



The shape of the Variscan Belt in Central Europe: Strike-slip tectonics versus oroclinal bending

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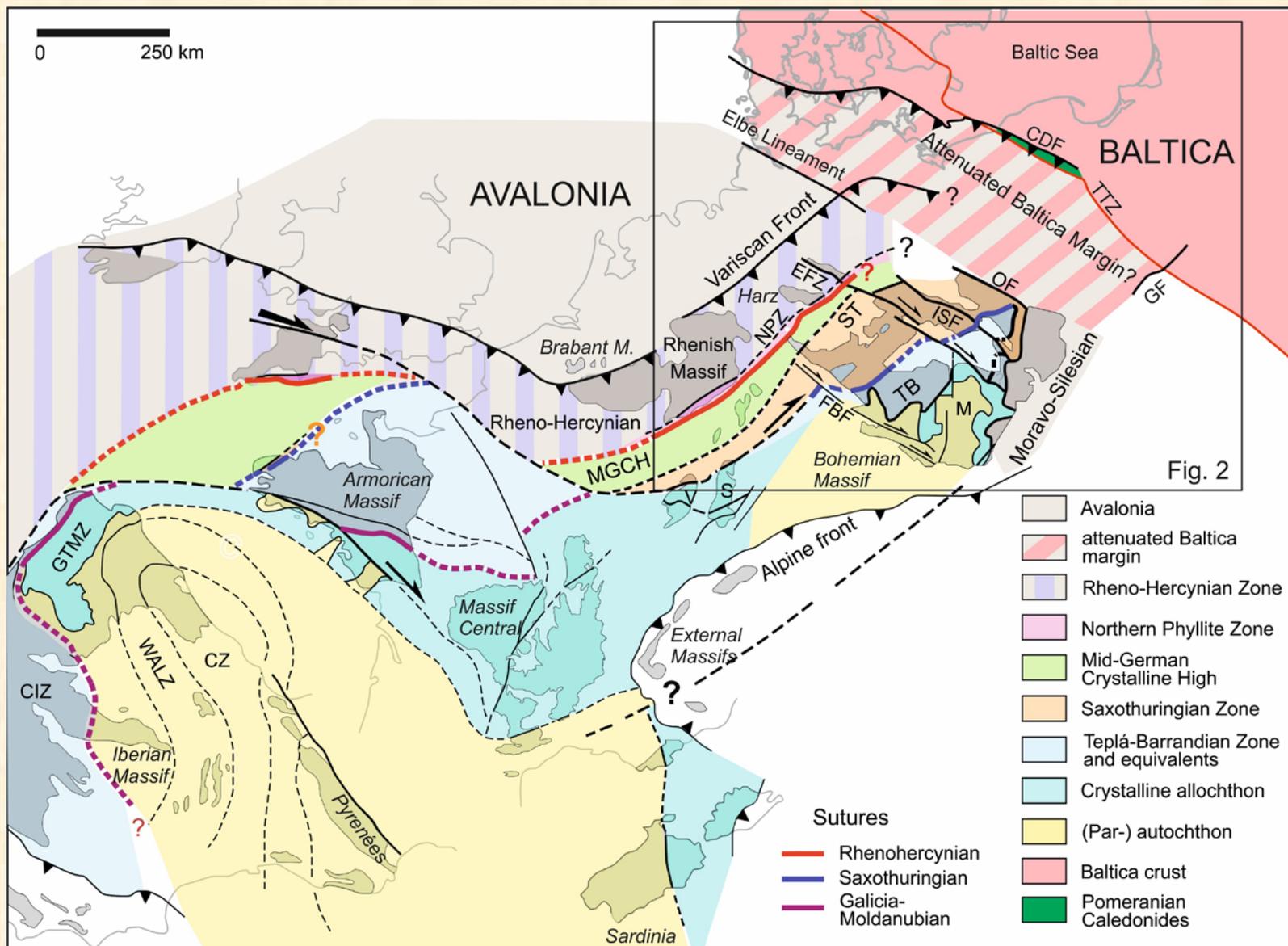
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Objective

In this study, we investigate directions and continuity of structural trends in the external zones of the Variscan orogen in Poland and map a foreland extent of Variscan deformations using seismic, gravimetric-magnetic and borehole data. These permit us testing the orocline- vs strike-slip concepts and develop an overall kinematic model for the NE Variscides.

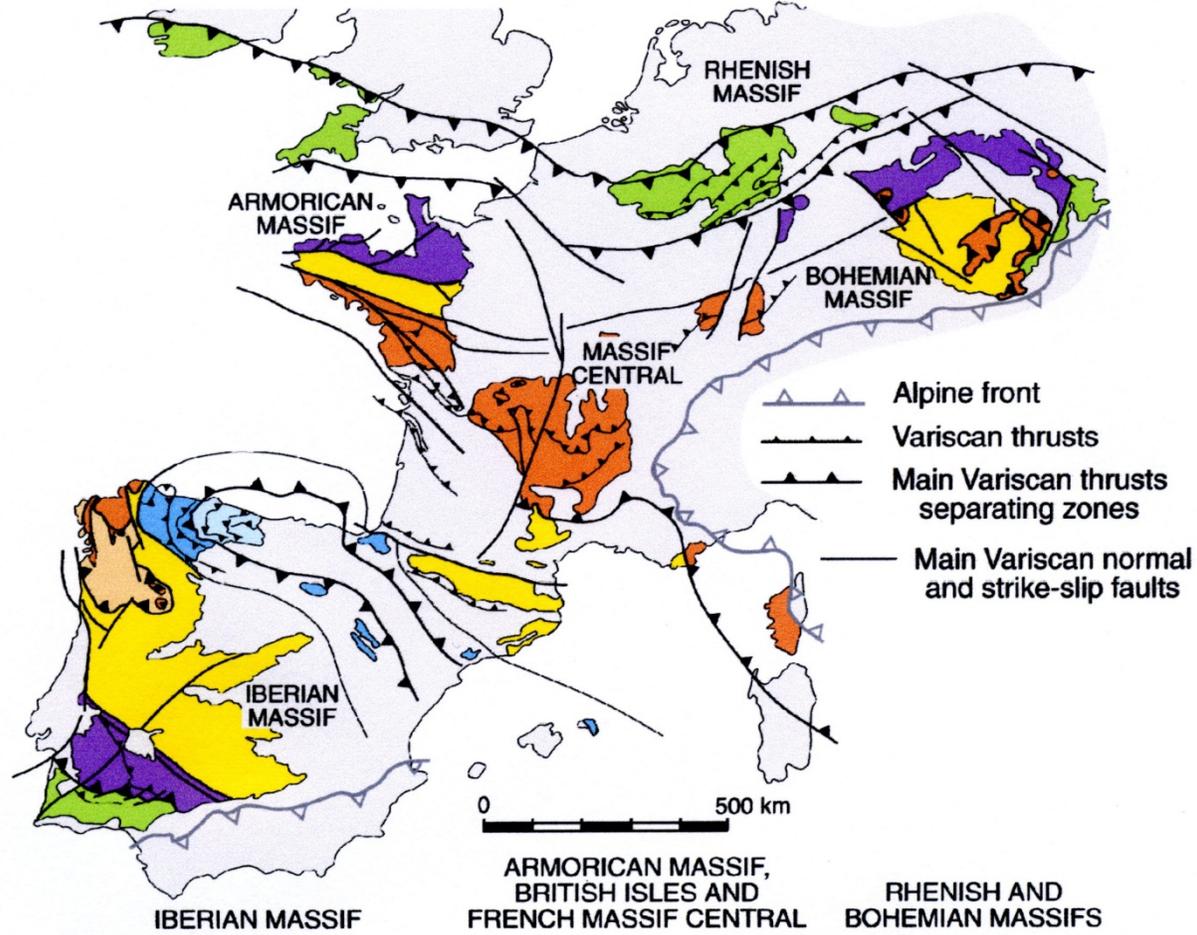


European Variscan belt with palinspastic restoration of Iberia prior to the opening of the Bay of Biscay. Modified from various sources including Martinez Catalan (2011) and Franke (2014). CZ – Spanish Central Zone; CIZ – Central Iberian Zone; EFZ – Elbe Fault Zone; GTMZ – Galicia-Tras os Montes Zone; ISF – Intra-Sudetic Fault Zone; M – Moldanubian Zone; NPZ – Northern Phyllite Zone; OF – Odra Fault Zone; S – Schwarzwald; ST – Saxothuringian Zone; TB – Teplá-Barrandian Zone; V – Vosges.

Variscan orocline in Central Europe

The European Variscan belt sharply changes its trend in easternmost Germany and western Poland, where the ENE- to NE-striking structures are replaced by the ESE- to SE-trending ones. The structures of still another, NNE-SSW strike, take the lead, however, along the SE margin of the Bohemian Massif. The Variscan belt seems, thus, to make nearly a U-turn, encircling the Bohemian Massif from the north. This has been explained for almost a century by assuming a 180° oroclinal loop, in which the Rhenohercynian and Saxothuringian tectonostratigraphic zones inarm the core of the Bohemian Massif. According to this classical view, the outermost tectonostratigraphic zone of the Variscan belt, the Rhenohercynian Zone, continues eastward in the deep substratum of the Permian-Mesozoic basin and reappears at the surface along the eastern rim of the Bohemian Massif.

