GEOGRAFIE – SBORNÍK ČESKÉ GEOGRAFICKÉ SPOLEČNOSTI
ROK 2006 ● ČÍSLO 1 ● ROČNÍK 111

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CONCEPTUAL REMARKS FOR TECTONIC GEOMORPHOLOGY BY TERRAIN MODELLING WITHIN GIS

V Voženílek: *Conceptual remarks for tectonic geomorphology by terrain modelling within GIS.* – Geografie–Sborník ČGS, 111, 1, pp. 3–14 (2006). – The paper deals with term of digital tectonic geomorphology as an integration of structural geology, geomorphology and digital terrain analysis. The author extends traditional set of methods for tectonic geomorphological research and gives general conceptual remarks for methods of tectonic geomorphology developed for the integration of tectonic geomorphology into GIS based on digital terrain modelling. The emphasis is given on selected problems: morphological features associated with fractures, feature recognition and parameter extraction, digital geomorphometry analysis, digital image processing of terrain data and spatial analysis of lineaments. The paper gives fundamental topics for understanding instead of particular algorithms and procedures.
KEY WORDS: tectonic geomorphology – terrain modelling – GIS – landforms.

The paper has been completed within project 205/02/0211 "Geography of selected natural extremes, their impacts and cartographic visualization" supported by Grant Agency of Czech Republic.

Introduction

In addition to various methods and sophisticated geophysical, geological and geodetic data handling a structural analysis of topographic features is well-established field of study in modern geomorphology, and aerial photographs and remotely sensed images have long been used within its approaches. Recent developments in information technology and digital elevation data acquisition have resulted mainly in an increasing interest in digital terrain modelling for tectonic geomorphology. Methods of surface investigation such as remote sensing and morphological analysis provide fast and relatively cheap information, complementary to traditional field geological research in order to study subsurface geology. Morphological analysis of topographic features, in particular lineaments, has long been applied in structural and tectonic studies (Hobbs 1912), and has become a fundamental tool in tectonic analyses using aerial (stereo-)photographs and other remotely sensed imagery (Siegal, Gillespie 1980; Drury 1987; Salvi 1995; Woldai et al. 2000). Although the interpretation of surface morphology in terms of geological structures is commonly applied (Fabbri 1984; Prost 1994; Keller, Pinter 1996; Voženílek et al. 2001) there are relatively enough examples of GIS implementation in such studies, and there are only few case studies involving the consistent application of available digital methods for tectonic geomorphology.

Review of literature on digital morphotectonic analysis shows that large variety of methods (and their combinations) has been used, such as shaded relief models together with remotely sensed images, three-dimensional view with image drape, digital cross-sections, slope, aspect and curvature maps, DEM histograms, and trend and spectral analysis. The most important limitations in general are that:

- most of the studies use a single method (or only a few methods) for surface feature recognition and description
- all of the studies are at the regional scale, although landform observations are at the local scale
- most of the studies use visual methods of feature (mostly lineament) extraction
- there are very few cases involving the analysis and extraction of landforms specific to tectonic structures
- most of the methods can be applied to neotectonic landforms only
- there is a lack of rigorous study of the relationship between tectonic processes, secondary geological processes, and their representation in DEMs.

Digital tectonic geomorphology

Systematic digital tectonic geomorphology analysis is limited by the lack of such studies in literature, and the non-uniform description and use of relevant digital methods in different fields of the Earth Sciences. Essentially identical methods are often used in these different fields with different names and for different purposes that makes their adoption to digital tectonic geomorphology difficult. GIS software can easily perform most of the analyses but some procedures may be very difficult to implement. Many digital analyses require the use of an integrated system of many analytical and software tools based on principal topics of interoperability.

Digital tectonic geomorphology is the integration of three components (Jordan, Csillag 2001, 2003): structural geology, geomorphology and digital terrain analysis. Tectonic geomorphology has developed sophisticated methods for the integration of structural geology and geomorphology. The application of numerical methods in geomorphology has led to the field of geomorphometry, which has developed rapidly since the availability of digital terrain data. There is, however, a gap between structural geology and digital terrain analysis.

