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Differences Between Recent Heat Flow Maps of Poland and Deep Thermo-Seismic and Tectonic Age Constraints

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Abstract

Poland is situated in a place of contacts between three continental scale geologic structural units: the Precambrian East European Craton (EEC) to the northeast, the Variscan West European Platform (WEP) terranes to the southwest, and the younger Carpathian Alpine arc in the south. The Trans-European suture zone (TESZ) between the EEC and WEP is a deep-seated discontinuity zone reaching down to a depth of about 200 km. The conjunction of all these continental scale geologic units is reflected in the complex tectonic structure of this area. Apart from the complex seismic structure, this area is also associated with pronounced gravity, magnetic and heat flow anomalies. Significant differences exist between heat flow maps of Poland published in recent works, with values reaching 20 to 30 mWm⁻². Examples are differences in heat flow based on models that use well log interpreted mineral and porosity content and assigned world averages of rock and fluid thermal conductivities versus ones based on averaging thermal conductivity values measured using borehole cores only. These differences in heat flow between the methods are discussed in the context of their relationship with tectonic age. Also considered are depth differences between lithosphere – asthenosphere boundary (LAB) derived from thermal model vs those that obey seismological constraints. Higher heat flow estimates reaching up to or more than 100 mWm⁻², based on conductivity values derived from well-logs, are found to be quite improbable. This likely reason for overestimate of heat flow is discussed.

1. Introduction

Contrasts between heat flow (Q) maps of the European continent (Majorowicz and Wybraniec 2011), previous ones in the Geothermal Atlas of Europe (Čermak and Hurtig 1979; Čermak and Rybach 1979; Hurtig et al 1992), those of Cloetingh et al (2010), the European Permian basin Q maps (Guterch et al 2010; Doornenbal and Stevenson 2010) and the Central European maps (Majorowicz et al 2019a) are well known. These reveal that the transition in heat flow between Polish and German basins is continuous in its nature and magnitude across the German-Polish Basin (GPB).

In Central Europe, heat flow is significantly higher west of Trans-European suture zone (TESZ) compared with that for the East European Precambrian craton (see Figure 1). High surface heat flow of 70 to 80 mWm⁻² (Majorowicz et al, 2019b; Majorowicz and Šafanda, 2018) is a regional feature characteristic of the Western and South-Western regions to south west of TESZ, between Odra Fault to South-West and

Variscan deformation front to North-East (Figure 1a, b). This elevated Q (Figure 1b) continues to the northeastern part of the German Basin, where average Q is 77±3 mWm⁻² and reaches up to 91 mWm⁻², the range being 68–91 mWm⁻² (Norden et al 2008; Figure 2 in Cloetingh et al 2010).

There are differences in heat flow maps of Szewczyk and Gientka (2009; Geological Atlas of Poland 2017) and that of Majorowicz et al (2019a). This latter one is based on measured thermal conductivities in calculation of heat flow. The heat flow map of Szewczyk and Gientka (2009) and (1997) Geological Atlas of Poland (2017) makes use of estimated values of thermal conductivity from composition of rocks, derived from standard geophysical well logs and assumed values from table averages for the components.

In this paper we focus on these apparent differences and demonstrate how they cause discrepancy in model estimates of the depths of thermal Lithosphere-Asthenosphere Boundary (LAB). Such differences also have implications in the relationship to the tectonic age of Poland. In addition, we

discuss age values related to expected estimates from general continental heat flow versus last tectono-thermal age for tectonic units in Poland. Also discussed are its implications for heat flow estimates derived from differing maps of Q for Poland.