Variscan orocline model for Central Europe

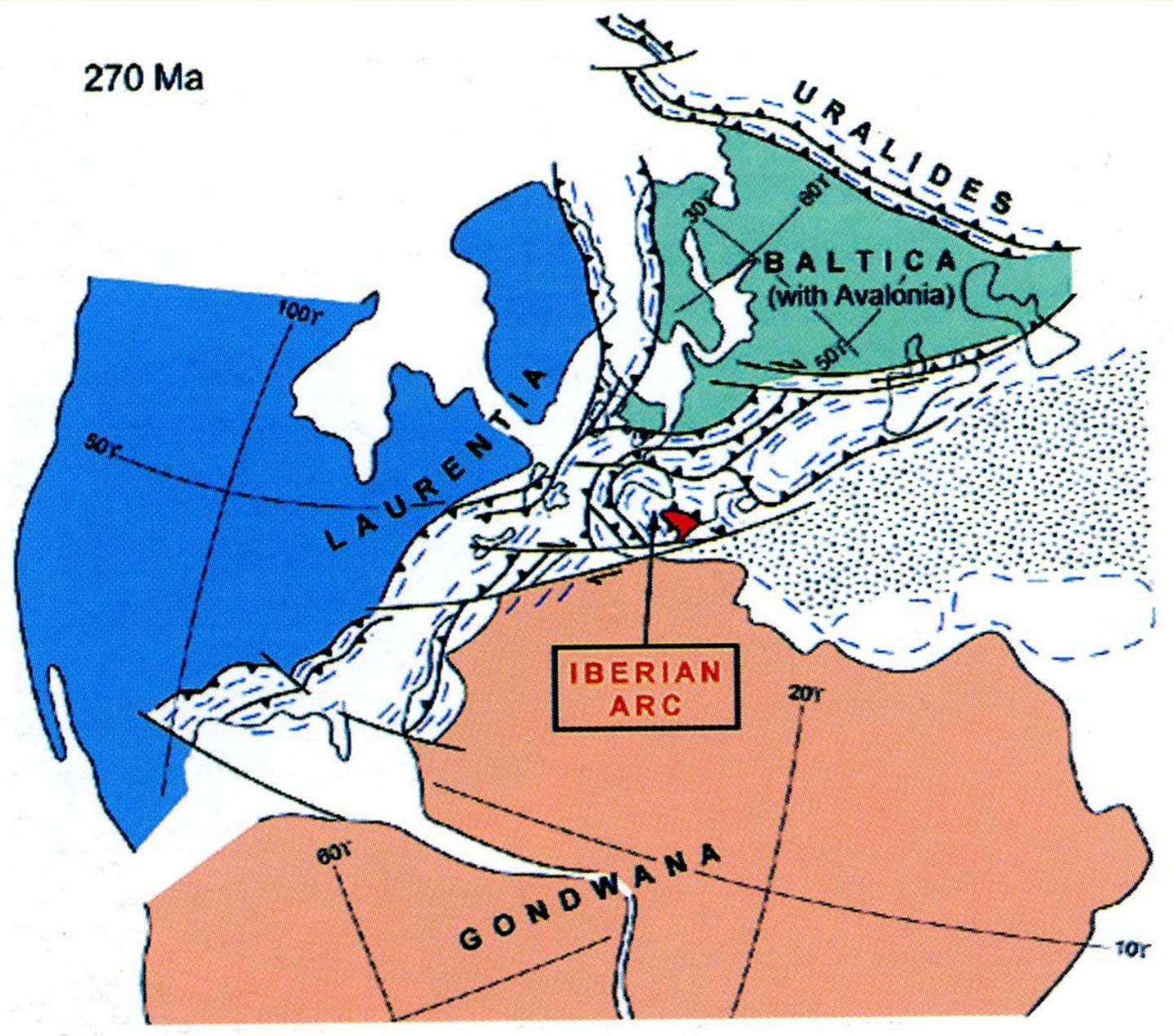


IBERIAN MASSIF			ARMORICAN MASSIF, BRITISH ISLES AND FRENCH MASSIF CENTRAL			RHENISH AND BOHEMIAN MASSIFS		
RELATIVE AUTOCHTHON:								
	Cantabrian Zone							
	West Asturian-Leonese Zone							
	Central Iberian Zone			Central Armorican Zone			Teplá-Barrandian Zone	
	Schistose domain of Galicia-Trás-os-Montes							
	Ossa-Morena Zone			North Armorican Zone			Saxothuringian Zone	
ALLOCHTHONOUS TERRANES:								
	Allochthonous complexes of Galicia-Trás-os-Montes			South Armorican and Arverno-Vosgian Zones			Gföhl, Erbendorf, Münchberg and Sowie Gory Massifs	
EXTERNAL THRUST BELT AND FOREDEEP BASIN:								
	South Portuguese Zone			Cornwall Zone			Rhenohercynian and Moravo-Silesian Zones	

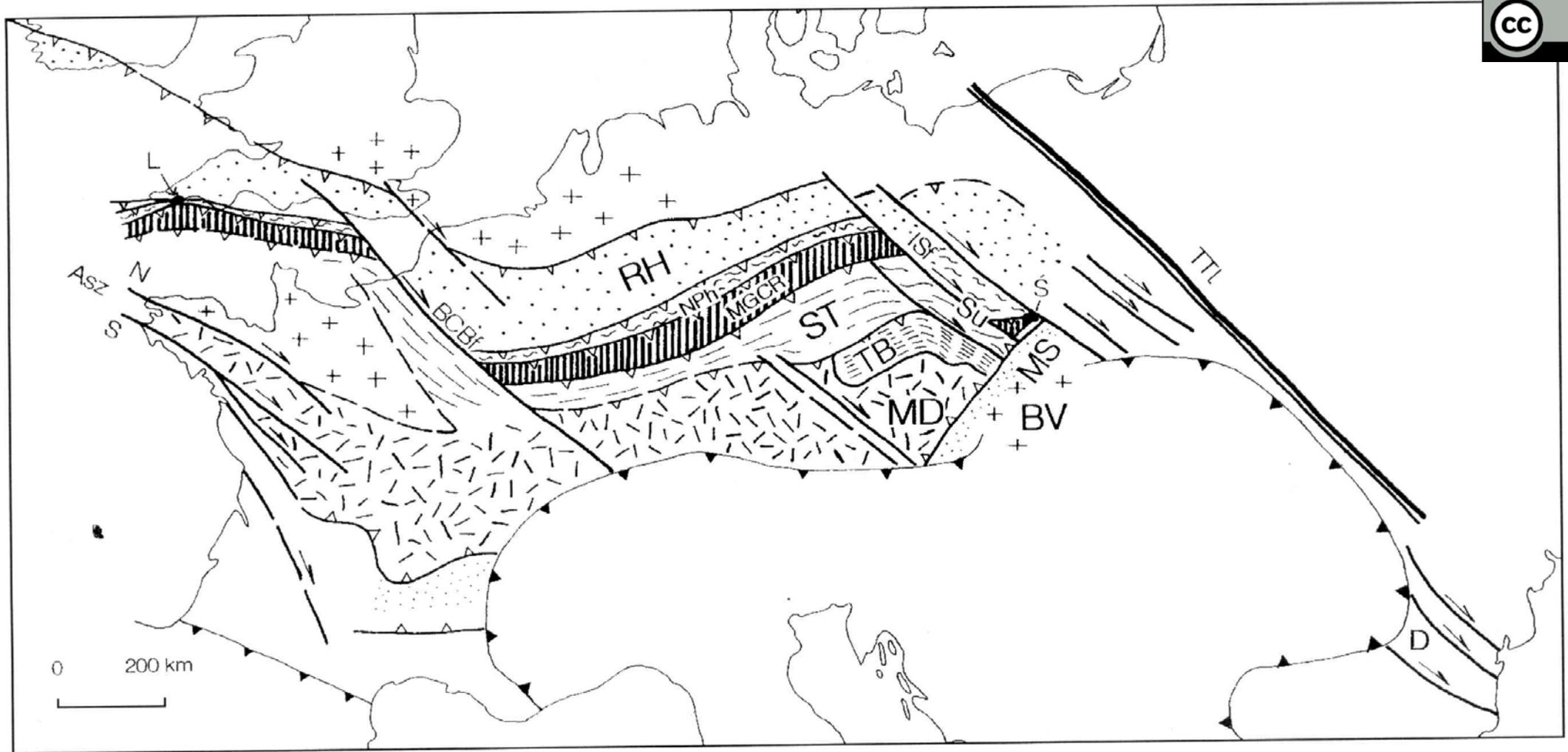
Strike-slip model

Since the late 1970s an alternative view has gained an increasing attention that postulates a dextral transpressional regime during the final accretion of the Variscan terranes. This transpressional tectonic context is believed to have resulted from sublatitudinal, right-lateral displacements between Gondwana and Laurussia. Near the Carboniferous-Permian boundary, Gondwana decoupled from the newly formed European Variscan belt and proceeded westward, toward the southern edge of the Laurentian segment of Laurussia, owing to the development of the Appalachian subduction system. Concomitantly with the peak of the Alleghanian orogeny during early Permian, the European Variscan belt experienced a crosscut of its major tectonic zones along a set of dextral strike-slip faults.

270 Ma



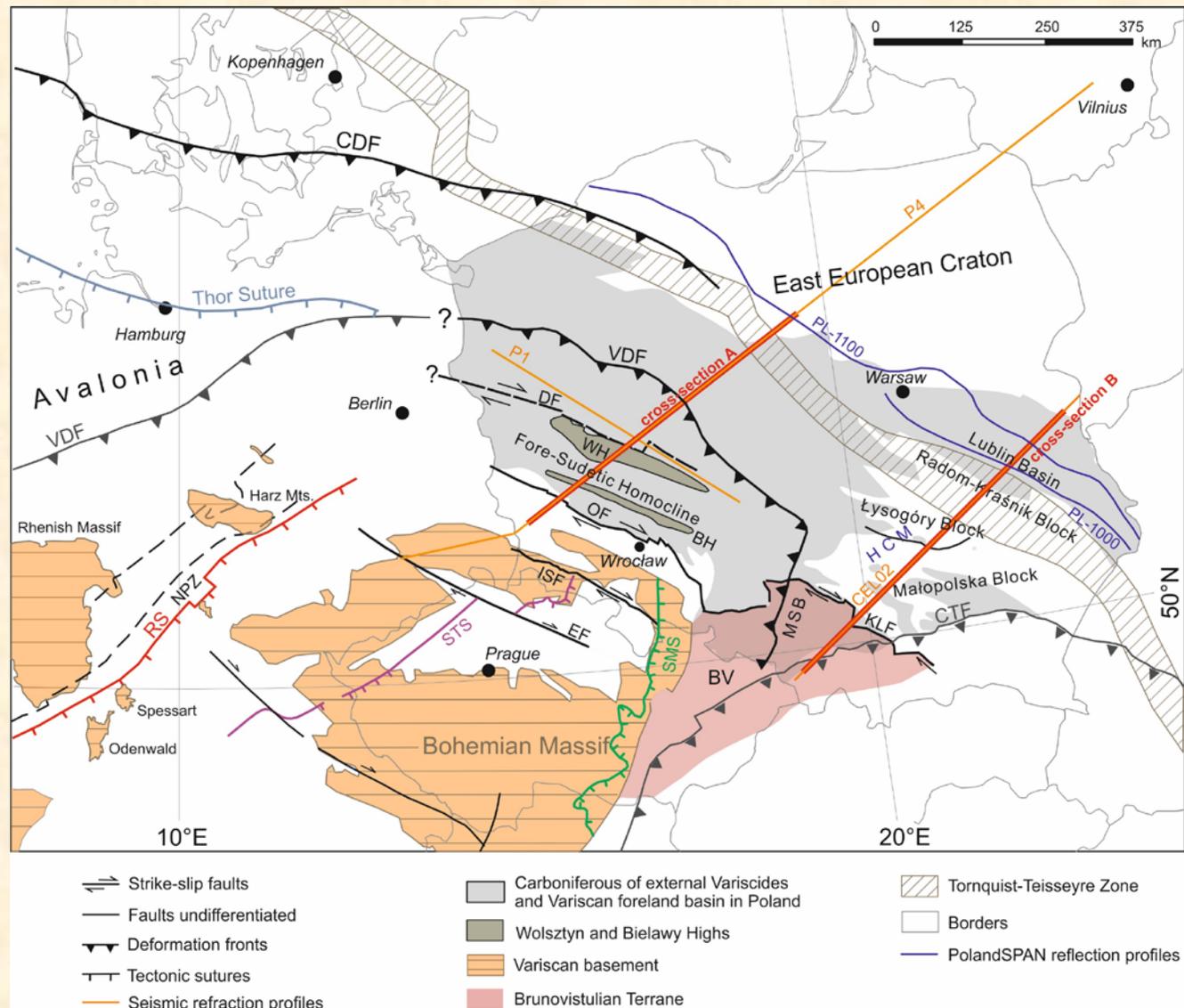
Dextral transpression regime between Gondwana and Laurussia