The basic geometric properties which characterise the terrain surface at a point are elevation, properties of the gradient vector: its magnitude defining slope, and its direction angle defining terrain aspect, surface curvature, convexity and surface-specific points and lines, i.e. local maxima (peaks), minima (pits), saddle points (passes), inflection points, slope-breaks, ridge and valley lines. The relationship of local geometric attributes and tectonic structures such as relationship between slope-breaks and fractures is often straightforward (Siegal, Gillespie 1980; Drury 1987; Prost 1994; Salvi 1995).

In contrast to local geometric analysis, general geomorphology also studies the statistical and spatial characteristics and relationships of point attributes (Evans 1972, 1980). Relationships between point attributes were used by Evans (1980) to further characterise the terrain. For example, the elevation-average slope curve and the cumulative percentage area-elevation curve ('hypsometric curve') can be used to study slope conditions. By fitting a trend surface to the studied area or its parts, the overall tilt due to tectonic activity can be studied (Doomkamp 1972; Fraser et al. 1995; Guth 1997). Autocorrelation, spectral, wavelet and variogram analysis can reveal anisotropy and periodicity present in the digital elevation model. Both features often result from tectonic control on terrain morphology (Harrison, Lo 1996).

Morphological features associated with fractures

Structural discontinuities in rocks most often result in linear morphological features along the intersection of fracture plane and land surface. Linear morphological expressions of fractures include mainly linear valleys, linear ridgelines and linear slope-breaks. The main geometric characteristics of a single line are orientation, length (continuity) and line curvature. Linear fracture traces are most obvious in the case of high-dip faults of normal, reverse and strike-slip type whilst thrust faults tend to appear irregular in topography (Prost 1994; Drury 1997; Goldsworthy, Jackson 2000). Intersection of topographic surface and fold structures can also result in linear and planar features depending on the geometry and orientation of the folds with respect to the erosion surface (Ramsay, Huber 1987).

Planar features such as uniform hillsides also develop along fractures. Geometry of planar surfaces is described by uniform aspect and high and constant slope values. Shape and extent are also important characteristics. Large elongated areas with linear boundaries can be associated with faults. The measure of curvature is important in case of complex curving fracture surfaces.

Specific geomorphological features forming along faults are diverse. Asymmetric geometry of slopes across valley and ridgeline axes, as measured by uniform slope angle differences, can result from tectonic influences on the morphology. Characteristic landforms, such as depressions, pressure bulges or tilt of flats are commonly seen in fault zones. Depressions and bulges are geometric locations of local elevation minima and maxima, respectively. Characteristic shape and slope conditions describe their geometry (Keller, Pinter 1996). Tilt of flats result in uniform surface gradients.

Most of the above morphological features, such as linear valleys, asymmetric slopes and depressions may be caused by secondary processes or can be associated with lithology. For example, wind erosion may create linear patterns; planar surfaces, linear valleys and ridges and asymmetric slopes are often associated with bedding; and linear morphological features may arise from lithological contacts between different rock types.

The spatial relationships among fractures can be described either statistically by a spatial frequency analysis of the above characteristics or topologically in statistical analysis, location of individual features is not considered within the studied population. For example, angular statistics (rose diagrams) are used for analysis of orientation distribution in the study area. Spatial statistics of fault length and intersection densities are important in structural geology, too. Note also that the density number of lineaments is sensitive to the scale and resolution of the used imagery, relief and thickness of soil cover (Tirén, Beckholmen 1992). Another approach in many fracture analysis considers fracture populations as networks, and focuses on their pattern of intersection in terms of lengths, angle and frequencies, mutual dislocations and shape and size of fracture-bounded areas, from which the stress field can be quantified (Ramsay, Huber 1987). This approach is commonly known as topological analysis, where the location and relationships of individual features are considered. Intersecting lineaments define rock blocks of various scales identifiable by digital terrain analysis (Tirén, Beckholmen 1992), an important feature of, for example, shear zone regimes (Sylvester 1988).

Lithological structures within rock units may also be represented by DEM and their description might help clarifying geological and structural relationships, but these features can also obscure tectonic structures. Secondary geomorphological indicators of tectonic influence are dislocations of geomorphic surfaces, such as erosional surfaces and alluvial plains, and these surfaces are the result of uplift, subsidence or tilting. Fluvial networks are the most common indicators: the drainage network pattern often reflects the regional or even the local tectonic framework (Deffontaines, Chorowicz 1991). In the absence of further morphological evidence, these morphological features can be distinguished from features of non-tectonic origin with the use of geological information. Geological data from various sources, such as geological maps, geophysical data, remotely sensed images and field measurements also have to be incorporated in the GIS database.

