Czech Academy of Sciences

Institute of Geonics

Regularly directed complex linear landforms in (central) Europe:

large-scale disperse or zone distribution, associated landscape phenomena

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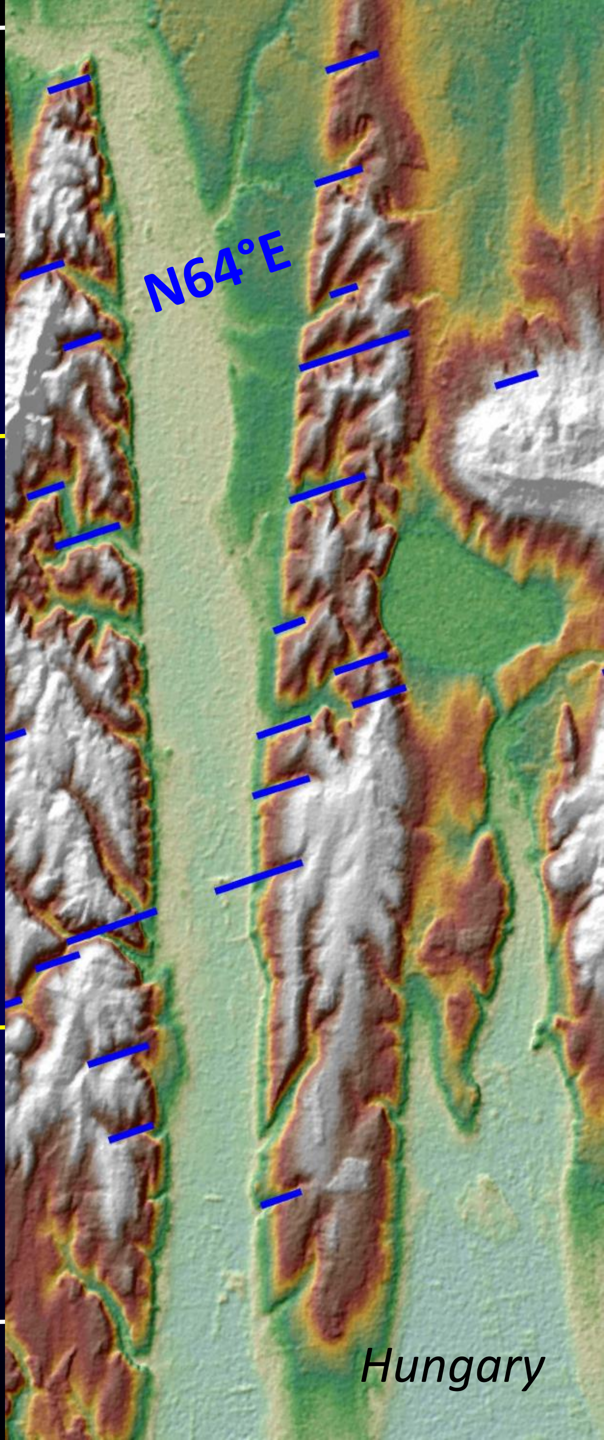
Supplemetary comments added at the end of this file



Introduction

- **Regular straight linear features:** very common in the crust, **largely manifested on its surface**
- For ~150 years as significant subject of research
- In central Europe: poor reflection of the features in recent geodynamic studies (last 30 years)
- In many cases, disputable or **uncomplete interpretations when** these features **not considered**

MAIN STUDY AIMS:

Support existence and outline basic geometry of systematic linear landforms in this area

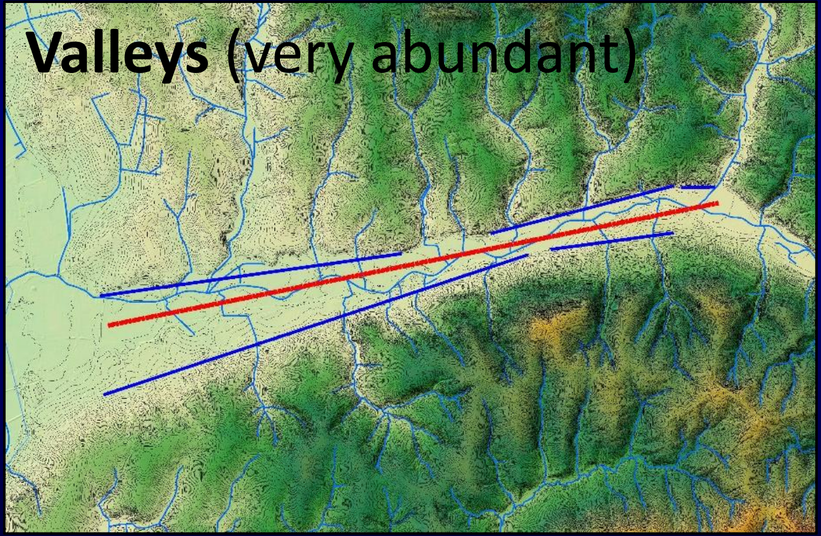
(~4000 km × 2000 km)

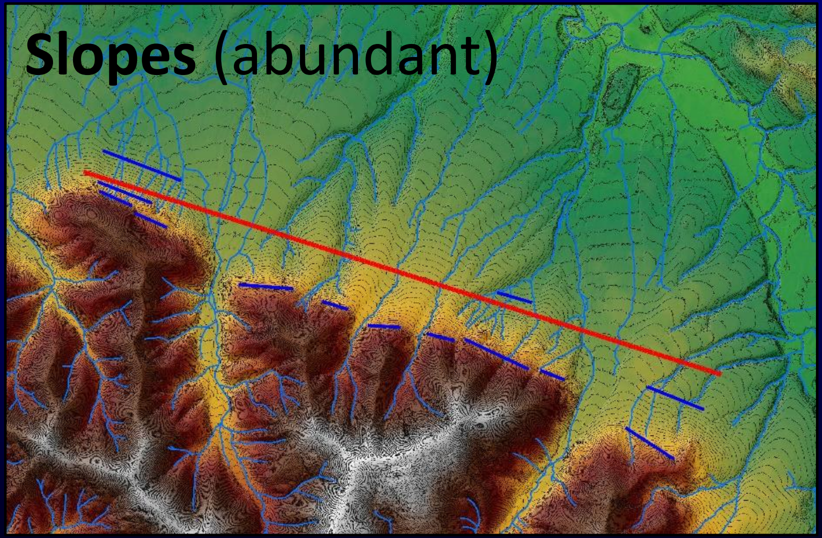
Work by Hobbs W. H. (1911): Repeating patterns in the relief and in the structure of the land. (Bull. GSA)

Frequent single linear or orthogonal joint patterns

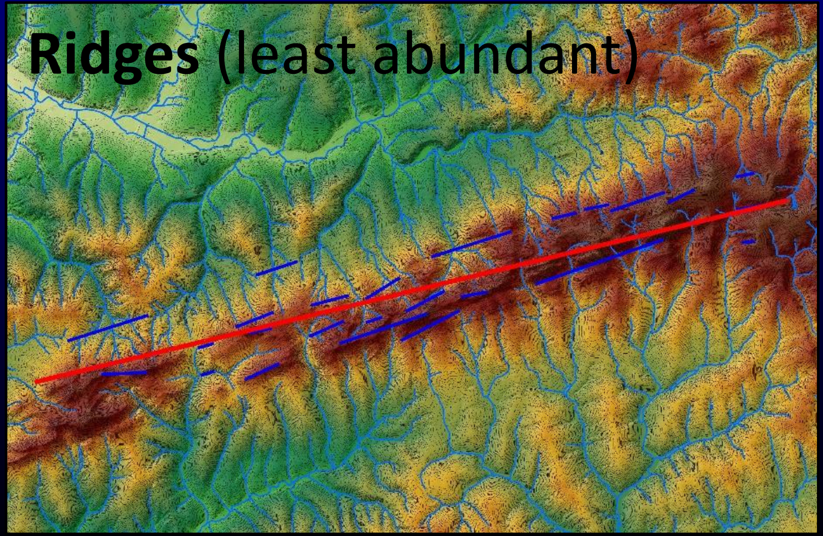
Approach: previous versus currently presented

- During recent time, automatic lineament extraction from **source** elevation data (mostly **SRTM** or **LIDAR**) applied as progressive approach in assessment of linear features allowed to represent only simple elements
- However, it provided only very small portion of whole existing linear phenomenon





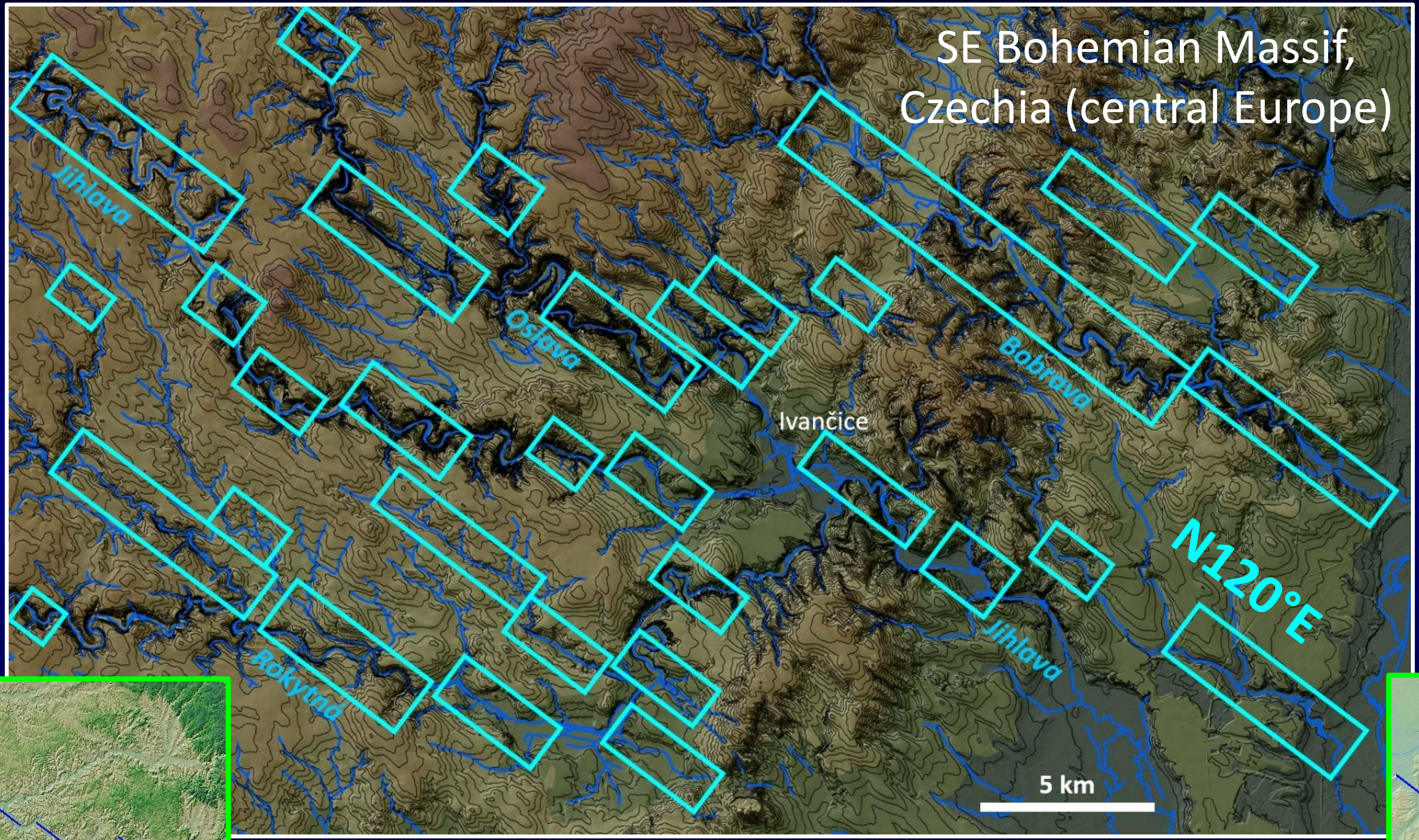
Cases of automatic lines – based on material and method by Šilhavý et al. (2016)



Manually vs. **Automatically** extracted lines

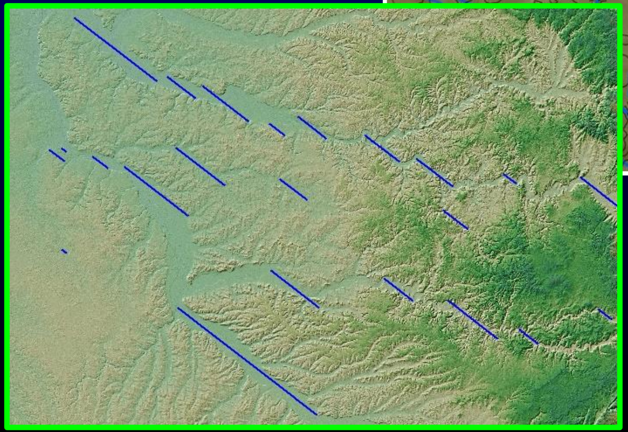
- **Newly cosidered complex linear patterns, hardly detectable automatically*:**

1. Linear belts of free or incised meandering streams and valleys



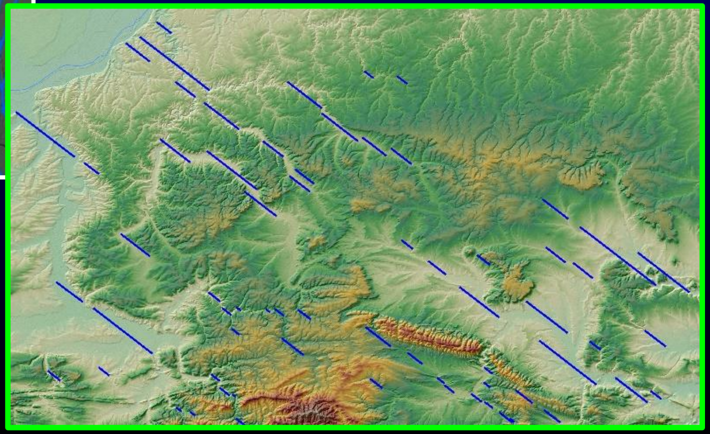
~1000 km to W:

W foreland of Massif Central, France (W Eur.)



~1000 km to E:

N foreland of Stara Planina Mts., Bulgaria (SE Europe)

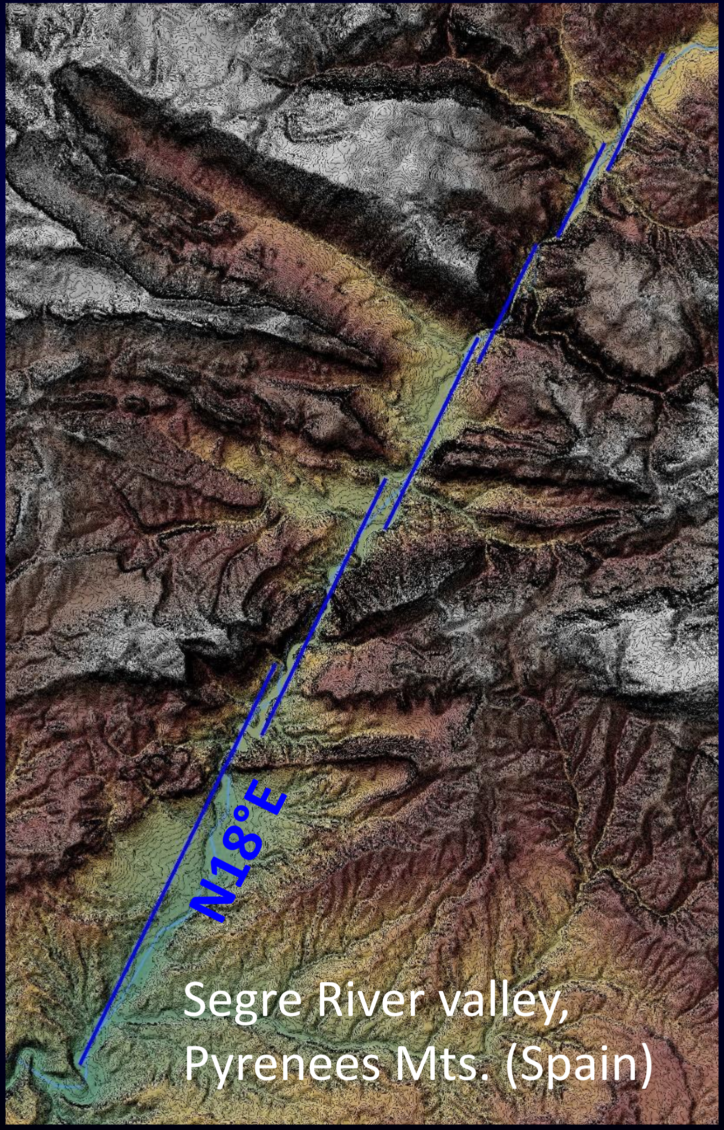


*Various visualisation modes used: hillshade, **dense contours**, colour or black-and-white DEM

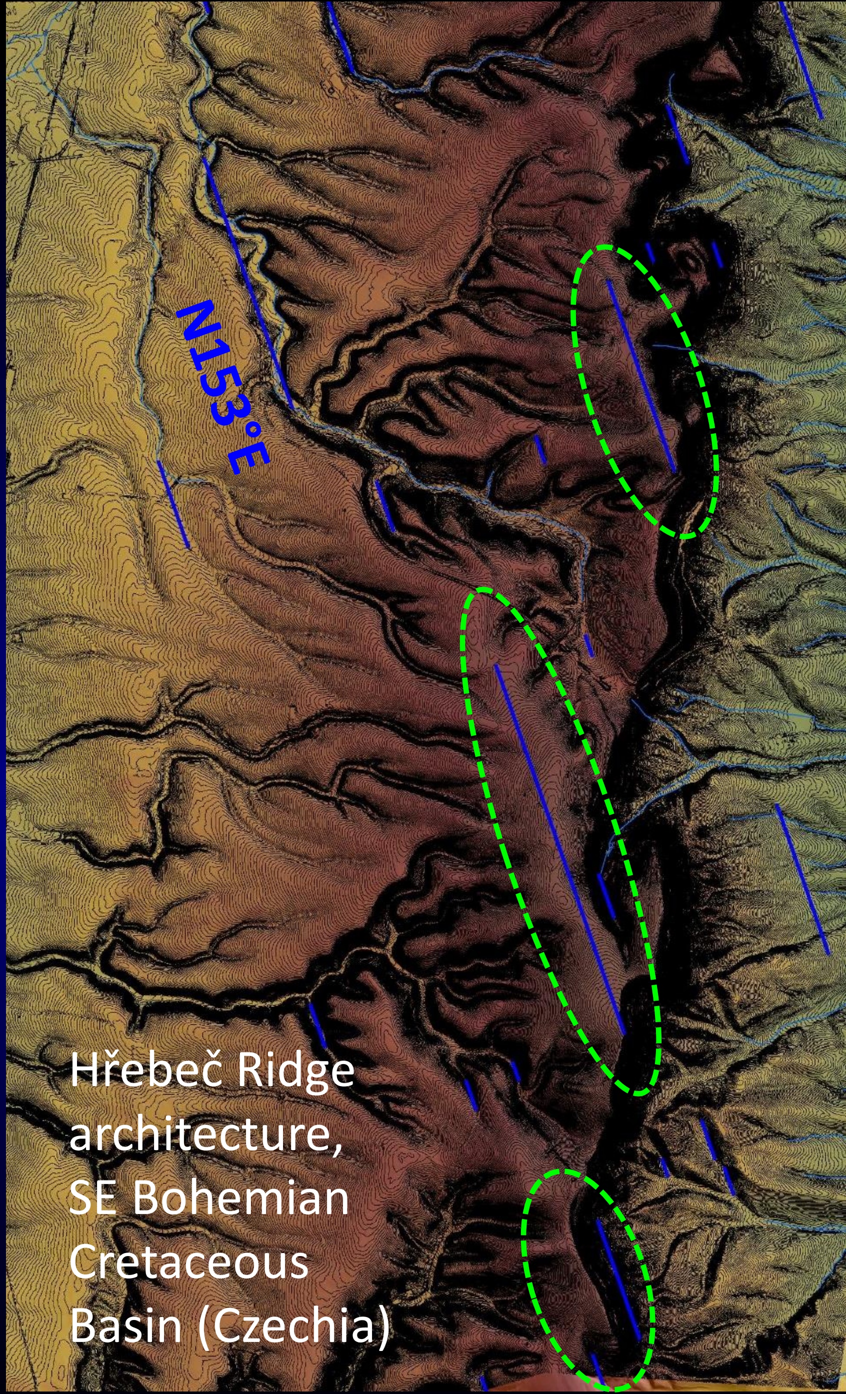
2. En échelon geometric element patterns

(concerning valleys, slopes or ridges)

Oslava River valley, Bohemian Massif (Czechia)

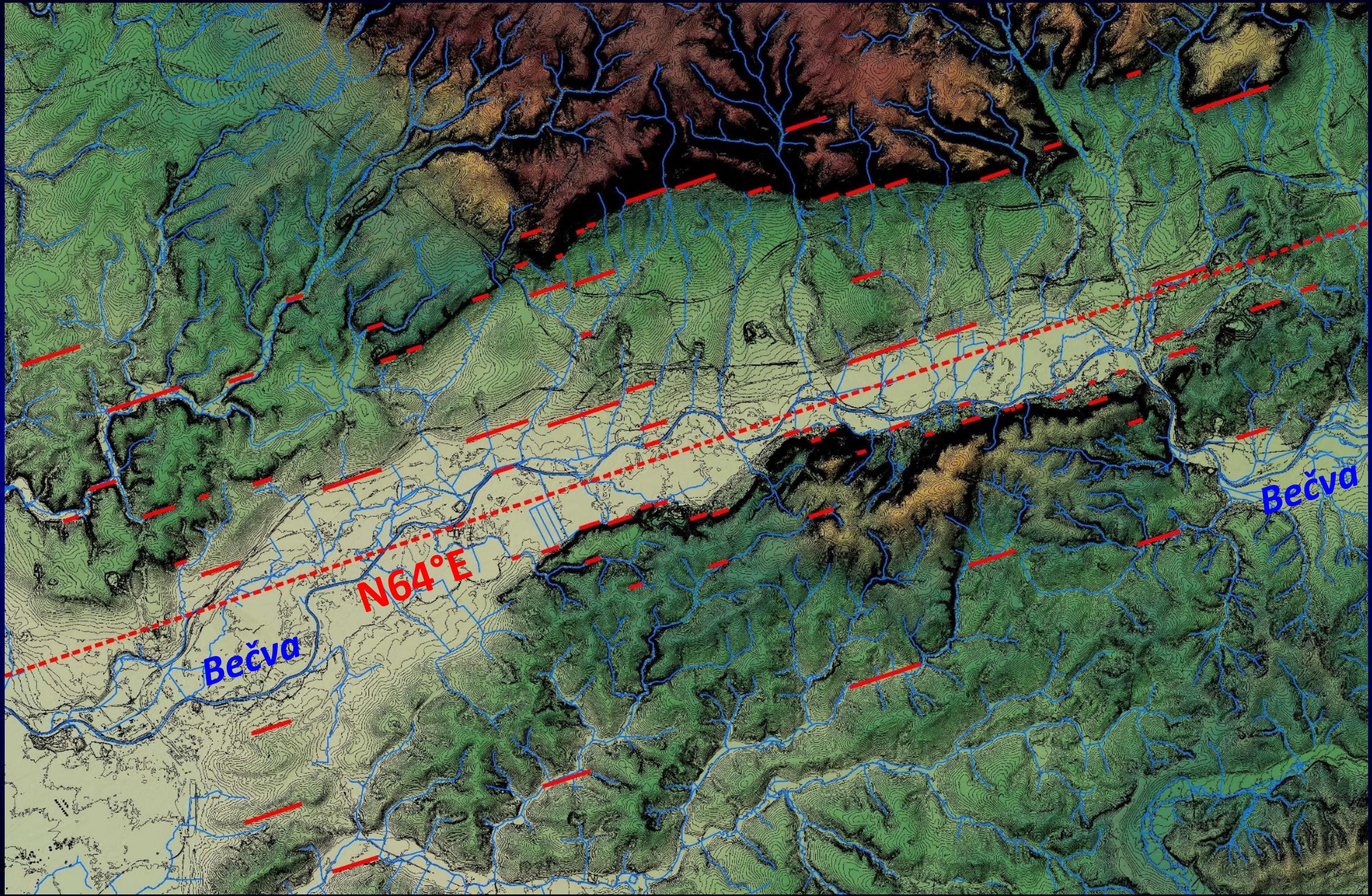


Segre River valley, Pyrenees Mts. (Spain)



Hřebeč Ridge architecture, SE Bohemian Cretaceous Basin (Czechia)

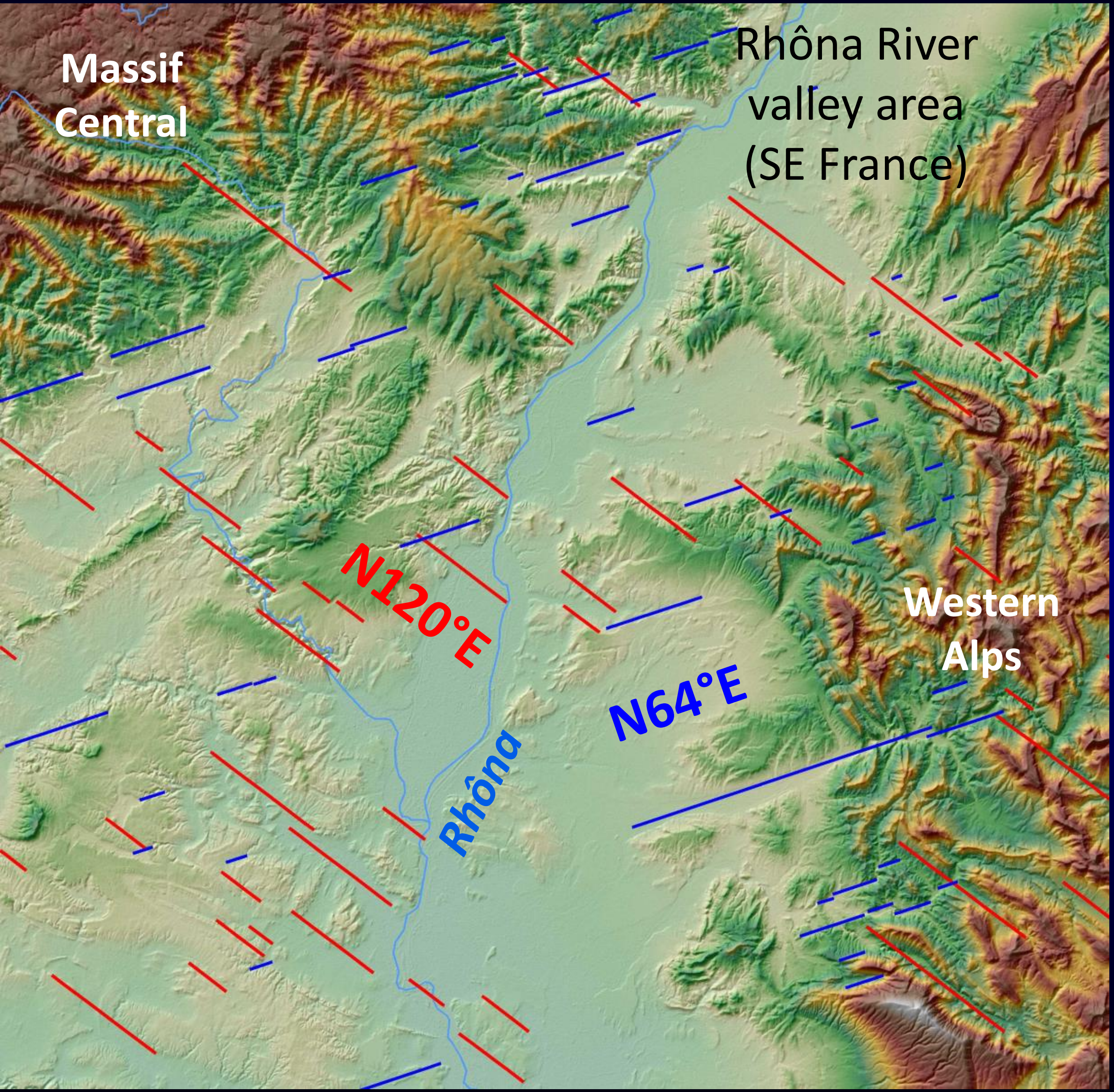
3. Sets of small linear surface elements within large zone structures

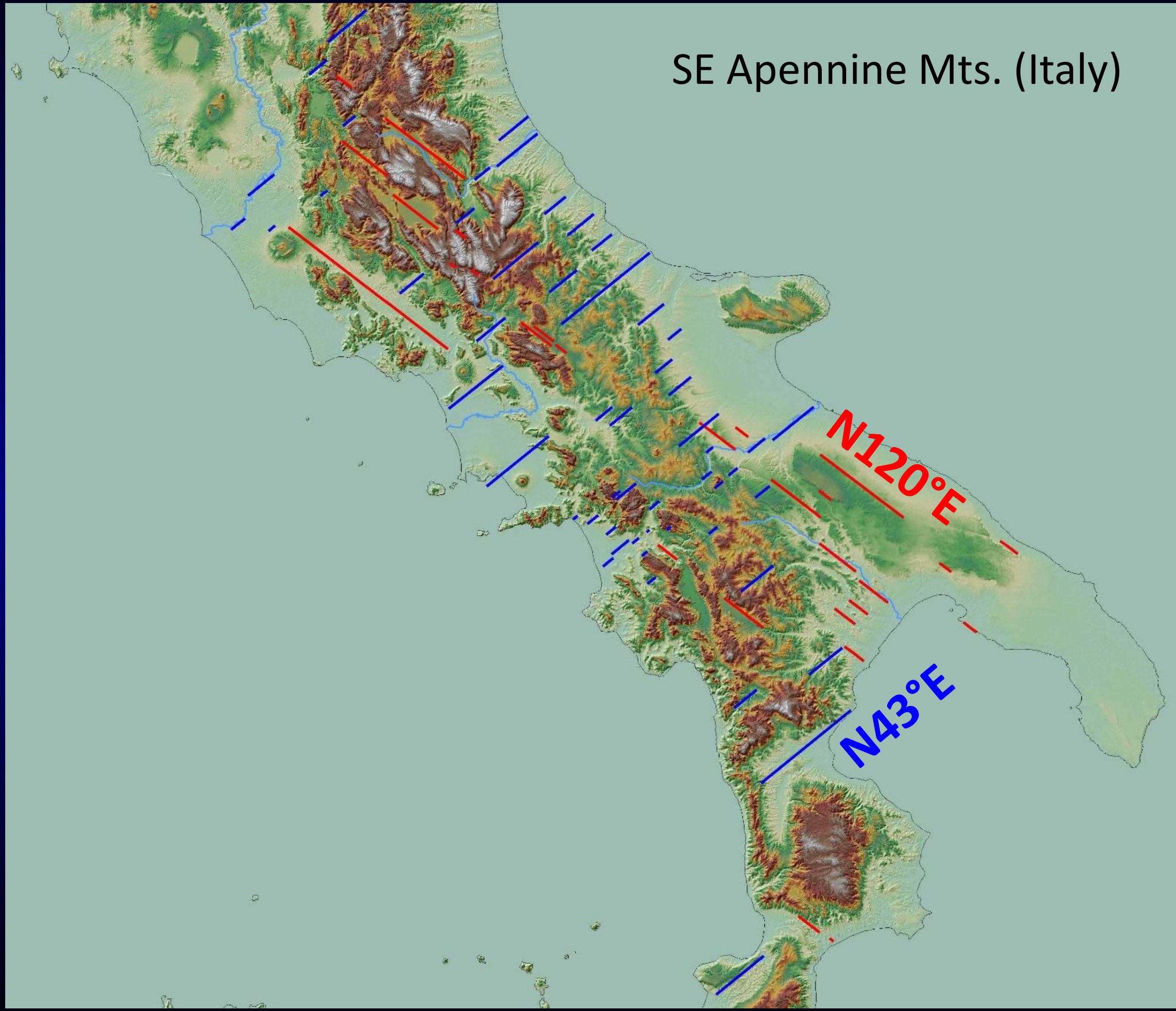


Moravska brána Graben example, Bohemian Massif / Western Carpathians transition zone (Czechia)

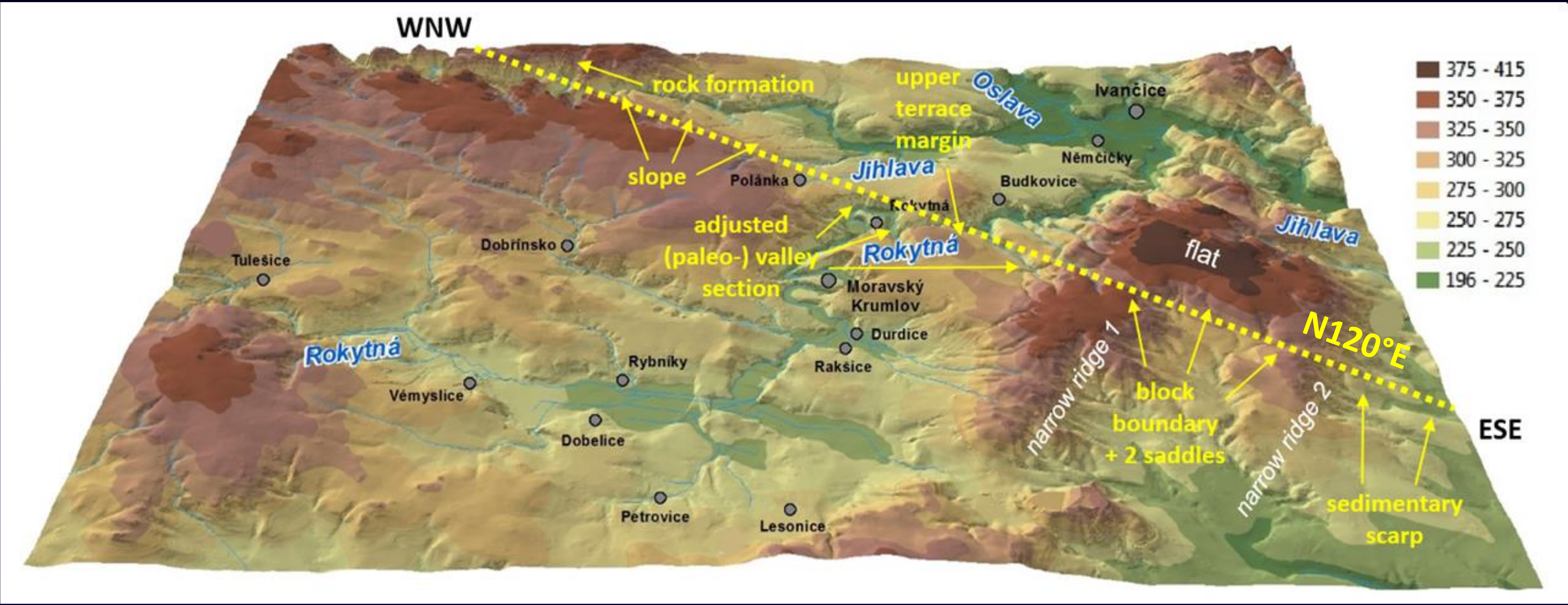
- Frequently, general trend of local surface considered instead of particular lines during detection of complex linear patterns; many possible elements added based on set of clear surrounding landforms