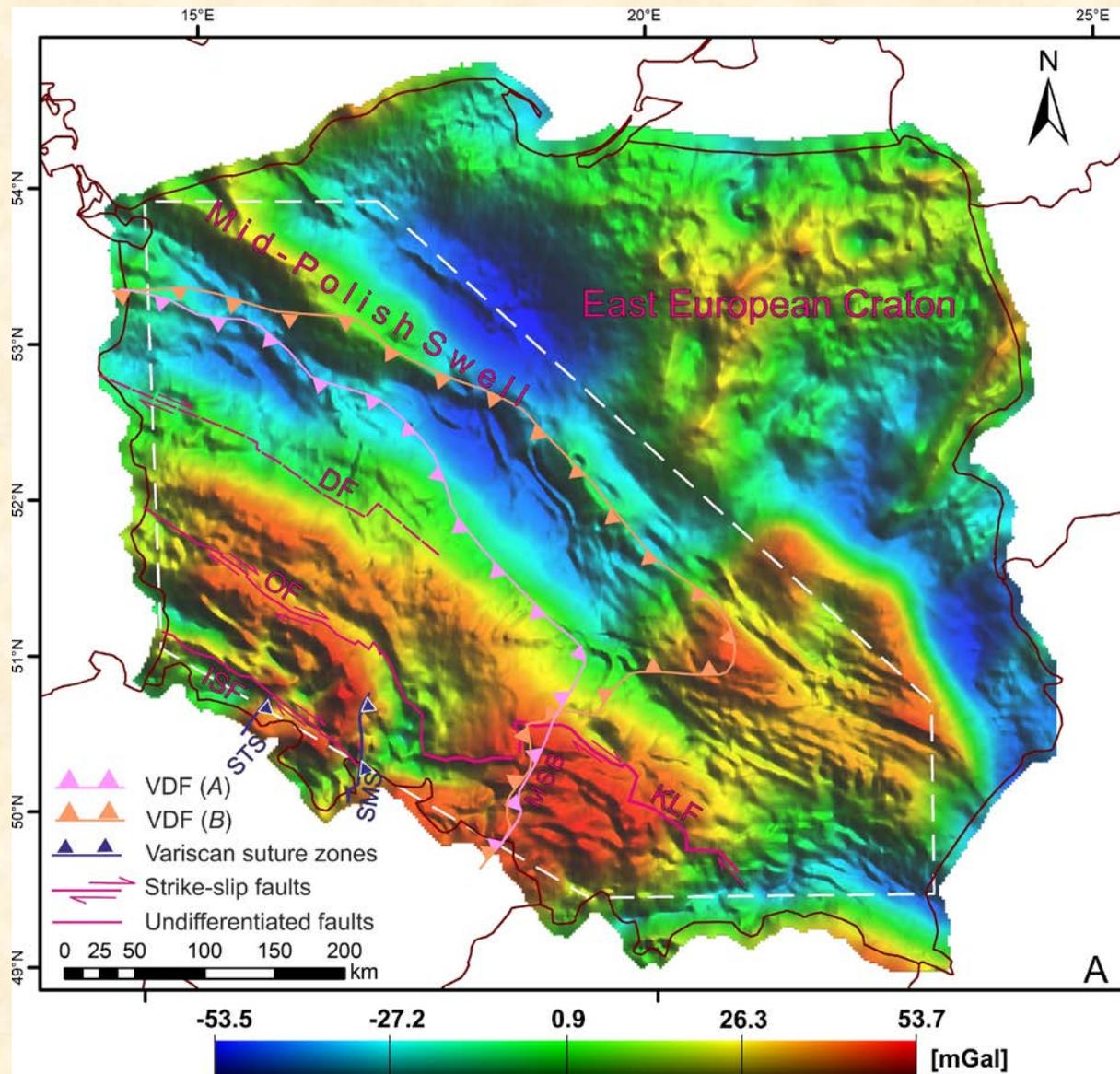
Strike-slip model for the eastern termination of the Variscides

Results

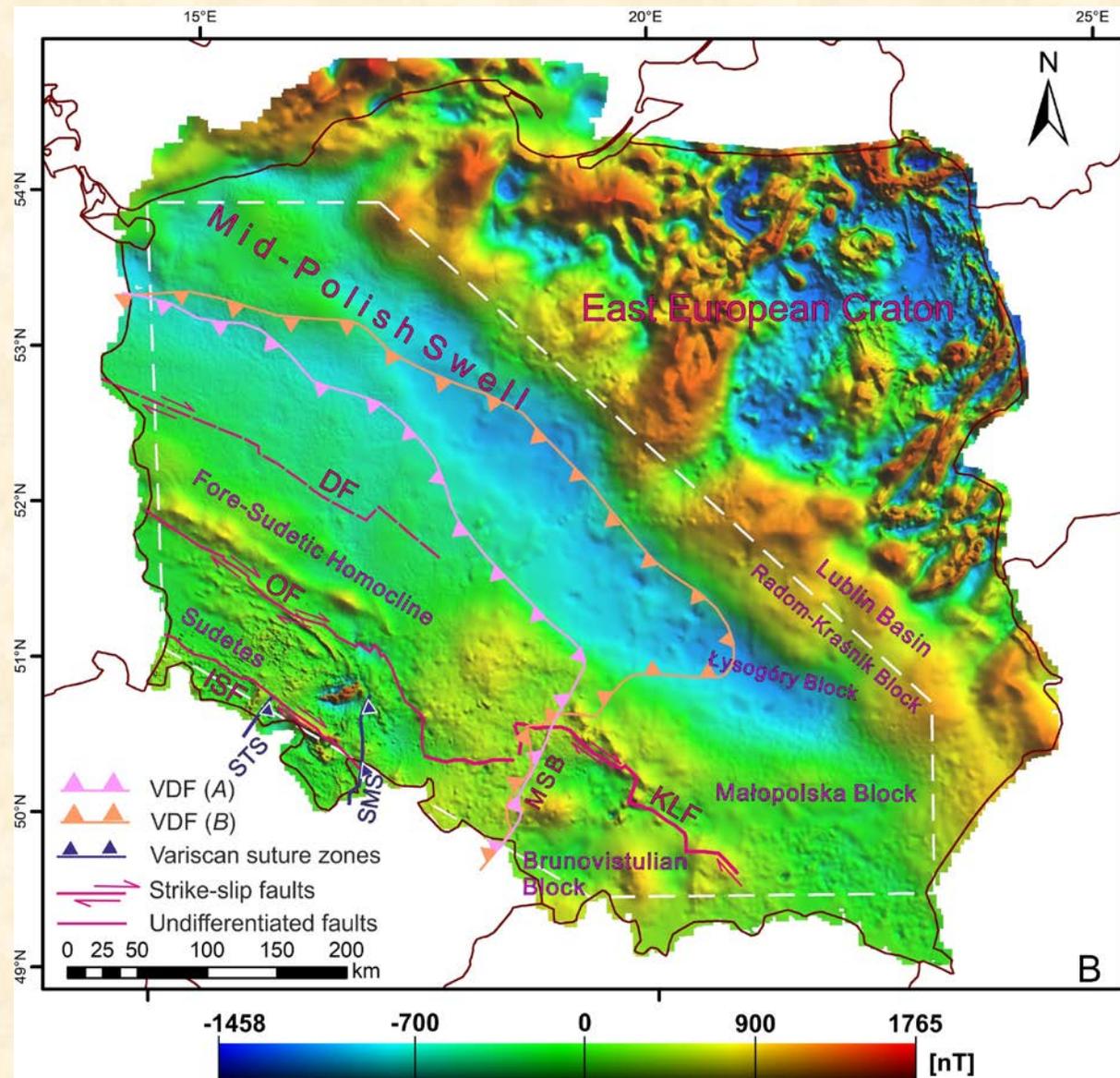
Matched filtering of isostatic gravity, guided by results of spectral analysis, along with other derivatives of gravity and magnetic fields reveal a dominant WNW-ESE-trending pre-Permian structural grain in the external zones of the Variscan belt in Poland. This trend is confirmed by regional distribution of dips in Carboniferous and Devonian strata that were penetrated by boreholes beneath Permian-Mesozoic sediments. Seismic constraints on the position of the Variscan deformation front come from (1) the GRUNDY 2003 seismic experiment, combining wide-angle reflection-refraction measurements with the near-vertical reflection seismics in central Poland and (2) PolandSPAN and POLCRUST-01 deep reflection profiles in SE Poland.