Feature recognition and parameter extraction

In order to maximise the tectonic geomorphology information obtained from a DEM, a sequential modelling scheme can be created and applied. The design of the modelling scheme has been based on the following considerations (Jordan, Csillag 2001):
- the objective is the quantitative geometric characterization of landforms
- the objective is providing reproducible outputs
- analysis proceeds from simple to the more complex analysis
- outputs from modelling steps are controlled by input data and parameters
- the procedure integrates a wide-range of available methods
- multi-source information is integrated in the database
- digital terrain analysis is implemented in GIS environment.

Analysis of multi-source data mostly use GIS techniques. Figure 1 illustrates the procedure of recognition and extraction of fault-related landforms and their tectonic interpretation. Based on the study of landforms related to faults, geomorphological characteristics are translated into mathematical and numerical algorithms. Topographic features represented by DEM of test areas are extracted and characterised by digital terrain analysis. Verification of structural implications uses other data sources in GIS. The development and application of numerical methods in GIS are

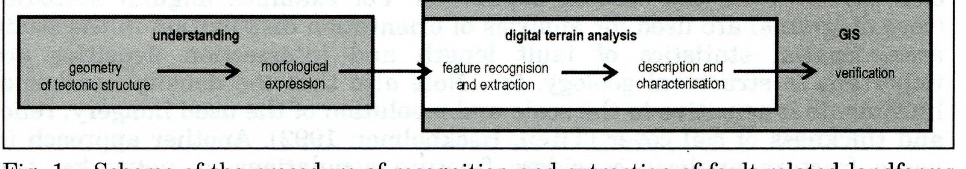

Fig. 1 – Scheme of the procedure of recognition and extraction of fault-related landforms and their tectonic interpretation

discussed in various papers (i.e. Jordan, Csillag 2001, 2003, Wood 2002, Voženílek 2002).

The components of digital tectonic geomorphology implemented with GIS are:

- numerical differential geometry
- digital drainage network analysis
- digital geomorphometry
- digital image processing
- lineament extraction and analysis
- spatial and statistical analysis and
- DEM-specific digital methods such as shaded relief models, digital cross-sections and 3D surface modelling.

The analysis within digital tectonic geomorphology proceeds from simple univariate elevation studies, through differential geometric surface analysis and drainage network analysis, to the multivariate interpretation of results using GIS technology. Reproducibility of morphological analysis is achieved by the application of numerical data processing algorithms. Each modelling module has a set of defined input parameters. Subsequent steps are based on output of previous terrain models. Prior to the spatial analysis of each terrain attribute, its histogram is studied for systematic error and statistical properties such as multi-modality. Histograms are interpreted in terms of morphometry and used for classification of terrain data. Image stretching for enhancement of visual interpretation is also based on histograms.

Digital geomorphometry analysis

Elevation and derivatives of altitude, called point attributes, form the bases for geomorphometric study of landscape (Evans 1972). The five basic parameters calculated are elevation, slope, aspect, profile and tangential curvatures (Evans 1980). For example, a peak in the elevation histogram that corresponds to a sharp increase in its cumulative graph indicates a flat planation surface. A peak in the aspect frequency histogram or a large petal in the rose diagram shows that a larger number of pixels has aspect in a preferred orientation. Where these pixels form one or more connected areas on hillsides with linear boundaries, a tectonic origin can be inferred.

Next in the analysis, bivariate and multivariate relationships between variables (derivatives and moments) can be studied. Slopes and aspects can be plotted in stereonet to study if steep slopes have preferred orientations, as steep slopes with the same orientation may be associated with faulting.

Finally, terrain 'texture' is conveniently studied by means of spatial statistical methods and network analysis techniques. Trend analysis, autocorrelation and spectral analysis are carried out for the entire area or specific parts of the area (e.g. basins only). The trend surface is fitted to all data points or to surface specific points, such as peaks or valley lines, to estimate regional dips, as the tilt of an area is often related to tectonic movements.