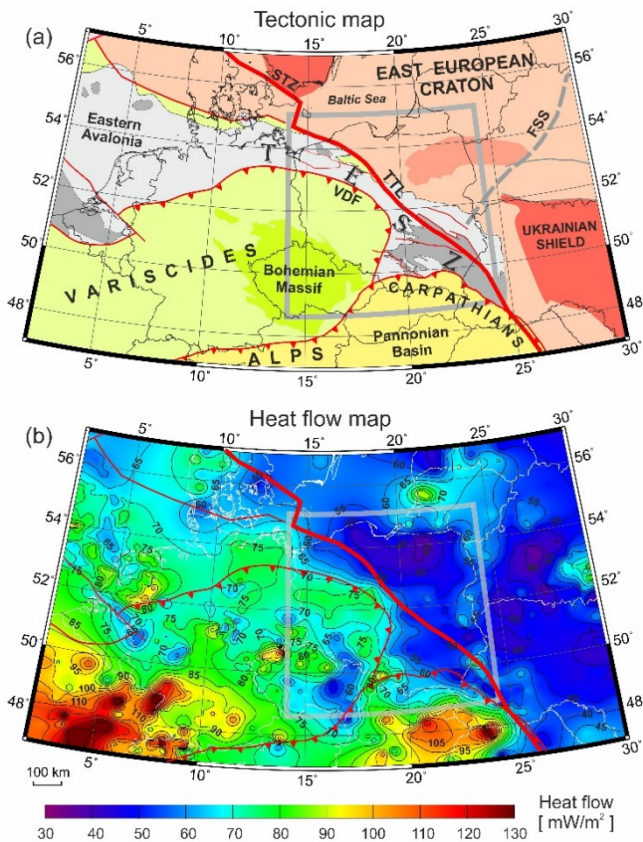


Figure 1 - Comparison of tectonics and heat flow maps. (a) Tectonic sketch of pre-Permian Central Europe in contact with East European Craton, Variscan and Alpine orogens (compiled mainly from Pożaryski and Dembowski, 1983; Ziegler, 1990; Winchester et al, 2002; Narkiewicz et al, 2011). FSS - Fennoscandia-Sarmatia Suture; STZ - Sorgenfrei-Tornquist Zone; TESZ - Trans-European Suture Zone; TTL - Teisseyre-Tornquist Line; VDF - Variscan Deformation Front. (b) Central European heat flow map based on values corrected for paleoclimate perturbations according to Majorowicz and Wybraniec (2011) and with outlines of main tectonic units. Grey frames indicate location of the study area.

2. Differences in recent heat flow maps of Poland

We observe significant differences between many historical heat flow maps of Poland (published during the period between 1970 and 1990) with no paleoclimatic correction and recent maps for which such corrections have been made. The differences in heat flow between old and new maps are of the order of 20 mWm⁻².

Such differences are also observed in recent maps that considered paleoclimatic correction for glacial-interglacial surface forcing (Szewczyk and Gientka 2009; Majorowicz et al, 2019a for Poland and Majorowicz and Wybraniec 2011 for Europe).

The terrestrial heat flow values were calculated as the product of geothermal gradient (grad) and thermal conductivity (λ) for the depth interval Δz in which measurements were made. Thermal conductivity λ for any interval Δz was determined by two methods:

(a) averaging the experimental values for core samples from that interval; and

(b) building geophysical log-based model of rock aggregates with thermal conductivity of mineral components occupying volume of fractions v_i .

Method (a) was used to calculate λ for Q determinations in deriving the first heat flow map of Poland (Majorowicz 1976). It makes use of 52 data sets. The same method was used by Plewa (1988), who in his late compilation listed 87 Q determinations. Majorowicz and Plewa (1979) listed 49 Q values and Karwasiecka and Bruszevska (1997) listed 274 Q values. The map of Q illustrated in Figure 2 is derived from such data sets. These maps incorporate paleoclimatic corrections employed in the heat flow map of Europe by Majorowicz and Wybraniec (2011).

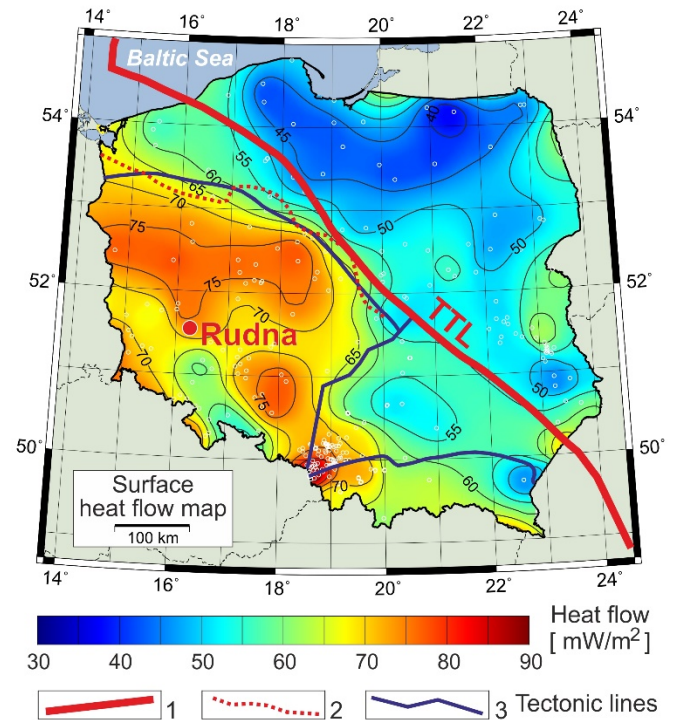


Figure 2 - Surface heat flow map of Poland, modified from Majorowicz et al (2019a). It is based on heat flow data corrected for paleoclimate perturbation, according to Majorowicz and Wybraniec (2011). Small white circles indicate locations of boreholes with heat flow data. Big red dot indicates location of test site Rudna.