4. Consistent block segmentation in large areas



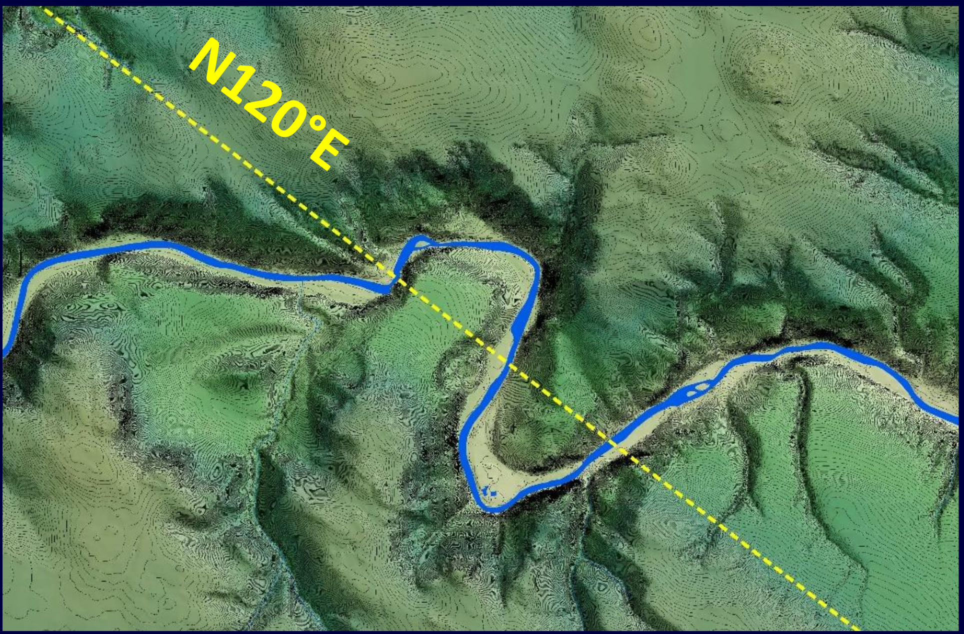


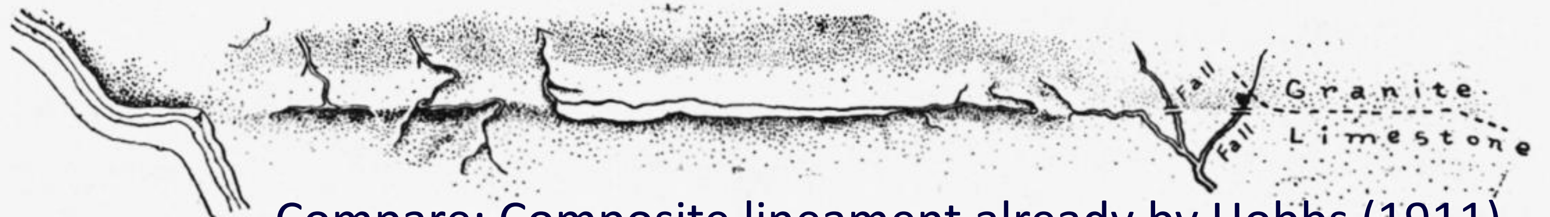
5. Composite lineaments – chaining elements of different character



Primary such line in beginning of our study, SE margin of Bohemian Massif (Czechia)

- Some chains include also elements of non-linear character

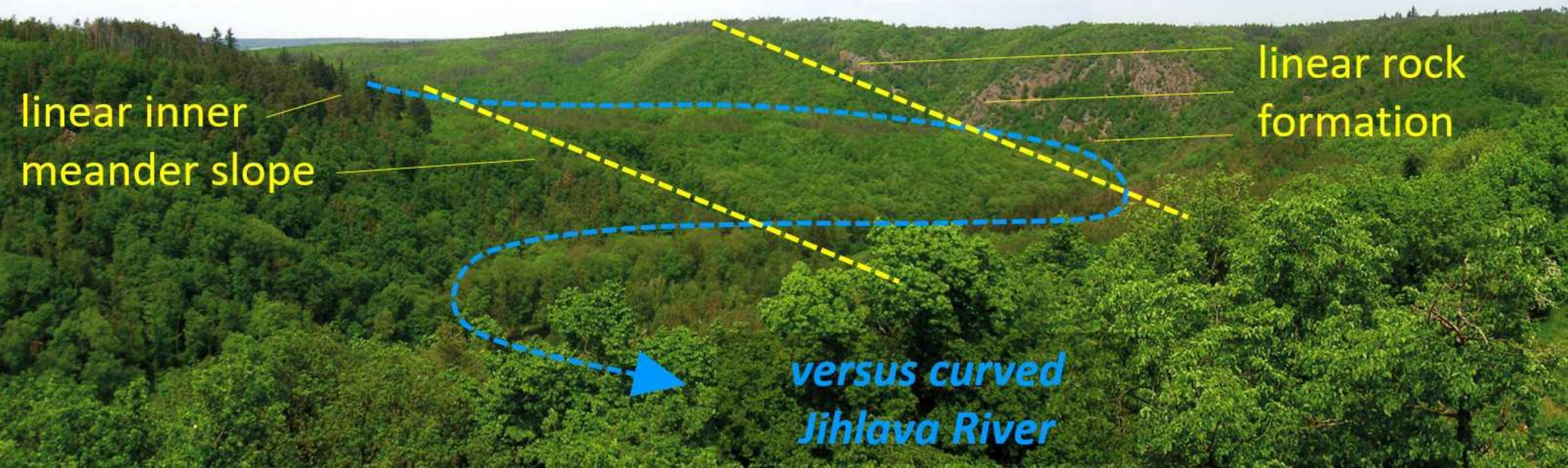




Compare: Composite lineament already by Hobbs (1911)

FIGURE 20.—*Schematic Diagram indicating the composite Expression of a Lineament*

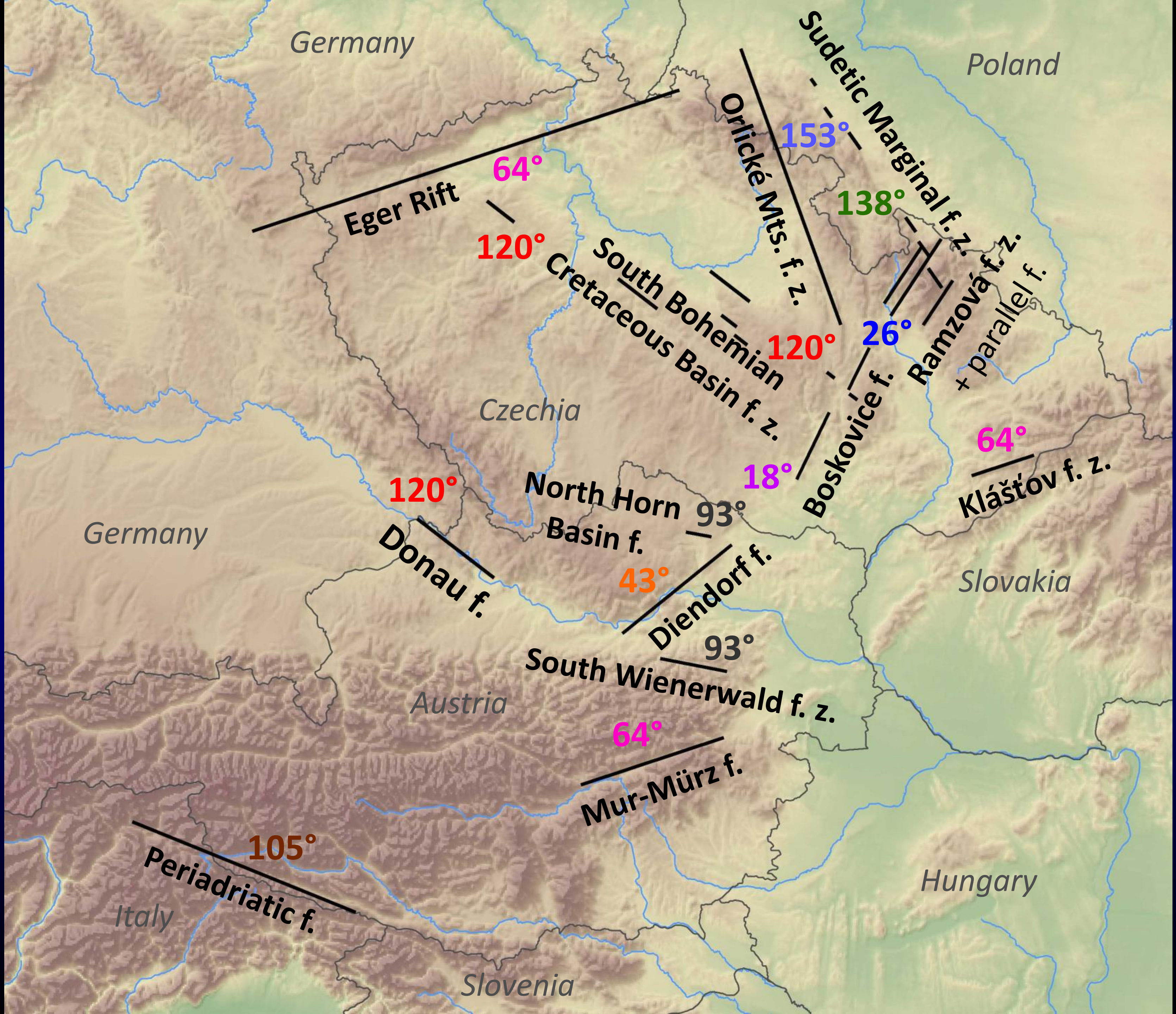
One of unique landform within the primary composite lineament: Anomalous-shape meander



Results

- To date, **9 main** systematic linear **trends** detected **using various generalisation modes**
- **Direction** of each **corresponds to** some **significant fault** structure(s)

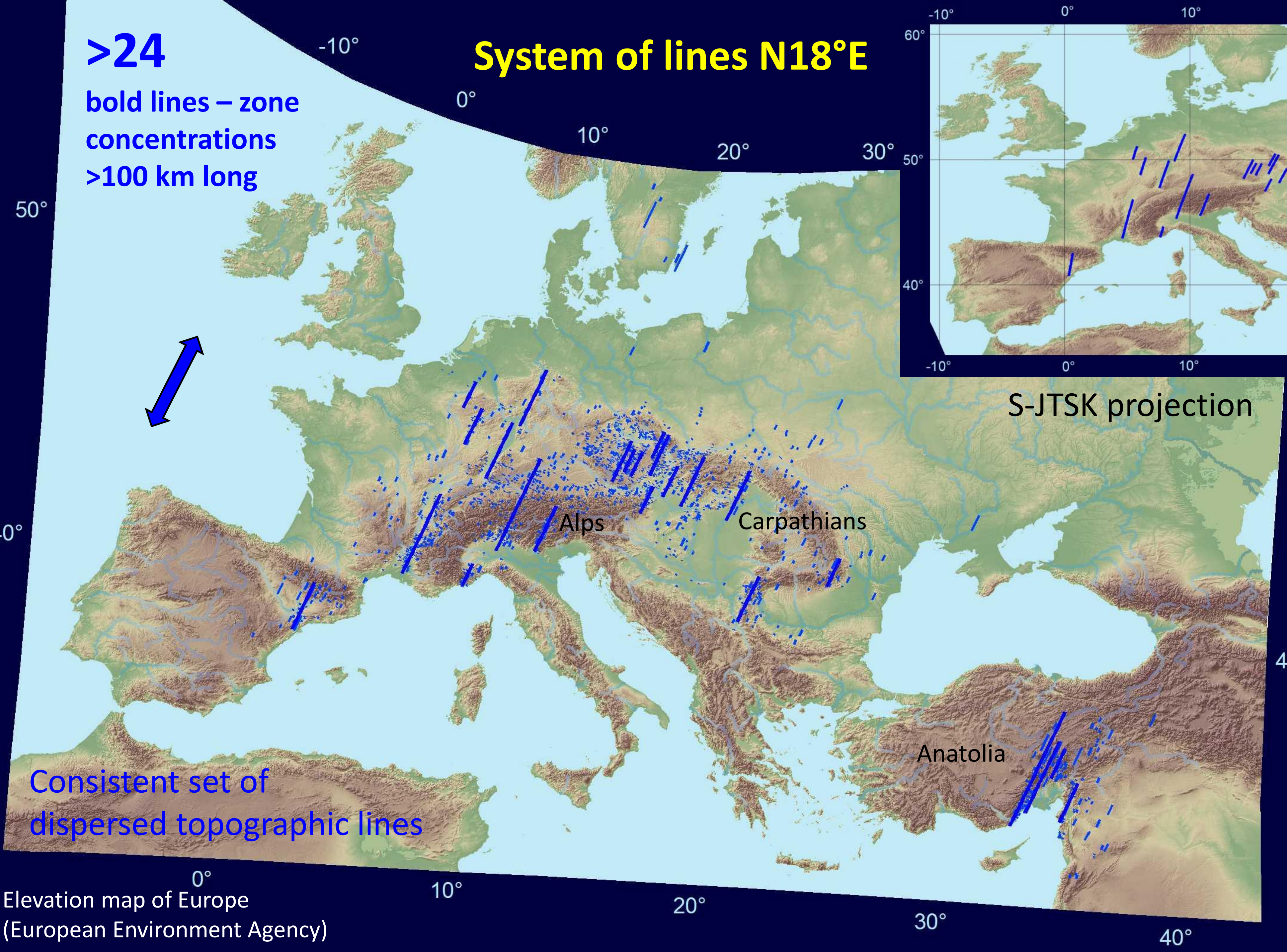
Direction at: 50°N, 0°W/E	Direction at: 50°N, 15°E	Direction at: 50°N, 30°E	Trend-defining fault structure	Current No. of elements
~7°	**~18°**	~29°	Boskovice Graben – south	~3400
~15°	**~26°**	~37°	Boskovice fault	~3800
~32°	**~43°**	~54°	Diendorf fault	~3200
~53°	**~64°**	~75°	Eger Rift	~6200
~82°	**~93°**	~104°	Horn Basin – northern fault	~3100
~94°	**~105°**	~116°	Periadriatic fault	~5800
~109°	**~120°**	~131°	Bohemian Cretaceous Basin – southern faults	~6600
~127°	**~138°**	~149°	Sudetic Marginal fault	~3000
~142°	**~153°**	~164°	Orlické Mts. marginal zone	~4600

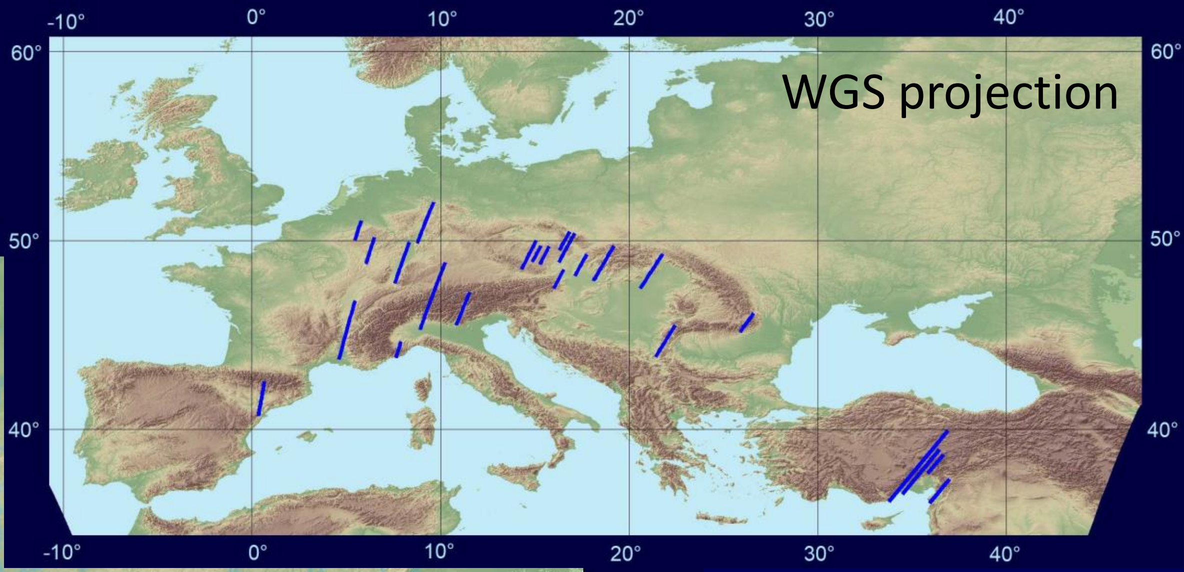


Defining fault structures in central Europe and their general strikes used at drawing of extensive topographic linear systems elsewhere

During research, some other fault systems found spatially fitting (in the working cartographic projection used) to the presented defining structures in central Europe

System of lines N18°E



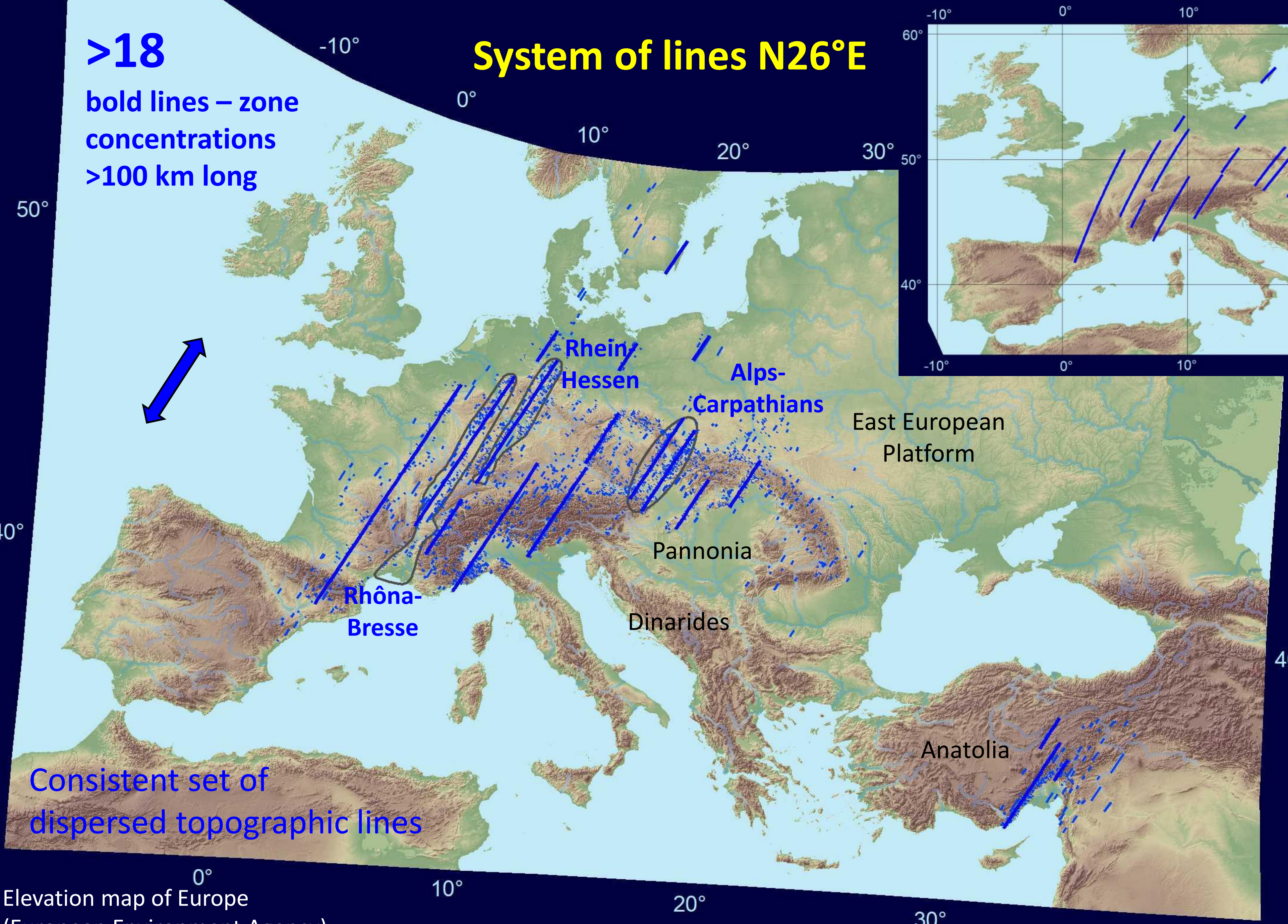


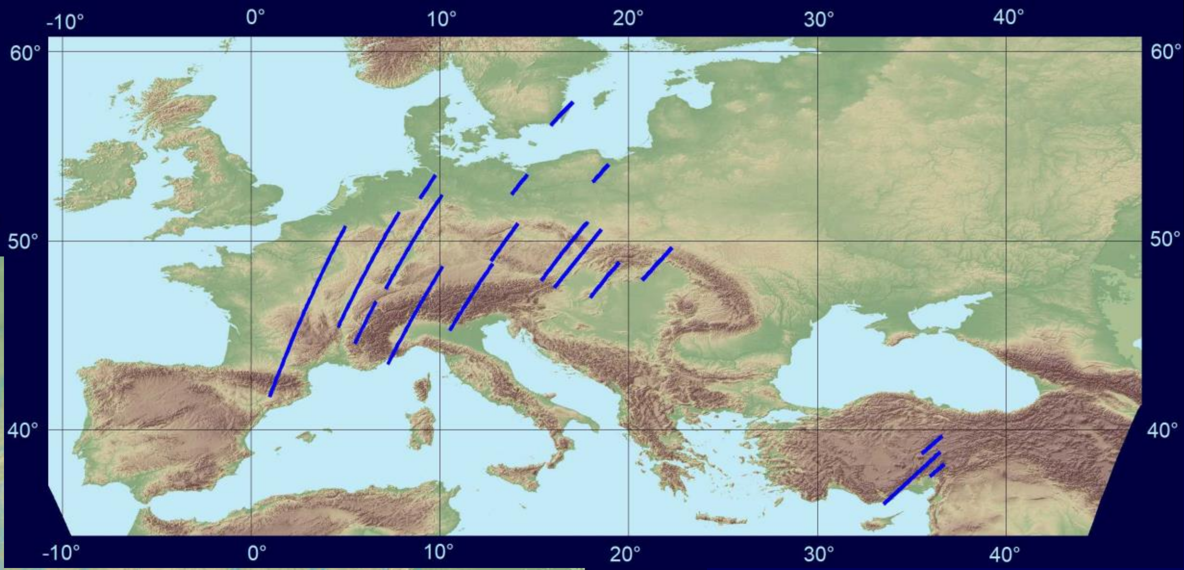
Elevation map of Europe (European Environment Agency)

Working S-JTSK (conformal conic Czech + Slovak national) projection vs. WGS projection

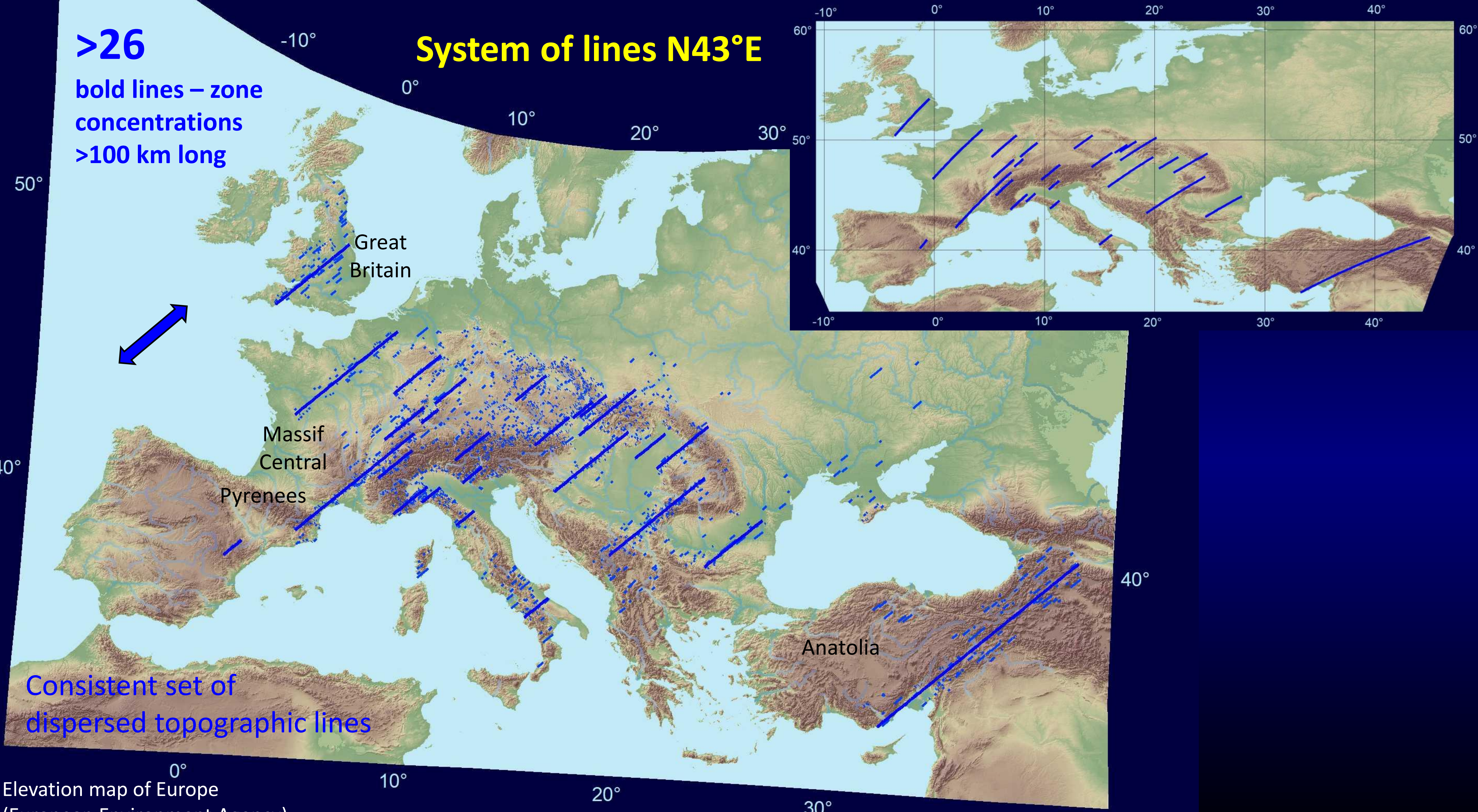
Linear zones mostly correspond to large landforms (elongated basins, mountain ranges, wide valleys, significant fault zones)

System of lines N26°E

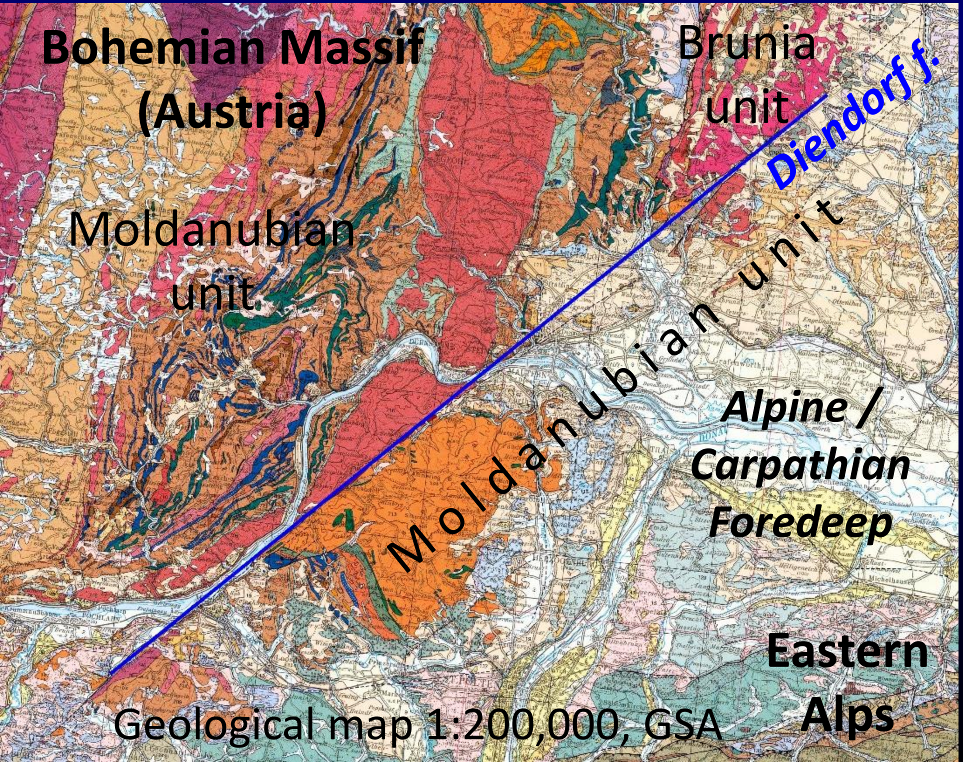


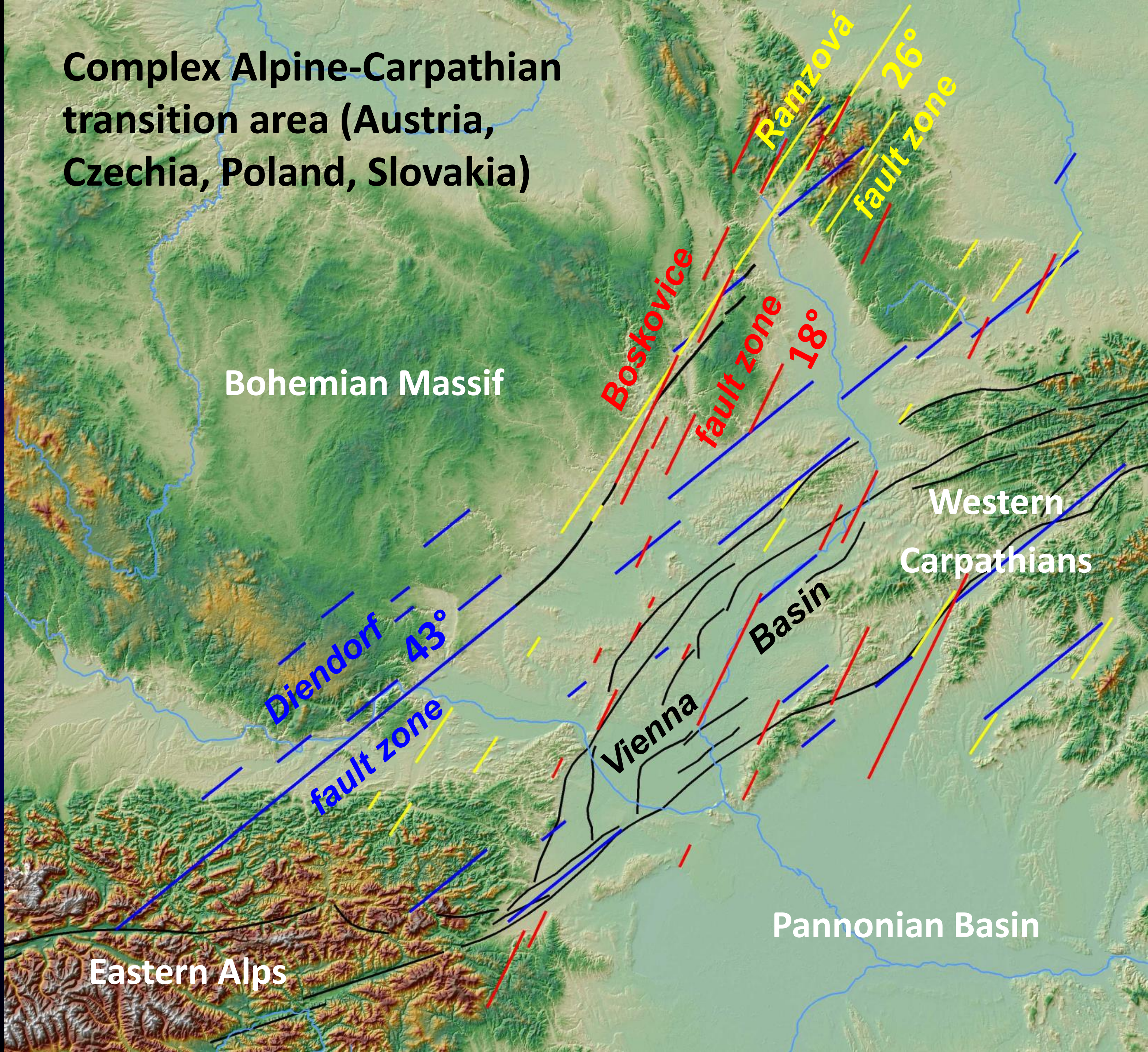


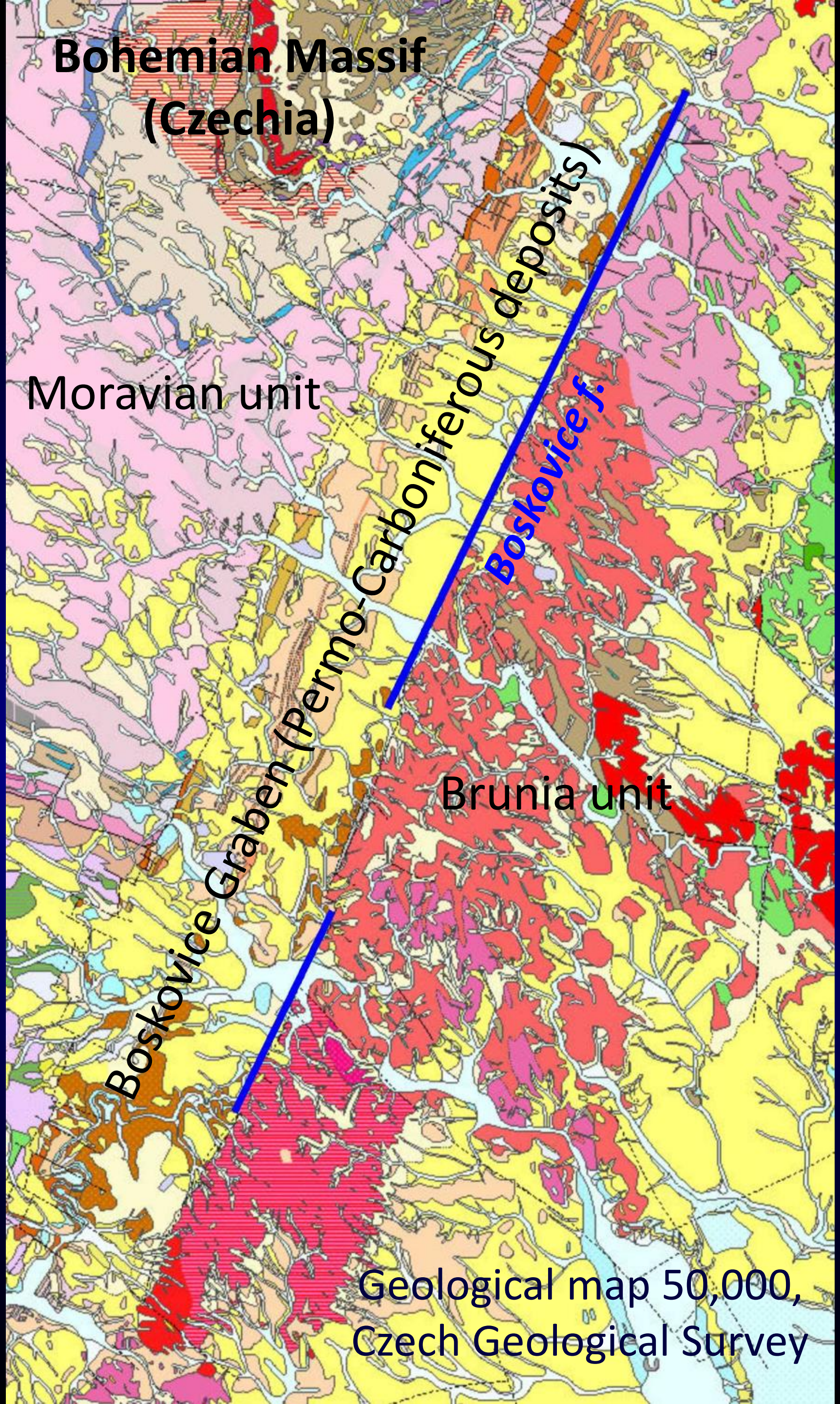
- Correspondence to general direction of three significant elongated depressions in central Europe (outlines + blue letterings); see also below