Autocorrelation, spectral and wavelet analyses reveal lineation (anisotropy) and periodicity of a landscape due to faulting or folding. The autocorrelation property can also be studied by calculating semivariograms in different directions (Curran 1988). Problems emerge from the fact that valleys often curve and there are confluences down-valley and that ridge height and spacing may vary (Evans 1972). In order to overcome the problem of converging ridges of alternating height, analysis can be limited to valley lines only. Then valley lines are defined by the digital drainage network identification method.

Digital image processing of terrain data

DEM and each terrain attribute map derived by digital terrain analysis can be viewed as raster images and hence be processed using digital image processing procedures to increasing the apparent distinction between features in the scene (Sauter et al. 1989; Fabbri 1984; Woldai, Bayasgalan 1999). Point operations of histogram slicing and contrast stretching have basically two applications. Slicing of an image histogram by dividing pixel values into specified intervals can been used to display discrete categories of elevation, slope, aspect and other terrain attributes (Lillesand, Kiefer 1994). Aspect data can been displayed and analysed by means of rose diagrams and circular statistics (Wells 1999; Baas 2000). Areas of uniform geometric attribute are then examined for area distribution, continuity and shape whilst contrast stretching was performed on grey-level images to enhance visual interpretations of the terrain models (Lillesand, Kiefer 1994).

Spatial operations of gradient filters are processed by local operators of gradient filters which can be applied only to terrain data and not to grey-scale images in order to preserve the original geometric information in terrain models. In this way, edges (valleys, ridges and slope-breaks) are extracted on geometric bases. For example, slope-breaks can be recognised as edges if change in slope in the gradient direction (profile curvature) exceeded a predefined threshold. Low-pass filters such as median and average filters are used to reduce noise and emphasise areas of similar topographic attributes. For example, aspects calculated from a smoothed DEM could reveal a hill slope of uniform aspect related to faulting (Voženílek et al. 2001). The enhanced images were then used for analysis of shape, spatial distribution and for interactive lineament extraction.

Hill shading methods producing relief maps are unusual to DEM images and are fundamental for morphostructural analysis (Simpson, Anders 1992). Hill shading increases the contrast of very subtle intensity variations of an image, much more than contouring or pseudo-colour representation do (Drury 1987). Onorati et al. (1992) used multi-image operation of false colour composites (i.e. RGB colour components) in morphotectonic studies to simultaneously analyse three DEMs. In their study colour separated geological maps and remotely sensed images were combined with a shaded relief map. These in turn were draped on the three-dimensional view of the study areas to enable the study of the relationship between geology and morphology.

Spatial analysis of lineaments

Lineaments are defined as straight linear elements visible at the Earth's surface and which are the representations of geological and/or geomorphological phenomena (Clark, Wilson 1994). In geomorphometric analysis, a linear feature can have geometric origin only and represent