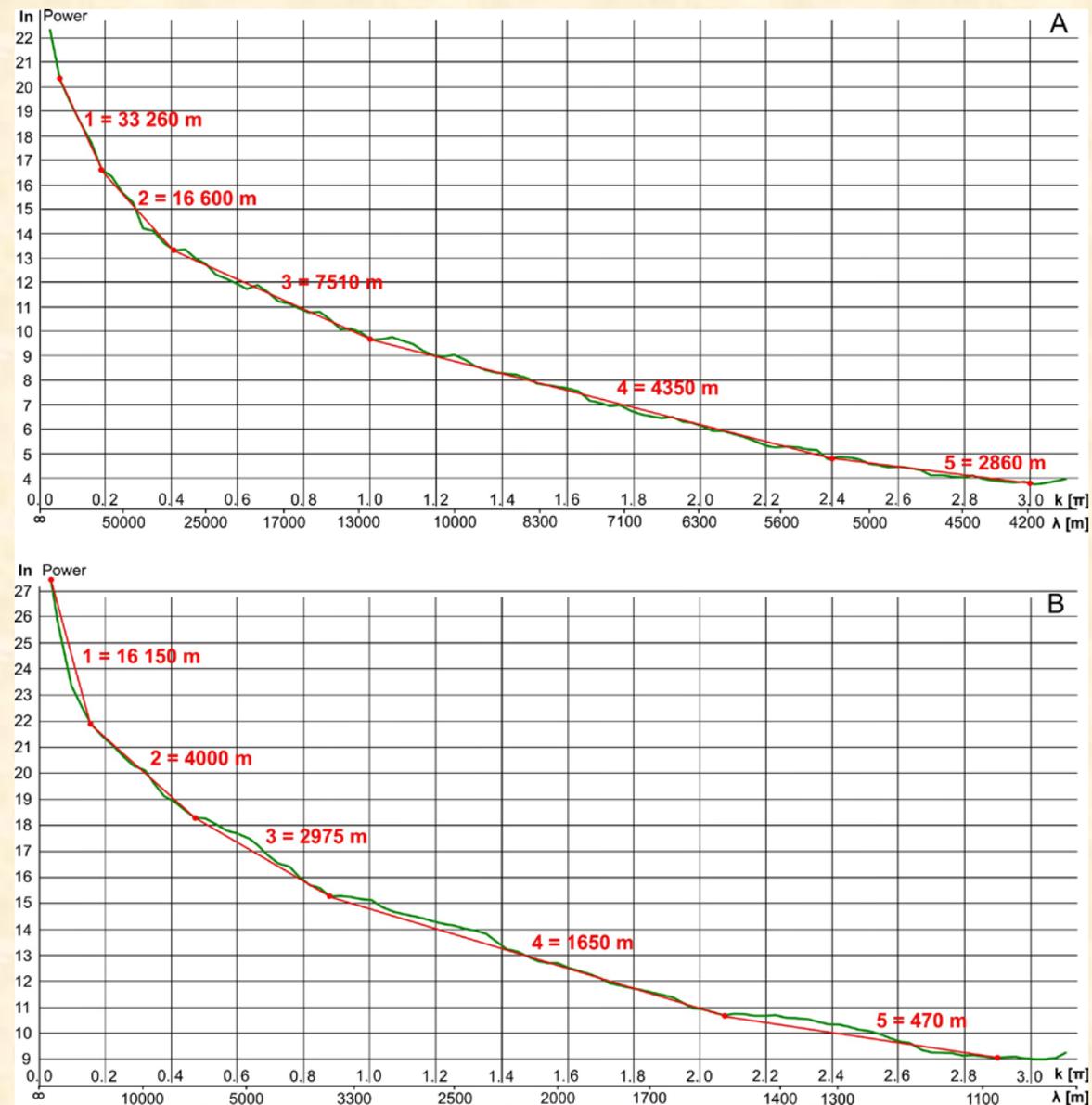
Simplified tectonic map of Central Europe showing tectonic sutures and strike-slip faults. Base map modified from several sources including Franke et al. (1995), Pharaoh (1999) and Banka et al. (2002). BH – Bielawy High; BV – Brunovistulian terrane; CDF – Caledonian deformation front; CTF – Carpathian thrust front; DF – Dolsk Fault; EF – Upper Elbe Fault; HCT – Holy Cross Thrust; ISF – Intra-Sudetic Fault; KLF – Kraków-Lubliniec fault; MSB – Moravo-Silesian Belt; NPZ – Northern Phyllite Zone; OF – Odra Fault; RS- Rhenohercynian Suture; SMS – Staré Město (Moravian) Suture; STS – Saxothuringian Suture; VDF – Variscan Deformation Front; WH – Wolsztyn-Leszno High.



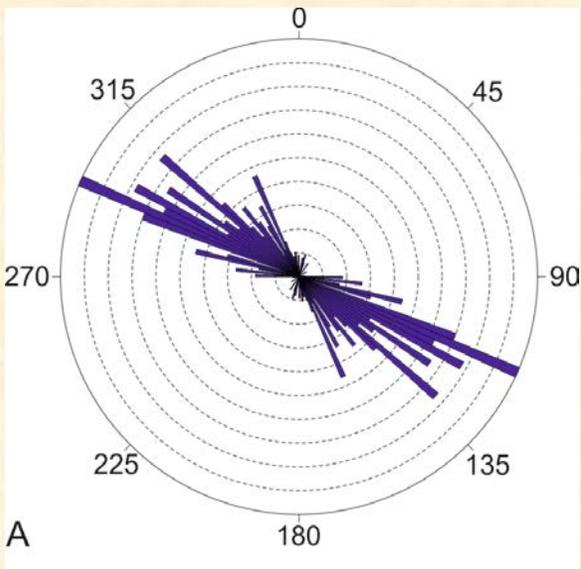
Isostatic residual gravity map of Poland with main structural elements overlaid. White dashed polygon shows the range of data used in spectral analysis. DF Dolsk Fault, OF Odra Fault, ISF Intra-Sudetic Fault, KLF Kraków-Lubliniec Fault, MSB Moravo-Silesian fold-and-thrust belt, SMS Staré Město Suture, STS Saxothuringian Suture, VDF (A) Variscan Deformation Front after Jubitz et al. (1986), VDF (B) Variscan Deformation Front after Pożaryski et al. (1992)



Reduced-to-Pole magnetic map of Poland with main structural elements overlaid. White dashed polygon shows the range of data used in spectral analysis. DF Dolsk Fault, OF Odra Fault, ISF Intra-Sudetic Fault, KLF Kraków-Lubliniec Fault, MSB Moravo-Silesian fold-and-thrust belt, SMS Staré Město Suture, STS Saxothuringian Suture, VDF (A) Variscan Deformation Front after Jubitz et al. (1986), VDF (B) Variscan Deformation Front after Pożaryski et al. (1992)

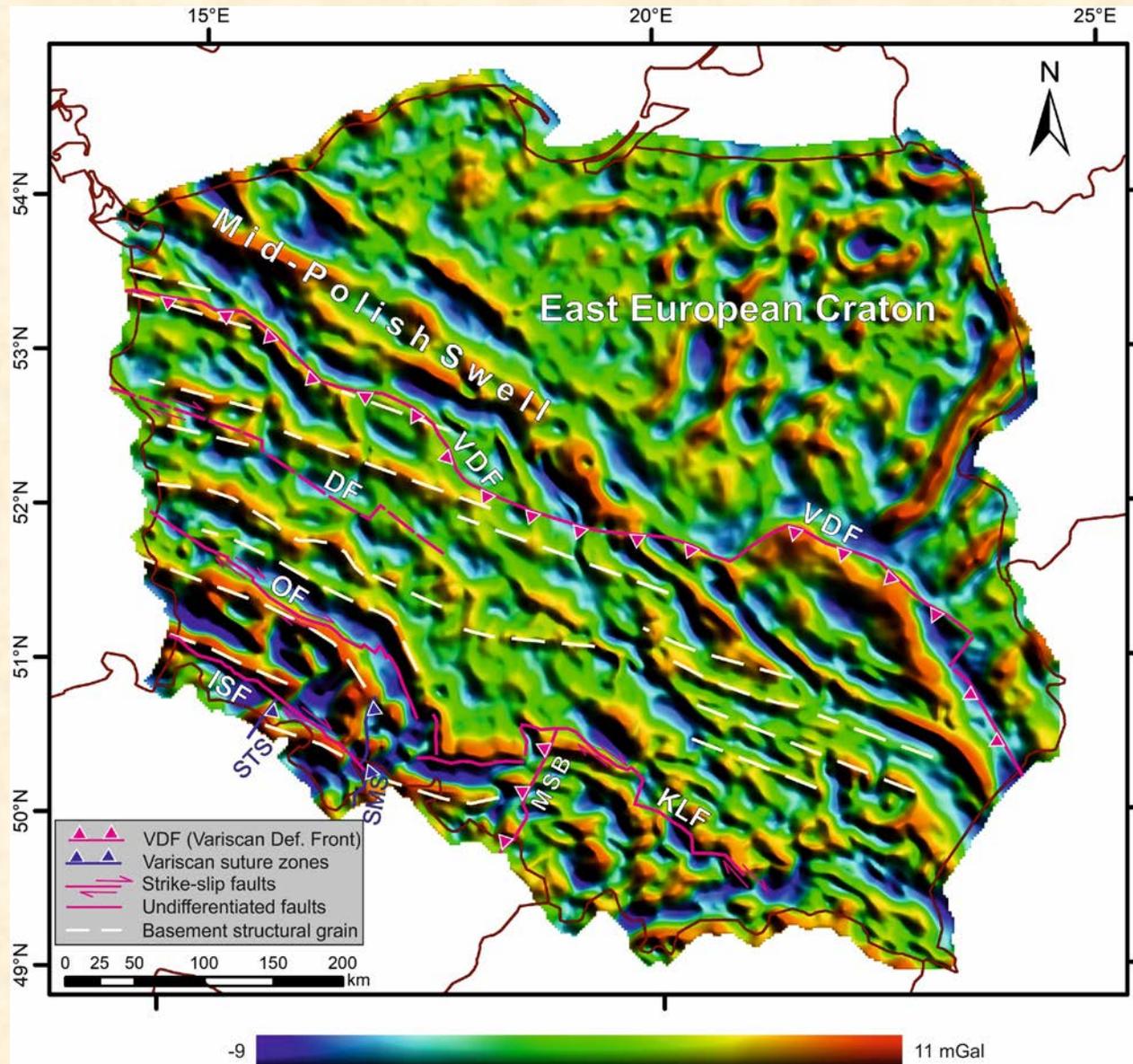


Power spectra and depth slicing results for isostatic residua anomalies **(a)** and reduced-to-pole (RTP) magnetic anomalies **(b)**. The extent of data used is shown in the previous figure. The wavenumber k on the horizontal axis has the value $2 \times \text{cell size} \times \pi/\lambda$, where λ represents wavelength in ground units (metres). For the gravity grid **(a)**, $k = \pi$ at $\lambda = 4000$ since the grid cell size is 2000 m. For the magnetic grid **(b)**, $k = \pi$ at $\lambda = 1000$ since the cell size is 500 m. Depths are calculated based on formula: $h = 1/4\pi \times \Delta \ln P / \Delta k$, where $k = 1/\lambda$