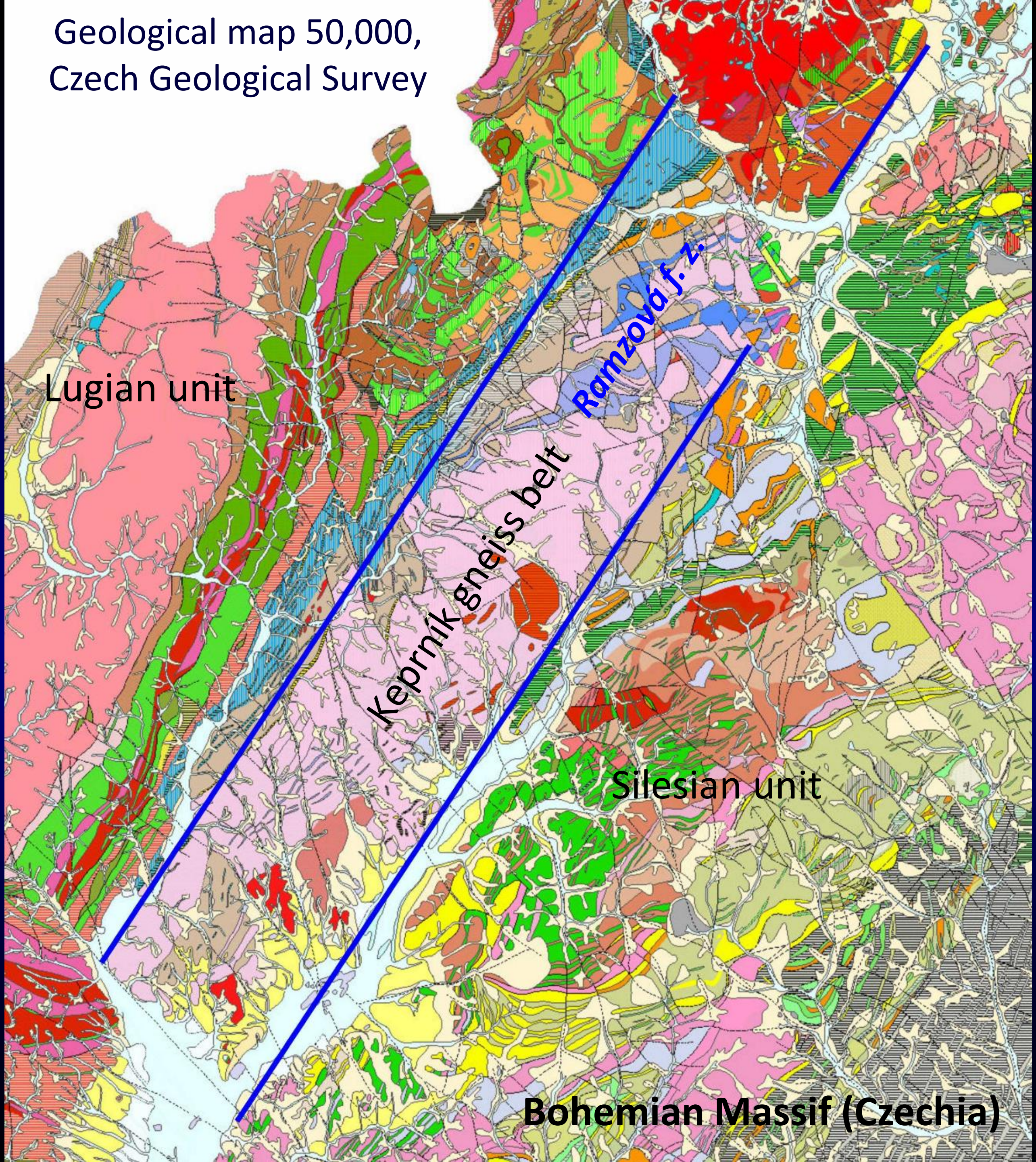

System of lines N43°E
>26
bold lines – zone concentrations >100 km long
Great Britain
Massif Central
Pyrenees
Anatolia
Consistent set of dispersed topographic lines
-10°
0°
10°
20°
30°
40°
50°
60°
Elevation map of Europe (European Environment Agency)

Three previous linear systems played a role in character of significant central European depressions: **Rhôna-Bresse(-Mosel)** structure, **Rhein-Hessenian graben**, **Alpine Molasse Basin**, and **Alpine-Carpathian transition area**. Fault-related lithological boundaries:

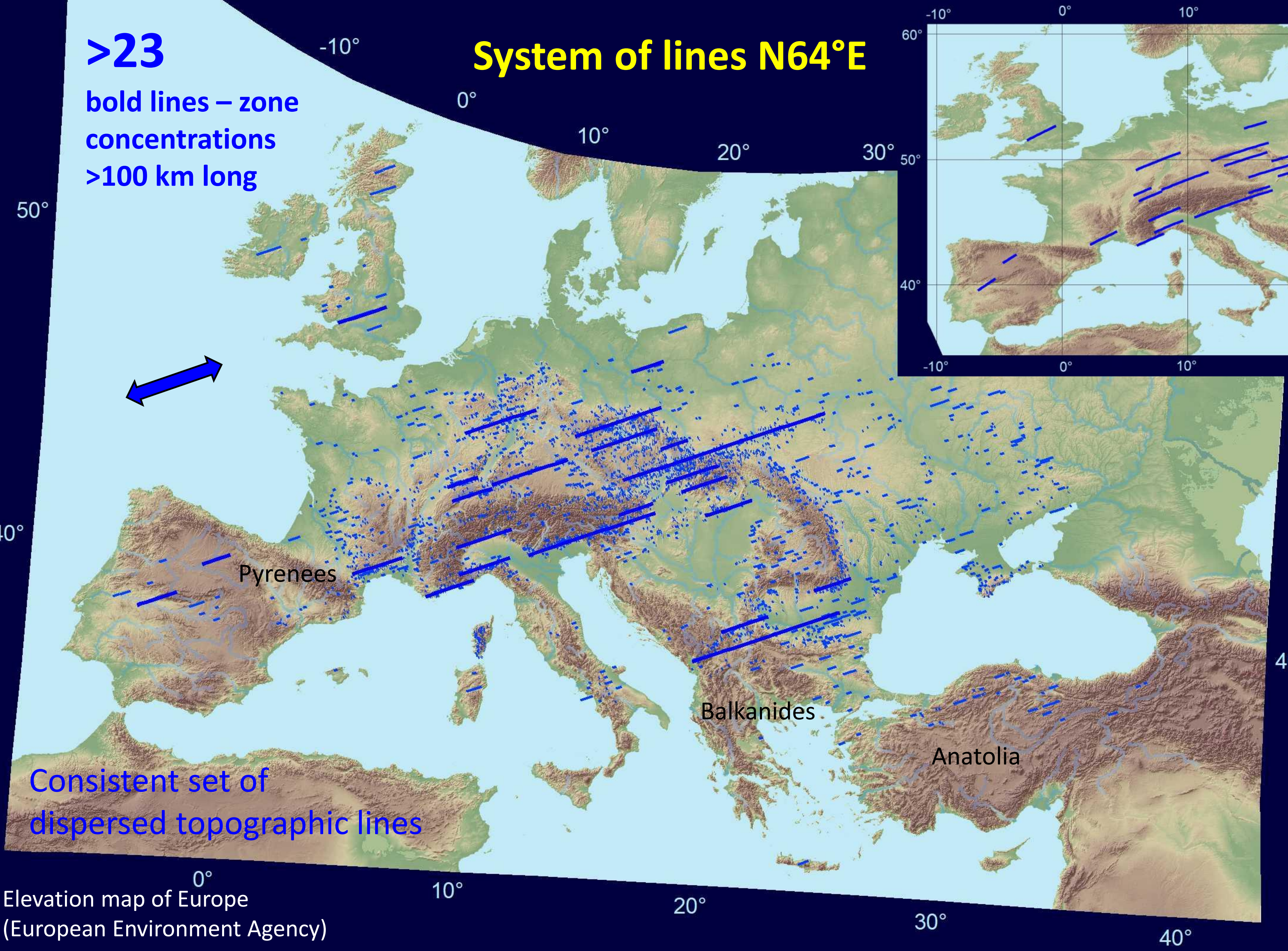


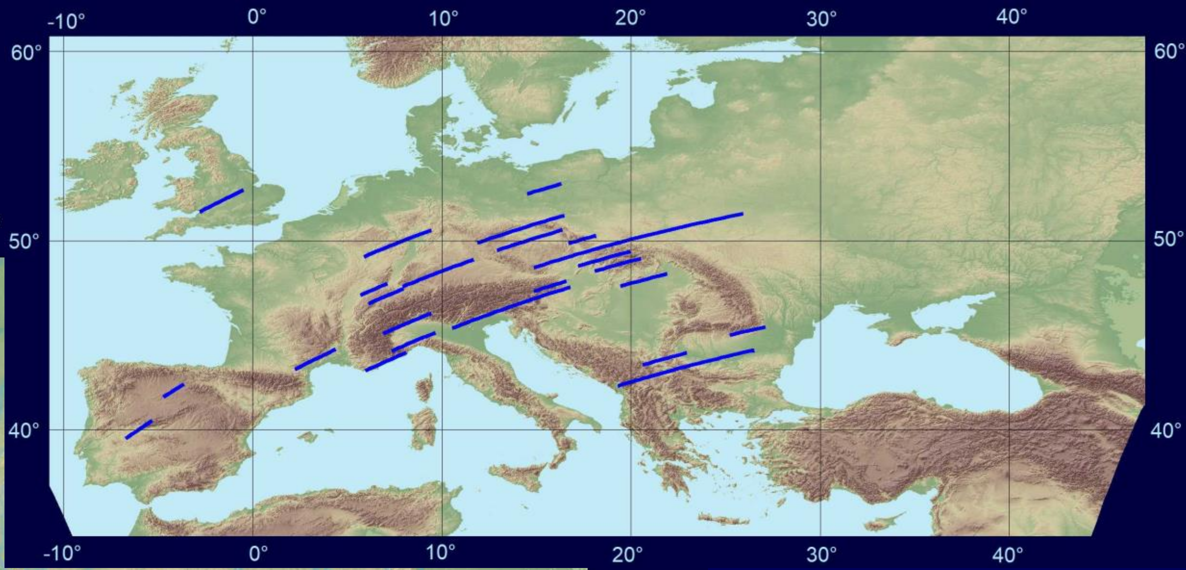



Bohemian Massif
(Czechia)
Moravian unit
Boskovice Graben (Permo-Carboniferous deposits)
Boskovice f.
Brunia unit
Geological map 50,000,
Czech Geological Survey


Geological map 50,000,
Czech Geological Survey
Lugian unit
Ramzová f. z.
Keprnik gneiss belt
Silesian unit
Bohemian Massif (Czechia)

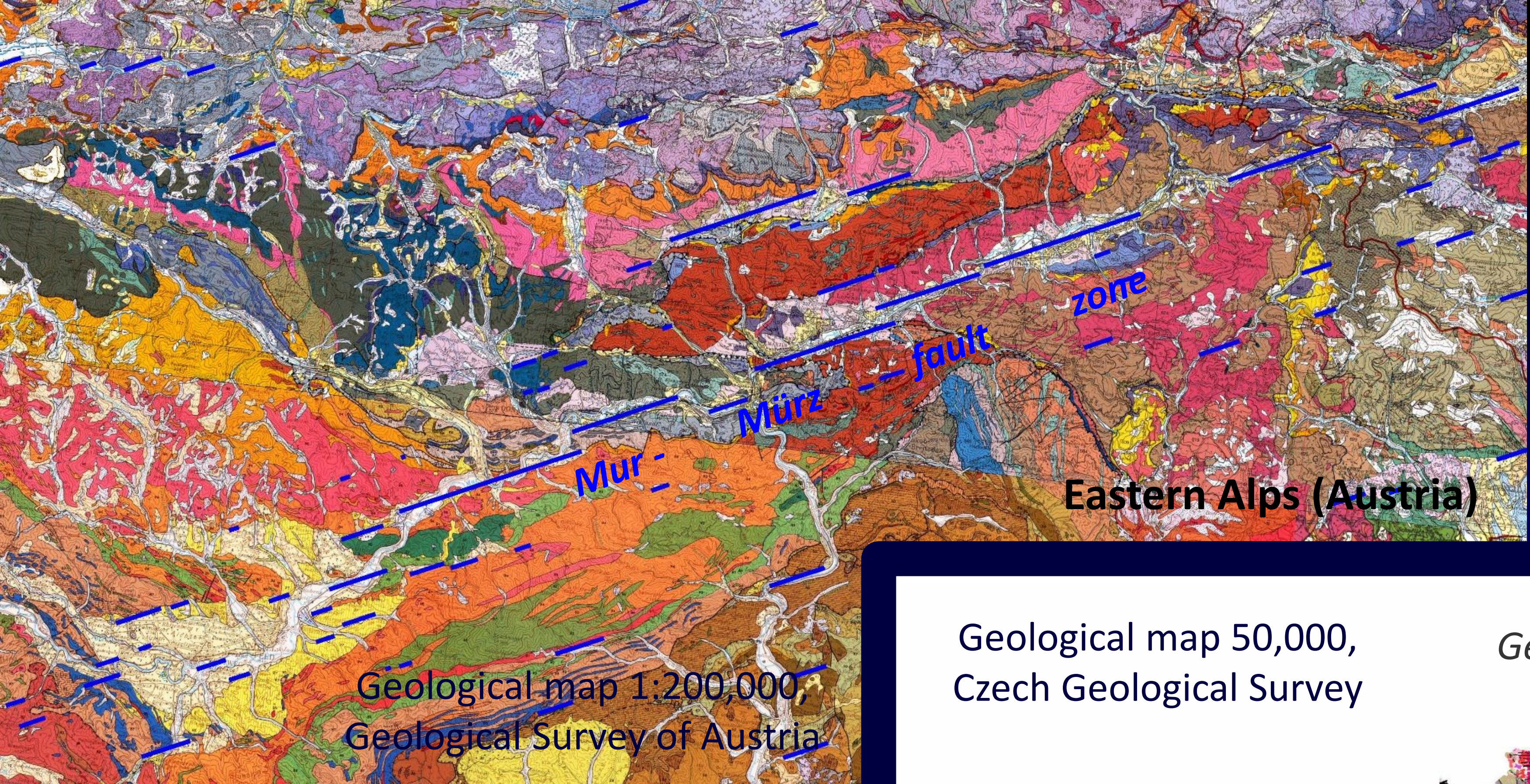
System of lines N64°E

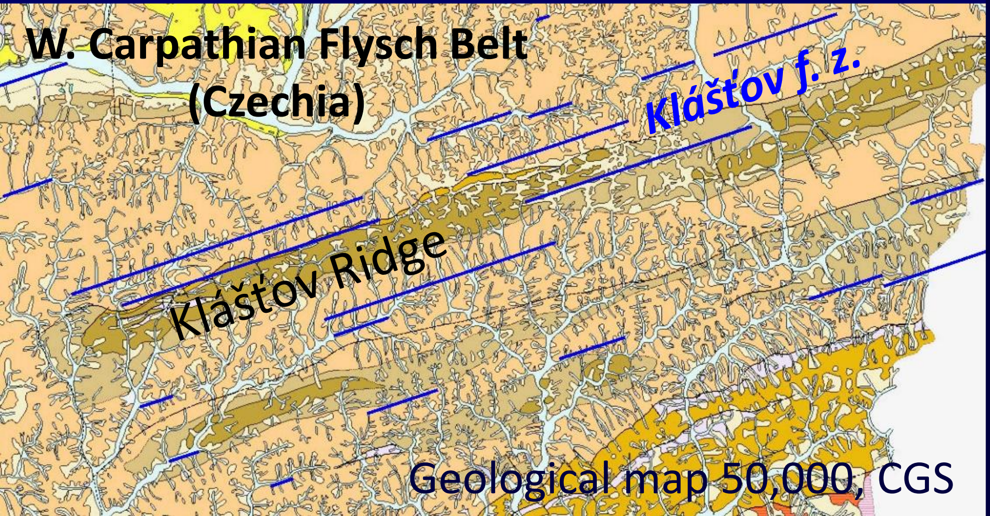


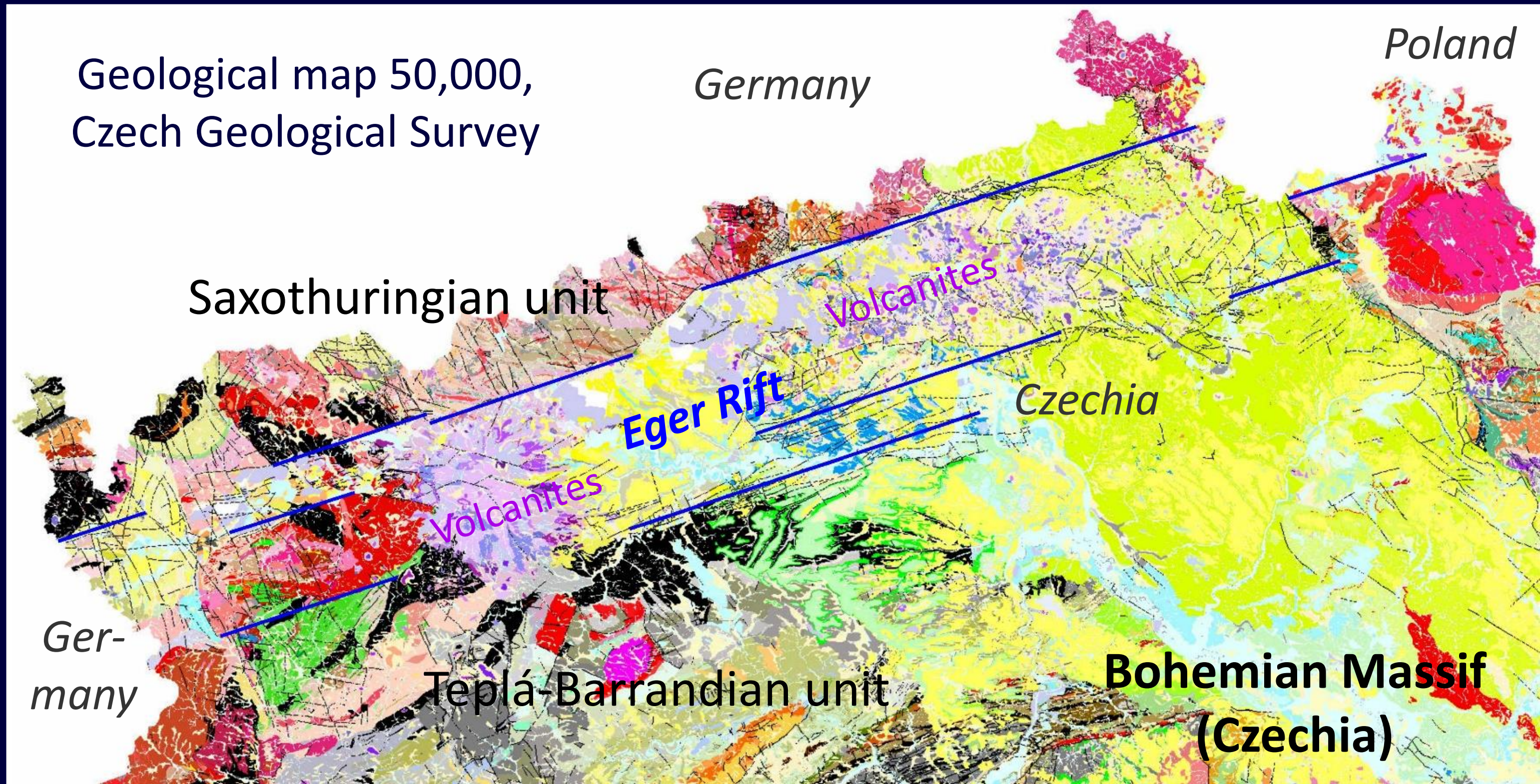


Local agreement with linear boundaries or erosional limits of rocks of various stratigraphic members:

N64°E linear lithological boundaries – examples from Eastern Alps, Western Carpathians and Bohemian Massif



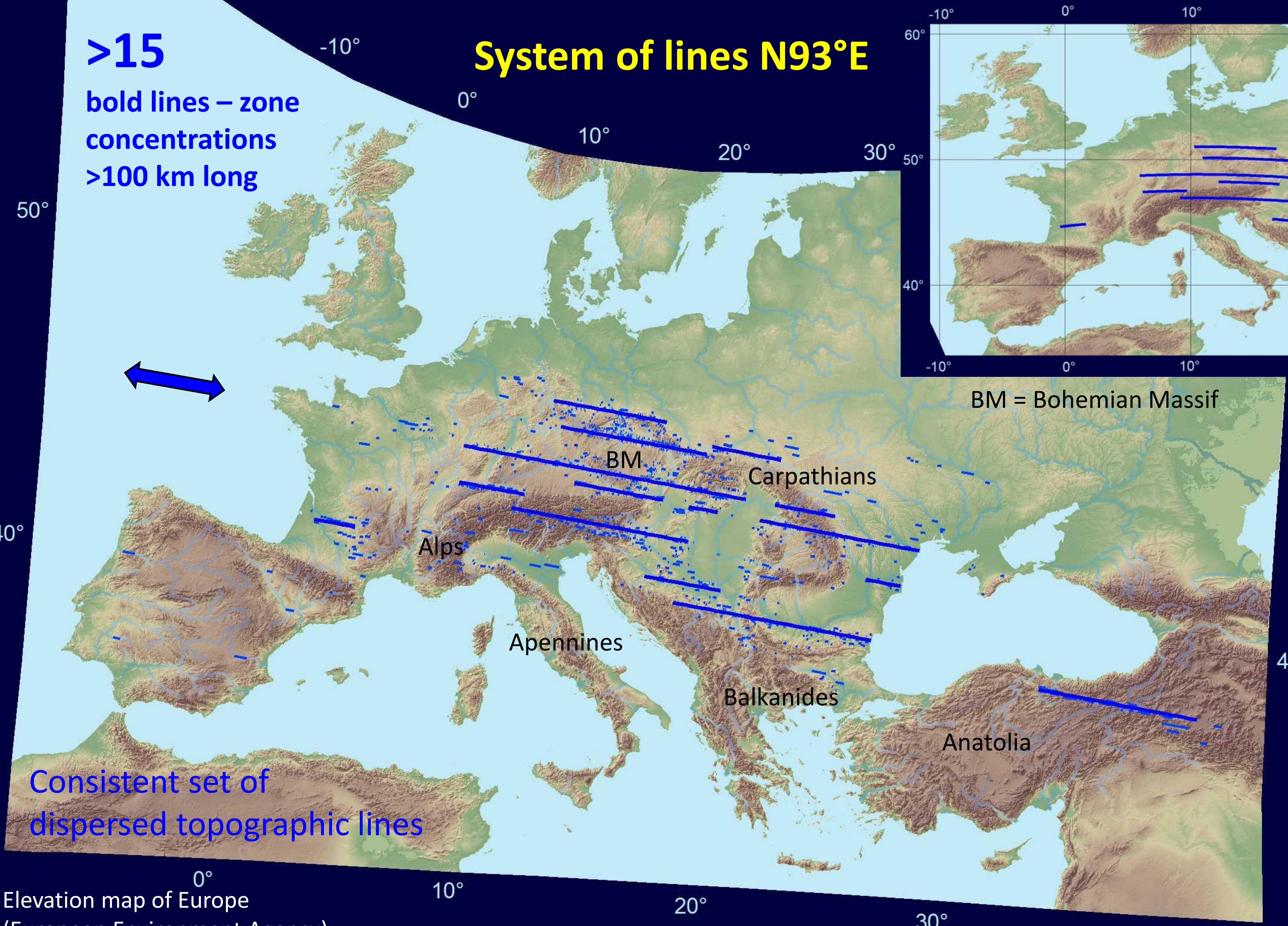


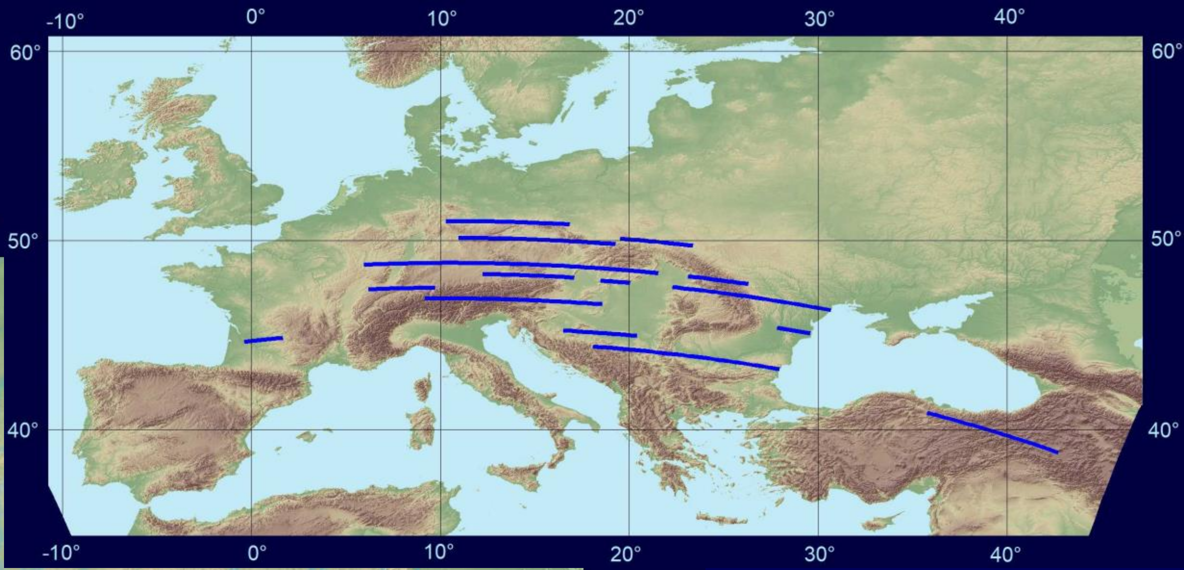


System of lines N93°E

>15

bold lines – zone concentrations >100 km long



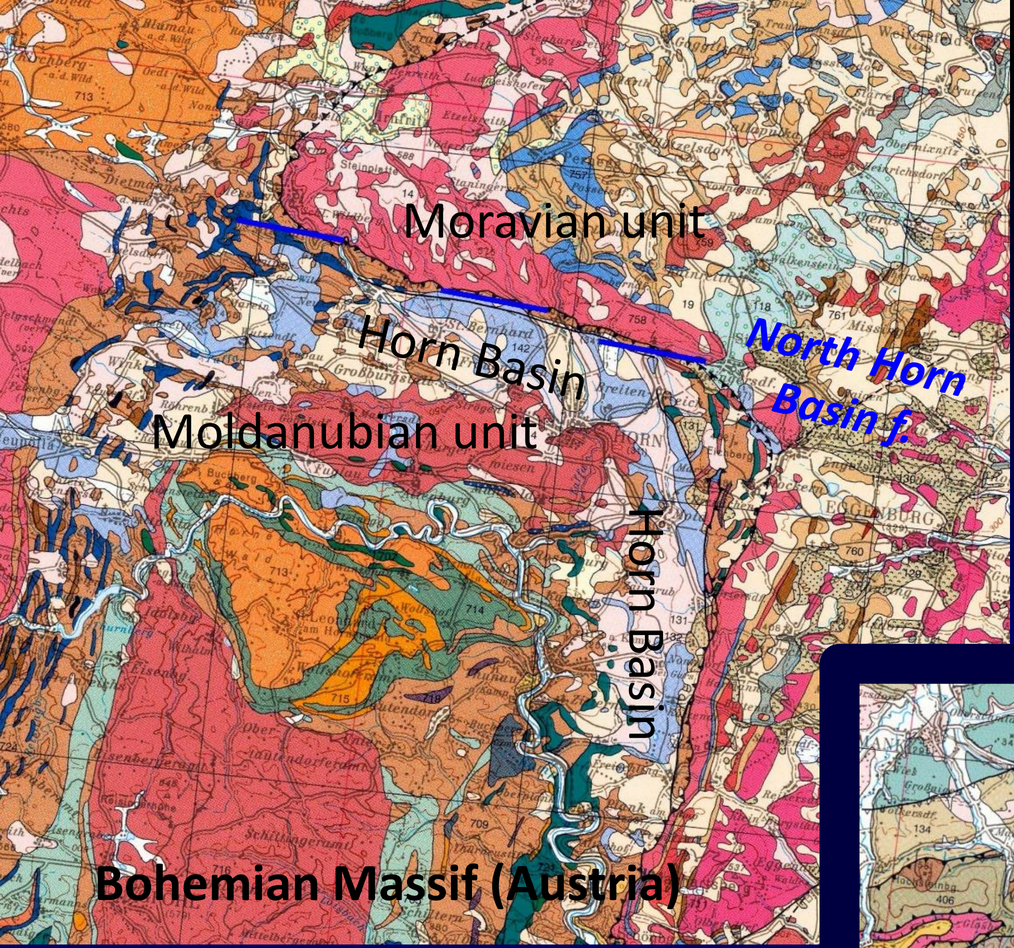


Consistent set of dispersed topographic lines

Elevation map of Europe (European Environment Agency)

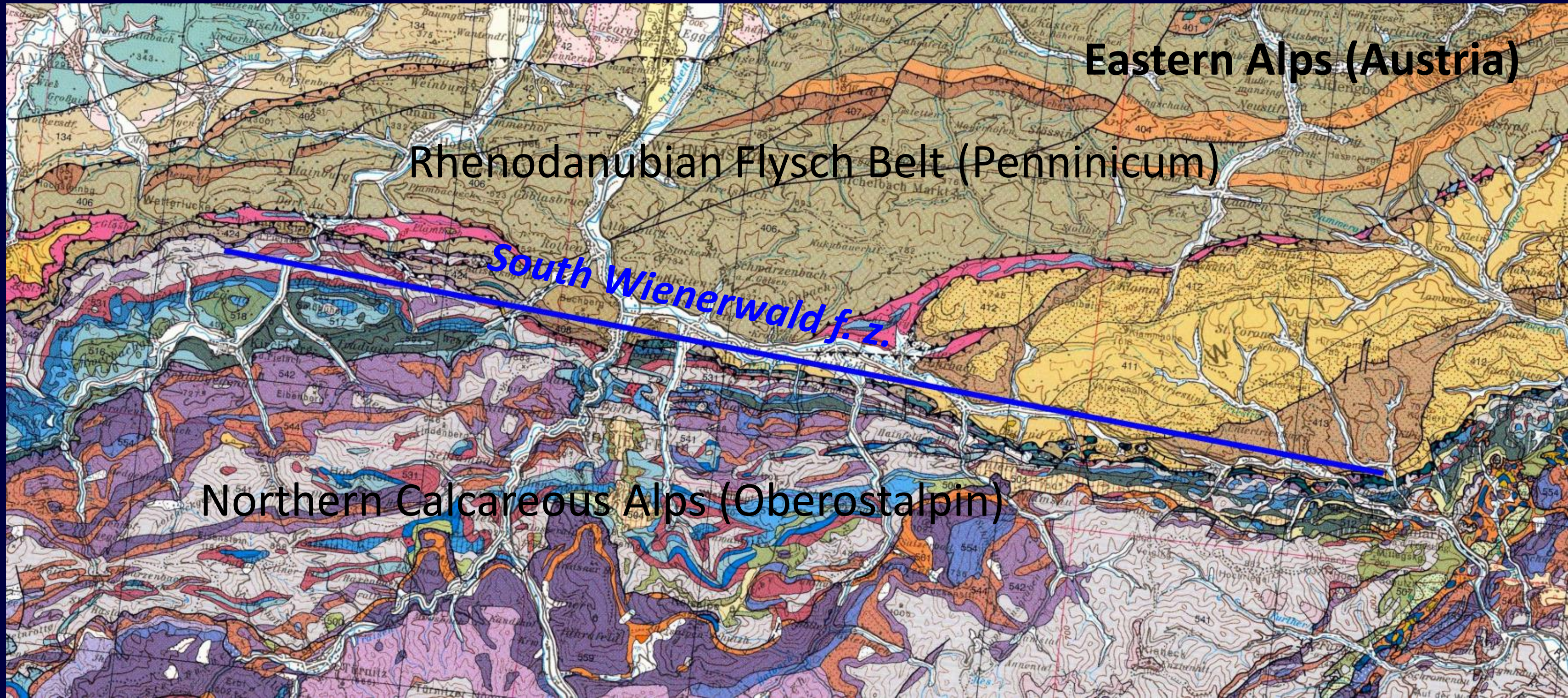
Boundaries of:

- Proterozoic, Paleozoic (basement) or
- Permo-Carboniferous, Mesozoic, Oligo+Miocene, Pliocene, Quaternary (cover) rocks

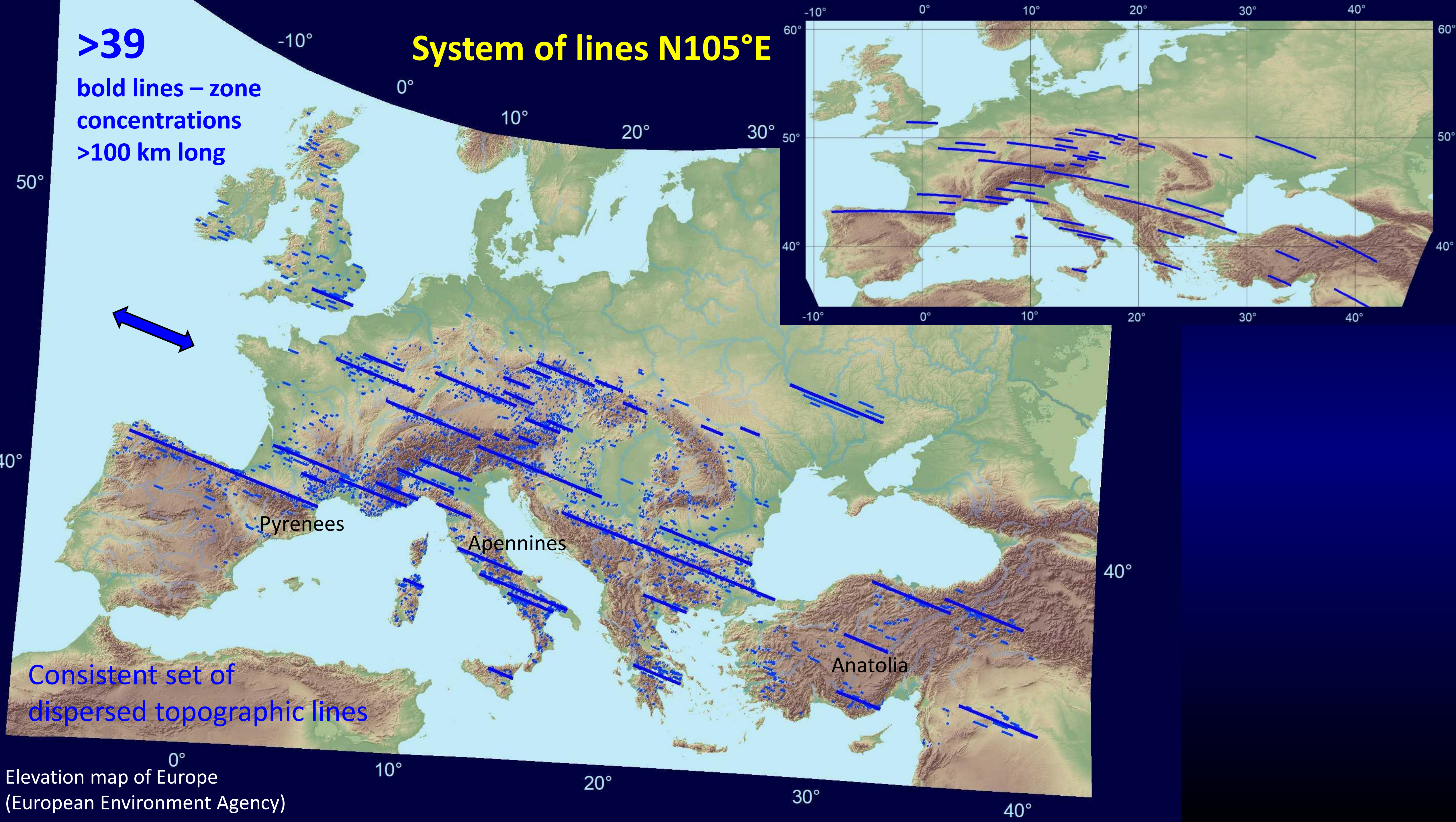


N93°E linear lithological boundaries – examples from Bohemian Massif and Eastern Alps

Both: Geological map 1:200,000, Geological Survey of Austria

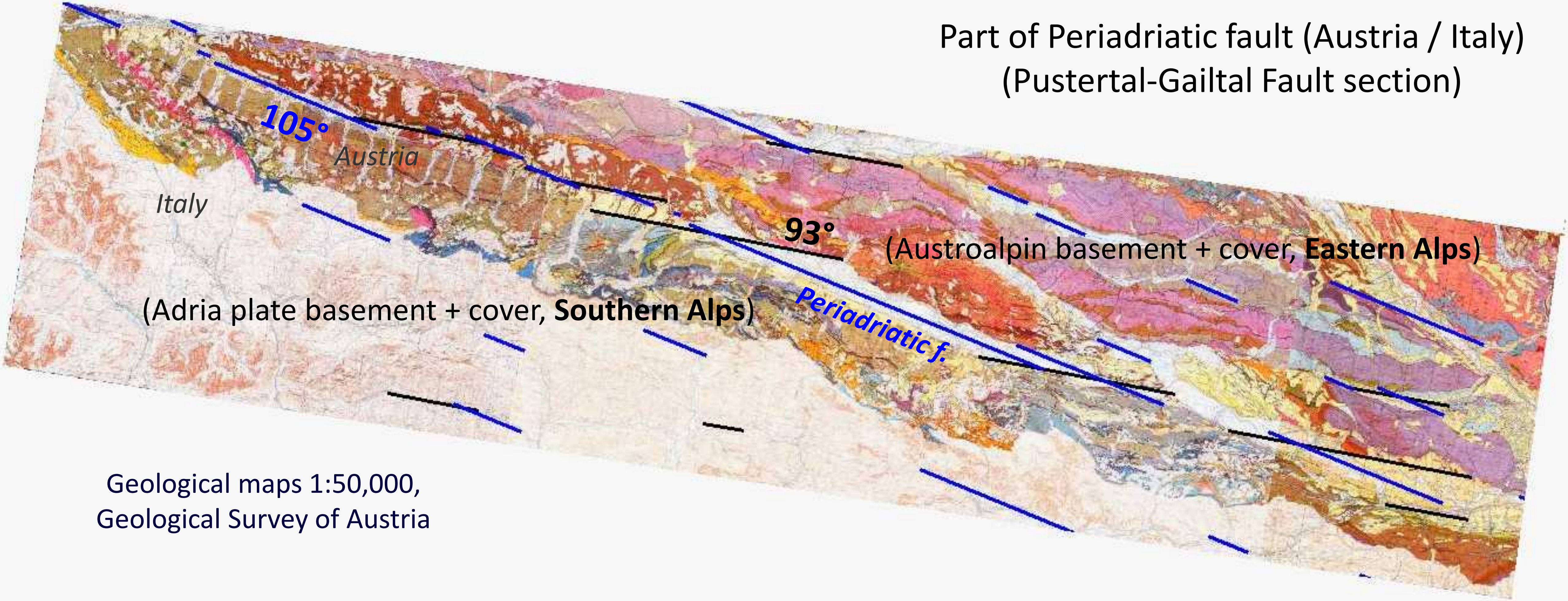


System of lines N105°E



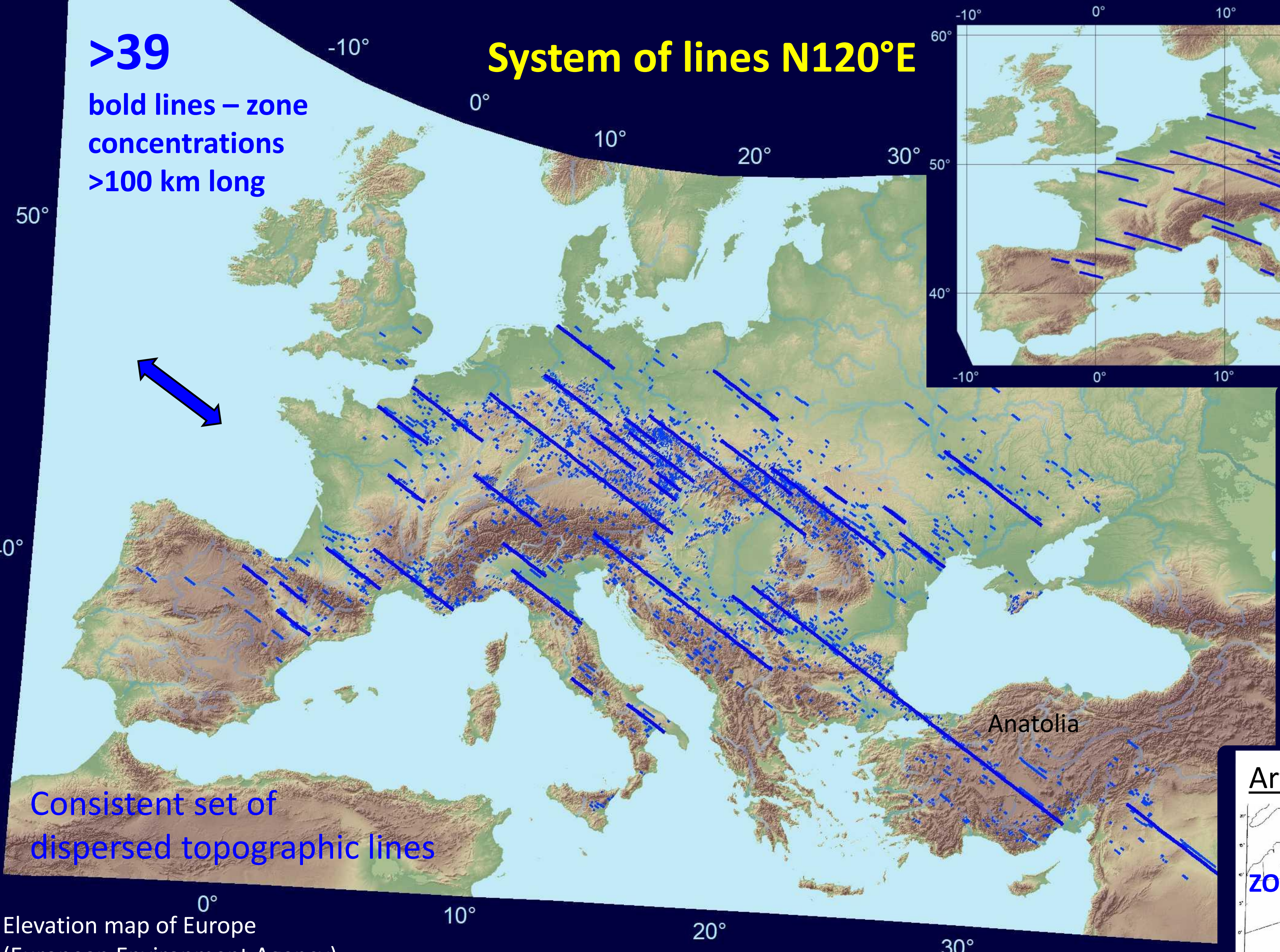
Elevation map of Europe (European Environment Agency)

N93°E and N105°E linear lithological boundaries – example from Eastern / Southern Alp Mts. (plate boundary)

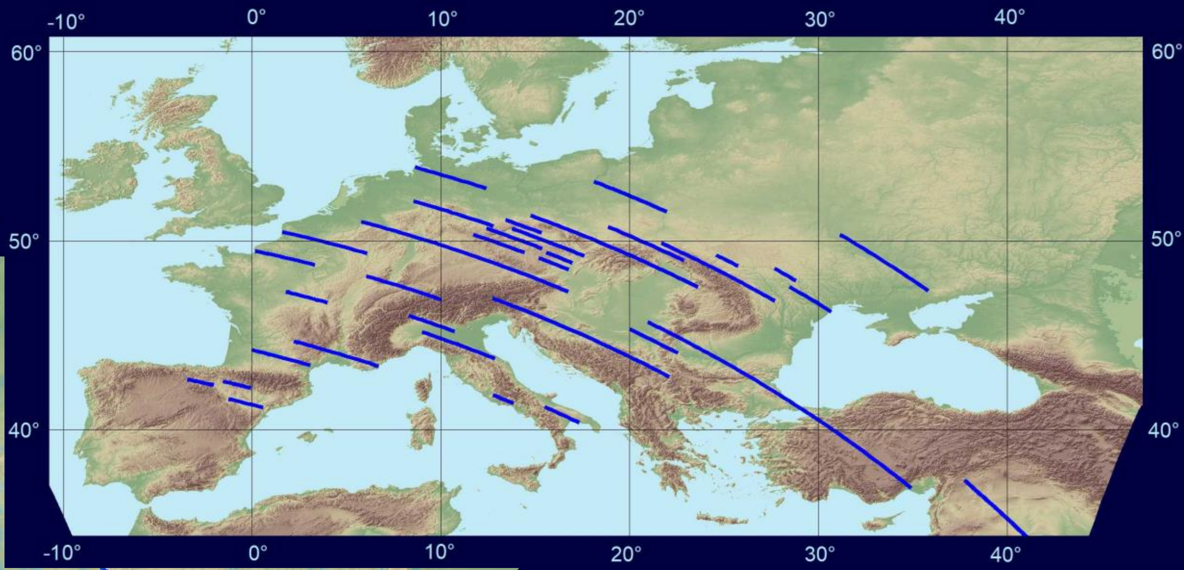


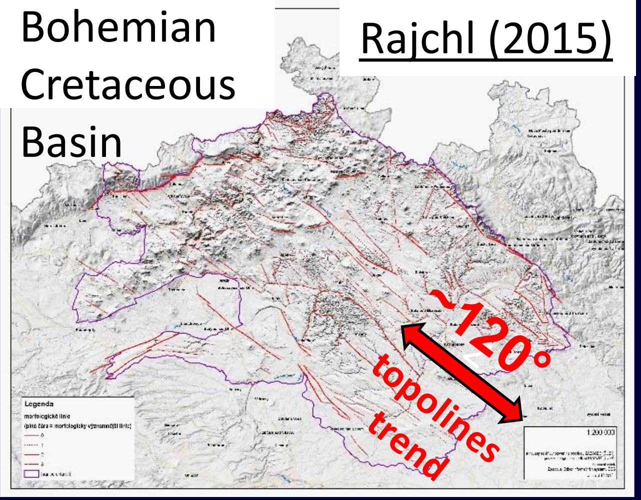
Geological maps 1:50,000,
Geological Survey of Austria

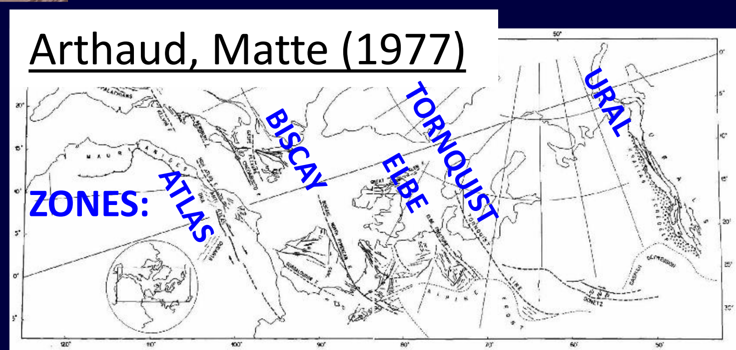
System of lines N120°E

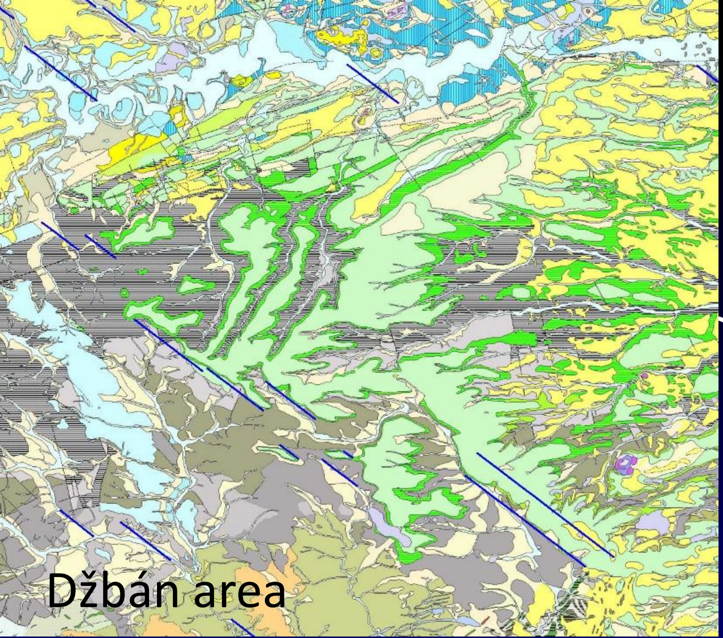


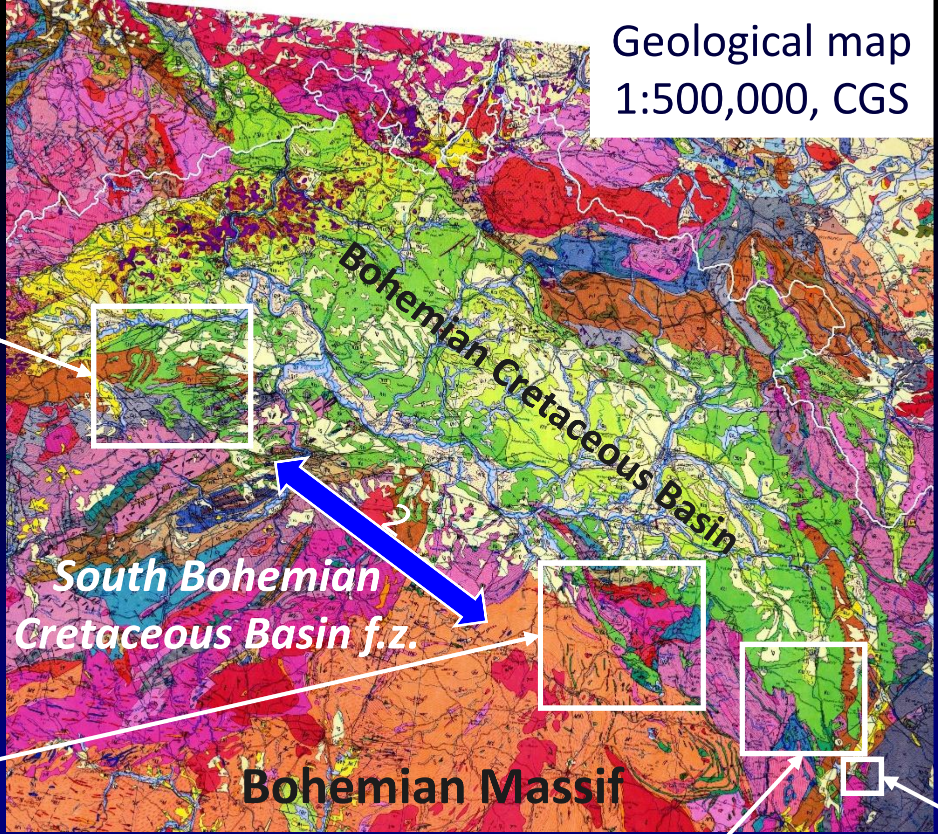
Elevation map of Europe (European Environment Agency)

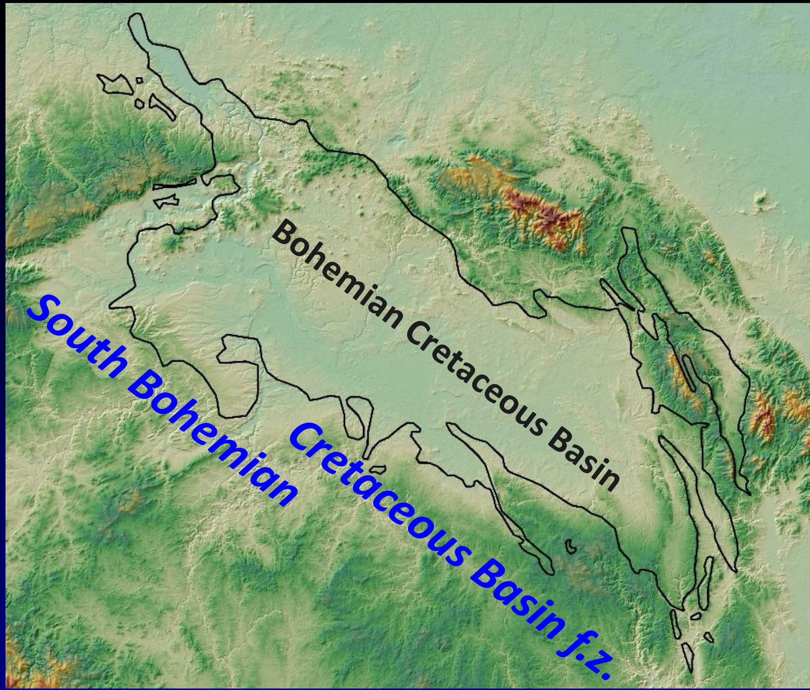


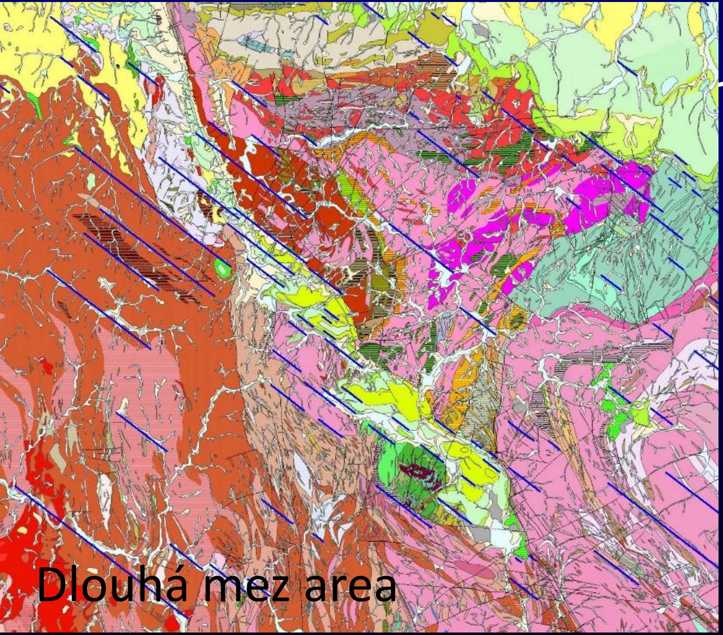






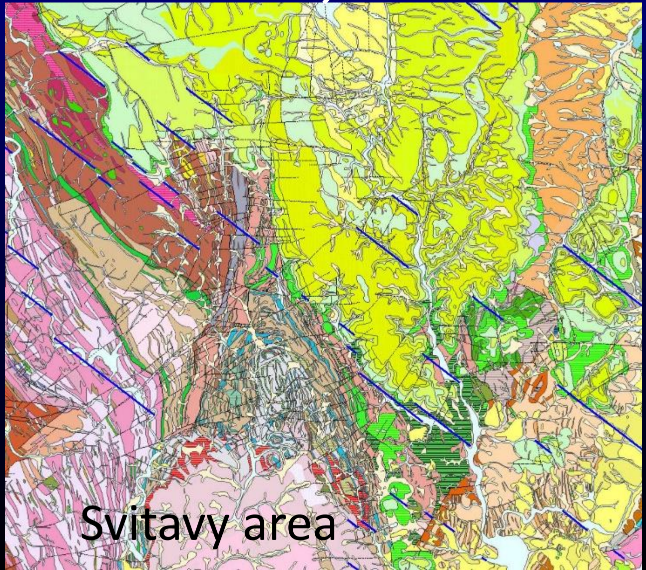


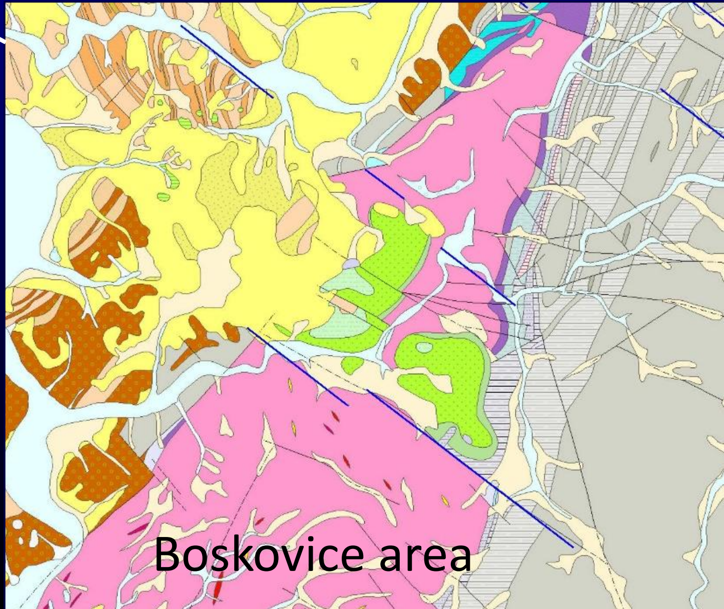




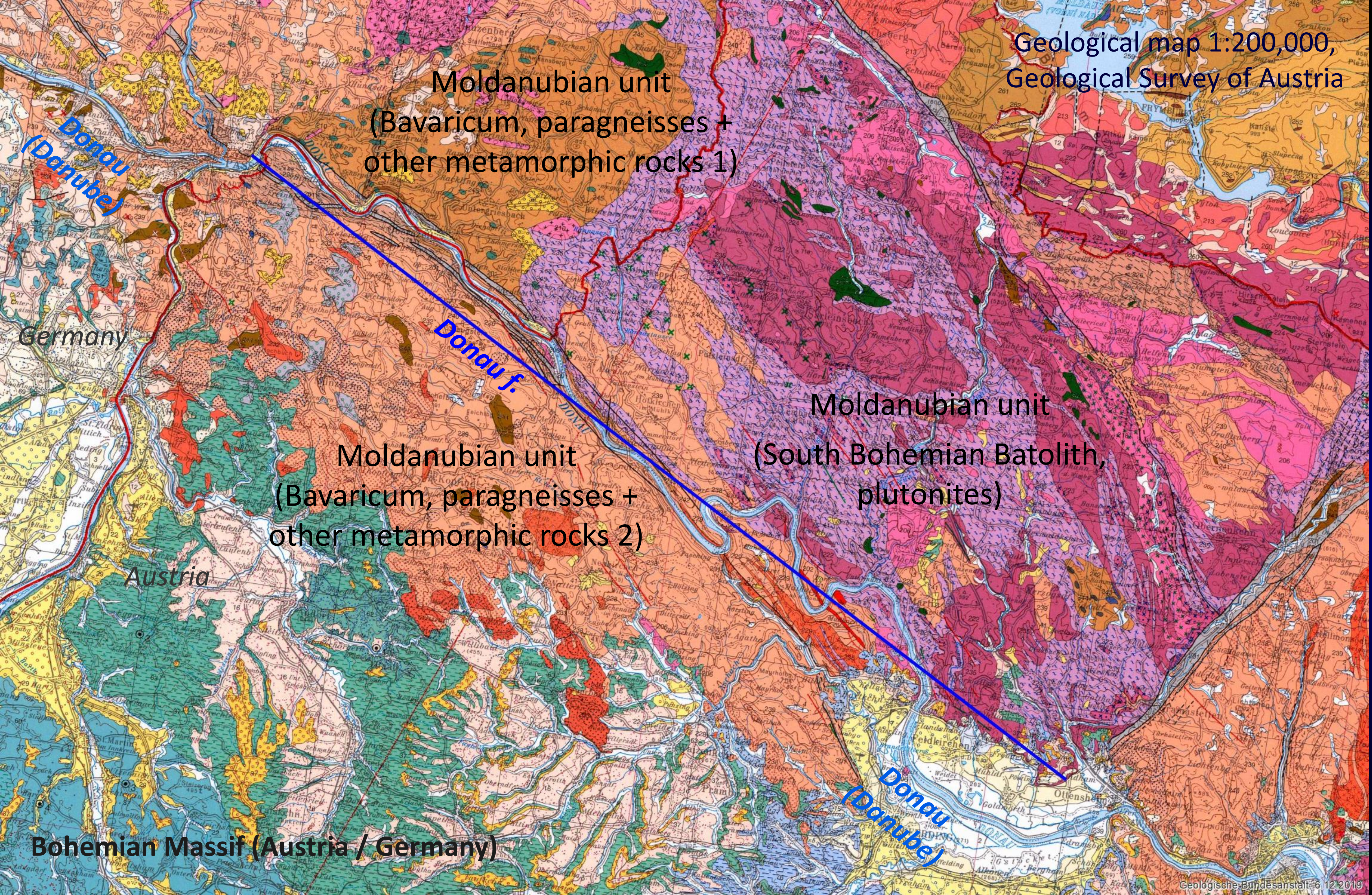
Consistent N120°E trend of southern margin of Bohemian Cretaceous Basin covering part of Elbe fault system