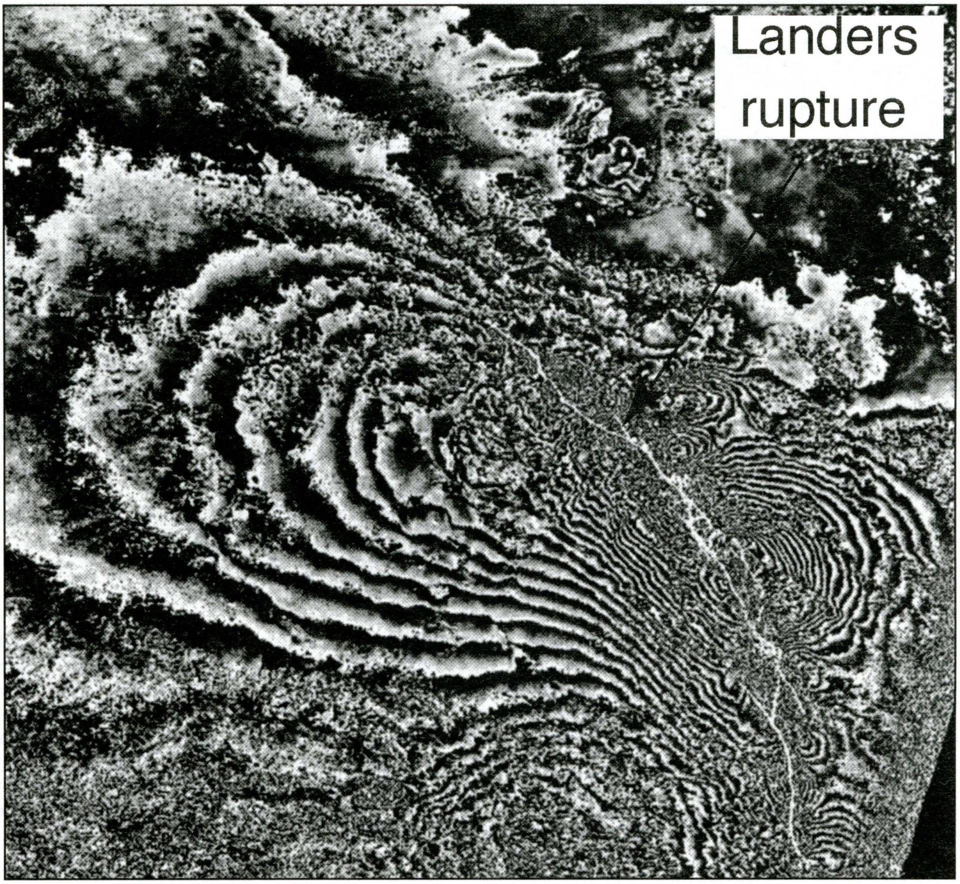

Fig. 2 – Radar SAR interferogram of ground displacement associated with the Landers Mw 7.3 earthquake (June 1992). Each fringe represents 28 mm of displacement and at least 20 fringes are visible near the fault (equal to 560 mm of displacement). Coherence is lost as the ground rupture is approached, probably because the displacement gradient is greater than 28 mm/pixel. Note the broad, asymmetric deformation in an east-west direction covering >75 km and the abrupt termination of major deformation near the ends of the fault. The detailed deformation patterns seen here can be used to constrain models of surface displacement due to the Landers rupture (Burbank, Anderson 2001).

a change in terrain elevation, such as a valley or ridgeline, slope-break or inflex line. In terms of digital modelling, a lineament is a continuous series of pixels having similar terrain values (Koike et al. 1998, Krcho 1983, 1990). Each line can be characterised by length and orientation. Distribution and relationships among lines are described by length and orientation frequencies calculated for the entire area or a sub-area. Then lineament intersection density, total length per area and frequency per area can been analysed. Two lineament extraction procedures are frequently applied:

– an automatic procedure using digital drainage extraction to identify valley and ridgelines
– interactive lineament interpretation of terrain models.

Wavelet analysis is used to identify and measure periodicity and location of lineament zones.