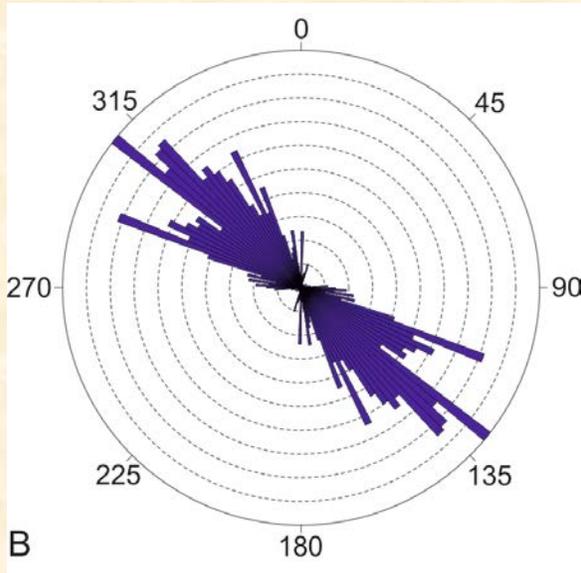


A

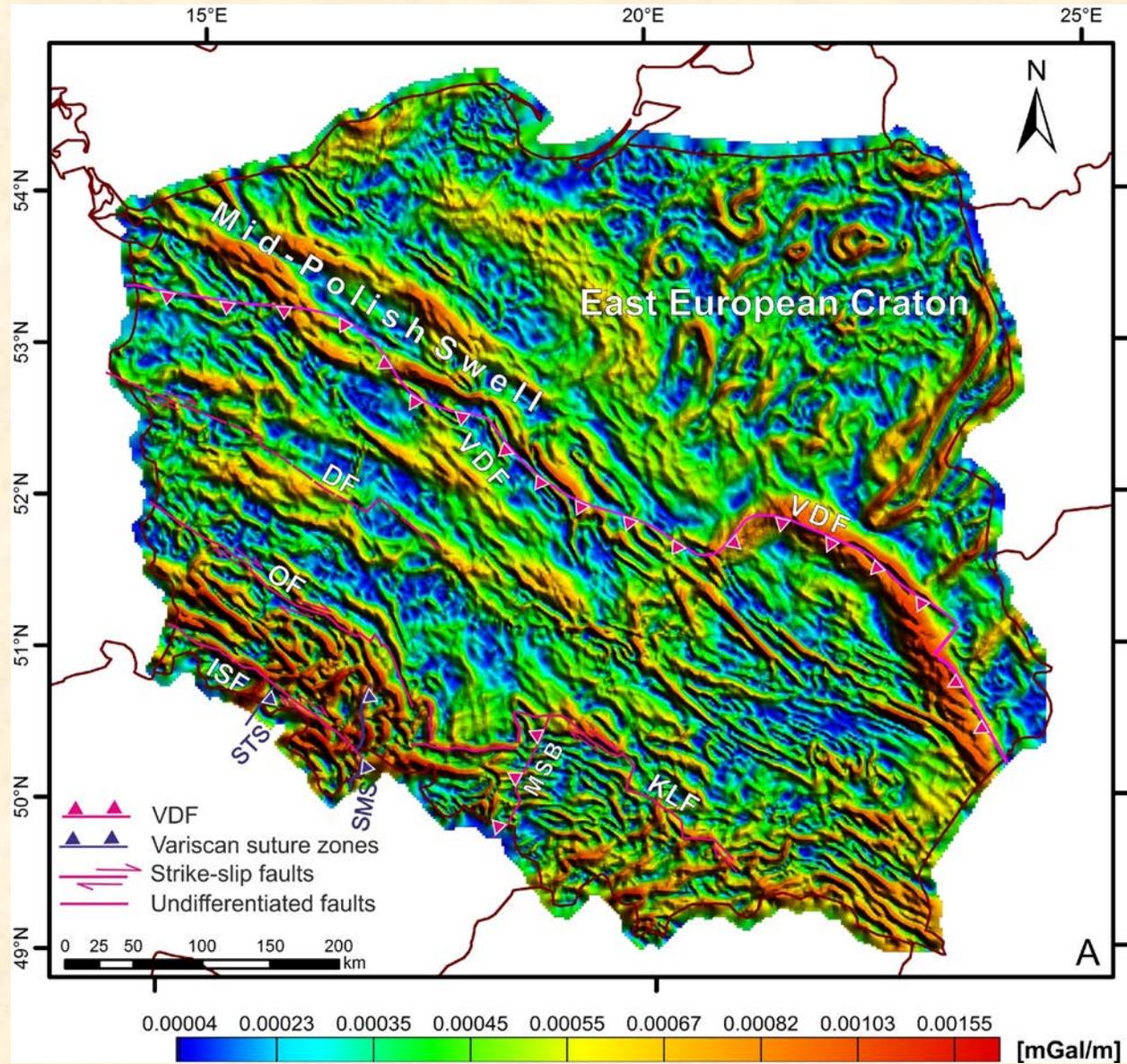
Circular histogram plot (rose diagram) displaying direction and frequency of lineaments in bandpass filtered isostatic residual gravity. There are two maxima:
 WNW-ESE – Variscan grain
 NW-SE – Late Cretaceous basin inversion



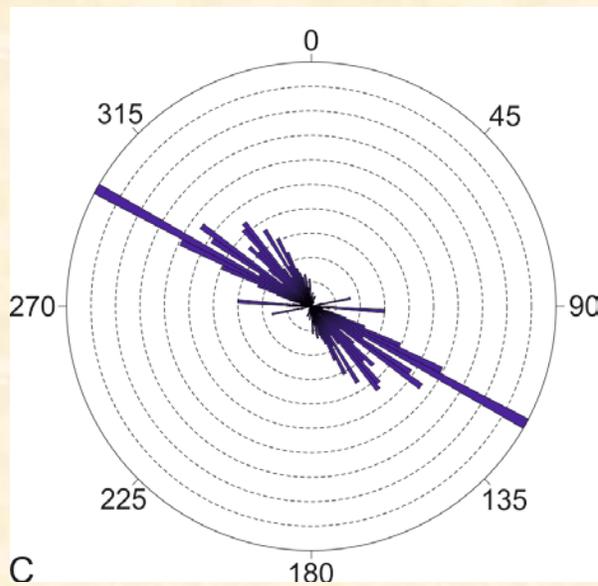
Butterworth bandpass filter of the isostatic residual gravity with cut-off wavelengths of 50 and 13 km. Match-filtering highlights anomalies arising from sources located between the top of pre-Permian rocks (~ 4300 m) and the top of crystalline middle crust (~ 16,500 m). Pale yellow dashed lines emphasize WNW–ESE oriented Variscan structural grain. *DF* Dolsk Fault, *OF* Odra Fault, *ISF* Intra-Sudetic Fault, *KLF* Kraków-Lubliniec Fault, *MSB* Moravo-Silesian fold-and-thrust belt, *SMS* Staré Město Suture, *STS* Saxothuringian Suture, *VDF* Variscan Deformation Front



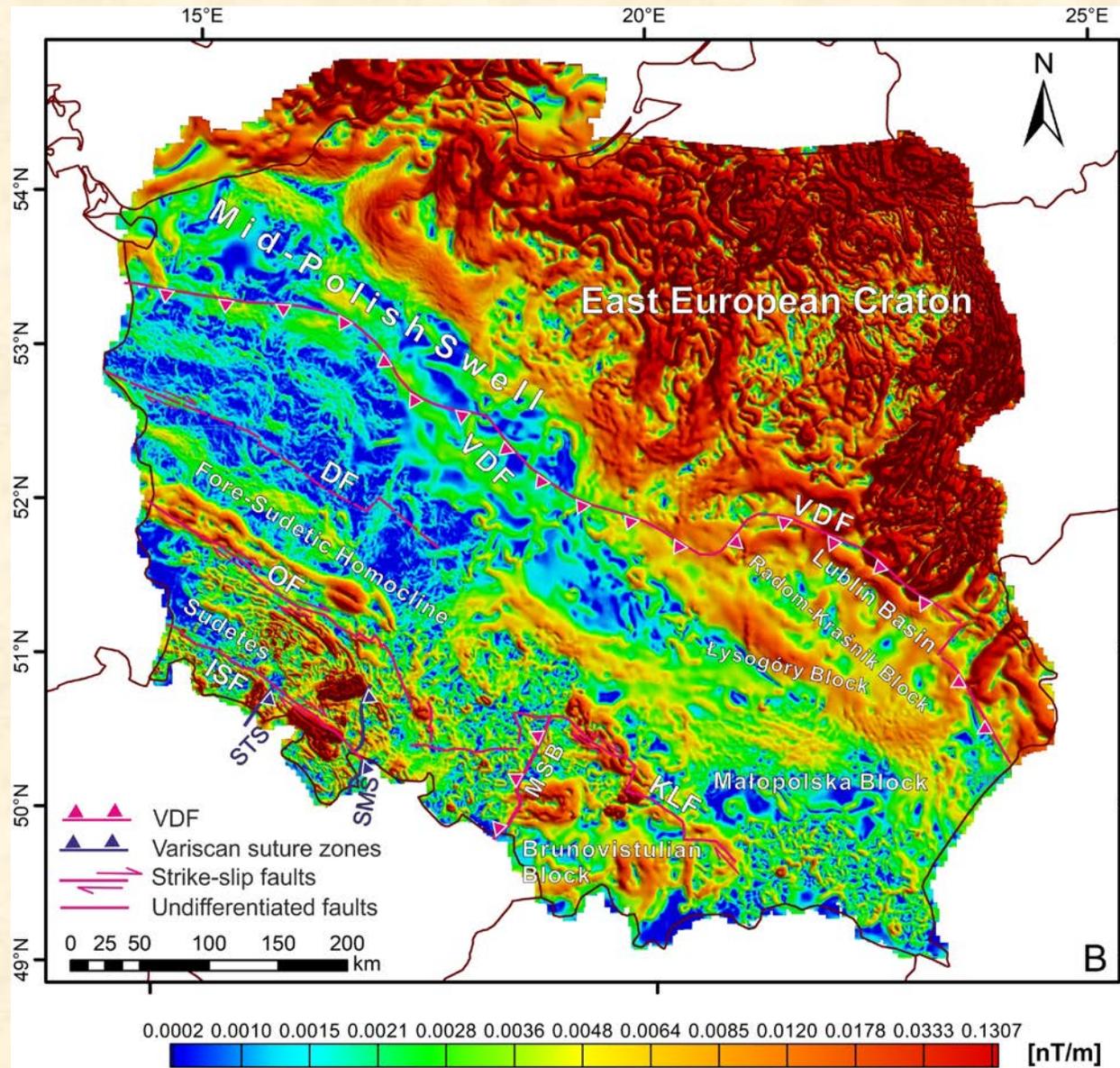
Circular histogram plot (rose diagram) displaying direction and frequency of lineaments in total horizontal derivative of isostatic gravity. There are two maxima:
 WNW-ESE – Variscan grain
 NW-SE – Late Cretaceous basin inversion