Geological map 1:50,000, CGS

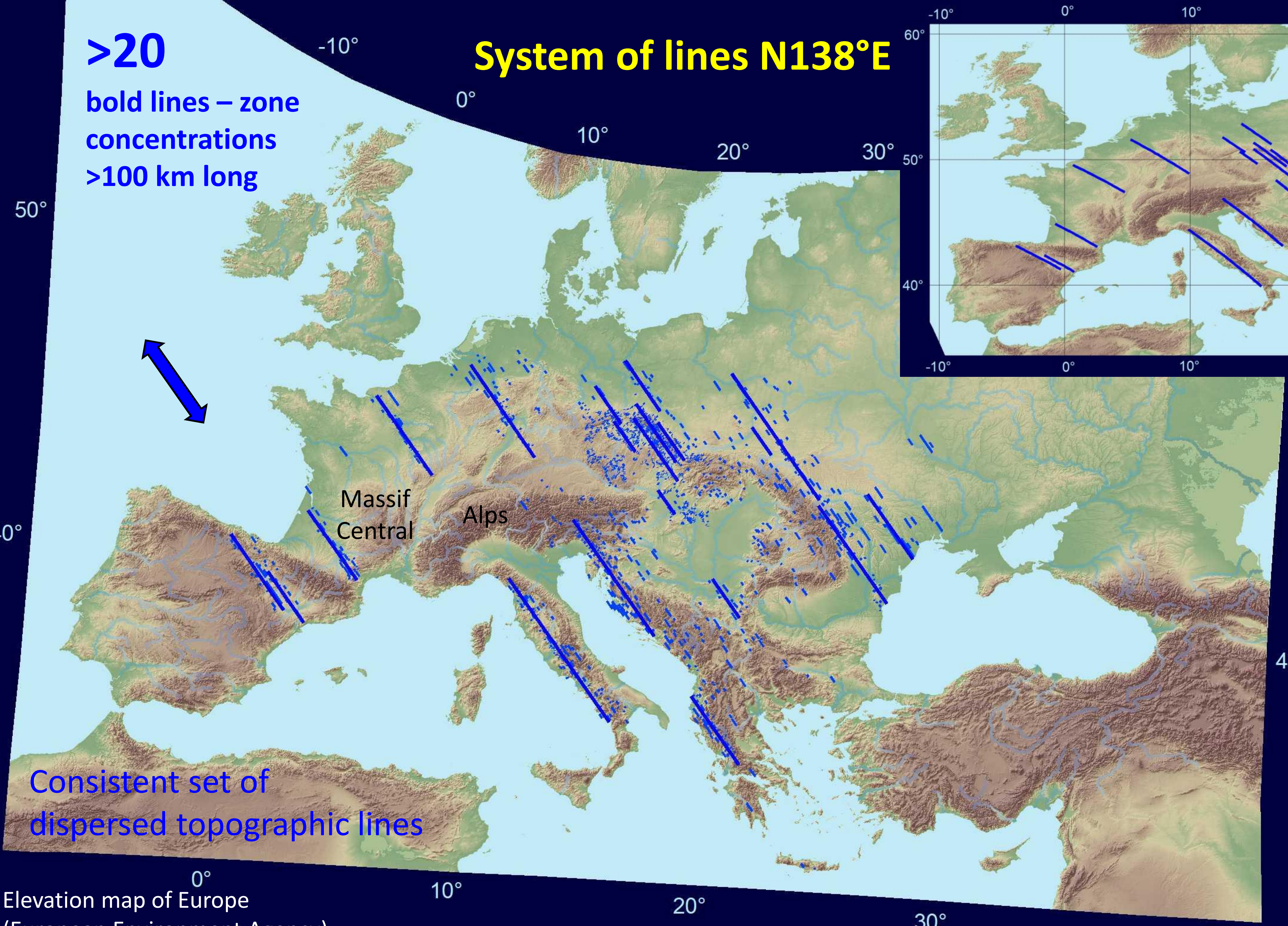


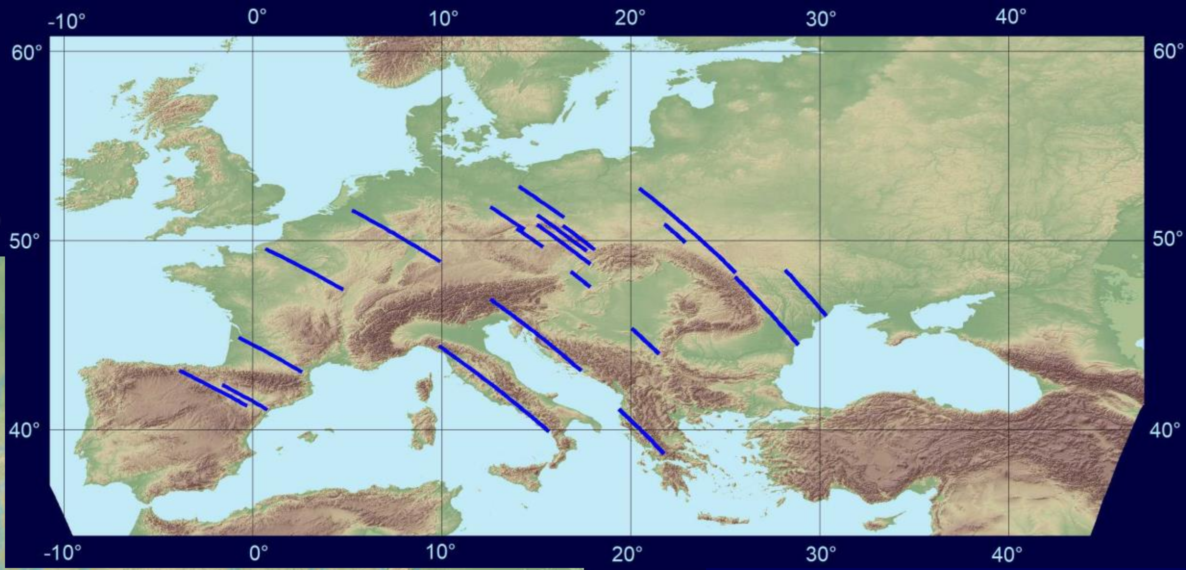


N120°E striking fault system in SW part of Bohemian Massif

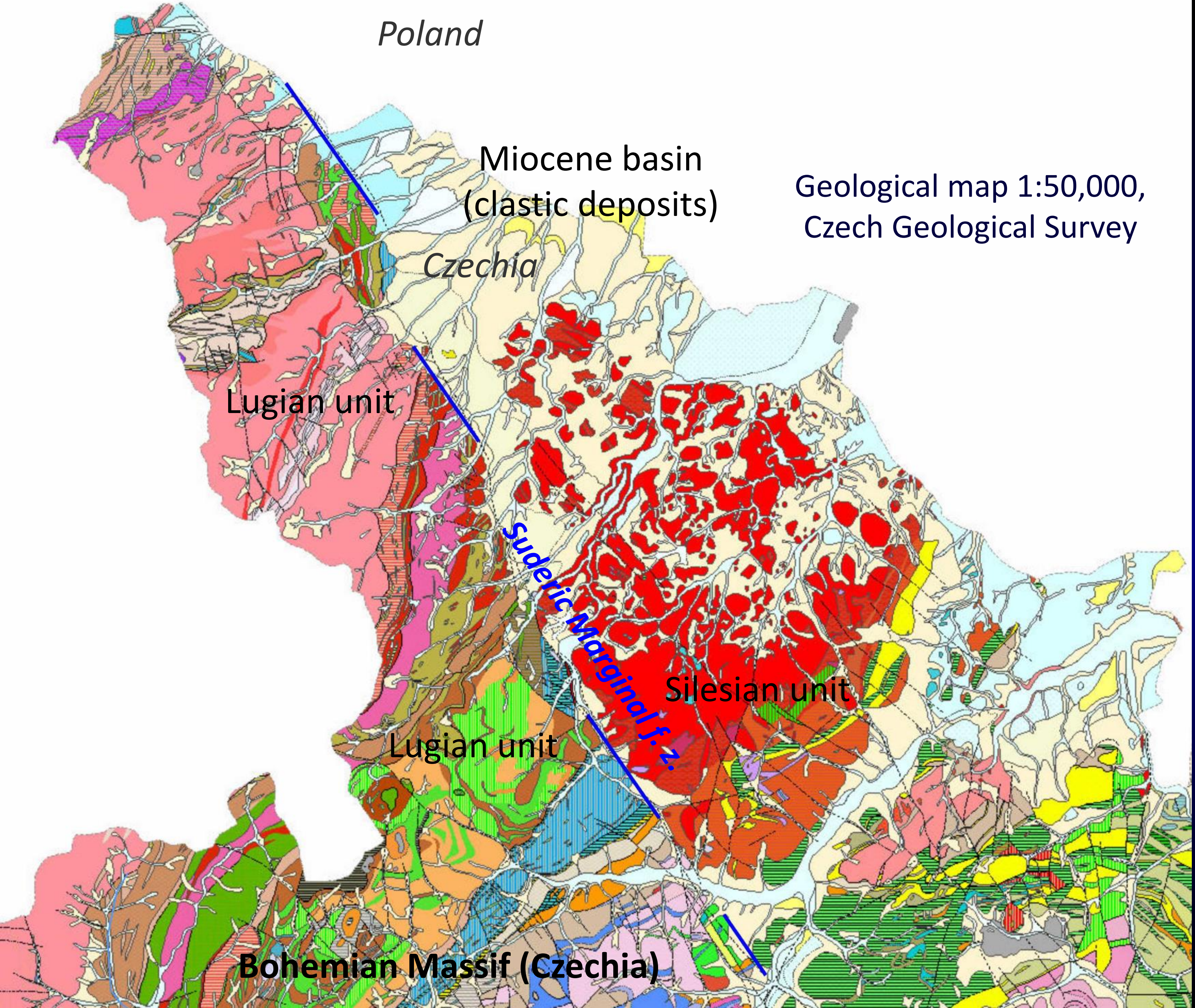


System of lines N138°E



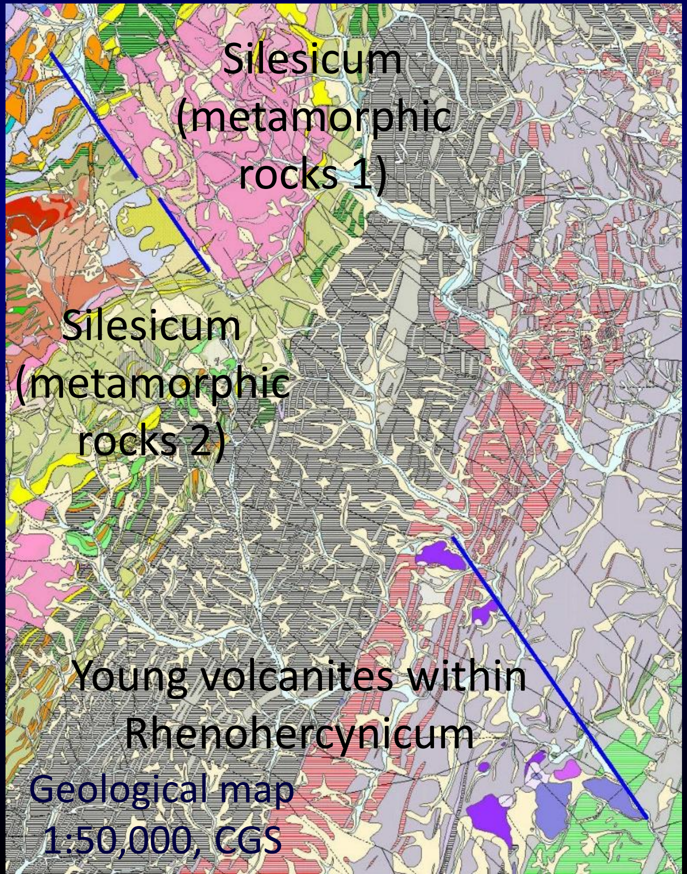


Elevation map of Europe (European Environment Agency)



N138°E linear lithological boundaries – example from Sudetic Marginal fault zone (Czechia / Poland)

Similarly trending Bělá fault system, continuing to the SE within Jeseníky Mts. (Czechia)

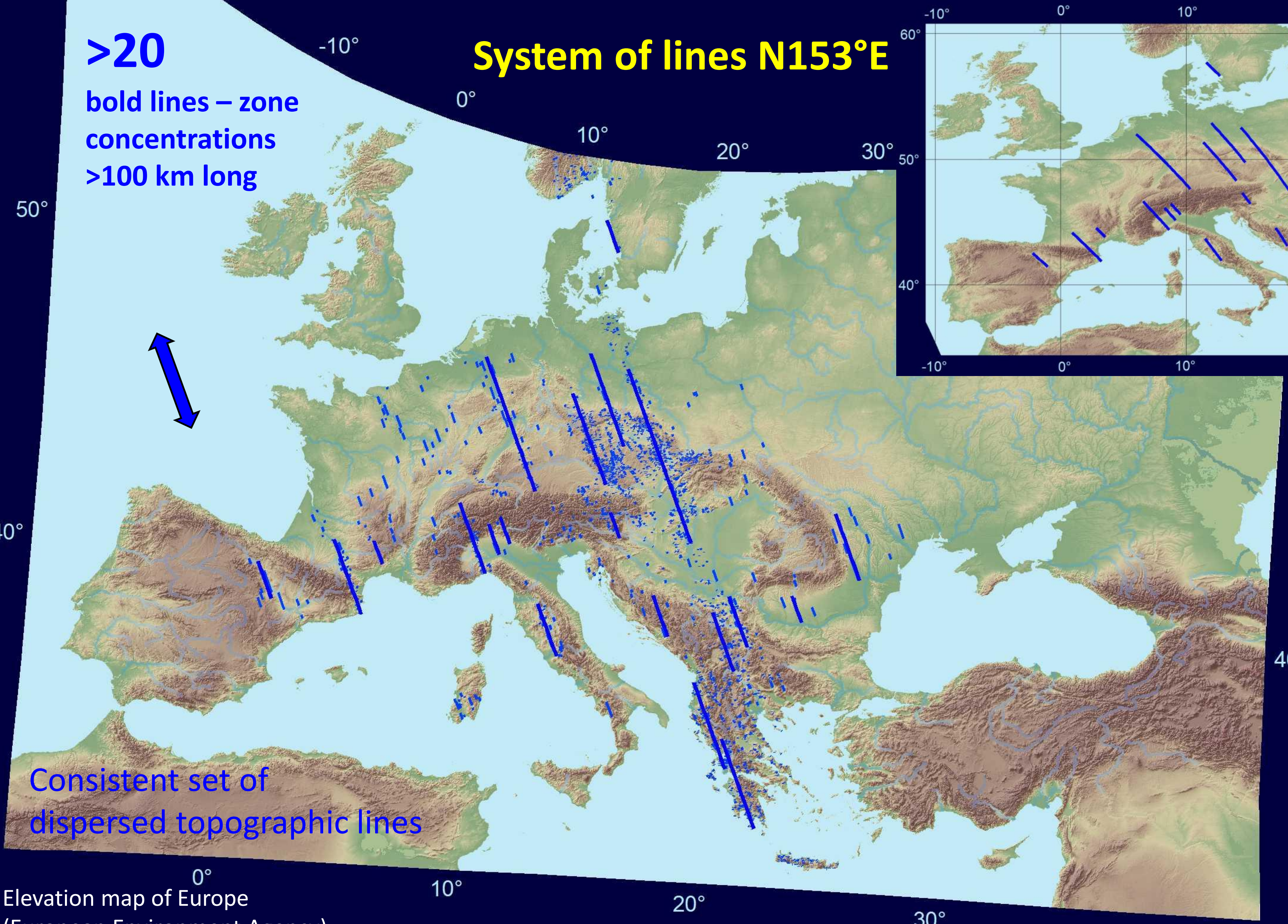


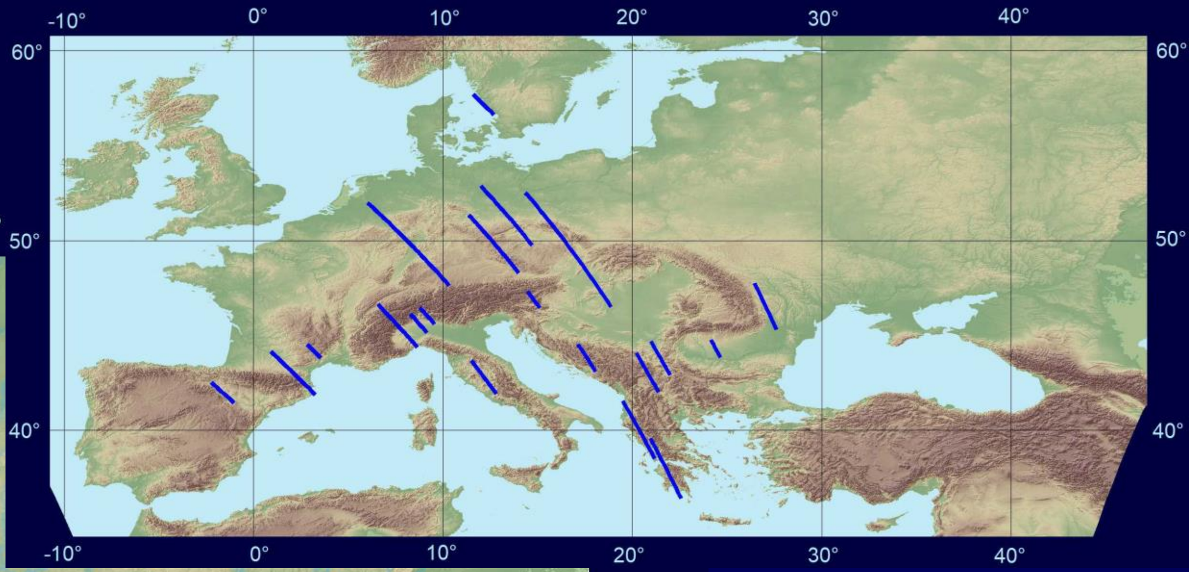
System of lines N153°E

>20

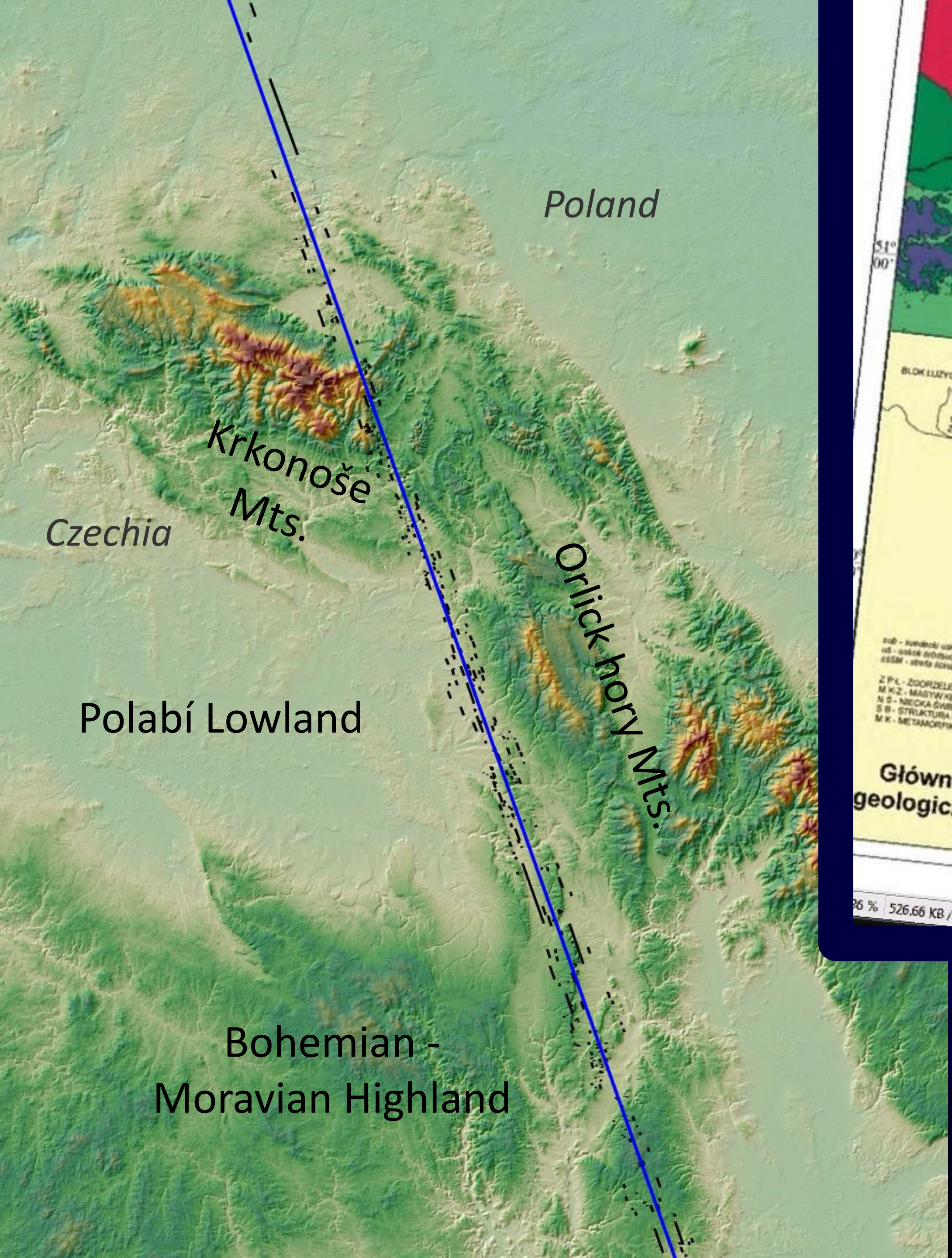
bold lines – zone concentrations >100 km long

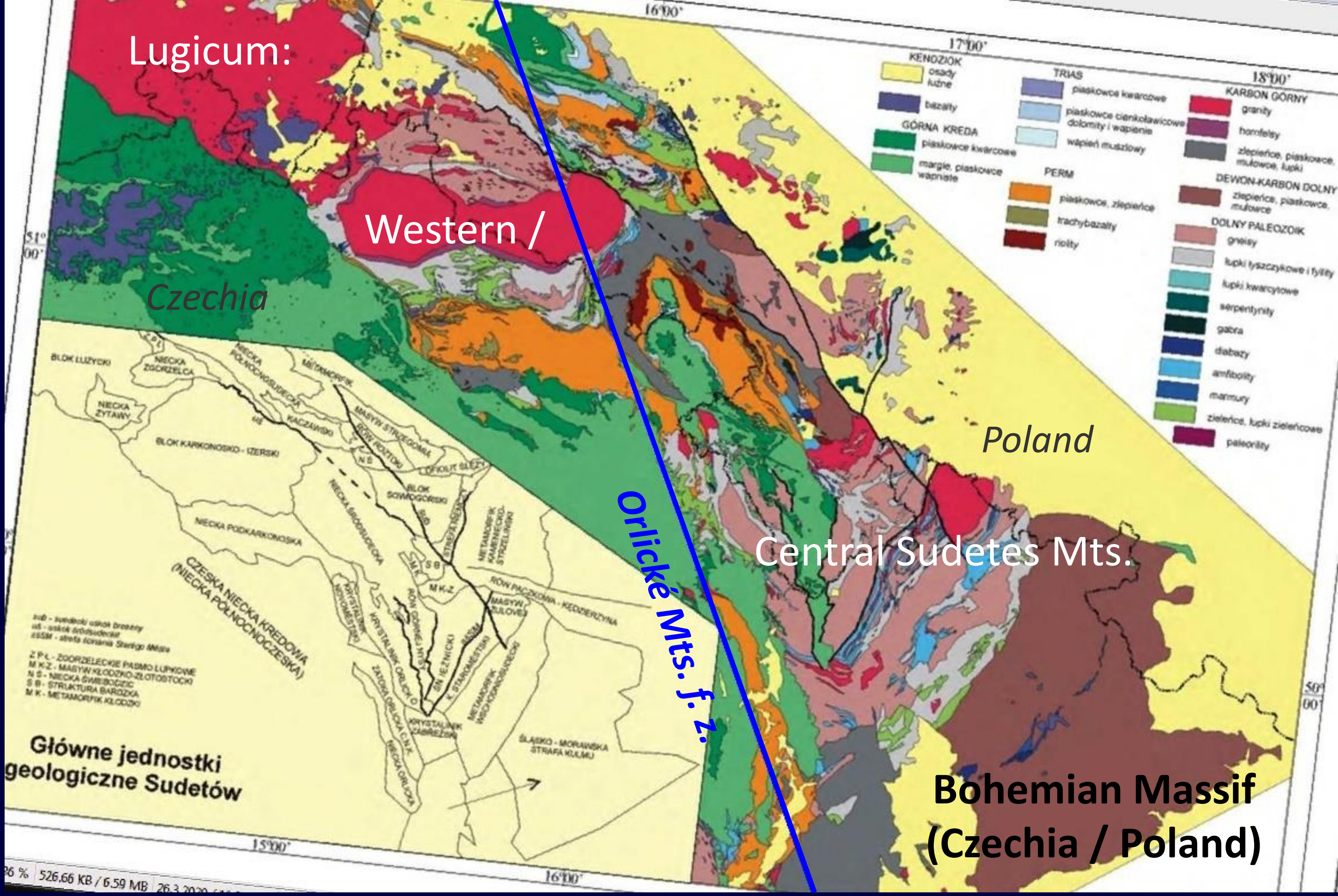
Consistent set of dispersed topographic lines





Elevation map of Europe (European Environment Agency)

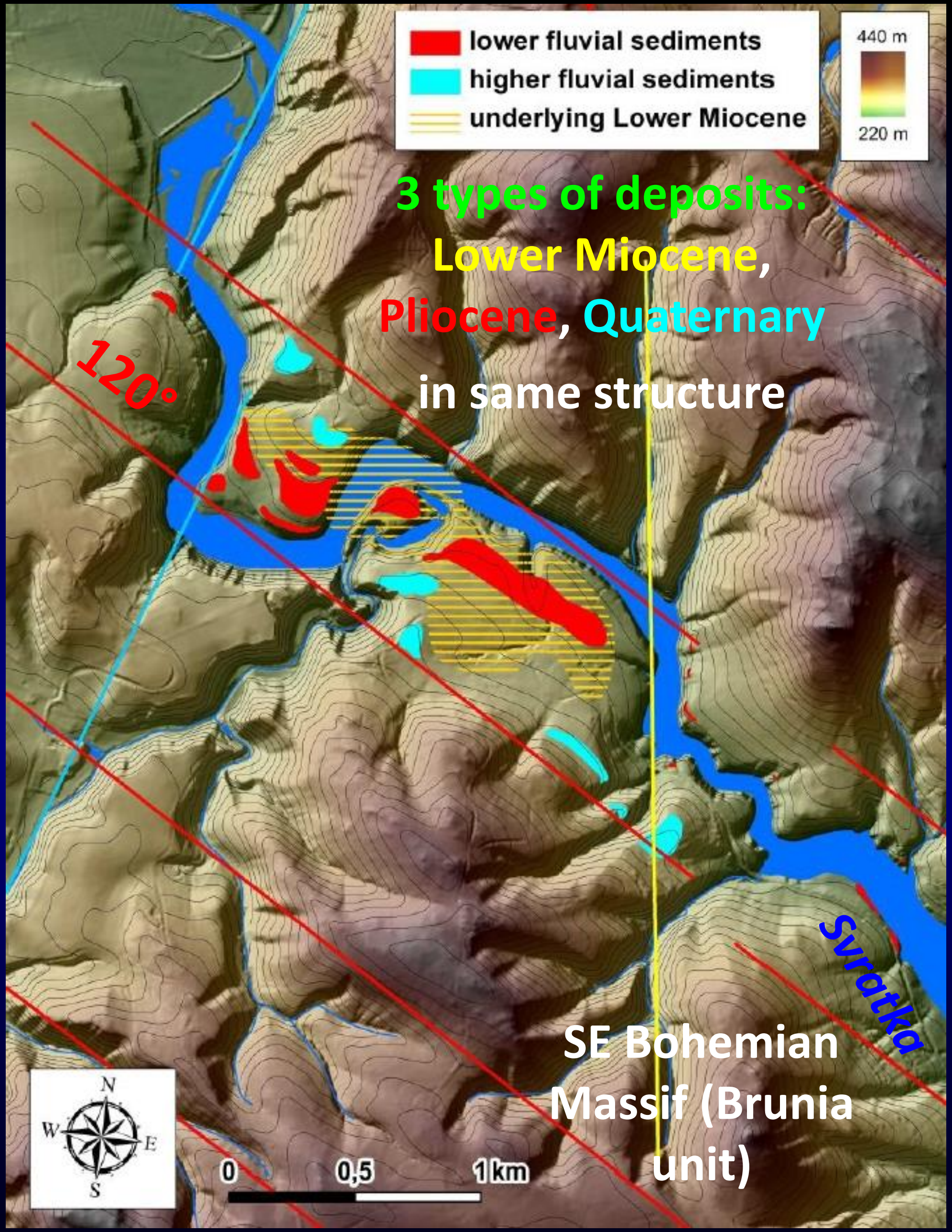




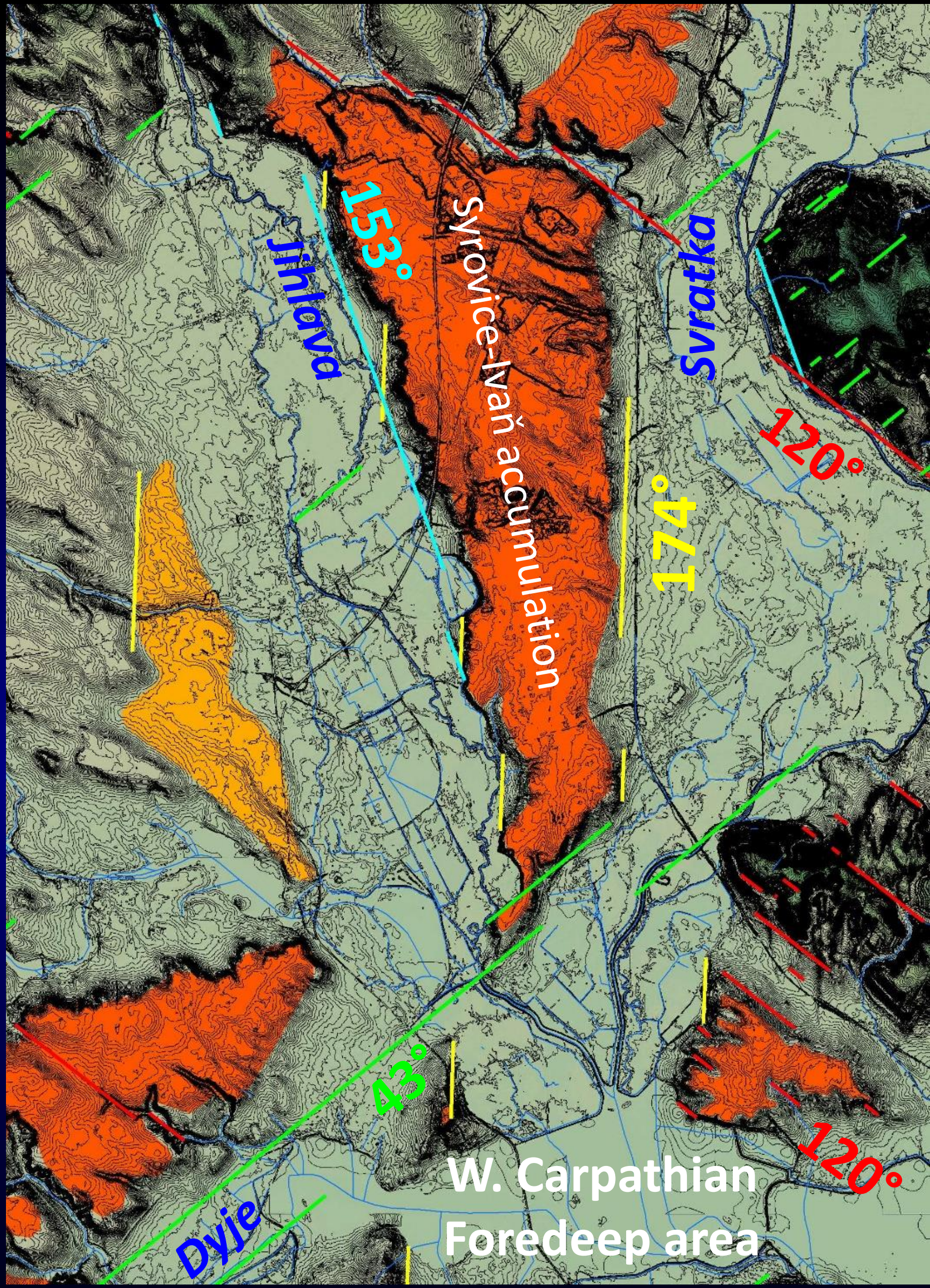
Geological scheme by Placek (2011)

N153°E trending zone of Orlické hory Mts., roughly sepapating different topographic and geological patterns within the Bohemian Massif (Czechia / Poland)

Examples of local consistency with approximate linear boundaries or erosional limits of cover rocks (Miocene, Pliocene, Quaternary age)

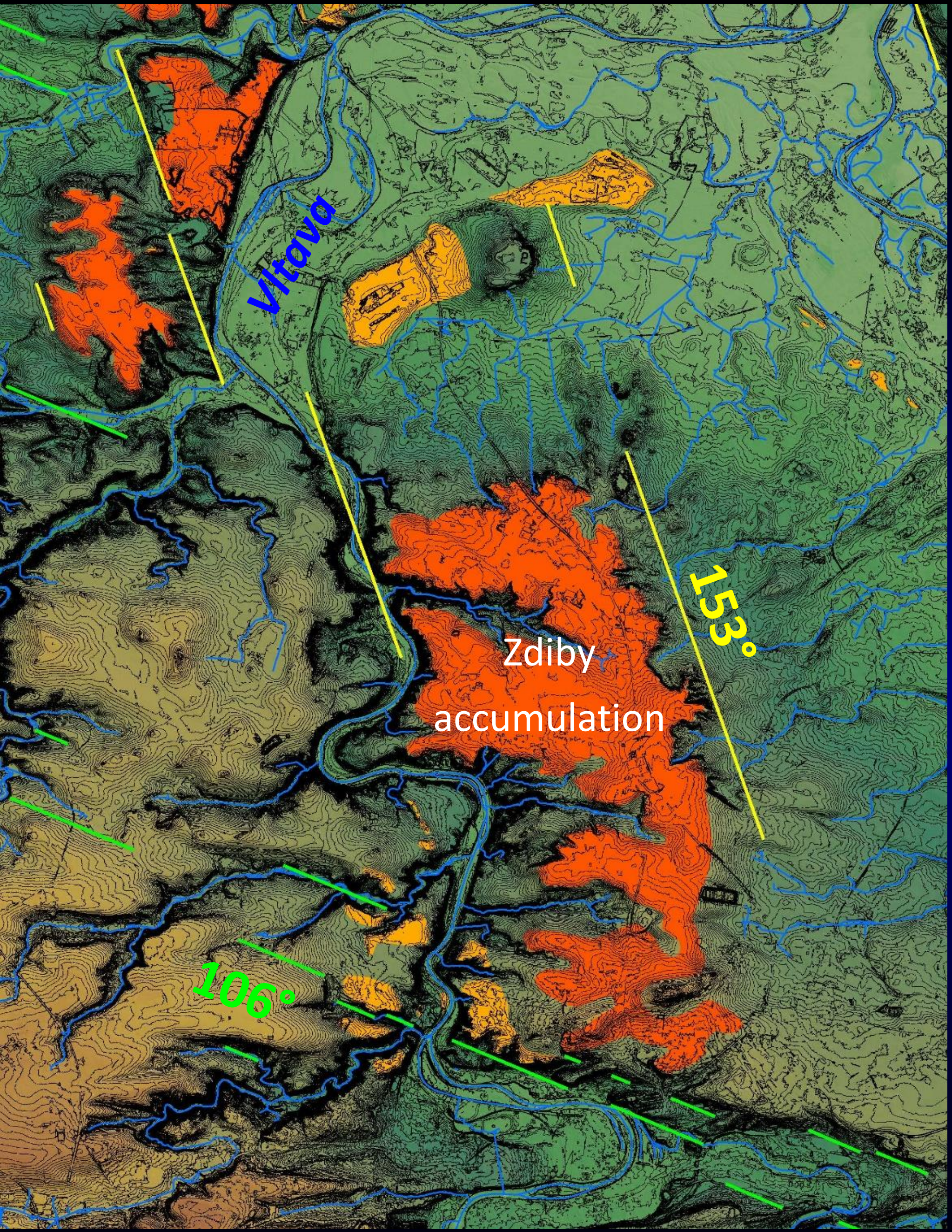


Graben structure at Brno reservoir (Czechia)

