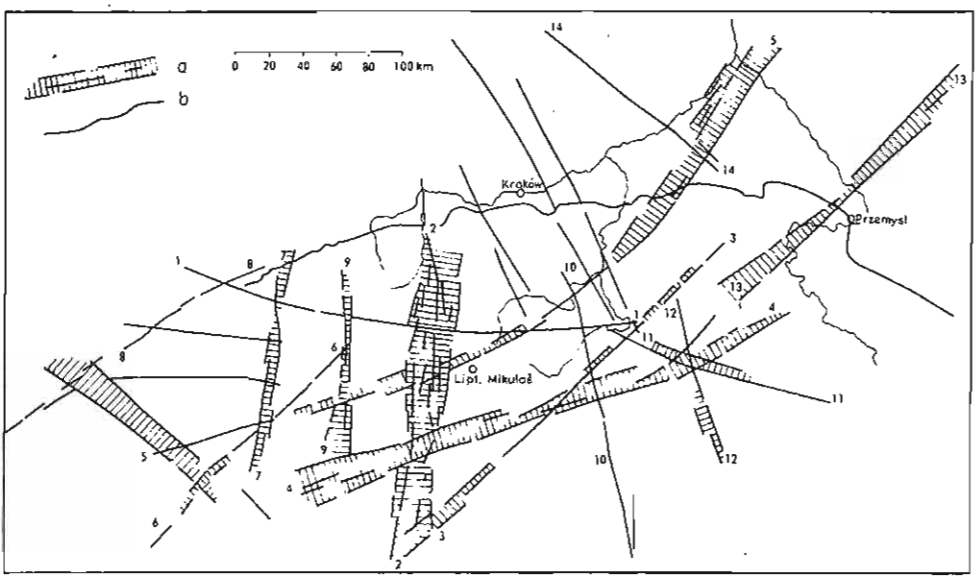


Fig. 2. The main lineament systems of the Western Carpathians
Główne systemy fotolineamentów Karpat Zachodnich

a – Carpathians boundary; b – main lineament systems; 1 – northern Tatra (Tatry północne), 2 – Central Slovakian (Środkowa Słowacja), 3 – Muran, 4 – Hron, 5 – Myjava, 6 – Vah, 7 – Inovec, 8 – Hranice, 9 – Rajec, 10 – Štitnik, 11 – East Pieniny (Pieniny wschodnie), 12 – Slańske Vrchy, 13 – Przemyśl, 14 – Rzeszów

a – granica Karpat, b – systemy fotolineamentów

deformations. The main characteristics of the lineaments are a big diversity of azimuths and variability of lengths. In the eastern part of the Carpathians, the NE–SW and close to N–S directions prevaile, while in the central and west parts the NW–SE, N–S and ENE–WSW directions dominate (S. Doktór et al. 1984).

A lot of elements are characterized by considerable length. They often cross the border of the Carpathians towards the foredeep and are also assembled in zones. There are many signs showing that the lineaments are of regional nature and suggesting their connection with deep seated faults (geofractures). According to W.J. Chain (1974) the deep seated faults are characterized by several geomorphological and structural features.

To the geomorphological features belong:

– sharp rectilinear borders between mountain massifs, highlands and lowlands;
– sudden changes of height of peneplane surfaces and terraces;
– long rectilinear parts of big river valleys;
– bead-like system of lake dells or broader parts of river valleys a change of drainage patterns in certain strips.

To the structural features belong:

– a congestion of faults in certain strips;
– regional faults with step like system of fault surface;
– a sudden increase of intensity of folding in certain zones;
– sharp changes of folds and local faults directions in particular zone.

Many of above mentioned facts may be observed on the satellite images, where features of the Earth's surface are pictured in synthetized form.

The main lineament systems recognized on satellite images in the Western Carpathians are presented in Fig. 2.

1. The Northern Tatra lineament is characterized by the direction W–E. It is best visible between Valašske Meziriči and Plaveč. In its middle part the lineament emphasizes the northern margin of the Tatra Mts. In this place it has been considered as a flexure zone and only locally was interpreted as a fault (J. Gołąb, 1952; A. Kulikowski, 1967). S. Ostaficzuk (1975), applying the method of condensed contour lines, noticed the sharpness of outline of the northern margin of the Tatra Mts and marked it also on a satellite image (S. Ostaficzuk, 1978). The lineament coincides only in small parts with the hitherto mapped faults. It cuts transversely the folds of the Magura nappe. On the cross line a sigmoidal displacement of the folds can be observed. Sigmoidal displacements of folds observed in Magura nappe can be related to the possible horizontal movement along the lineament. The course of the lineament coincides in its western part along Roznovska Bečva river valley with tectonic contact, where the narrow slices of Fore-Magura unit are present.

Several known mineral and low-thermal water springs are located along the lineament or on the cross-cutting with the smaller lineaments oriented NE–SW and NW–SE e.g. Oravice, Teplice upon Bečva river, Vyšne Ružbachy. These data should be verified in the future by further hydrogeological studies.