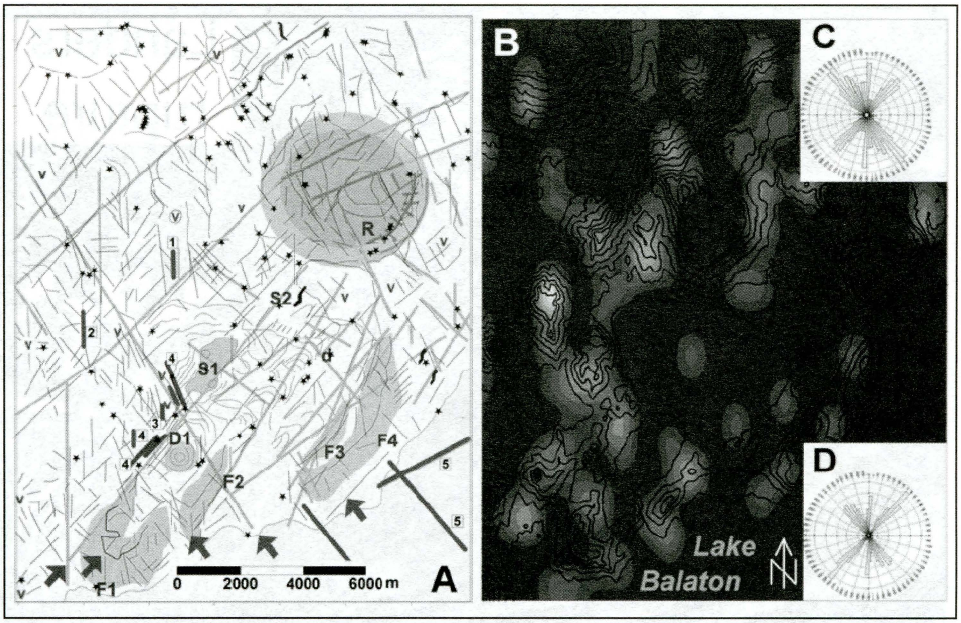

Fig. 2 – Graphic documentation for spatial analysis of lineaments (Jordan, Csillag 2003). Explanation: A – Lineament map (black lines are line features digitised from elevation images, grey polygons emphasise major morphological feature, thick light-grey lines show fracture lines extracted from geological maps, thick dark-grey lines show fracture lines recognised by early studies, asterisks represent springs and large arrows show zones of springs; D1: main depression, S1 and S2: S-shaped expressions, F1-F4: fold features, R: ring structure, d: asymmetric depressions, v: volcanic features). B – Lineament density map for N-S (N±10°) lineaments (light tones indicate higher densities). C and D – Frequency and length rose diagram of lineaments.

Conclusions

To study basic geometry of faults and associated morphological features is going to be commonly used methods of tectonic geomorphology. Also topographic parameters necessary to recognise and characterise them can be easily identified. Numerical methods to extract specific parameters are now developed and can be applied within GIS environment.

Digital terrain analysis gives reproducible results and provides quantitative landform description. It allows geomorphologists reproducibility as an improvement to traditional morphological analysis and visual image interpretation. Quantitative geometric characterisation of landforms based on DEM analysis is an advantage if compared to digital processing of remotely sensed images or analysis of grey-scale terrain images (Voženílek et al. 2001).

Evan's (1972, 1980) general geomorphometric method has been developed for all GIS packages and then adopted to digital tectonic geomorphology. So now the five basic geometric attributes (elevation, slope, aspect, profile and tangential curvatures) can be complemented with the automatic extraction of surface specific points and ridge and valley lines (Voženílek 2002). Evan's univariate and bivariate methodology is also extended with texture (spatial) analysis methods such as trend, autocorrelation, wavelet, variogram and spectral analysis and network analysis.

Digital image processing techniques of spatial operations and histogram manipulations can be integrated in the GIS procedure and applied at almost all stages of digital tectonic geomorphology analysis.

A method for the extraction of high-density drainage and ridgeline extraction can be used to create an artificial DEM to overcome problems of periodicity analyses using original topographic data. The advantage of digital drainage extraction over traditional lineament extraction methods is that identified.

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Shrnutí

KONCEPČNÍ POZNÁMKY K PROBLEMATICE TEKTONICKÉ GEOMORFOLOGIE ŘEŠENÉ MODELOVÁNÍM RELIÉFU V PROSTŘEDÍ GIS

Strukturní analýzy topografických témat jsou vedle širokého spektra tradičních metod a analýz specializovaných geofyzikálních, geologických a geodetických údajů osvědčenou metodou studia geomorfologie. Vývoj informačních technologií a metod získávání digitálních dat zapříčinily vzrůstající zájem o využití digitálních modelů terénu v oblasti tektonické geomorfologie. Metody aplikované geoinformatiky, jako např. dálkový průzkum či geomorfometrické analýzy, poskytují rychlé a poměrně levné informace a doplňují datové zdroje potřebné pro studium geologických podmínek.

Digitální tektonická geomorfologie představuje sloučení tří komponent: strukturní geologie, geomorfologie a analýzy digitálních modelů reliéfu. Tektonická geomorfologie vyvíjí sofistikované metody sloužící k integraci strukturní geologie a geomorfologie. Aplikaci numerických metod v geomorfologii se věnuje geomorfometrie, která zaznamenala největší vývoj po odhalení potenciálu digitálních modelů terénu. Přesto zde existuje určitá mezera mezi strukturní geologií a analýzami DMR.