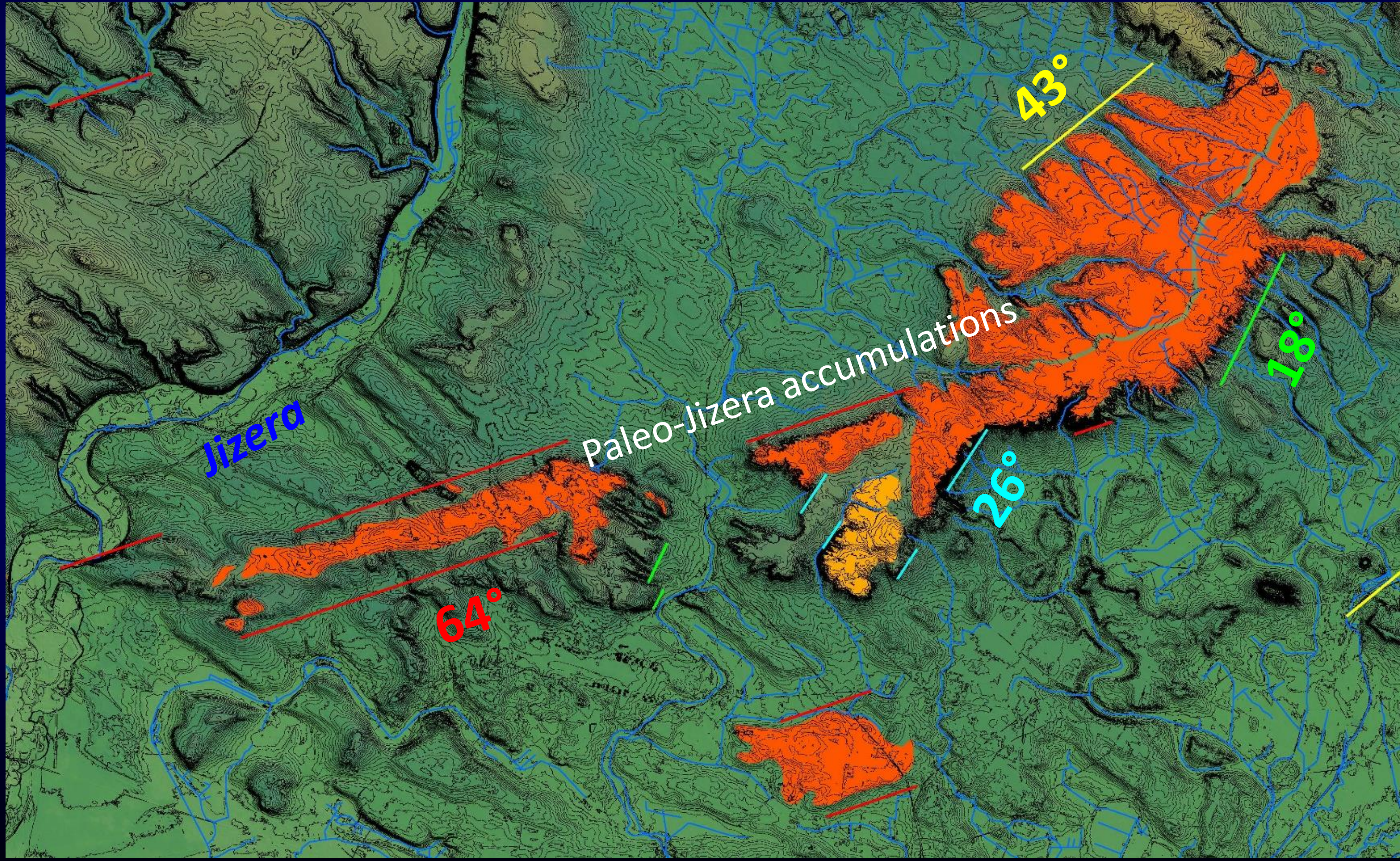


Linear limits of Quaternary fluvial deposits

Two areas within or near Bohemian Cretaceous Basin surface



Linear limits of Pliocene and Quaternary fluvial deposits

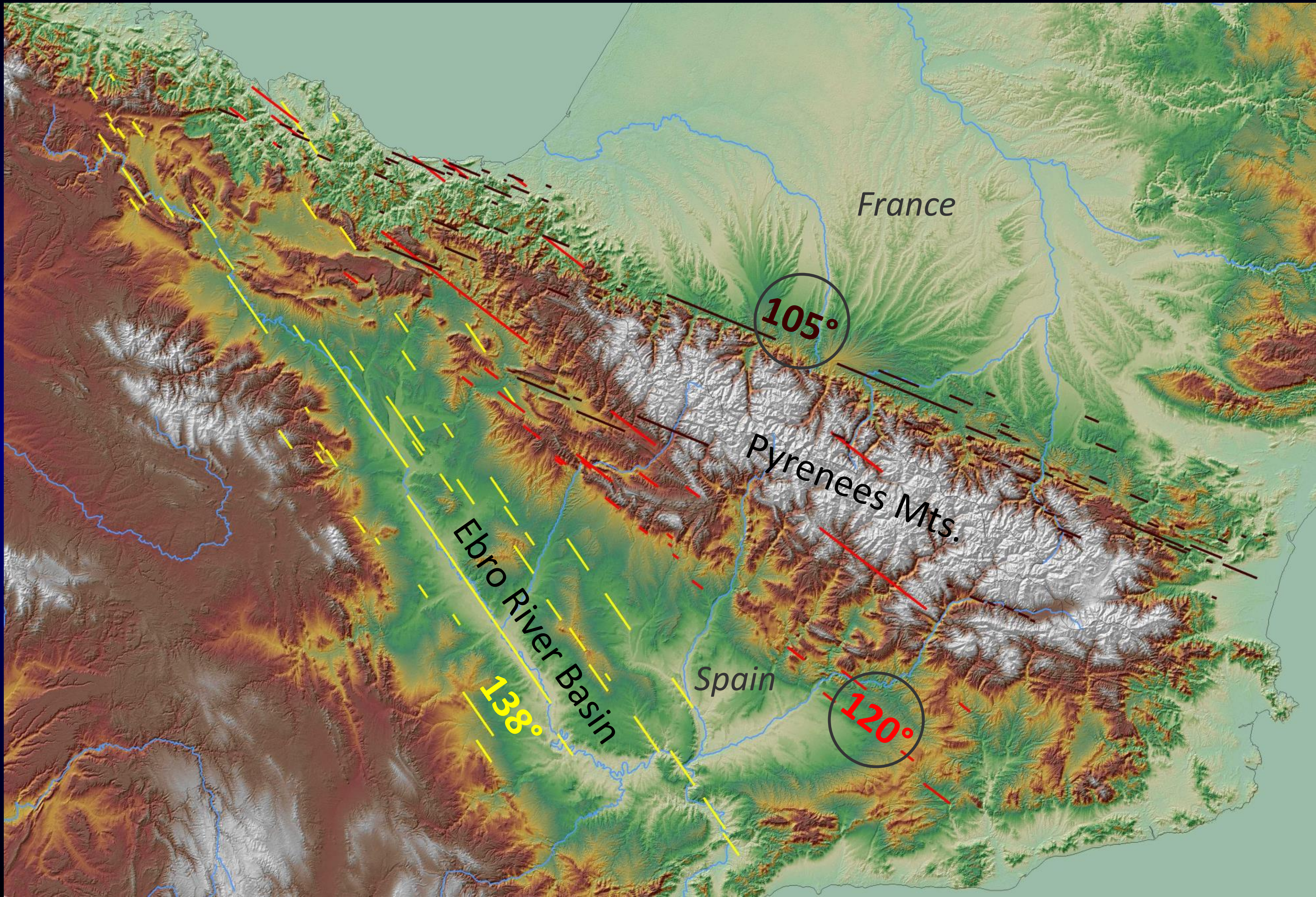


Phenomena related to topographic lines

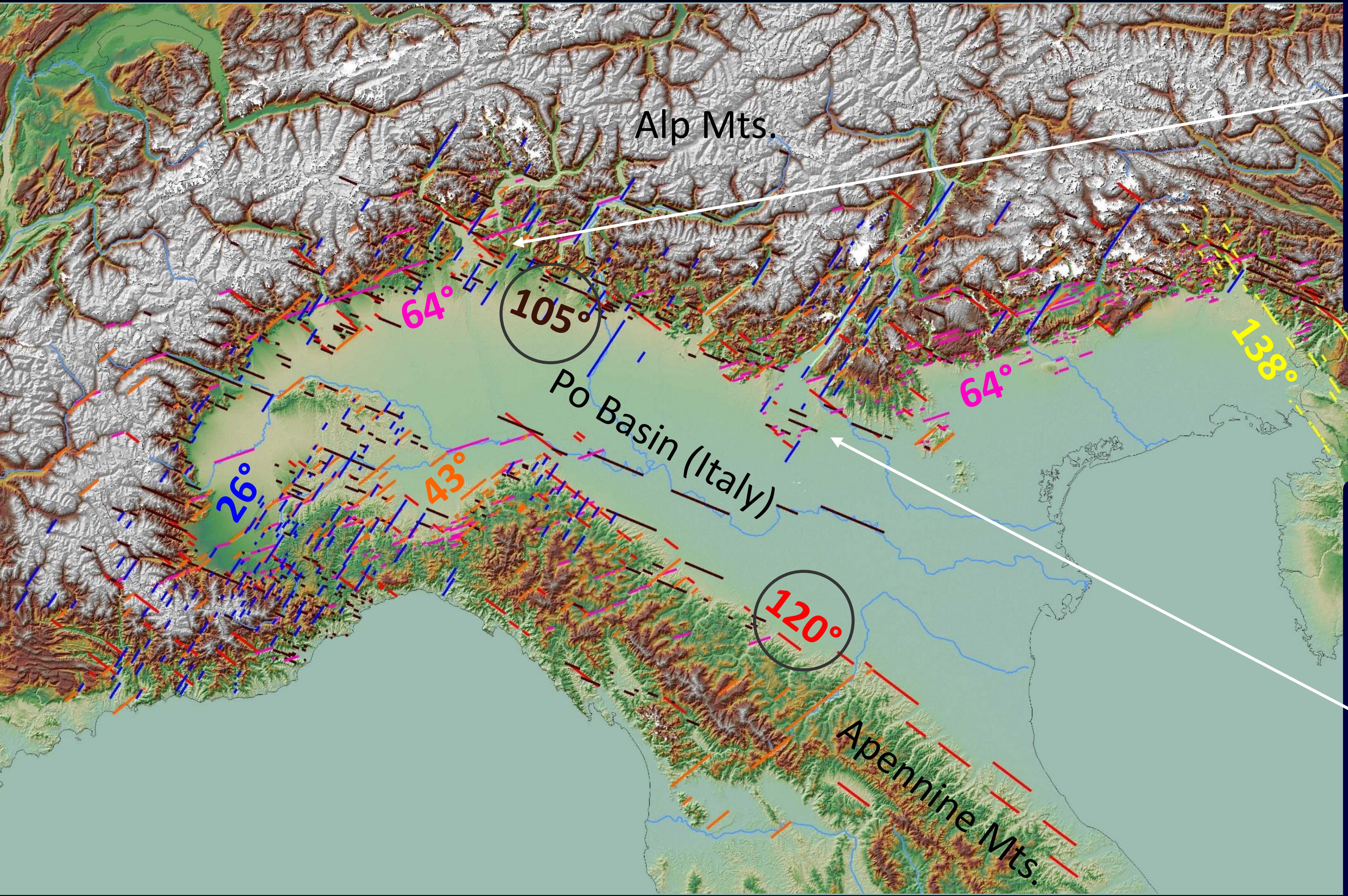
- Many related large-scale features occur,
- as well as a lot of small-scale landscape elements

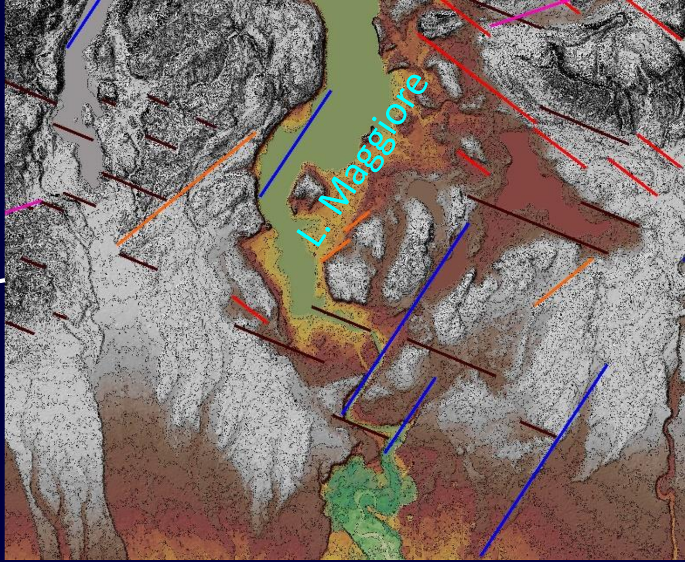
Examples of common combination of N105°E and N120°E trends in large landscape units

Mountain ranges and basins *(including related horsts and grabens)*

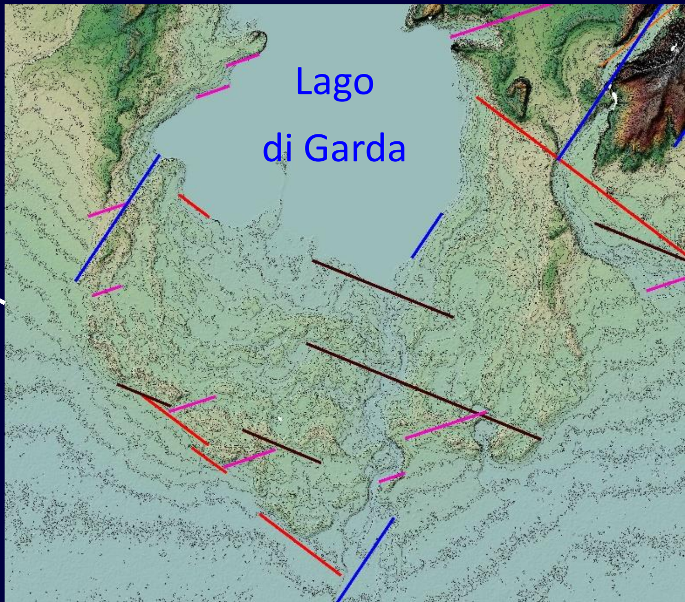


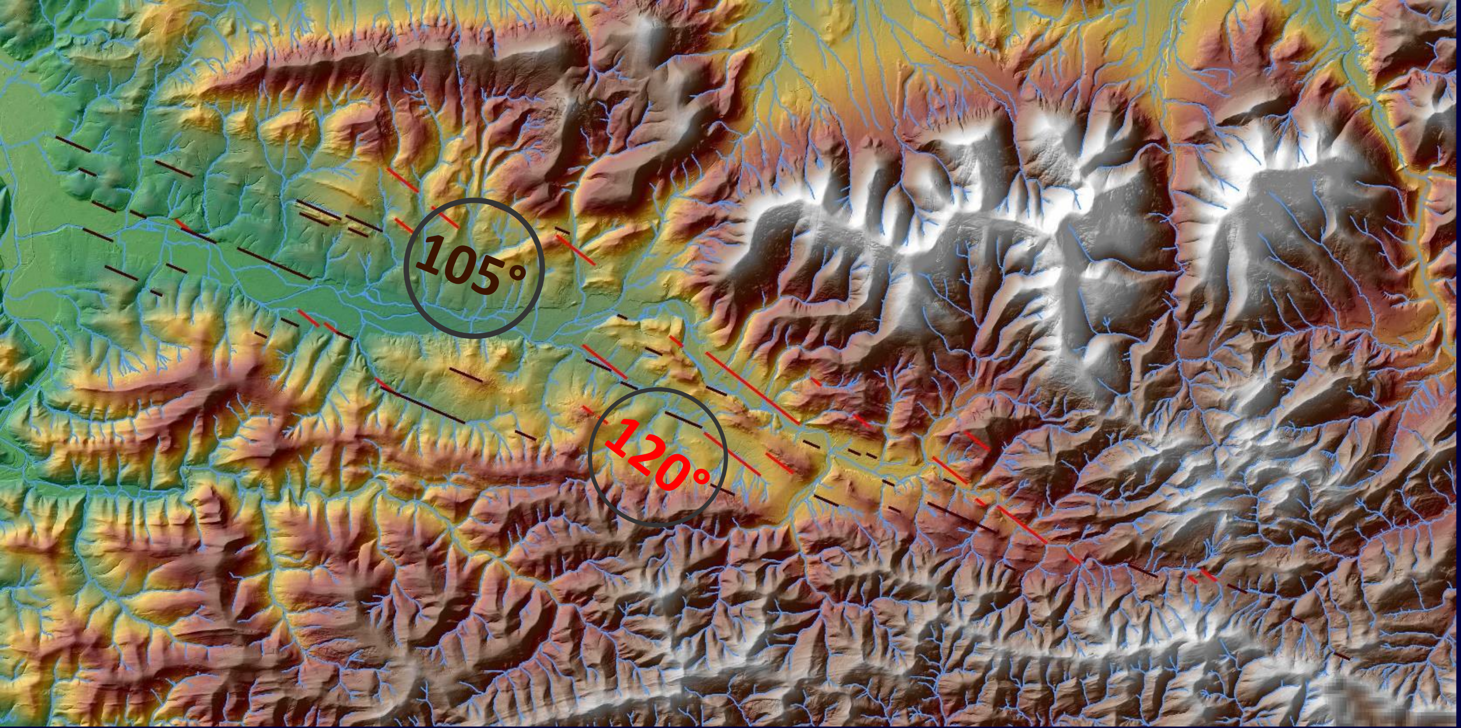
Main linear trends at margins and within large intermontane basin





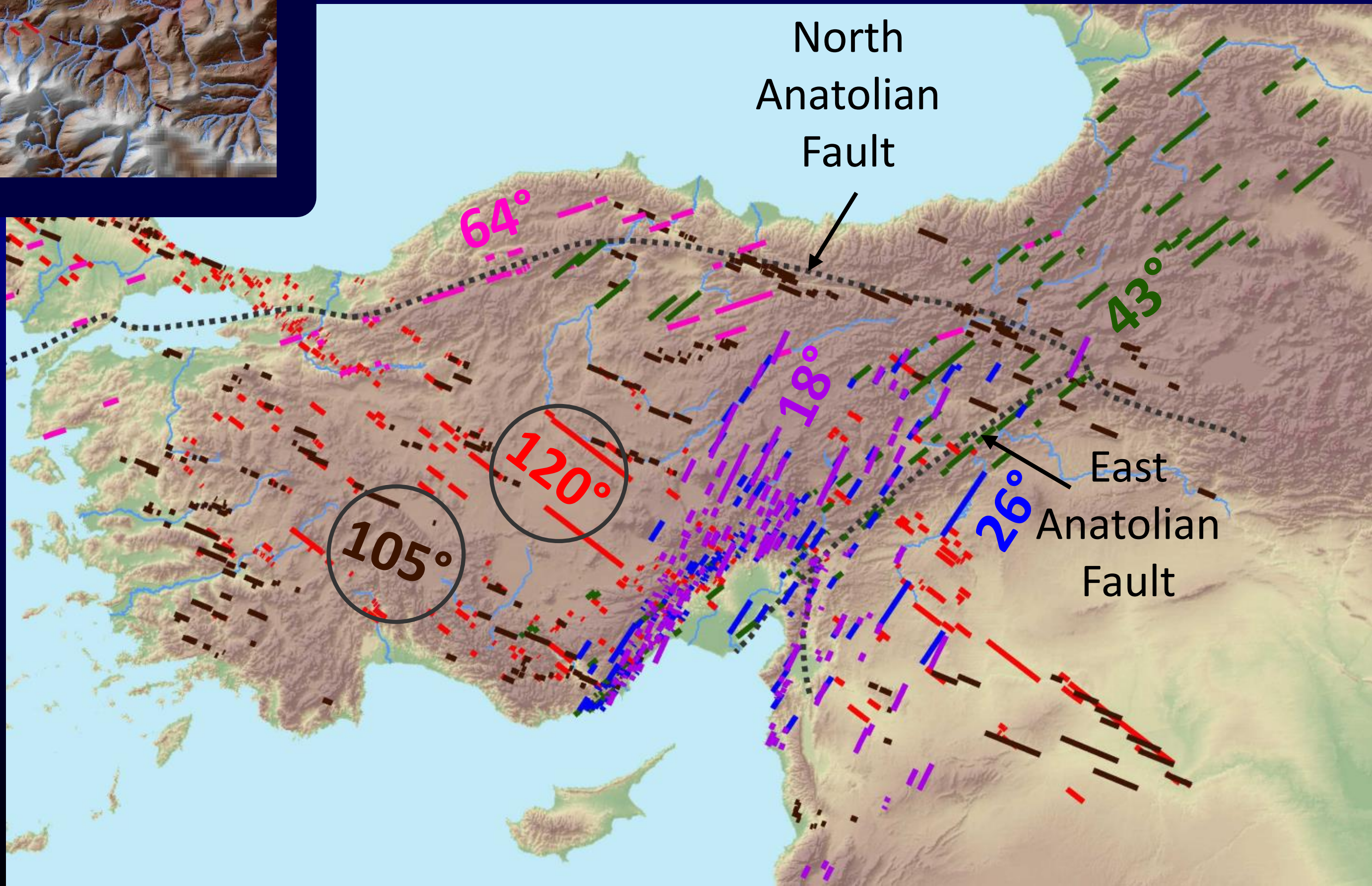
Indication of linear features in moraine terrain





Other cases of N105°E and N120°E topolineaments occurring together

Mountain and plateau areas, Anatolia (Turkey) and surroundings



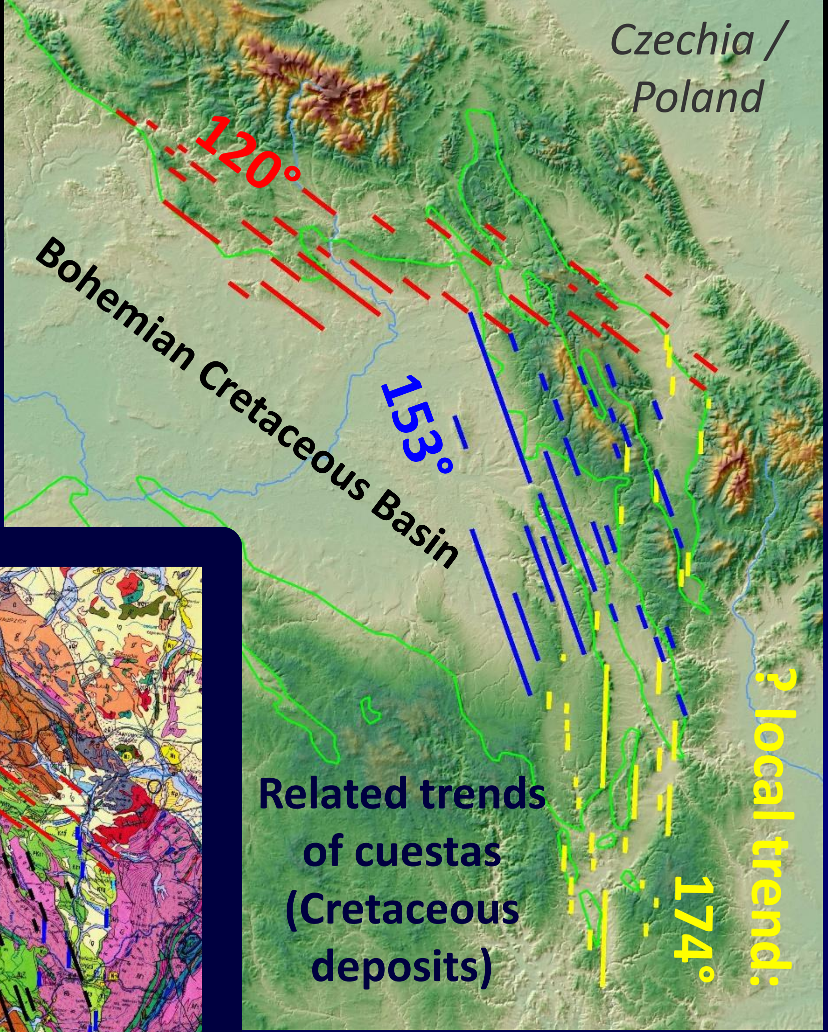
Rožnov Trough, mountain area in Western Carpathian Flysch Belt (Czechia)

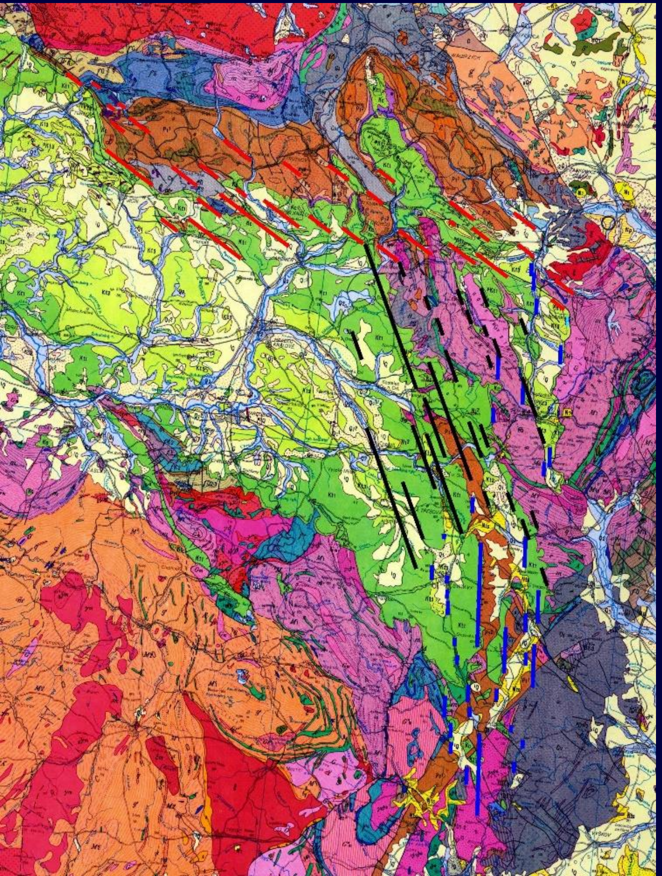
- Indication of possibly genetically conjugated linear trends in many regional structures:

18° + 26° + 45° / 64° + 105° /

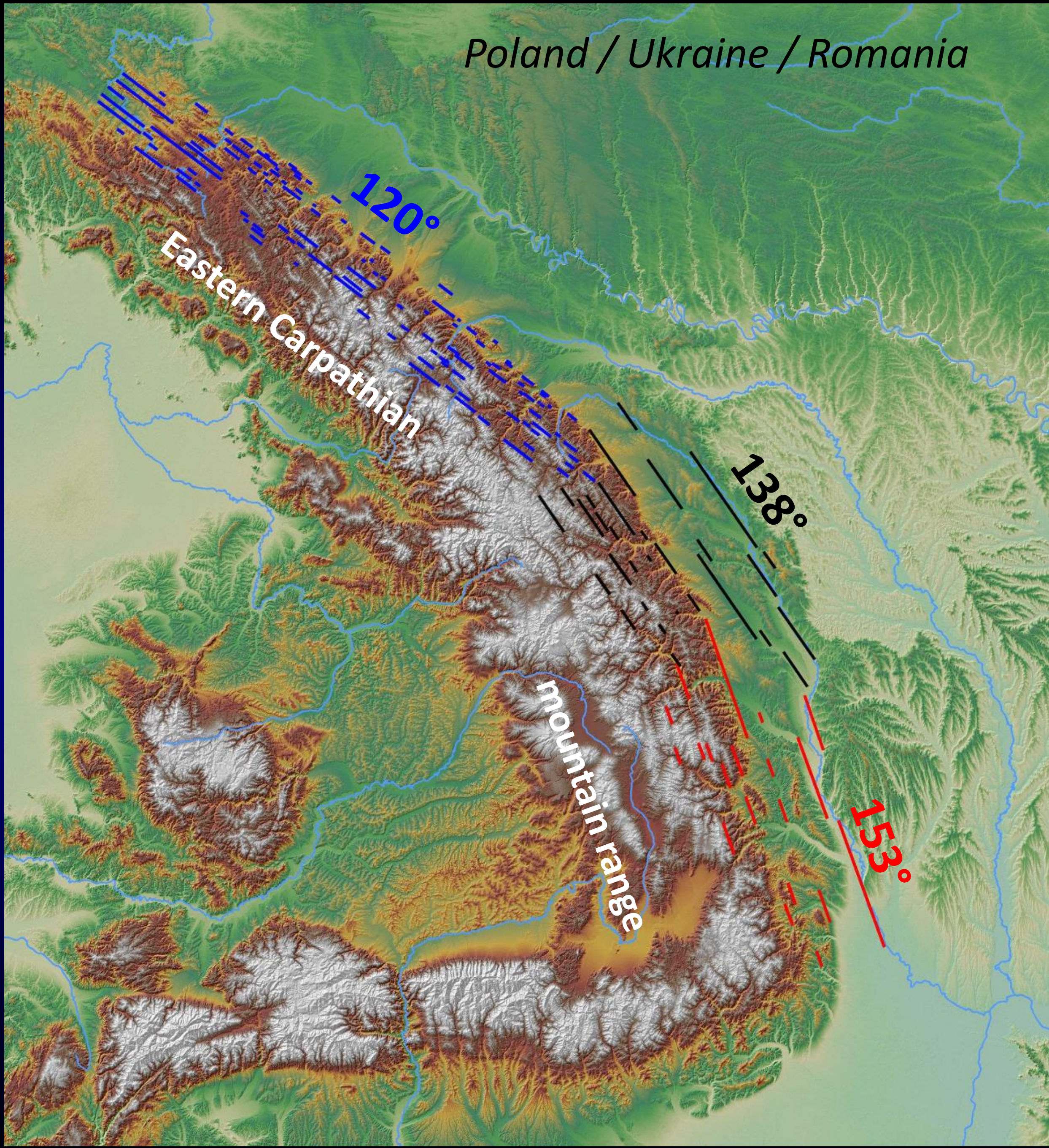
105° + 120° / 138° + 153° / others…

Combination of trends on complex evolution of landforms at



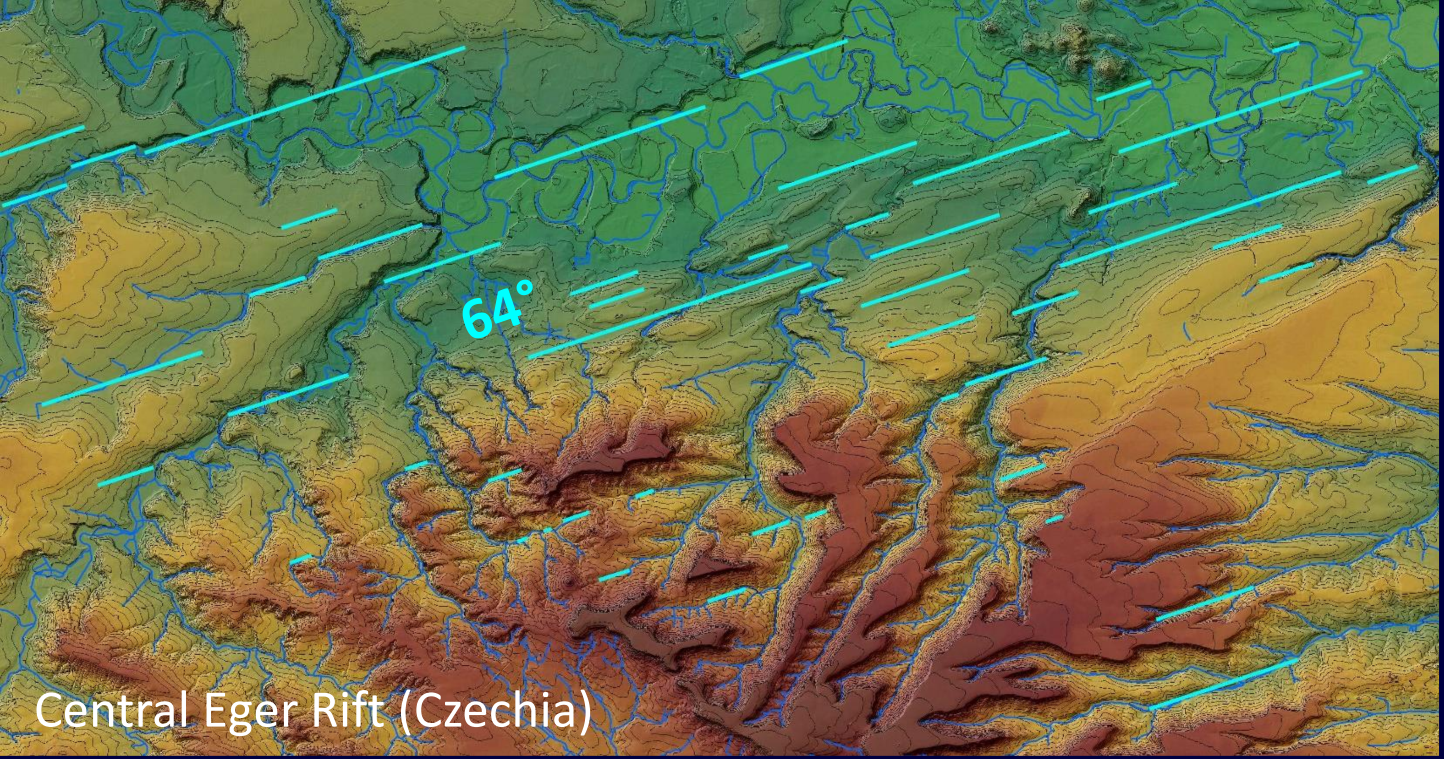


… margins of basin or upland structures

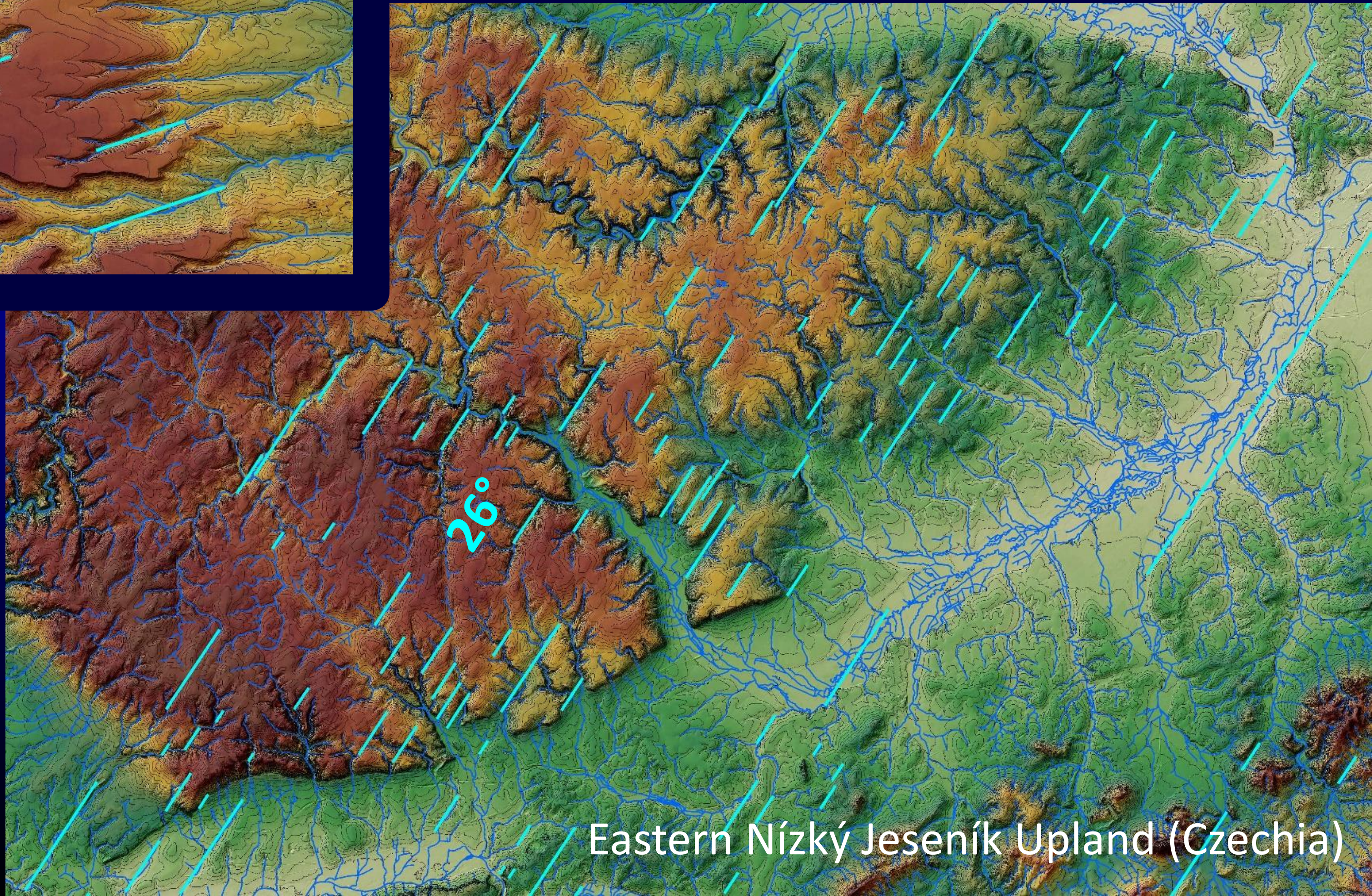


Surface block segmentation

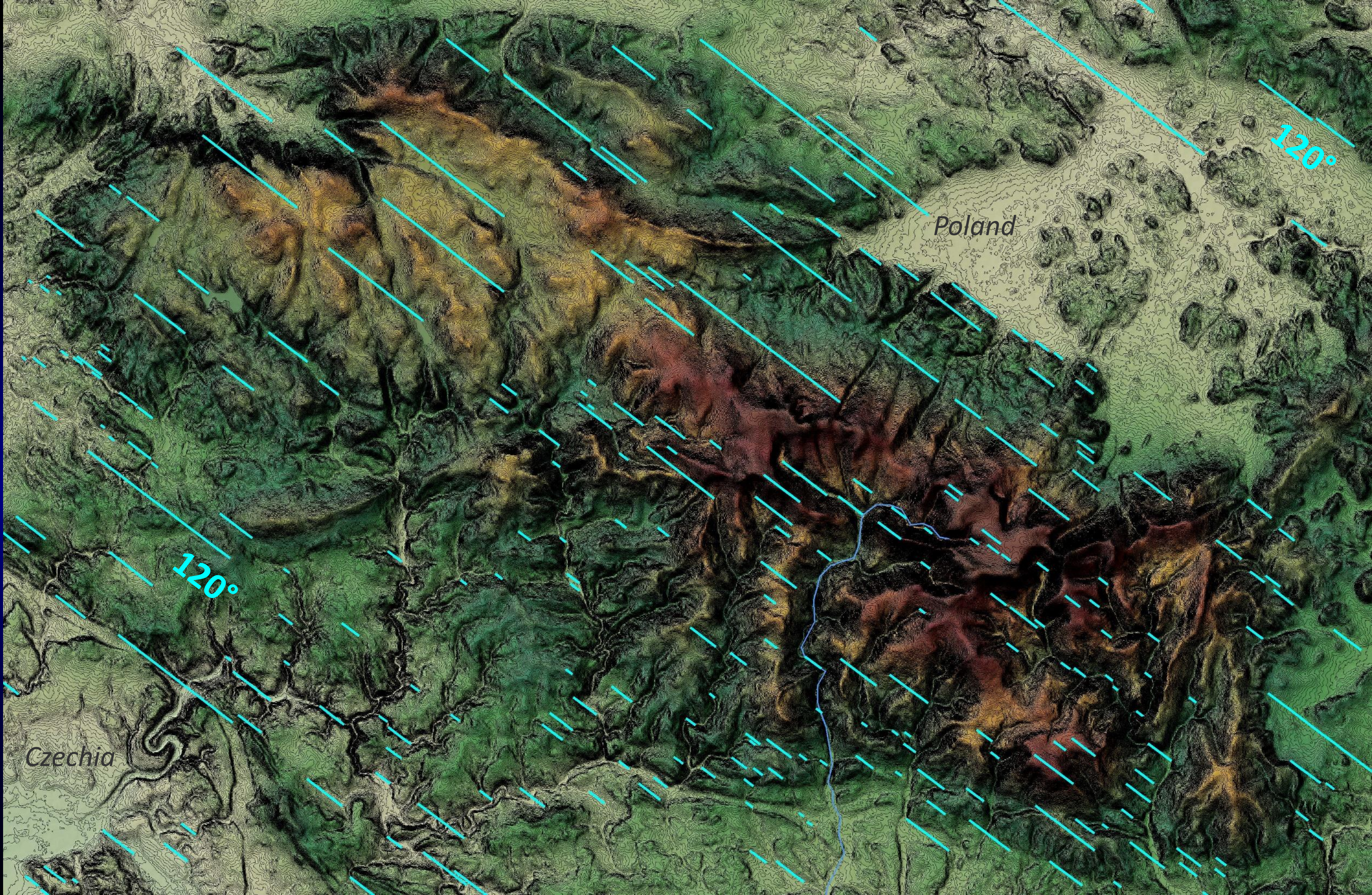
Different directions have played role at segmentation evolution; one, two or more trends dominate at particular places