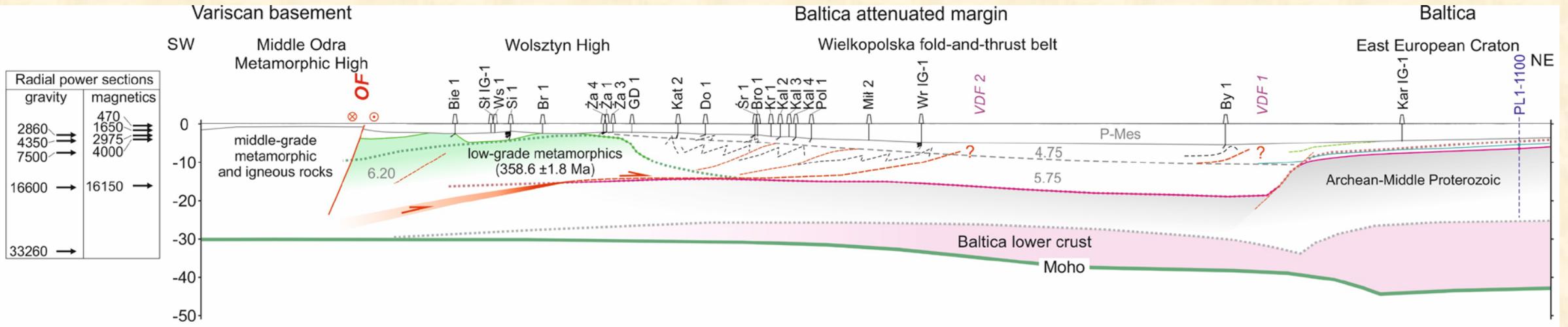
Total horizontal derivative of isostatic gravity map of Poland with main structural elements overlaid. *DF* Dolsk Fault, *OF* Odra Fault, *ISF* Intra-Sudetic Fault, *KLF* Kraków-Lubliniec Fault, *MSB* Moravo-Silesian fold-and-thrust belt, *SMS* Staré Město Suture, *STS* Saxothuringian Suture, *VDF* Variscan Deformation Front



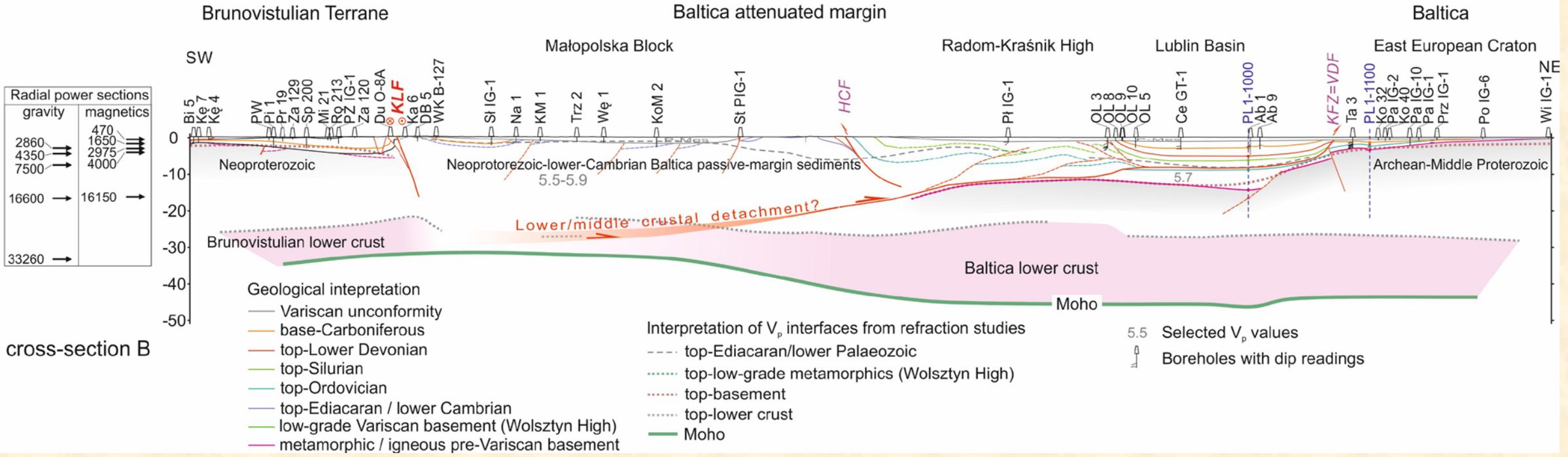
C
Circular histogram plot (rose diagram) displaying direction and frequency of lineaments in total horizontal derivative of RTP magnetic anomaly. There is one maximum: WNW-ESE – Variscan grain



Total horizontal derivative of RTP magnetic anomaly ma of Poland with main structural elements overlaid. *DF* Dolsk Fault, *OF* Odra Fault, *ISF* Intra-Sudetic Fault, *KLF* Kraków-Lubliniec Fault, *MSB* Moravo-Silesian fold-and-thrust belt, *SMS* Staré Město Suture, *STS* Saxothuringian Suture, *VDF* Variscan Deformation Front