Prostorové analýzy geomorfologických tvarů spojených se zlomy: Prostorový vztah mezi jednotlivými povrchovými tvary může být popsán jednak statisticky, prostřednictvím prostorových analýz vybraných charakteristik nebo topologicky. V případě statistických analýz, není umístění jednotlivých tvarů reliéfu zvažováno pro celé území. Například, pro ana-

lýzy rozdělení orientace jsou používány úhlové statistiky. Pro potřeby strukturní geologie jsou však důležité i prostorové analýzy, např. délky zlomů nebo křížení puklin. Hustota zlomů je závislá na rozlišení a měřítku použitých snímků, reliéfu a mocnost sedimentů. Další přístup k analýzám zlomů uvažuje strukturu zlomů jako síť a zabývá se jejich vzájemnými vztahy z hlediska jejich délky, úhlu, který svírají, tvaru a velikosti rozhraní, kde dochází k uvolňování napětí. Tento přístup je všeobecně znám jako topologická analýza, ve které je hodnocena jak poloha, tak vzájemné vztahy mezi jednotlivými tvary. Protínající se zlomy vymezují bloky hornin různých velikostí, které je možné identifikovat pomocí analýz digitálního modelu reliéfu. Litologické tvary různých horninových jednotek mohou být také reprezentovány prostřednictvím digitálních modelů terénu, což významně napomáhá při objasňování vzájemných geologických či strukturních vztahů. Druhotným geomorfologickým indikátorem tektonických vlivů jsou poruchy geomorfologických povrchů, jako např. erozní povrchy nebo údolní nivy, které vznikají působením zdvihu, poklesu či sklápění povrchu. Typickým indikátorem je říční síť. Její tvar velmi často odráží regionální nebo lokální tektonický systém. V případě, že tyto geomorfologické znaky nejsou známy, lze geomorfologické tvary lokalizovat pomoci tvarů, které sice nemají tektonický charakter, ale nesou určitou geologickou informaci.

Identifikace tvarů reliéfu a získávání parametrů: Pro získání maximálního množství informací z digitálního modelu terénu se používají metody sekvenčního modelování. V prostředí GIS se pro řešení této problematiky implementují vybrané komponenty digitální tektonické geomorfologie, např. numerická diferenciální geometrie, síťová analýza povodí, digitální geomorfometrie, zpracované digitální snímky, analýzy lineamentů, prostorové a statistické analýzy apod. Po analýze tvarů georeliéfu souvisejících s tektonikou jsou geomorfologické charakteristiky začleněny do matematických modelů. Jednotlivé tvary a typy zemského povrchu, reprezentované DMR, jsou pak charakterizovány pomocí patřičných povrchových analýz. Následná verifikace a testování důsledků jsou prováděny v prostředí GIS na datech z jiného zdroje (viz obr. 1). Podobné analýzy postupují od jednoduchých studií profilů, přes analýzy tvarů georeliéfu a síťové analýzy povodí, až ke složitým interpretacím výsledků, vše v nejčastěji prostřednictví GIS.

Digitální geomorfometrické analýzy: Vstupem do geomorfometrických studií jsou atributy elementárních (tvarově homogenních) ploch georeliéfu. Využíváno je zejména pět základních parametrů: nadmořská výška, sklon, orientace ke světovým stranám, horizontální a vertikální křivost reliéfu. Například, vrchol v histogramu nadmořských výšek, který koresponduje s ostrým nárůstem v jeho grafu kumulativních nadmořských výšek, indikuje plochý povrch. Vrchol v histogramu orientací nebo široký pruh v hvězdicovitém diagramu ukazují, že velké množství pixelů je orientováno v preferovaném, tedy námi vybraném směru. Pokud tyto pixely vytvářejí jednu nebo více spojených ploch s lineárními hranicemi na svazích kopce, lze z nich odvodit tektonický původ. V analýze jsou dále studovány vzájemné vztahy mezi proměnnými. Orientace a sklony jsou vyjádřeny v pravidelných intervalech, aby bylo možné zjistit, zda například převažuje v některém směru příkrý sklon, nebo zda se příkrý sklony ve stejném směru spojují do zlomové oblasti. Na závěr se využívají prostředky prostorových statistických metod a techniky síťových analýz. Analýzy trendu, autokorelace a spektrální analýzy jsou uskutečněny pro konkrétní oblast nebo pro vybranou část zájmového území. Trend může být odvozen buďto od všech bodů nebo pouze od vybraných bodů, např. vrcholy. Autokorelace a spektrální analýzy odhalují obrys povrchu jako důsledek vrásnění či zlomové stavby. Vlastnosti autokorelace mohou být studovány i pomocí výpočtů semivariogramu.