Examples of prevailing one-direction (linear) block segmentation in the Bohemian Massif

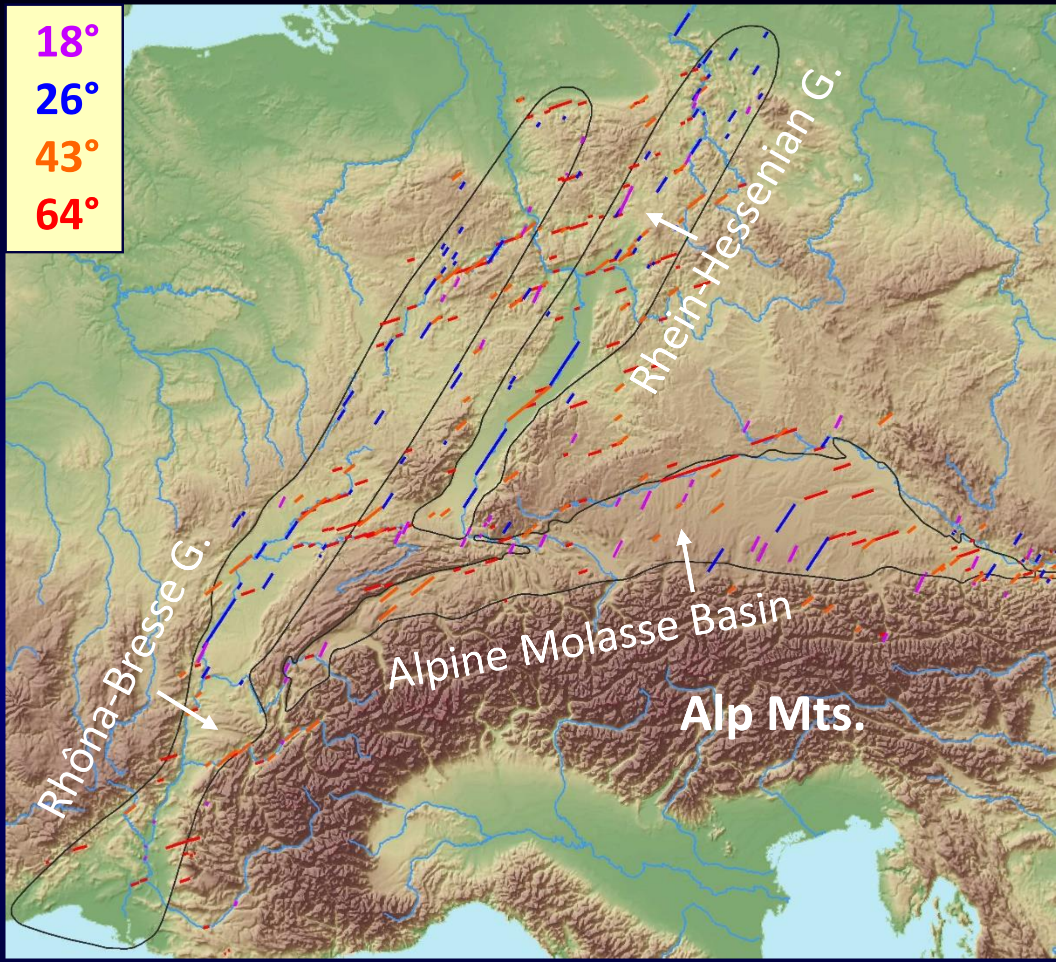


Jizerské hory - Krkonoše Mts. area (Czechia / Poland)



River and valley networks (and their changes)

Main stream-section trends in foreland depressions of Alps



- Enormous influence of linear features on stream trends and valley morphology, including headwater or water-gap sections; possible relations also to common events of river piracy
- Abundance of features indicate pervasive character of linear phenomena in the crust

Type list of some linear systems-related small-scale phenomena
(location, trend, morphology)

– linear contrast in slope gradient

– linear coastline

– elongated strait

– linear cuesta

– sharp stream or valley direction change

– water gap valley

– shape of incised or free meander

– valley-floor phenomena

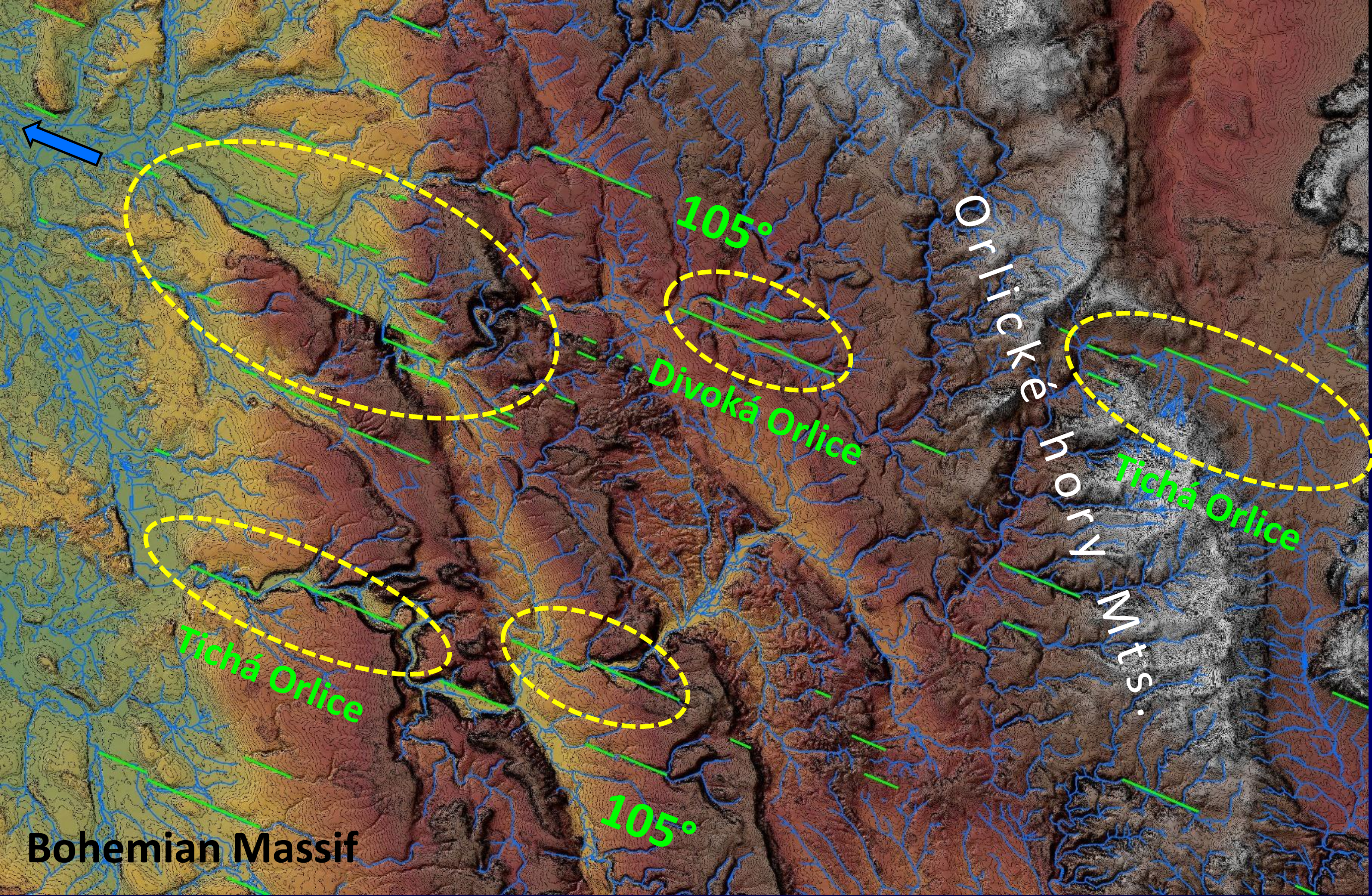
– linear gully

– linear chain of saddles

– linear chain of karst sinkholes

– slope deformation (landslide) shape or inner structure

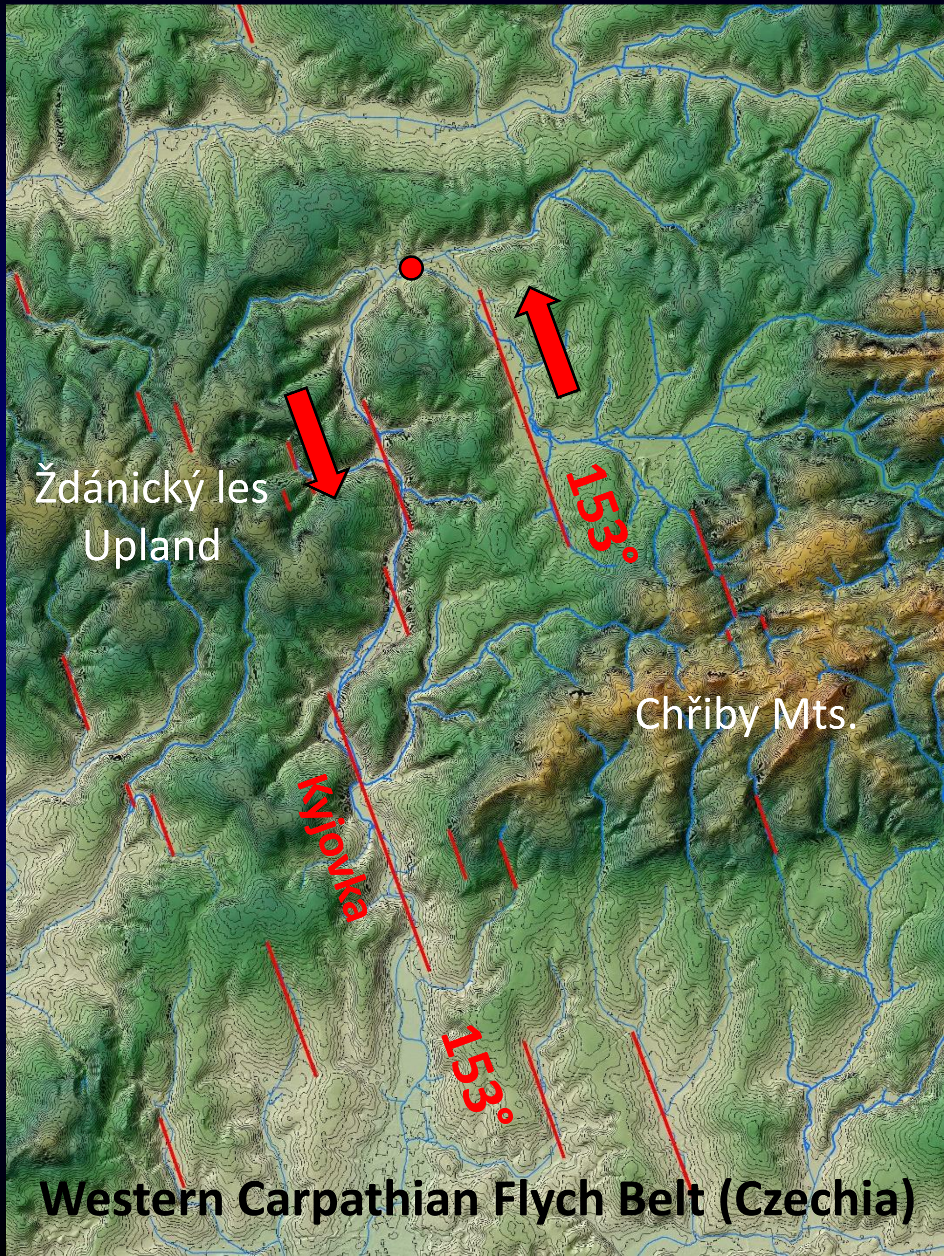
– cirque shape or inner structure



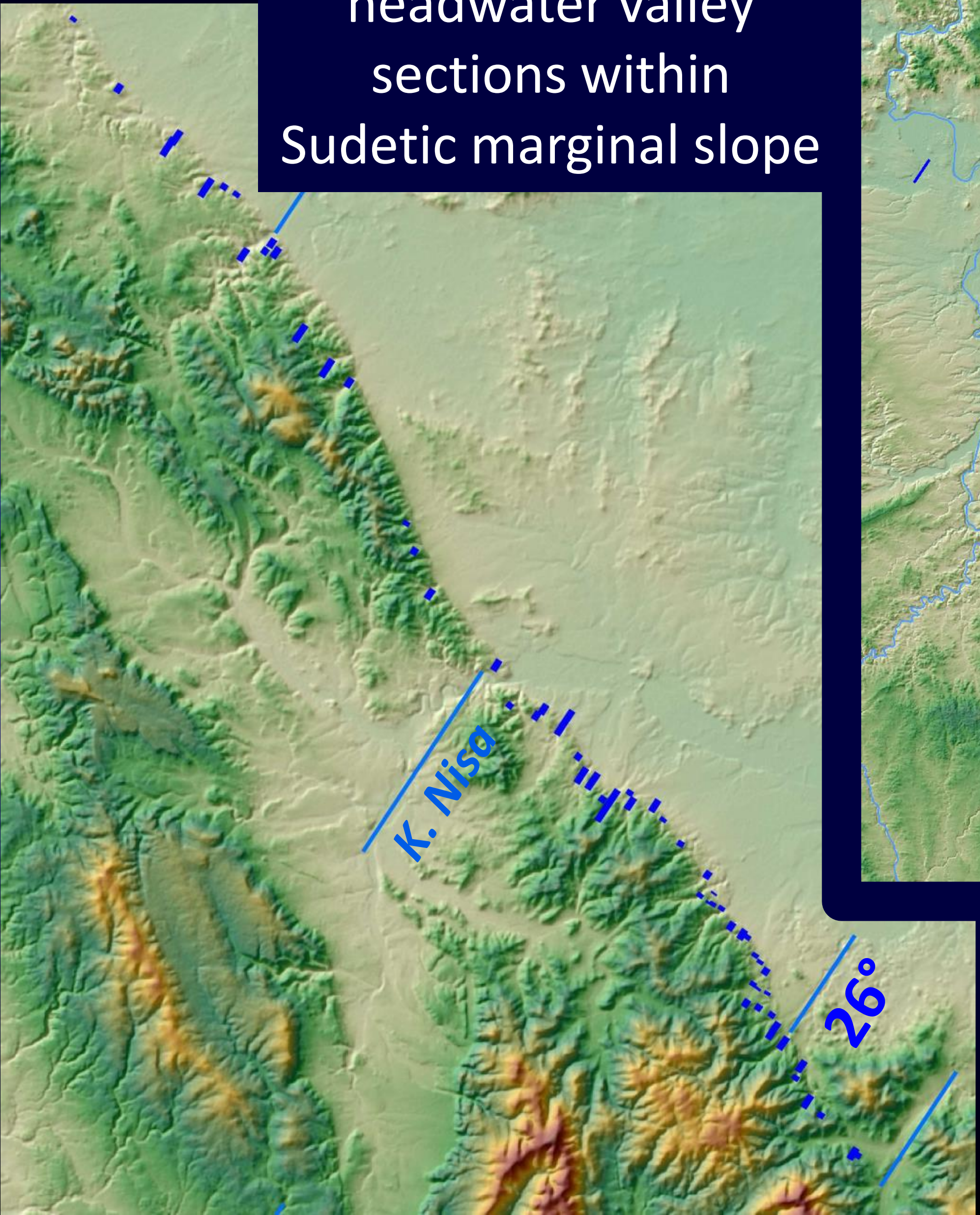
Consistent water gap valley sections across Orlické hory Mts. (Czechia)

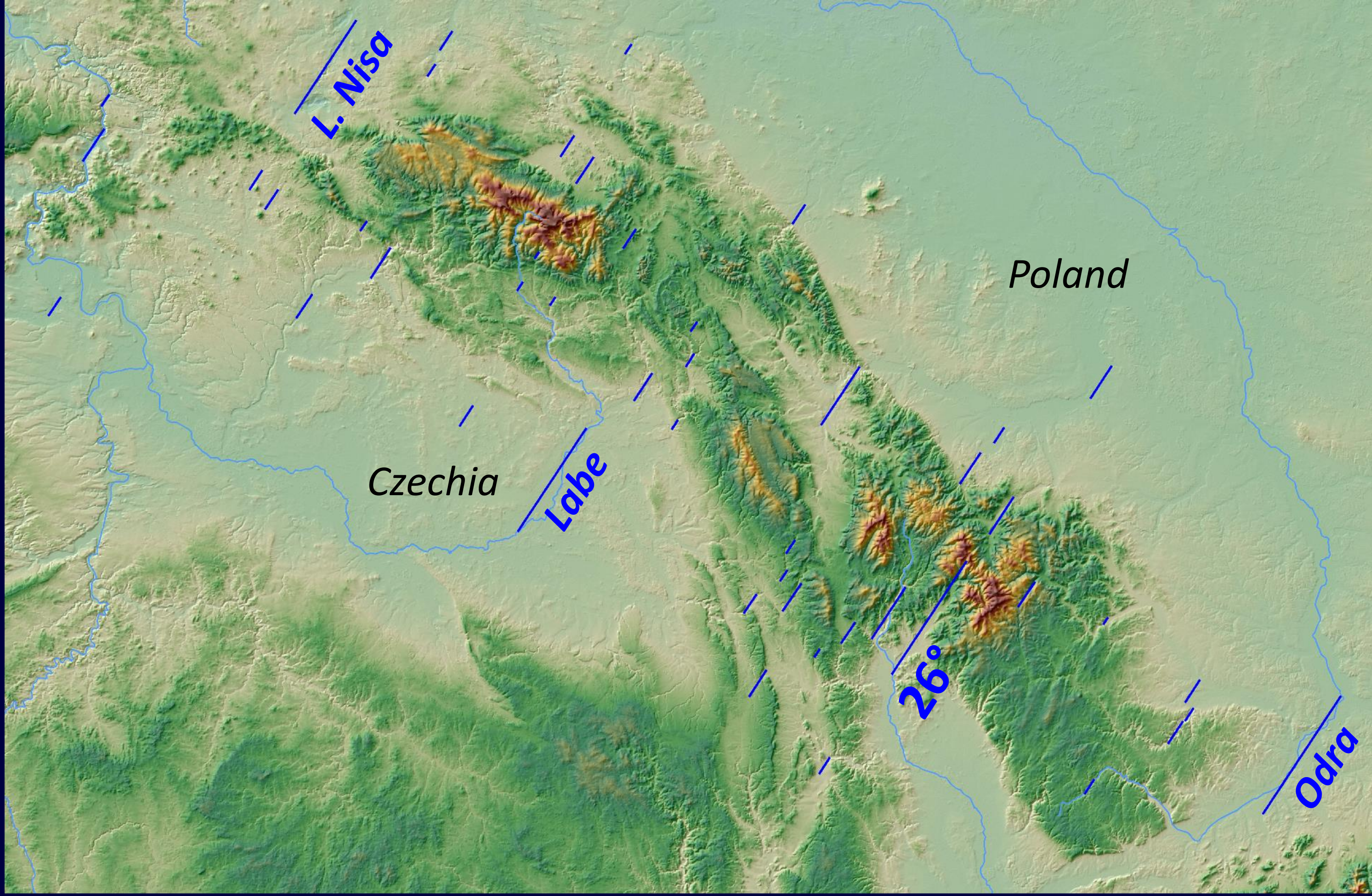
- Most of the water gap valley sections in the Bohemian Massif related to one of the 9 indicated main large-scale linear systems

Reversal of Kyjovka River trending into water gap across mountain range

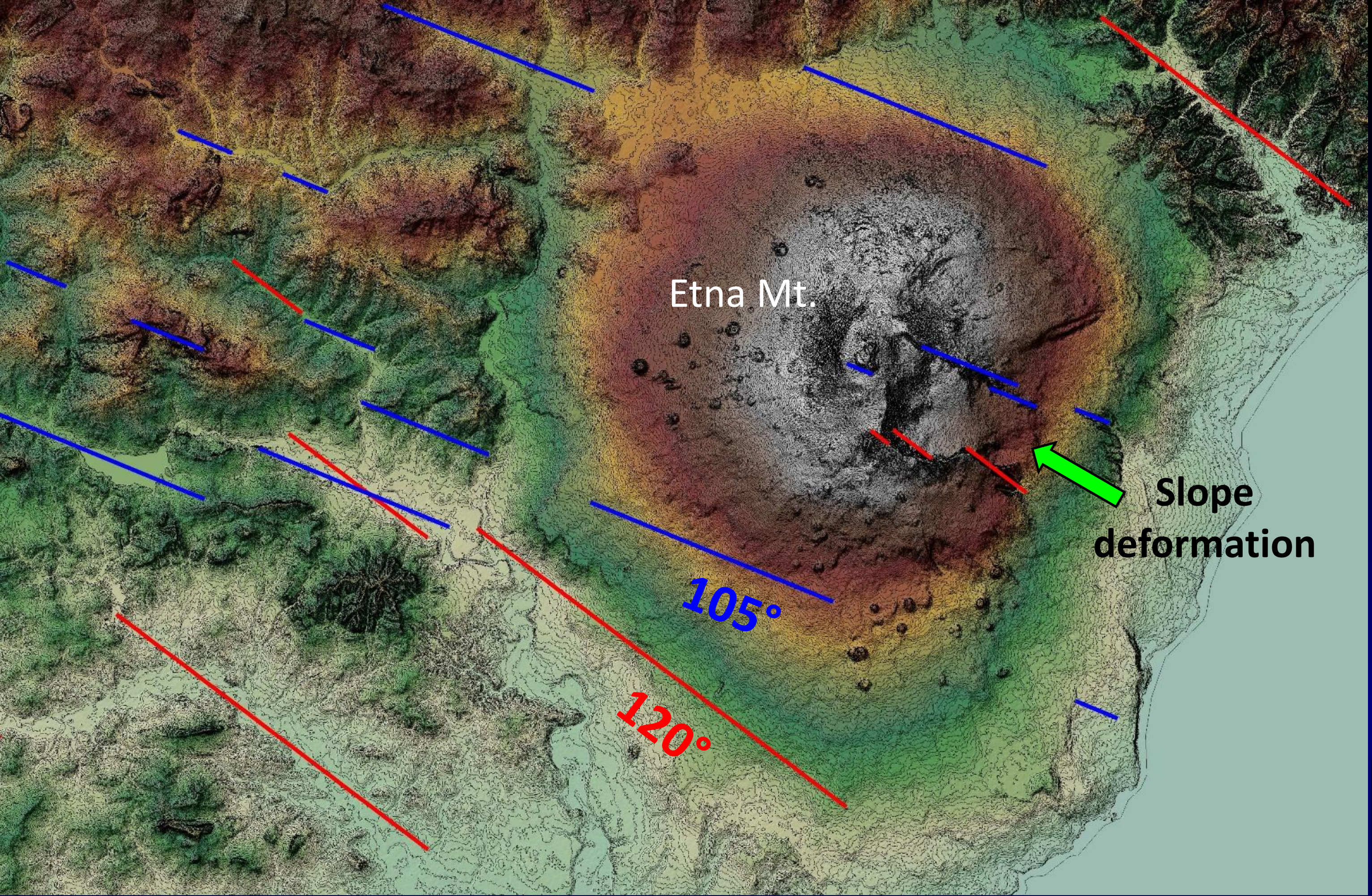


Consistent N27°E trend of numerous headwater valley sections within Sudetic marginal slope



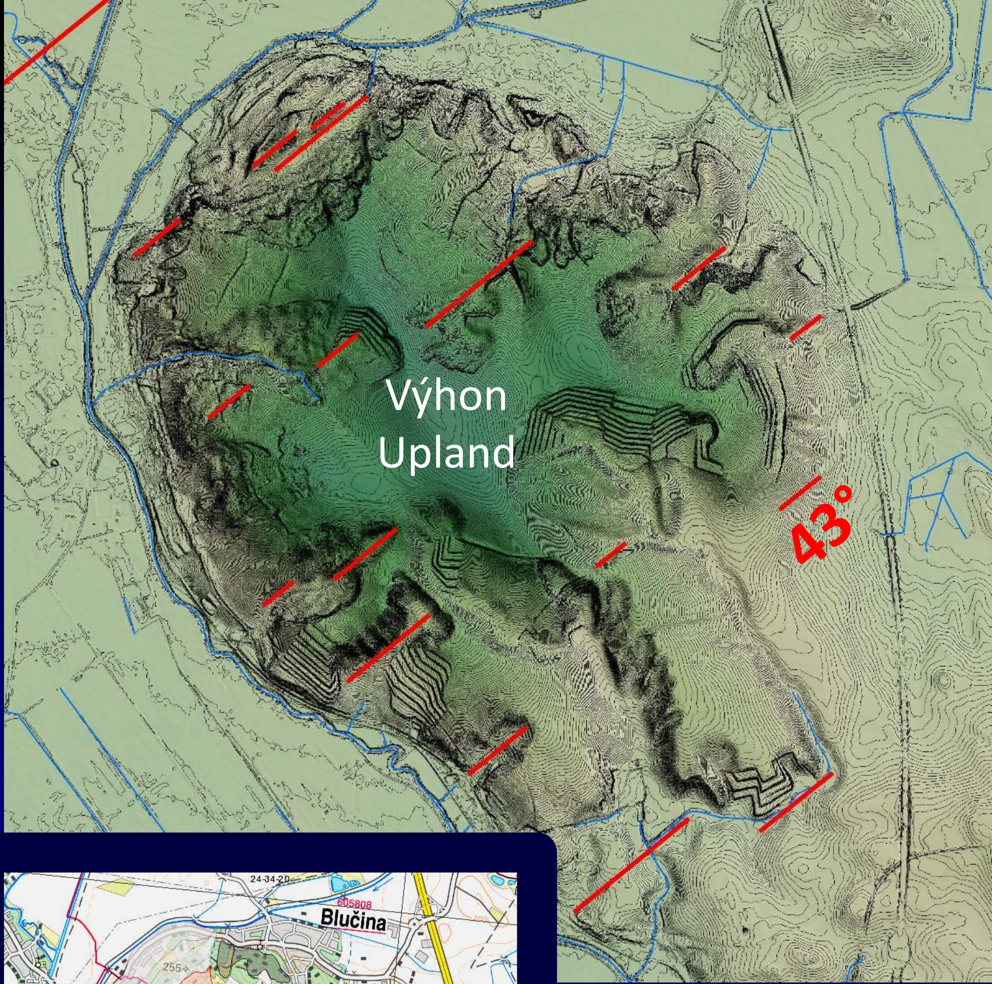


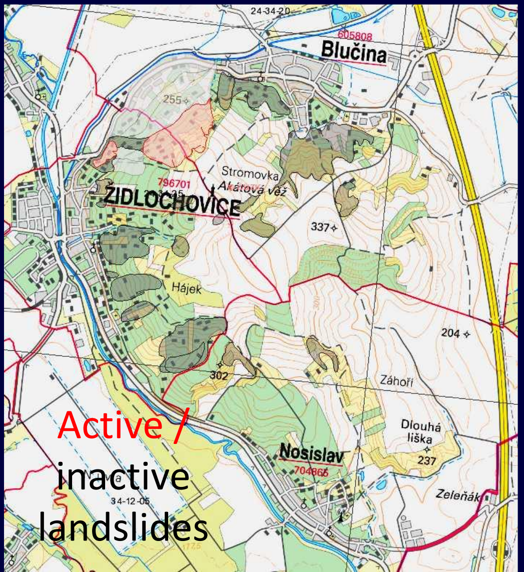
Common N27°E general trend of significant valleys in and close to Sudetes Mts. (Czechia / Poland)



Large slope deformation on eastern flank of volcanic Etna Mt., Sicily (Italy), limited by lines of two strikes consistent with surrounding lineament pattern

Consistent pattern of depressions, mostly with or within landslide areas, on small elevation in Carpathian Foredeep (Czechia)



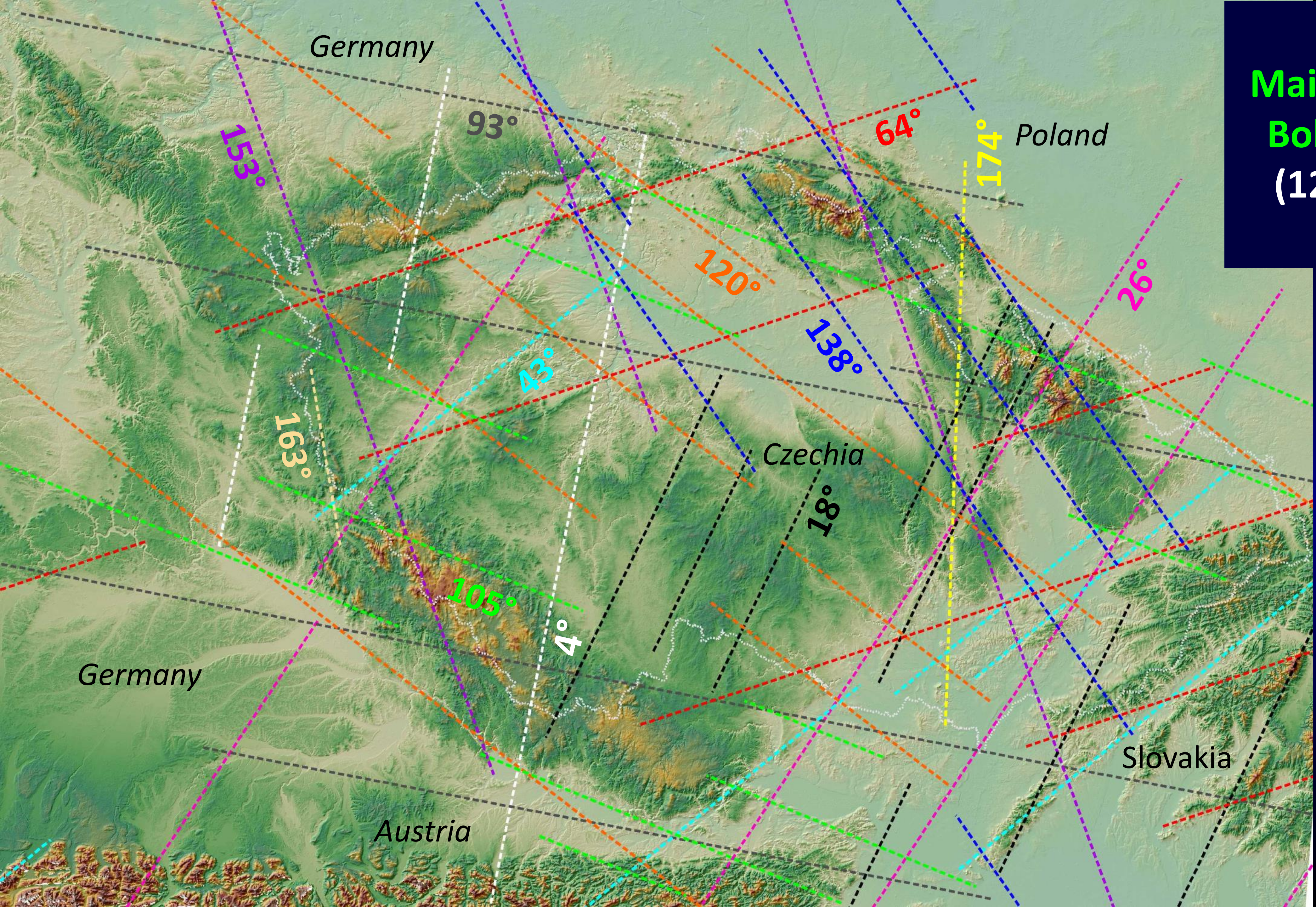


Výhon Upland, middle Miocene clastic area in NE continuation of Diendorf fault

Discussion

The European landscape seems to be dependent on linear regularity.

- Enormous influence of fairly consistent linear systems on landscape (near-surface) geometry occurs in this territory.
- Their dispersed and zone patterns continuously penetrate large parts of the whole area, regardless highland, lowland or plateau topography.
- While somewhere clear correspondence of topographic lines to lithological boundaries exist, elsewhere lineaments run across them.
- Associated features of various size have developed, from metres to a few hundred kilometres long.
- Previous famous focus on detection of orthogonal pair joint systems is in the European territory discussable – current knowledge does not support their dominant existence, conjugated oblique systems are more indicated.