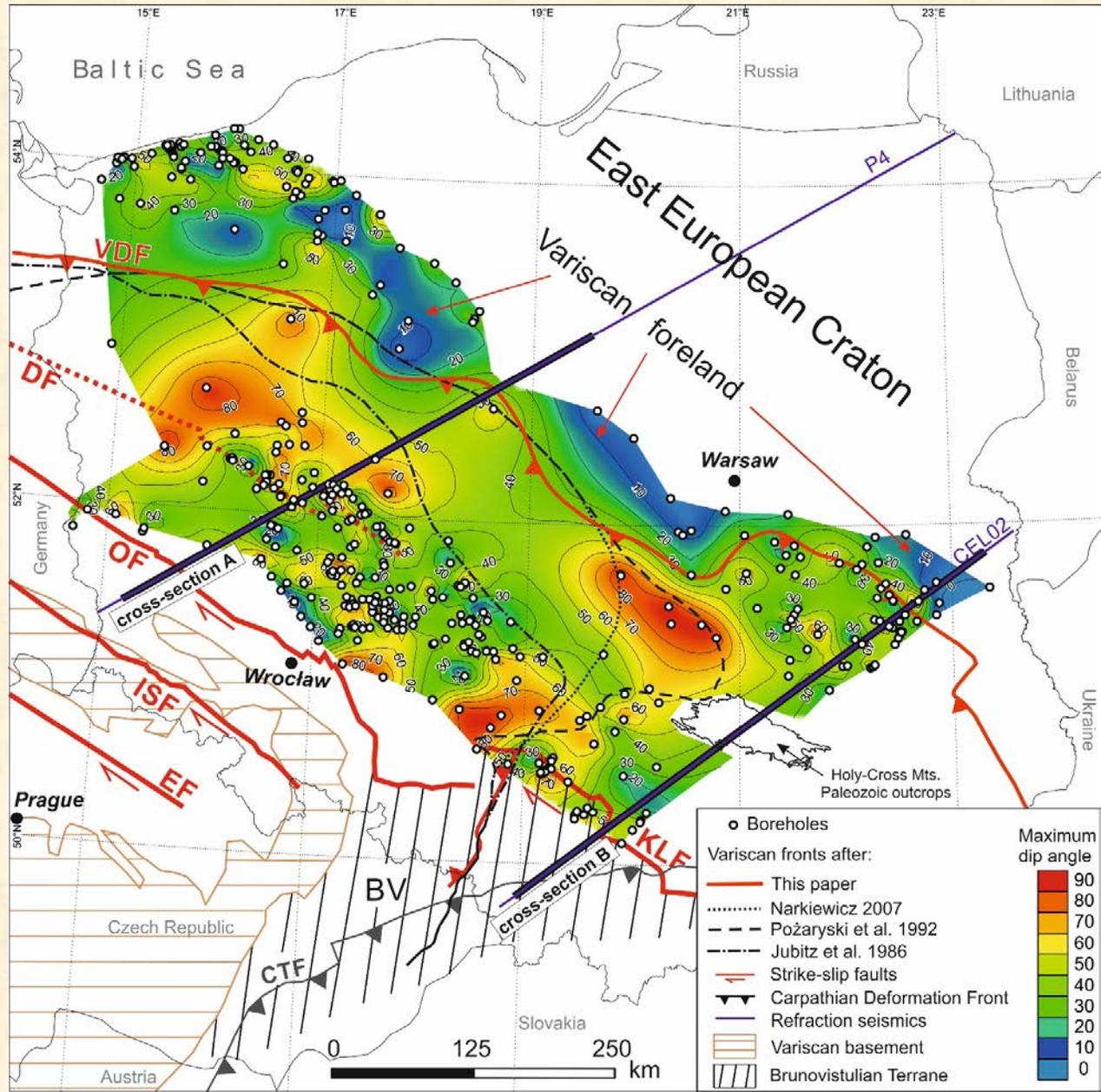
cross-section A



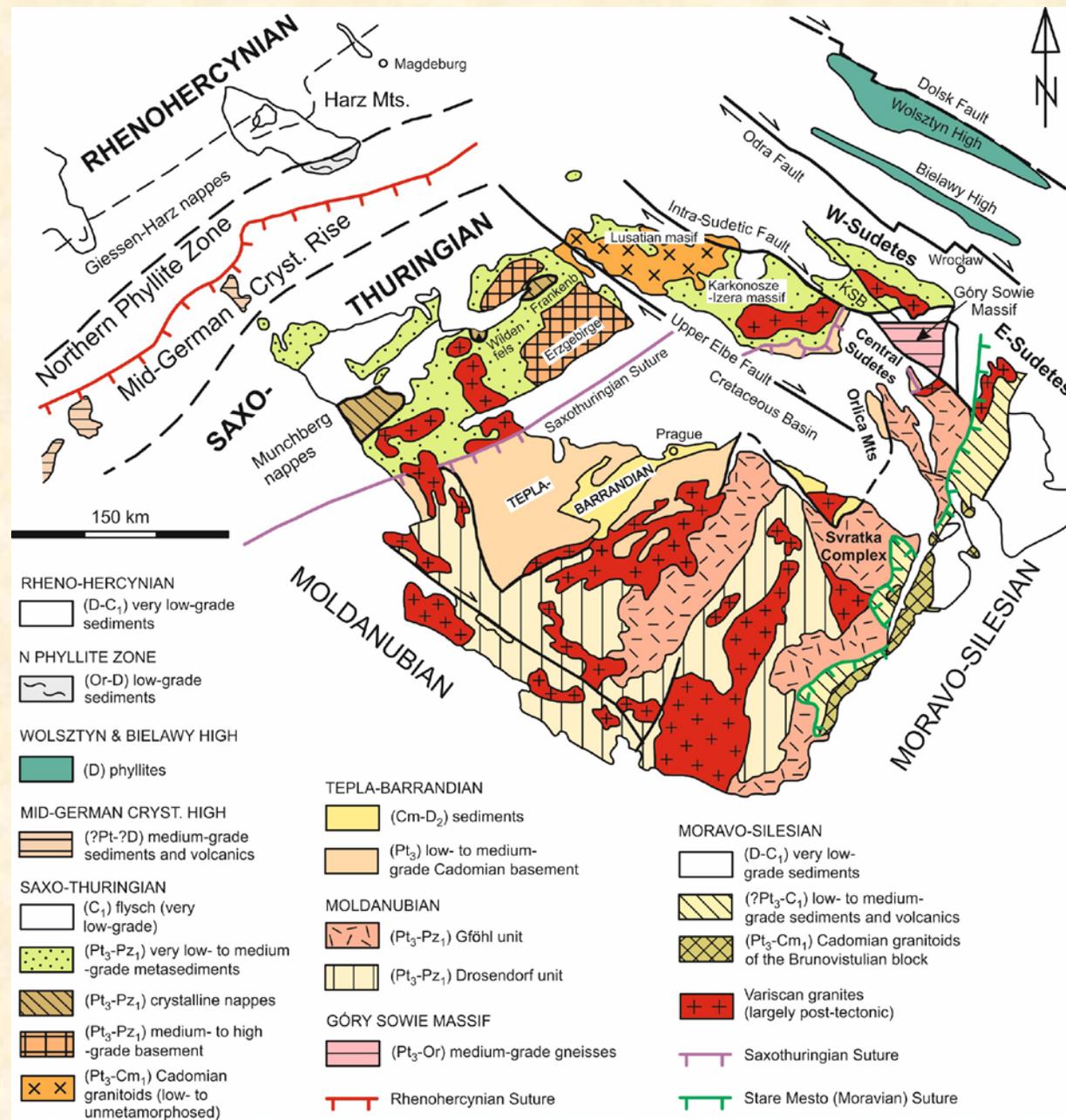
cross-section B

Regional cross-sections through the eastern part of the Variscan belt in Poland. For locations see Figure 2.





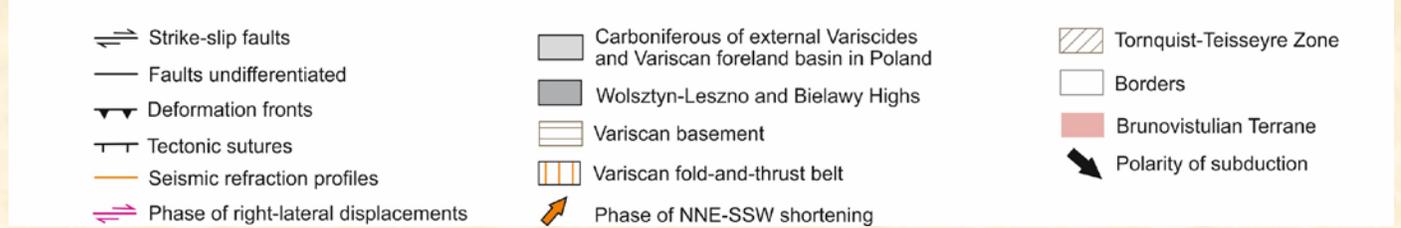
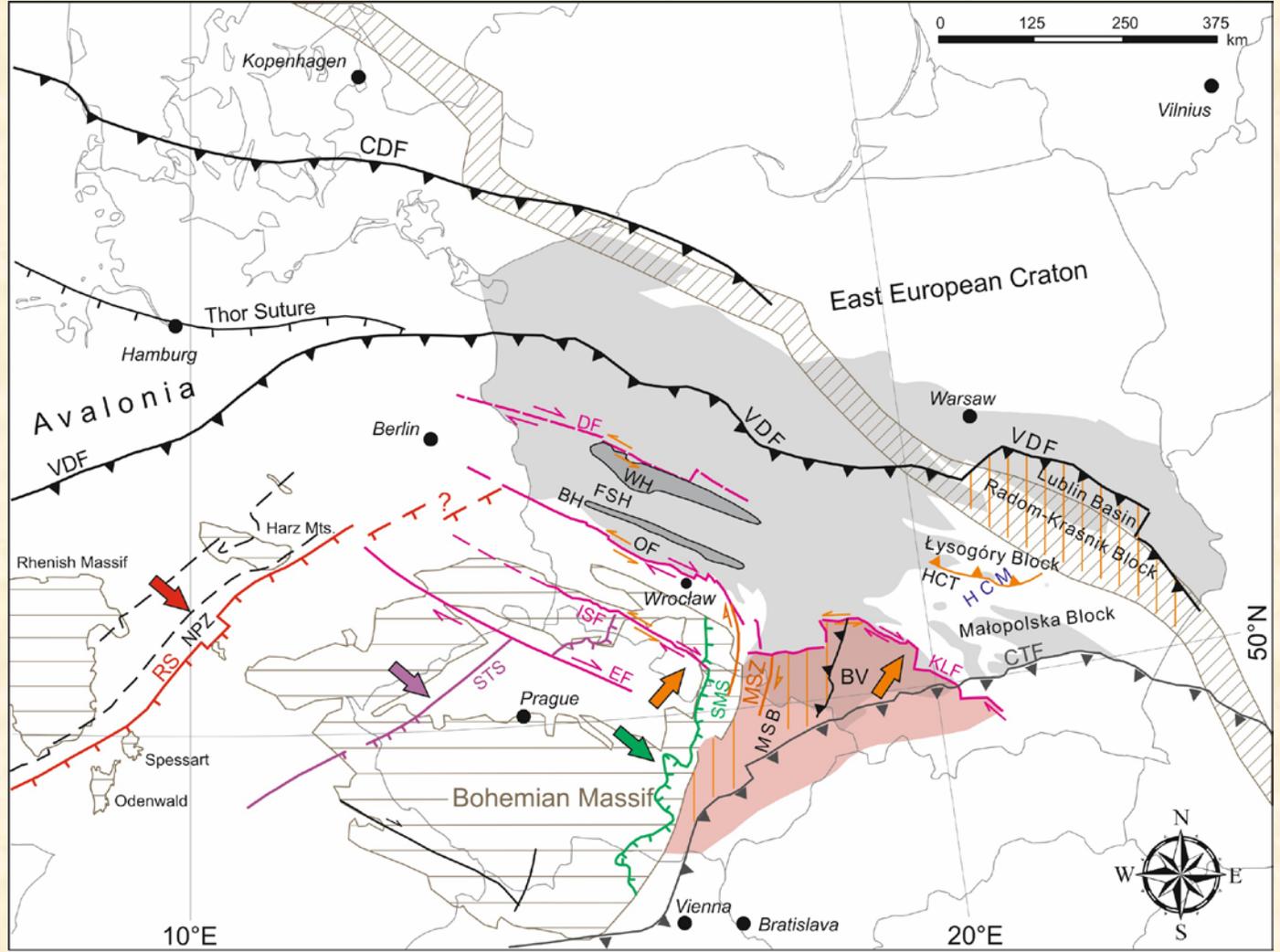
Distribution of maximum dip angles in the Devonian-Carboniferous succession of the external zone of the Variscan orogen in Poland. *VDF* admissible trace of the Variscan deformation front in W Poland



Variscan suture zones and major strike-slip faults overlaid on the tectonostratigraphic division of the Bohemian Massif (modified from Franke et al. 2017, following Kossmat 1927). *KSB* Kaczawa Slate Belt.



- BH* Bielawy High
- BV* Brunovistulian terrane
- CDF* Caledonian front
- CTF* Carpathian thrust front
- DF* Dolsk Fault
- EF* Upper Elbe Fault
- HCM* Holy Cross Mountains
- HCT* Holy Cross Thrust
- ISF* Intra-Sudetic Fault
- KLF* Kraków-Lubliniec fault
- MSB* Moravo-Silesian belt
- MSZ* Moravian Shear Zone
- NPZ* Northern Phyllite Zone
- OF* Odra Fault
- RS* Rhenohercynian Suture
- SMS* Staré Město (Moravian) Suture
- STS* Saxothuringian Suture
- VDF* Variscan Deformation Front
- WH* Wolsztyn High