Zpracování digitálních snímků terénních dat: Digitální modely terénu a atributy ploch z nich odvozené lze zobrazit jako rastrovou vrstvu a z toho důvodu mohou být také zpracovány použitím procedur pro zlepšení rozlišení. K zobrazení diskrétních kategorií atributů se vytvářejí řezy histogramu, což představuje rozdělení hodnot pixlů do přesně vymezených intervalů. K zobrazení a analýzám dat orientace se užívá hvězdicový diagram a kruhové statistiky. Oblasti se stejnými geometrickými vlastnostmi jsou následně zkoumány z hlediska rozdělení, kontinuity, tvaru i dalších atributů. Kontrast je transformován do stupnice šedi (pro visuální interpretaci tvarů georeliéfu). Např. náhlá změna svahu může být rozpoznána jako hrana, pokud změna sklonu překročí předdefinovaný práh. Dolní práh, např. medián nebo průměr, se používá k redukci šumu a ke zvýraznění oblastí se stejnými topografickými vlastnostmi. Orientace terénu vypočtena z vyhlazeného digitálního modelu terénu může odhalit svahy o určitém sklonu se stejnou orientací související s tektonickými poruchami. Vrstvy jsou pak používány pro analýzy prostorového rozdělení. Metody stínovaného reliéfu, produkující reliéfní mapy, jsou základem morfostrukturních analýz. Stínování reliéfu zvyšuje kontrast obrazu mnohem lépe než pseudobarevná reprezentace. V dnešní době jsou pro vytvoření stínovaného reliéfu kombinovány barevně separované geologické mapy a obrazy dálkového průzkumu země. Z toho je nakonec vytvořen trojrozměrný obraz zájmové oblasti umožňující studium vzájemných vztahů mezi geologií a geomorfologií.

Prostorové analýzy lineamentů: Lineamenty jsou definovány jako přímé lineární elementy viditelné na zemském povrchu a reprezentující určité geologické či geomorfologické fenomény. V geomorfometrických analýzách mají lineární tvary vždy geometrický základ a reprezentují změny v převýšení povrchu, jako např. údolí nebo brázdy. V případě digitálního modelování, jsou lineamenty chápány jako kontinuální série pixlů o stejné hodnotě. Rozdělení a vzájemný vztah mezi liniemi jsou charakterizovány prostřednictvím délky a četnosti orientací v zájmové oblasti.

Obr. 1 – Schéma postupu určování a odvozování povrchových tvarů souvisejících se zlomy a jejich tektonická interpretace.

Obr. 2 – Interferogram posunů povrchu souvisejících se zemětřesením o síle 7,3 Mw v oblasti Landers rupture (červen 1992) vyhotovený pomocí radaru SAR. Každý pás představuje posun o 28 mm a poblíž zlomu je vidět nejméně 20 pásů (což odpovídá posunu o 560 mm). Směrem ke zlomu klesá soudržnost, patrně proto, že gradient posunu je větší než 28 mm/pixel. Všimněte si široké asymetrické deformace ve směru východ–západ >75 km a náhlého ukončení hlavní deformace u konců zlomu. Podrobný model zdejší deformace může být využit k prokázání modelů posunu povrchu způsobeného Landers rupture (Burbank, Anderson 2001).

Obr. 3 – Grafická dokumentace prostorové analýzy lineamentů (Jordan, Csillag 2003). Vysvětlivky: A – mapa lineamentů (černé čáry jsou liniové znaky digitalizované z obrazů převýšení, šedé mnohoúhelníky zdůrazňují hlavní morfologické znaky, tlusté světle šedé čáry znázorňují zlomové linie vytažené z geologických map, tlusté tmavě šedé čáry znázorňují zlomové linie identifikované prvními studiemi, hvězdičky znázorňují prameny a velké šipky pramenné oblasti; D1: hlavní pokles, S1 a S2: projevy se tvaru písmene S, F1-F4: vrásové útvary, R: prstencová struktura, d: asymetrické poklesy, v: sopečné útvary). B – mapa hustoty lineamentů pro lineamenty ve směru sever-jih (sever ±10°) (světlé odstíny označují vyšší hustotu). C a D – frekvenční a délkový růžicový diagram lineamentů.

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Arrived to the editorial board on November 4, 2005