2. The Central Slovakian lineament is the most conspicuous fault zone of the N–S direction. It is well pronounced from the northern margin of Carpathians near Oświęcim to its innermost parts. It is formed by the wide zone of lineaments characterized by different length. The lineaments interpreted on the satellite images in this zone usually correspond very well to the faults known from previous geological and geophysical studies.

It is worth mentioning that the lineament coincides with such tectonic features as: the Zazriva sigmoidal structure of the Pieniny Klippen Belt, the Revuca fault zone and faults within the neovolcanic region etc.

3. The Muraň lineament characterized by NE–SW direction is one of the most pronounced lineaments on the satellite images and fully corresponds to the Muraň fault. It is clearly interpreteable especially in its central part. In the comparison with other lineaments distinguished in the Carpathians the Muraň lineament is formed by single fault line. The continuation of the lineaments is traceable into the Outer Carpathians. Both terminations of the lineament are not clear in the areas of Flysch Carpathians and Central Slovakian neovolcanic region.

4. The Hron lineaments zone is characterized by the ENE–WSW direction. It is traceable from Vienna Basin to Medzilaborce at the length of more than 350 km. The lineament zone is formed by many paralell lineaments which are not continuing for its full length (usually they reach several tens of km.). Numerous lineaments forming this zone correspond to faults proved geologically and geophysically. However the using of remote sensing data enabled recognition of these individual geological structures as parts of one regional tectonic zone. The lineaments forming this zone correspond to such geological structures as:

– course of Sub-Tatric nappes in middle part of the Little Carpathians between Rohoźnik and Smolenice;

– south-eastern margin of Považský Inovec Mts;

– faults separating the Bánovce depression from the Topolčany bay of the Danube Basin:
– faults on the northern margin of the Tribeč Mts;
– some faults in the Vtačnik and Kremnické Vrchy Mts;
– faults on the northern margin of the Žiar depression;
– faults along the Hron valley east from Bánska Bystrica.

Its continuation eastward from the Muraň fault has not clear correlation with known geological structures.

5. The Myjava lineament is one of the most conspicuous feature visible on the satellite images. It is continuing from Vienna Basin to the western limit of Tatra Mts in the ENE–WSW direction. Its northern continuation can be observable in Outer Carpathians on the Polish territory between Nowy Sącz and Stalowa Wola. In this area it slightly changes direction to NE–SW. Before interpretation of the satellite images this lineament was unknown as continuous structure. It is parallel to Horn lineament and its parts have close correlation with many geological structures and geomorphological features of different origin e.g.:

– the most widespread occurrence of Upper Cretaceous of "Gosau formation" in the Myjava area;
– northern margin of the Považský Inovec Mts and the Bánovce depression;
– northern margin of crystalline complexes in the Strážkowské Vrchy Mts (the Suchý and the Mala Magura Mts);
– faults in neogene of the Turiec depression;
– western margin of the Liptov depression;
– western termination of the Tatra Mts.

Along the above mentioned lineament occurrences of hydrocarbons are reported in the Polish territory.

6. The Vah lineament in its middle part between Žilina and Nové Mesto n. Váhom follows the course of the Vah river valley. Its continuation SW from Nové Mesto is observable along SE margin of the Little Carpathians. The lineament has distinct morphological expression e.g.:

– several elongated depressions follow its course along the Vah river valley,
– limit of the Danube Basin against the Little Carpathians. The Vah lineament seems to be disturbed by the NW–SE oriented faults. It has a good correlation with known geological structures.

7. The Inovec lineament is one of well pronounced N–S oriented features visible on the satellite images. It is formed by system of faults running along the western margin of Považský Inovec Mts. Its northern continuation in the Outer Carpathians is not so clear. The course of lineament is also followed by the Vah river southward from Nové Mesto n. Váhom.

8. The Hranice lineament (NE–SW oriented) corresponds to the north-western margin of the Carpathians and front of flysch nappes. The Morava Gate follow its course.

9. The Rajec lineament is a wide zone characterized by numerous N–S and NNW–SSE trending faults. Most of faults are well expressed geologically and geomorphologically, especially in the Inner Carpathians part of the zone. The continuation of the lineament can be seen in the Outer Carpathians but its expression is not so clear, because of appearance of NNW–SSE trends.

10. The Štitnik lineament is a narrow zone oriented NNW–SSE. It is directly related to the Štitnik fault. The satellite images reveal its possible continuation northward into the Tatra area. It is also possible that continuation of Štitnik

lineament can be traced in the Polish territory in the form of the NNW–SSE oriented lineaments near Kraków. The lineaments correspond to the tectonic zone Kraków–Myszków (W. Brochwicz-Lewiński et al., 1983).

11. The East Pieniny lineament indicates the course of the Pieniny Klippen Belt between Stara Lubowna in the west and Vyhorlat Mts in the east. In some places the lineament course is disturbed by cross-cutting faults and lineaments oriented NE–SW, NNE–SSW and N–S.