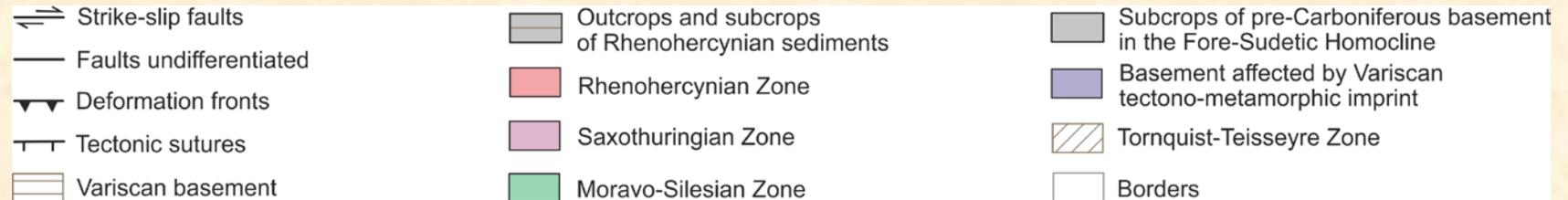
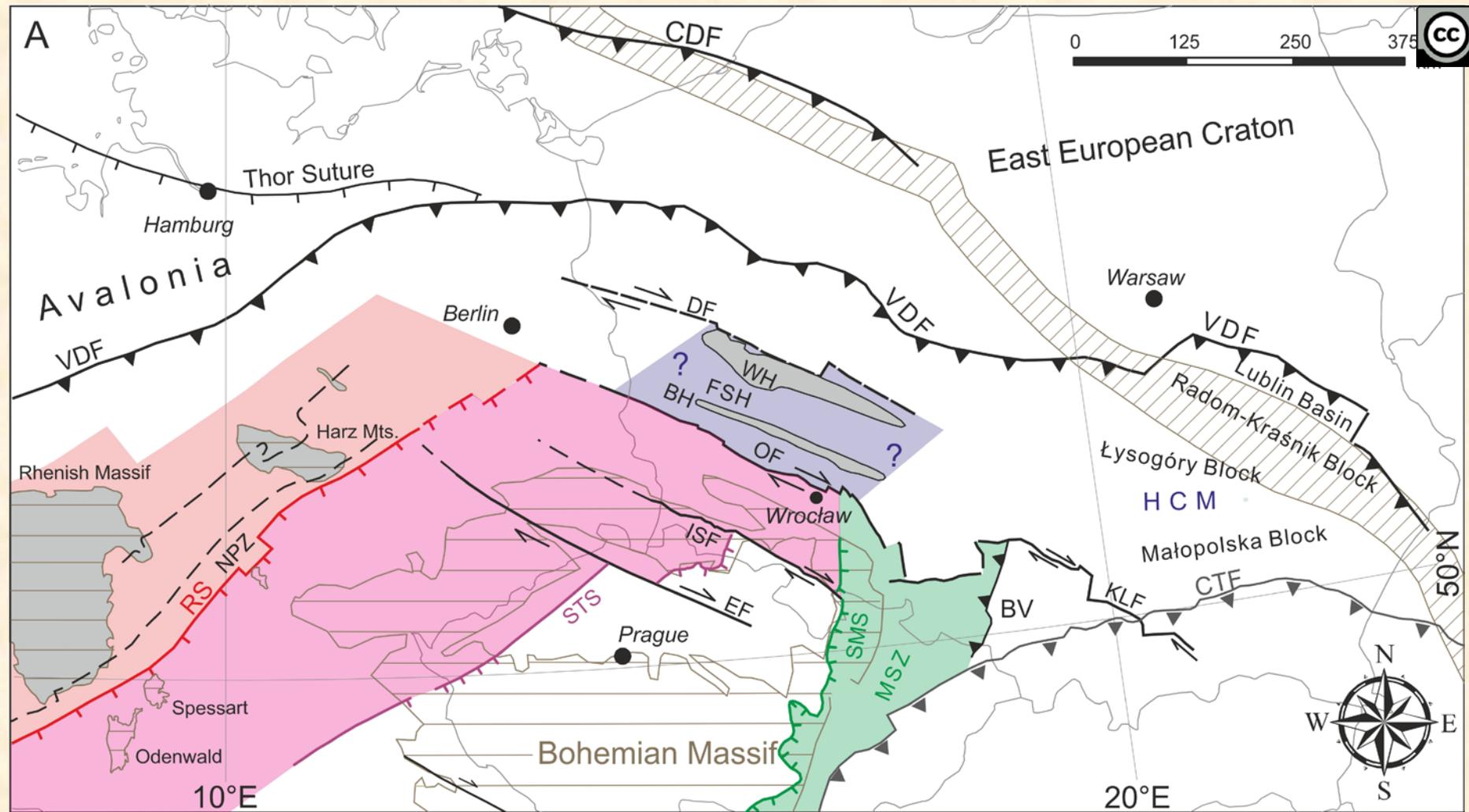


Generalized kinematic model for a junction between the Variscan belt and its NE foreland. Two post-collisional phases of deformation are indicated: dextral wrenching and NNE–SSW shortening. A uniform SW polarity of subduction prior to the Carboniferous collision is shown.

Interpretation

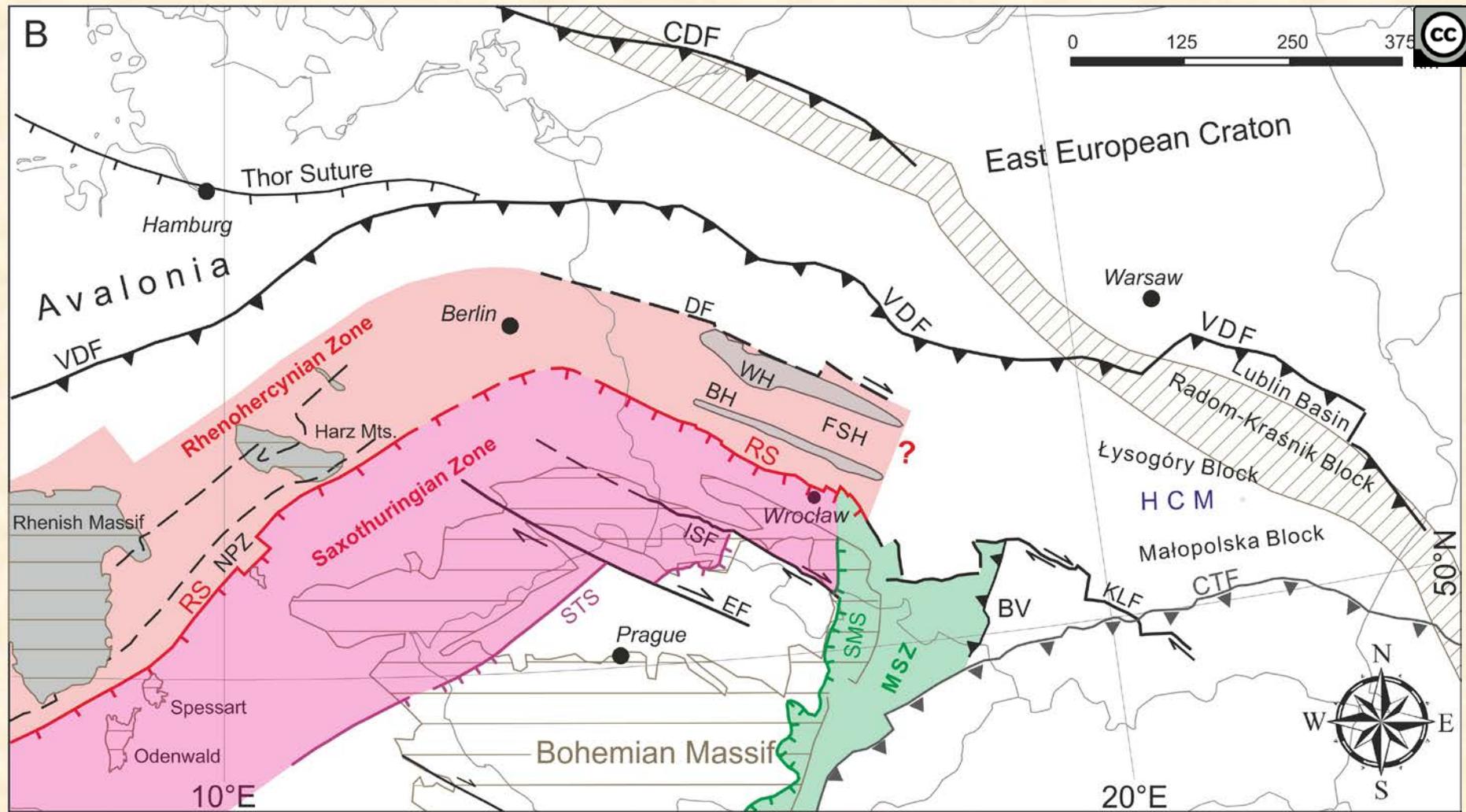
The strike-slip kinematic model proposed in this paper can be well correlated with the sequence of tectonic events in the European Variscan belt during late Palaeozoic times that was proposed by Edel et al. (2018). The late Palaeozoic relocation of subduction to the northern margin of the Palaeotethys Ocean was responsible for N–S shortening of the Variscan belt at around 335–325 Ma. This deformation resulted in dextral reactivation of transform boundaries associated with anticlockwise rotation of intermittent blocks as major strike-slip faults (Edel et al. 2018). These WNW–ESE trending faults remained active during the subsequent transtensional event at 325–310 Ma. During this event new sets of sinistral, NNE–SSW trending transfer faults originated, one of them being the Moravian Shear Zone. The whole system subsequently suffered a period of NNE–SSW shortening at 310–300 Ma that affected the Variscan belt along the former Laurussian plate boundary due to a hard collision with Gondwana. This deformation event corresponded to the final stage of the then orogenic shortening in Poland that created the Variscan deformation front.

BH Bielawy High
BV Brunovistulian terrane
CDF Caledonian front
CTF Carpathian thrust front
DF Dolsk Fault
EF Upper Elbe Fault
HCM Holy Cross Mountains
ISF Intra-Sudetic Fault
KLF Kraków-Lubliniec fault
MSZ Moravo-Silesian Zone
NPZ Northern Phyllite Zone
OF Odra Fault
RS Rhenohercynian Suture
SMS Staré Město Suture
STS Saxothuringian Suture
VDF Variscan Front
WH Wolsztyn High



Strike-slip tectonics model for the NE termination of the Variscan belt in Central Europe. Basement of the Fore-Sudetic Homocline may represent a laterally displaced section of the Rhenohercynian Zone or another part of the Laurussian margin.

BH Bielawy High
BV Brunovistulian terrane
CDF Caledonian front
CTF Carpathian thrust front
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EF Upper Elbe Fault
HCM Holy Cross Mountains
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OF Odra Fault
RS Rhenohercynian Suture
SMS Staré Město Suture
STS Saxothuringian Suture
VDF Variscan Front
WH Wolsztyn High



Alternative semi-oroclinal ($\sim 90^\circ$) model for the NE termination of the Variscan belt in Central Europe. Basement of the Fore-Sudetic Homocline (FSH) may represent a laterally continuous prolongation of the Rhenohercynian Zone.

Conclusions

1. The WNW-ESE structural trend in the Variscan foreland is parallel to a set of major strike-slip fault zones in the area that are considered to convey a significant dextral displacement between Laurussia and Gondwana.
2. The revised position of the Variscan deformation front shows a similar, uninterrupted, generally WNW-ESE trend, up to the SE border of Poland, which indicates an initial continuation of the more internal Variscan zones into the area of the present-day Carpathians.
3. The geometry of the Variscan deformation front along with the pattern of the Variscan structural grain are inconsistent with the idea of an oroclinal loop affecting the external, non-metamorphic Variscan belt.