Main lineaments in Bohemian Massif (12 main trends)

Additional 3 directions:

4° – Lhenice fault trend

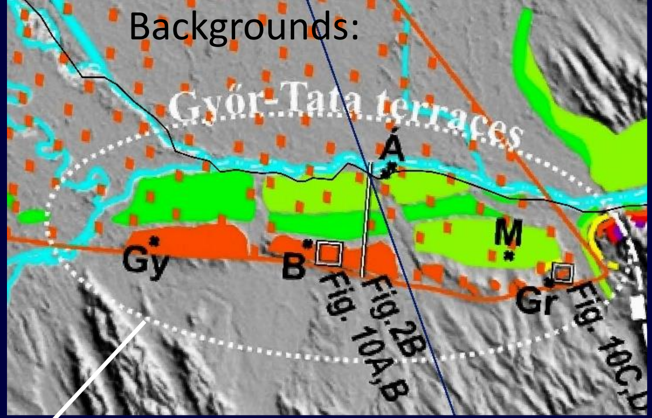
163° – Český les Mts. trend

174° – Blansko Graben or Hřebeč Ridge trend

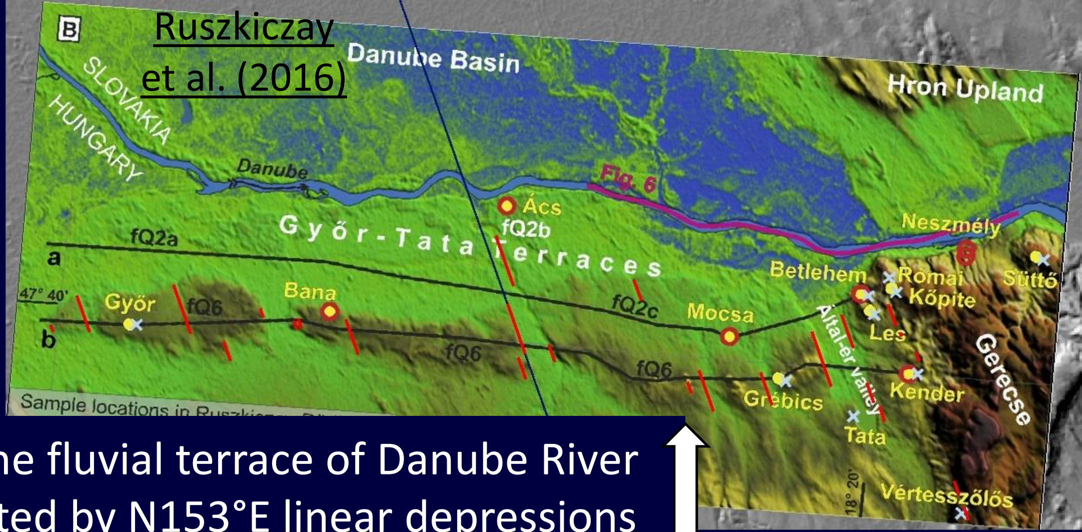
Significant reason for solving –

Disputable / incomplete previous interpretations

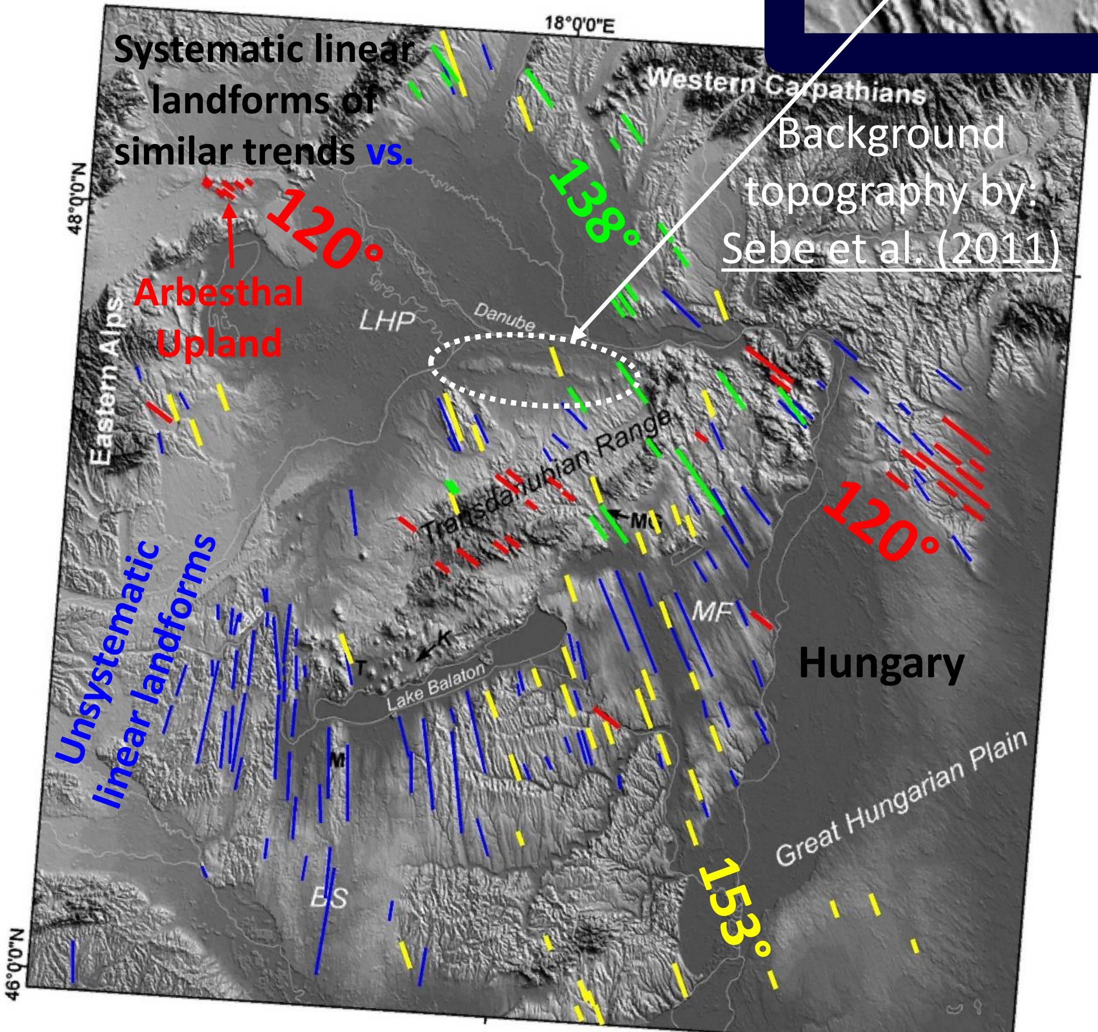
Backgrounds:

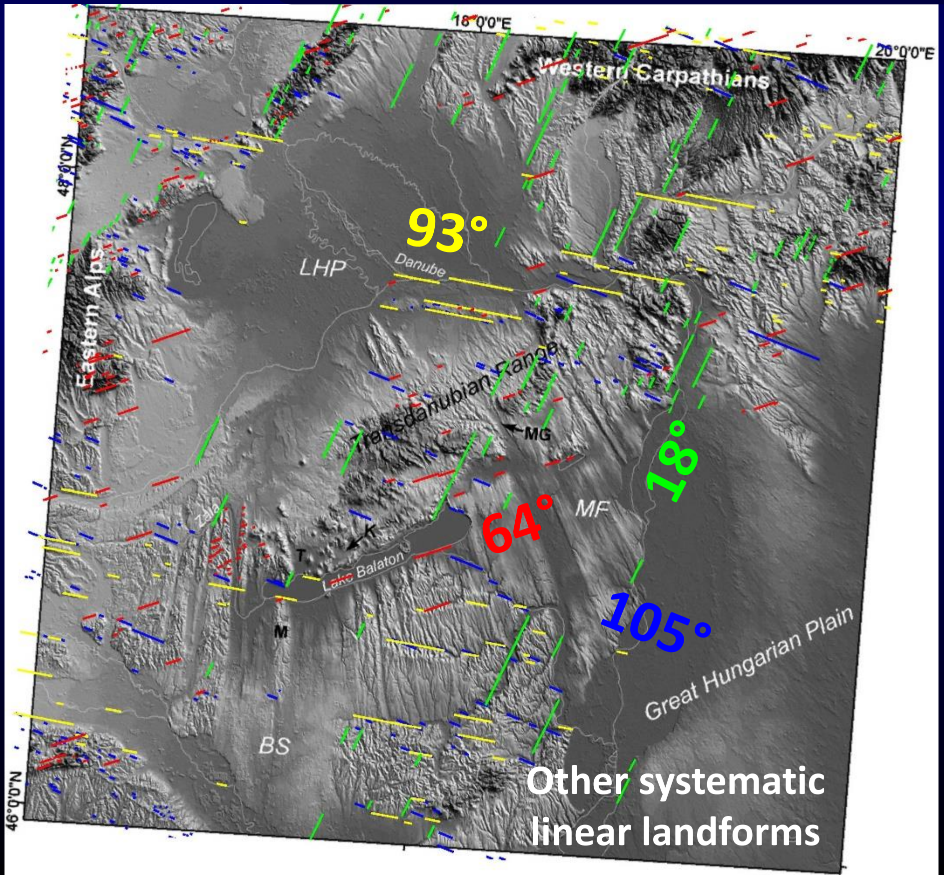


Ruszkiczay et al. (2016)



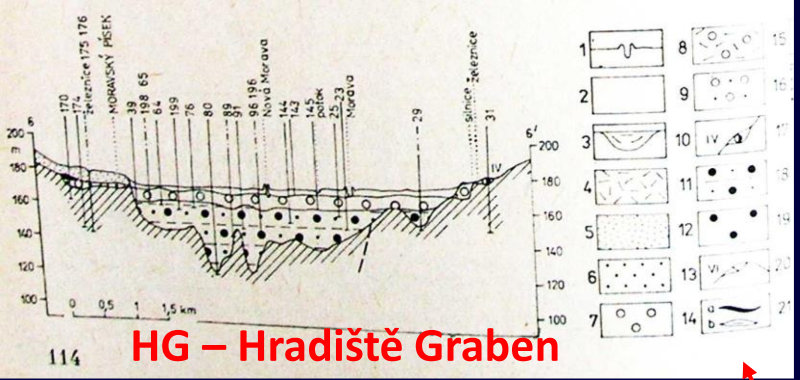
Early Pleistocene fluvial terrace of Danube River strongly dissected by N153°E linear depressions



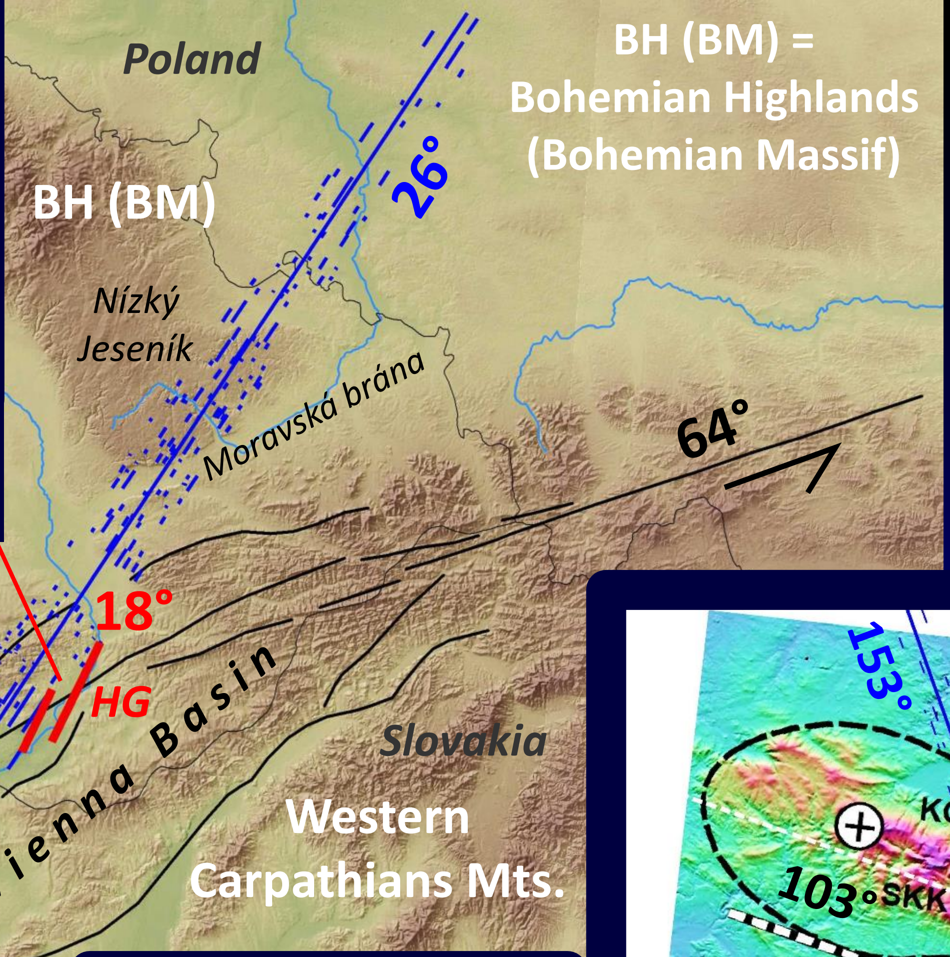


(1) **Pannonian Basin:**

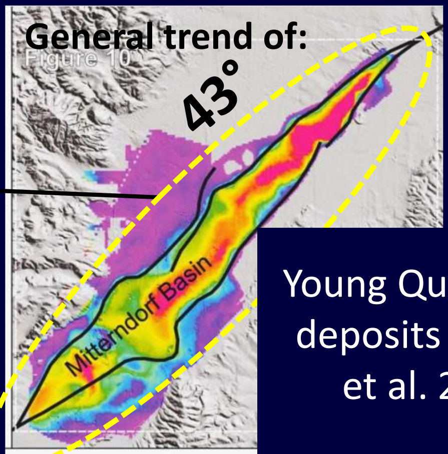
Exogenous (wind) vs. endogenous influence on current landscape (ridge / trough topography)



Young quaternary fluvial deposits in Hradiště Graben by Havlíček 1980)



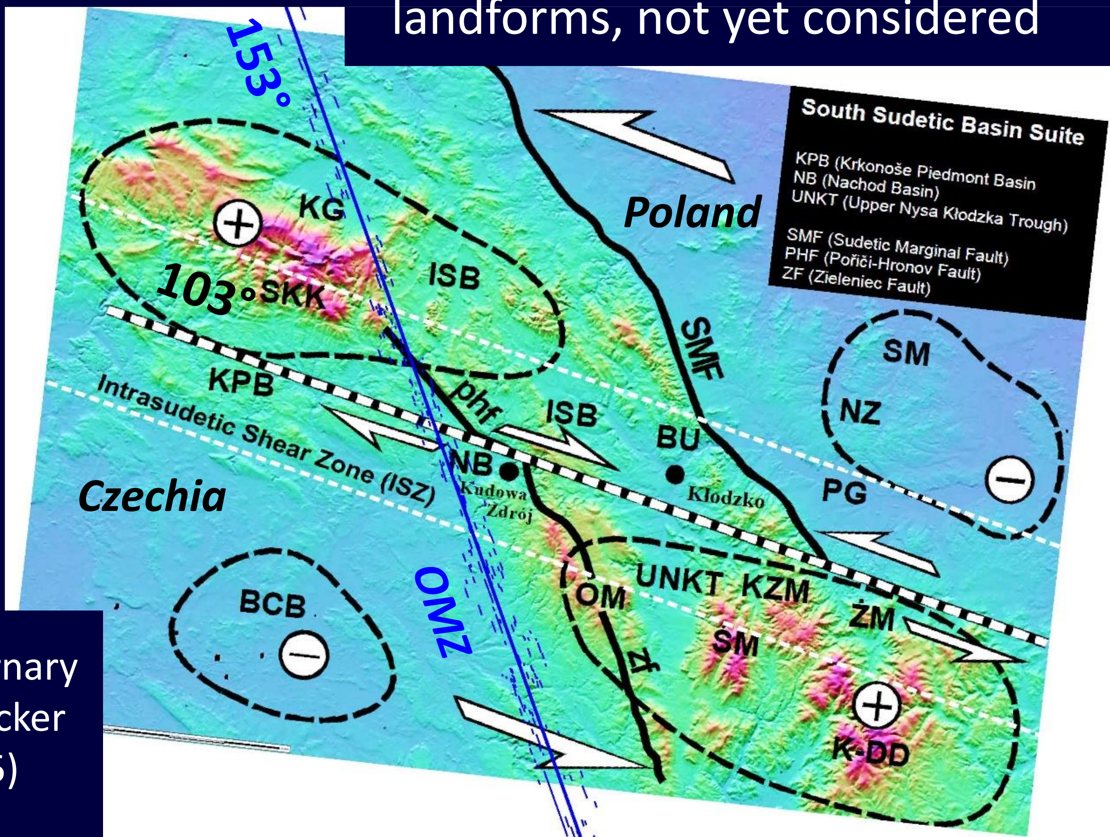
(2) Vienna Basin: yet poorly studied common elements of N19°E and N27°E trends within this pull-apart structure



Young Quaternary deposits (Decker et al. 2005)

(3) Location of hypothetical "**Intrasudetic Shear Zone**" and assumed young vertical movements of surrounding blocks by Wojewoda (2007)

vs. occurrence of transverse **Orlické Mts. marginal zone** consisting of numerous linear landforms, not yet considered

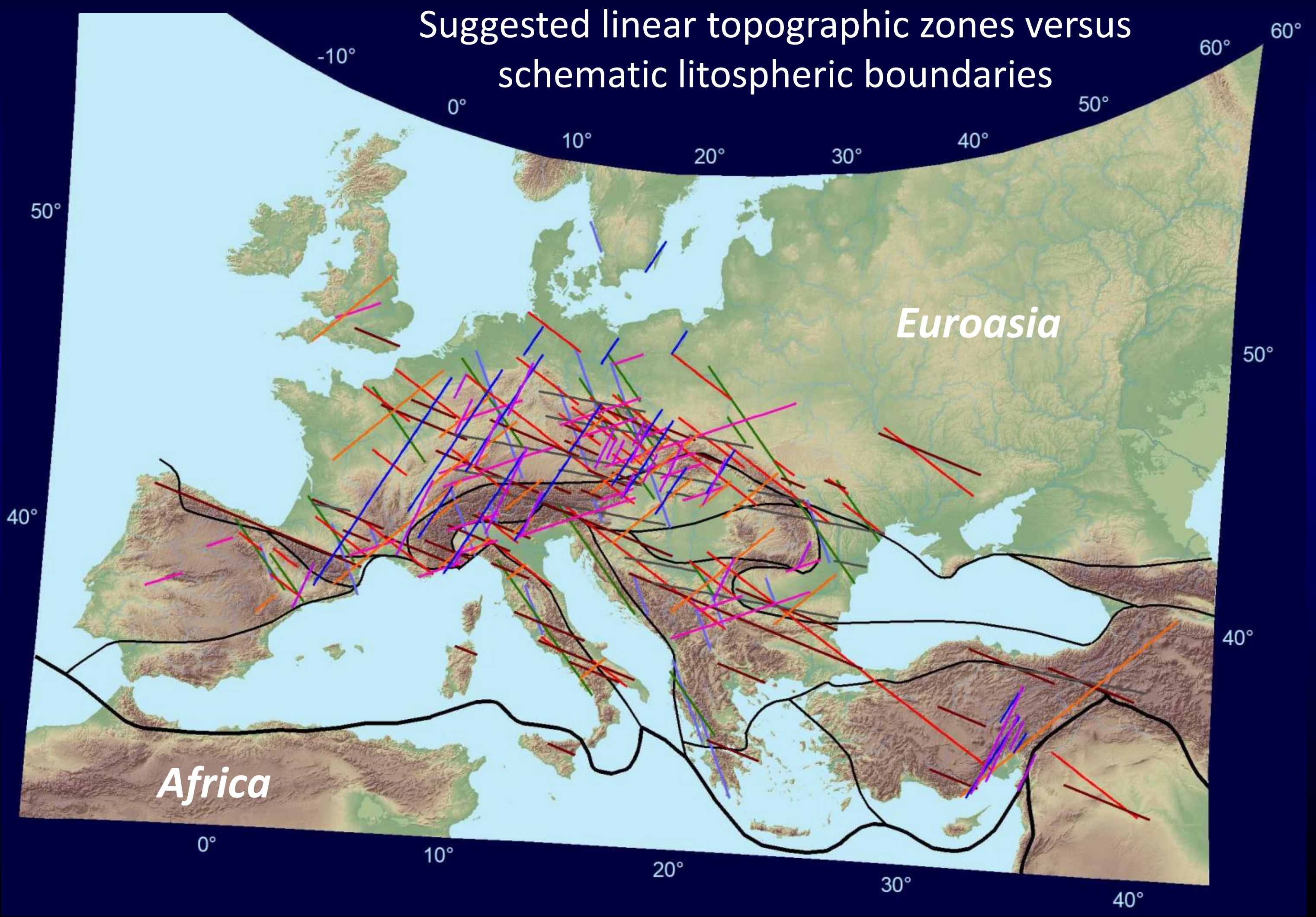


Call for debate

Presumably, various subjects related to linear systems have been yet addressed insufficiently. For instance:

- **Associated phenomena in the deeper crust** (and upper mantle)?
- **Relations to plate-tectonics components** (e.g., subduction zones, deformation areas, rotated blocks, main fault zones, stress fields)?

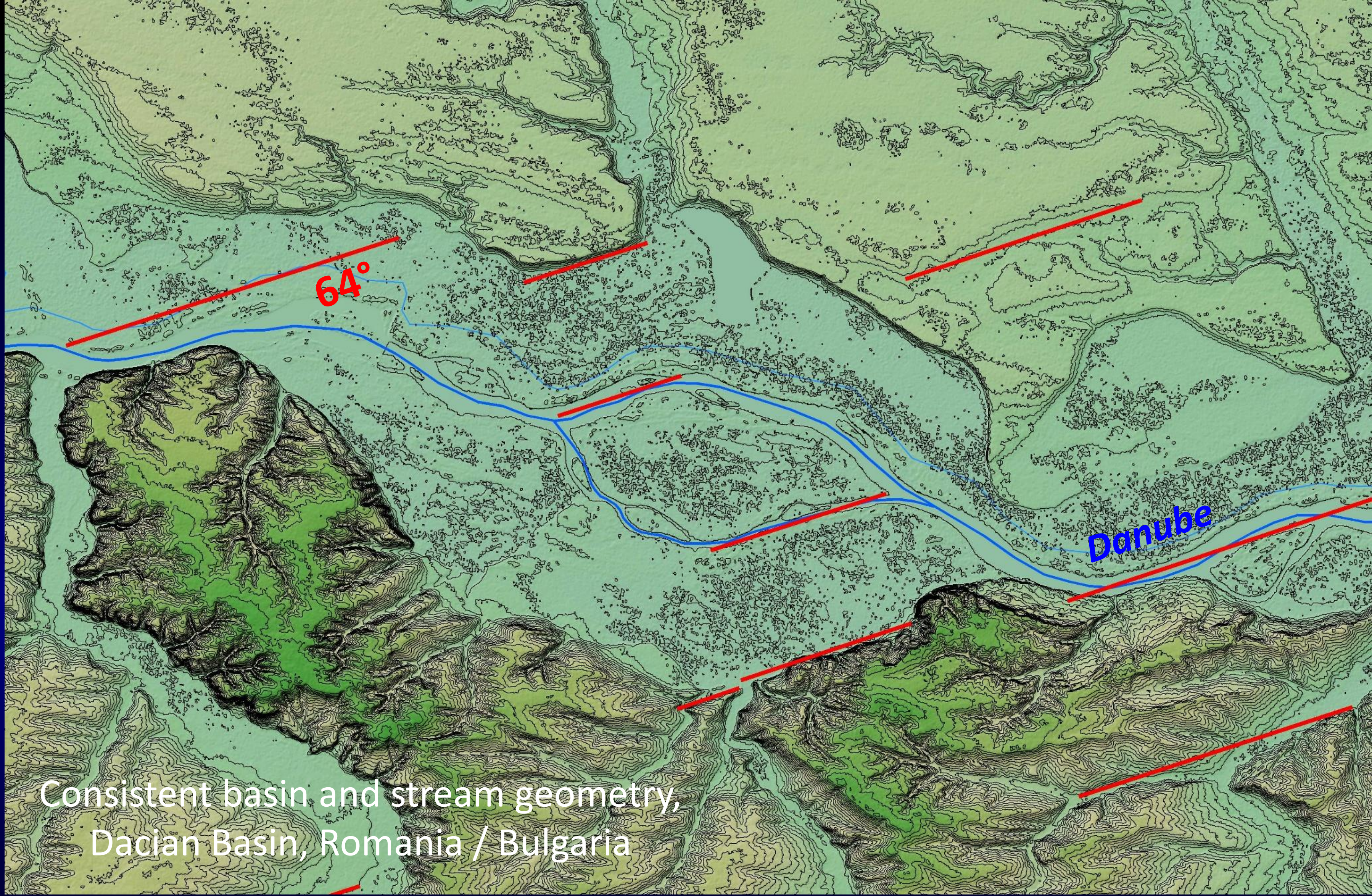
… and many others …



- Structural manifestation on surface (in outcrops)?
- Possible genetic mechanisms and development (reactivation phases) of particular linear fields?
- Do similar linear trends occurring in the mutually distant areas support analogous evolutionary stage(s) of particular structures?
- Conjugation of linear elements of two (or more) different trends?
- Differences in crust properties between areas densely linearly cross-cut and those withou abundant such features, where curved elements dominate
- Reason of occurence of long, one-direction valleys in places where a number of different-trending elements are present in vicinity?

General questions:

- Influence of cartographic projection used on the final sets of lineaments?
- Possible quantification of some properties related to complex linear features?



Thank you for attention.

This commentary mostly involves supplementary information not incorporated in the extended presentation.

First slide, image: Numerous consistent transverse linear landforms crossing the elongated ridge in the Pannonian Basin, considered to represent mega-yardang formed by long-term Quaternary wind erosion (subparallel streaming).

Introduction

In recent geodynamic studies from central Europe, we have not found any note, application or reference to relevant work concerning the presented systems of regularly distributed linear features on the land surface or in the uppermost crust. We call for information about any works considering such phenomena from the EGU General Assembly attendees.

Approach: previous versus currently presented

Input elevation data used for our current research came from the SRTM or LIDAR elevation models as well. In resulting empirical directional sets of linear features, stream and valley-related elements dominated, whereas slope-related elements were quite common and ridge-related elements scarce. The detection and drawing of lines has not been uniform for the whole area shown – primarily, the presentation should be illustrative.

Similarly N120°E oriented systems of meandering valleys occur across large part of Europe from the west to the east for a few thousand of kilometres.

En échelon patterns contain lineaments of various mutual distance, which influence final geometry of their systems.

Only simplified illustrations of block segmentation with dominating trends are presented; usually, lines of more directions influence this phenomenon at particular places.

During extraction of lines, a lot of inaccuracy, simplification or generalisation were used, for instance:

– approximate location and strike (not consistent procedure in the whole area used in a few years lasting process);

– primary searching for and drawing of elements of given trend (intended ignorance other close directions);

– merging of distinct consistent lines over areas of subsidiary ones of different trend ar without lineaments;

– ignorance of more possibilities of drawing – random selection of only one (e.g. delineation of flat-bottom straight valley by right marginal slope foot, left marginal slope foot, its axis or combination of more of these);

– much more accentuated similar problem (inaccuracy) exists at linear representation of meandering valley or stream sections;

– variable degree of substitution of undulating or angular piedmonts by lines (piedmont settings variously influenced by gentle transverse tectonics or dissected by eroding transverse streams).

Thus, many landforms are represented by lines of more directions and all of them do not need reflect real regular features in the crust. In spite of that, manual extraction procedure (if a number of elements is high enough) can distinguish linear trends differing by at least 3–5° and record linear landforms even about 2 m high (in dense contour image – based on the data used).

Results

Horn Basin: Consistently filled with erosional remnants of Oligocene clastic deposits.

N120°E system fairly corresponds to some of significant subparallel tectonic zones in Europe, including the Elbe fault system (Elbe Zone) or Tornquist-Teysseire Line (in original Late Paleozoic period rotated, as indicated by the corresponding illustration).

The Donau fault zone, as well as earlier South Wienerwald fault zone show examples of local linear adjustment of a number of rock belts within significant fault lithological boundaries (sometimes termed as "structural lineaments").

Orlické hory (Mts.) fault zone is the linear structure with the most densely concentrated linear landforms ever in the area investigated; it separates two domains of distinctly different spatial patterns of rock bodies in the Bohemian Massif yet only poorly considered in geological literature.

Besides clear lithological boundaries between dissimilar crystalline complexes in the basement, a number of roughly linear limits exist also of cover rocks, stratigraphically of various age from the Late Paleozoic up to the Quaternary.

In the first case given (Brno reservoir area), remnants of deposits of three stratigraphic levels occur in the same graben-like structure within crystalline margin of the Bohemian Massif. The following three figures show a few linear margins of Pliocene to Late Quaternary fluvial accumulations on the surface of or at two basin systems within the Bohemian Massif. Have already been formulated ideas of origin of such sharp linear limits of quite young deposits, (surely occurring also at some other places in Europe)?

Within other linear systems-related landform configurations, there can commonly be seen influence of the same pairs (or even triplets) on the surface geometry. As a significant case, combination of N105°E and N120°E trends for a distance of about 4000 km is given in the 4 following figures. Of course, these trends occur together with some others. At the northern margin of the Po Basin (Italy), landforms of the strikes mentioned above are frequent also within glacial moraine terrains of several Alpine lakes. In eastern Anatolia (Turkey), a combination of three significant landform trends similar to that in the Alpine-Carpathian transition area has developed (but mostly in mountain terrain, instead of prevailing lowlands in the latter region).

At many places, it is possible to see adjustment of large structures to several linear trends. Besides significant faults zones, where this phenomenon is quite common, these include margins of large basins or mountain ranges – as exemplified.

The intensive (near-)surface block segmentation as a very frequent feature related to the linear systems is illustrated already at Approach (Methodology) section. In the two slides here, we show three cases of dominant one-direction surface fragmentation of three different trends. In most such areas, elements of more directions (even >5) have taken role in development of this characteristic surface configurations (segmentation).

Besides large-scale landscape elements, various types of small-scale features are related to linear phenomena; their given list is far from completeness. Water gap valley sections belong to one such type. The specific Kyjovka stream reverse its direction by 180° before crossing a belt of higher topography within the Carpathian Flysch Belt. Numerous headwater valley sections of streams within the NE marginal scarp of the Sudetes Mts. along the Sudetic Marginal fault, considered tectonically active even in the Late Pleistocene, are consistent with single trend. Many large streams in the surrounding mountain or lowland areas have created linear valleys of the same or counter direction.

Shape of slope deformations or their inner structure represent another type of manifestation of linear surface elements. Their orientation commonly fit to a wider regional linear pattern, as is indicated for the large slope deformation on the eastern flank of the Mount Etna composed of quite young rocks (Pleistocene volcanites). Similar situation seems to exist in case of the Výhon Upland with dominant linear trend corresponding to strike of the significant Diendorf fault towards the SW. In the young period, the latter fault has presumably been associated with development of large linear depression within the Carpathian foreland basin of the same orientation, whereas during the original period in the Late Paleozoic the Diendorf fault was connected with the structure of the Boskovice Graben.

Discussion

At the local scale, the suggested 9 widespread linear systems can be supplemented with linear systems of other trends, as is indicated by the illustrated main zone features in the Bohemian Massif (as starting geological unit of our investigation of the linear phenomena).

At the end of the presentation, we added three examples of disputable or incomplete interpretations of particular structures from the central European area, published in the earlier studies in geosciences, including those primarily focused on geodynamic evolution – which did not take into account the occurrence of ubiquitous linear features.

(1) Radial system of ridges and troughs ("corridors") up to 150 m high / deep in the western Pannonia Basin. Largely based on a scarcity of fault deformations interpreted from numerous reflection seismic profiles in the area, all those landforms in slightly consolidated sedimentary rocks have been primarily considered to originate by Pleistocene aeolian activity (exogenously by strong air-streams uniformly coming from the depressed Alpine-Carpathian transition area in the NW). Besides general surface geometry, numerous finds of ventifacts and wind-blown sand in leeward settings were taken as other main supporting phenomena of this hypothesis.

Our own preliminary study of the area indicated there dense occurrence of linear systems fitting well to those suggested in the surrounding European regions.

The extracted linear elements correspond either to some of ridges or troughs (3 systems) or are oriented transversely (at least 4 systems). So strong, not sufficiently accentuated influence of structural plan can play a significant role in shaping of the present-day landscape in spite of existing previous knowledge. The related another inconsistency is represented by uniform N153°E trend of depressions crossing the W–E elongated (presumably) Early Quaternary fluvial accumulation of the Danube River in the Danube Basin (northern Pannonia), quite differently from dominant N120°E trend of ridges and troughs in the Arbesthal Upland at SE margin of the Vienna Basin (also of supposed wind-activity origin); this dissimilarity cannot be explain by the earlier proposed hypothesis without incorporating long-term function of air-streams of two dissimilar directions.

(2) Geometric pattern versus evolutionary scenario of the Vienna Basin. The N64°E striking left-lateral driving faults to the SW and NE and conjugated elements of approximately N43°E trend within the basin interior are considered as the main components of this middle Miocene pull-apart basin, active also in the present time. Less were considered function of obliquely crossing zone of N27°E trending elements or numerous N19°E striking features (e.g., Hradiště Graben) in development of the significant central European basin structure. What is its full extent – Does it include also easternmost outcrop part of the Bohemian Massif?

(3) Proposed "Intrasudetic Shear Zone" (NE Bohemian Massif; linear trend approximately of N103°E) versus significant Orlické hory (Mts.) fault zone (yet not properly considered) crossing the former zone structure. Thus, can be the suggested young vertical block differentiation of the Sudetes Mts. area in the existing model taken as believable?

Call for debate

It is not clear yet why just the S-JTSK projection used for drawing and displaying the lines indicates the presented large-scale linearity phenomenon in the whole study area (and not only for the Czech and Slovak territories it is fitting to).

In case of their real existence, a spectrum of important questions related to the widespread linear landscape systems can be enlarged much more than given (affinitive to various geoscience disciplines).

Last slide, two images: Other two unique landform linear configurations. Left: chaining of differently wide incised meander belts of the same stream. Right: correspondence of the Danube River branching in alluvial plain with to shape of the valley floor rimmed with two parallel steep scarps along both its sides. We met a number of many additional specific landscape patterns during our study.

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