12. Slańskie Mts lineament is characterized by the linear arrangements of several volcanic centres which are oriented NNW–SSW. It is continued probably to the Flysch Carpathians but its location beyond the East Pieniny lineament is not marked by volcanic rocks.

13. The Przemyśl lineament zone NE–SW oriented is one of the most interesting and best confirmed by many geological and geophysical data. It decisively influenced the tectonic configuration of this area. In this area the folds of Skole nappe with regular NW–SE direction rapidly turn to the north in the region of Przemyśl. This structure is called the Przemyśl Sigmoid Zone. This form was established in the period of Badenian and post-Badenian orogeny, as a result of the thrust of the initially folded nappes to NE (B. Świderski, 1952). Having met no major resistance to the north-west of Przemyśl, the nappes could be transported there more easily. On the other hand, having met an obstacle of accumulated folds of Stebnicka nappe reclined on the massif of the Holy Cross – Dobrogea anticlinorium, the nappes became acute folded and thrust-sliced to the south-east of this line. Is seems that the existence of tectonic zone, corresponding to mentioned above group of the Przemyśl lineaments is the factor which is confirmed by the satellite images. Further argument confirming the significance of this zone is the change of the "Carpathian" direction to the "Tatra" one in this area (with one exception of the groups of folds to the south of Gorlice–Jaśliska line, which is displaced to the south along the lineament of the same group).

On the schematic map of the Carpathians W.J. Chain (1974) marked there a transversal deep seated fault (geofracture).

The above presented data together with the gravimetric map indicate that the Przemyśl lineament zone is a surface picture of a deep seated fault. The latter may be recognized as the main cause of the observable geological phenomena in this part of the Carpathians.

14. The Rzeszów lineament (NW–SE) constitutes the southern section of the megalineament Szczecin–Poznań–Rzeszów. On the line Leszno–Sędziszów it corresponds to the fault zone (E. Stupnicka, 1972), which separates the Holy Cross anticlinorium from the Nida trough. It is typical in the area of the Carpathians that directions of folds prolonge the course of lineament.

Beside the lineaments several circular features were identified (S. Doktór et al., 1984). The interpreted circular features could be divided into three groups. First group comprises the features of the Slańske Mts and Vyhorlat. They could be directly related to the volcanic phenomena. The circular features interpreted in the Beskid Wyspowy area coincide with folds of brachysyncline type characteristic of this part of the Carpathians. The other circular features are of unknown origin but certainly they are related to the geological phenomena.

The above mentioned data were observed on the satellite images where features of the Earth's surface are pictured in synthesized form. This is the reason that along known geological structures the regional lineament zones were distinguished for the first time. Some of the lineament zones extend 400 km e.g. Myjava,

Hron, the distances of the other lineaments are very close to it Muraň, Przemyśl, Northern Tatra.

It seems that the above mentioned lineaments have played an important part for tectonic development of the Carpathians.

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СТРУКТУРНЫЕ ЭЛЕМЕНТЫ ЗАПАДНЫХ КАРПАТ И ИХ ПРЕДГОРИЙ В СВЕТЕ ИНТЕРПРЕТАЦИИ КОСМИЧЕСКИХ СНИМКОВ

Резюме

Результатом интерпретации космических снимков польских и словацких Карпат явилось выделение ряда региональных зон фотолинеаментов, отвечающих, вероятно, системам дис-

локаций. В статье описано положение главных фотолинеаментов в сравнении с данными геологических карт. Характерные черты космических снимков, отражающие генерализованные элементы земной поверхности, позволили объединить многие из известных геологических структур в региональные зоны фотолинеаментов. Большей частью эти зоны не были описаны в геологической литературе. О их значении может свидетельствовать многокилометровой протяженности (до 400 км) зоны Мыявы и Грона и другие также вытянутые зоны Мураня, Пшемысля, Северо-Татрская.

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ELEMENTY STRUKTURALNE KARPAT ZACHODNICH I ICH PRZEDPOLA W ŚWIETLE INTERPRETACJI ZDJĘĆ SATELITARNYCH

Streszczenie

W wyniku interpretacji zdjęć satelitarnych obejmujących Karpaty polskie i słowackie wyznaczono szereg regionalnych stref fotolineamentów odpowiadających prawdopodobnie systemom dyslokacyjnym. W artykule omówiono przebieg głównych fotolineamentów w stosunku do danych przedstawionych na mapach geologicznych. Charakterystyczne cechy zdjęć satelitarnych wiążące się z generalizacją elementów na powierzchni ziemi pozwoliły połączyć wiele znanych struktur geologicznych w regionalne strefy fotolineamentów. W zdecydowanej większości strefy te nie były prezentowane w literaturze geologicznej. O ich znaczeniu mogą świadczyć wielokilometrowe (do 400 km) strefy Myjavy i Hronu lub inne o zbliżonej długości: Murania, Przemyśla i północnotatrzańska.