The lineaments are: 1 - TTL within Poland (Narkiewicz et al, 2011); 2 - magnetic line along the southern margin of the Pomeranian Massif (Królikowski, 2006); 3 - basement borders (Karnkowski, 2008).

Heat flow maps for Germany derived on the basis of IHFC (International Heat Flow Commission, IASPEI) data compilation and more recent ones reported for the North German Basin (NGB) by Norden et al, (2008) exhibit similar features to the west of the Polish-German border. Norden et al (2008) report Q values based on temperature gradients for several deep wells in the NGB basin west of Polish part of the GPB in the study area. In such cases, heat flow was estimated for wells deeper than 1.5 km, in which core thermal conductivity values were used.

Data corrected for effects of paleo climate changes was used in calculating Q values by Szewczyk and Gientka (2009) and its updated version in the Geological Atlas of Poland

(2017) with 308 data points (Figure 3). Their map also considers paleoclimatic correction for shallower wells.

At depths greater than 1.5 km heat flow is less influenced by glacial to interglacial surface temperature cycle. The associated errors at such depth levels are less than the errors in determinations of gradient and thermal conductivity. According to Majorowicz and Šafanda (2008), Majorowicz and Wybraniec (2011) and Majorowicz and Šafanda (2018) the forcing signal associated with surface temperature changes decrease with depth to the point that the magnitude of paleoclimatic correction is less than 5 mWm^{-2} in the GPB.

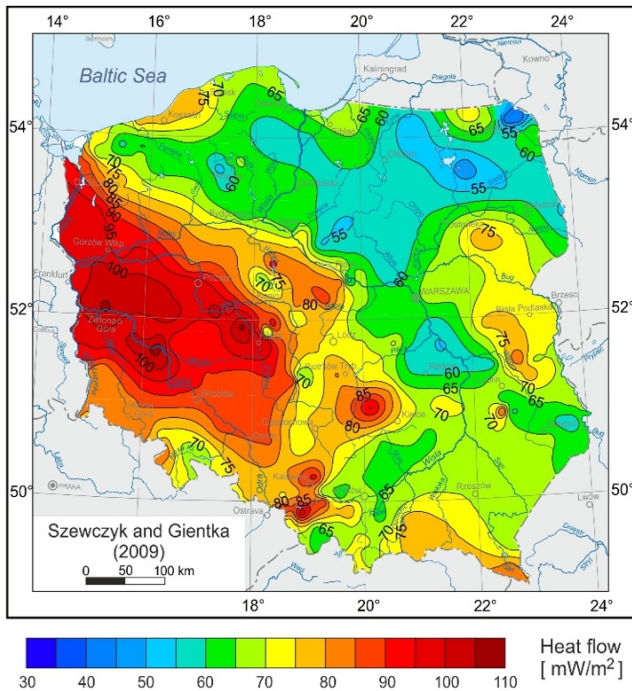


Figure 3 - Heat flow map of Poland according to Geological Atlas of Poland (2017) with modified color scale, based on Szewczyk and Gientka (2009). Notice the difference in average heat flow between this map and the map in Figure 2.

High surface heat flow of 60 to 80 mWm^{-2} in Figure 1b is a regional feature characteristic for the South-Western part of Poland and North-Western part of Eastern Germany. The region of anomalous heat flow is located between Middle Odra Horst and Variscan Deformation Front (Majorowicz and Wybraniec 2011; Majorowicz and Šafanda, 2018; Puziewicz et al, 2019). Changes in absolute values of 20 mWm^{-2} may arise due to differences in thermal conductivity models, estimated from well logs (Szewczyk and Gientka 2009) versus those measured on cores (Majorowicz and Plewa 1979; Karwasiecka and Bruszevska 1997; Majorowicz and Wybraniec 2011). However, the Q patterns are similar (compare Figure 2 and Figure 3). Analysis of this difference in Q between maps in this paper imply that values in the range of 100 to 110 mWm^{-2} are exceptionally high for an old West European platform area of Variscan age. Consequences of this observation are discussed in farther analysis.

3. Relationship of heat flow with tectonic age and crustal structure

Under certain suitable conditions, tectono-thermal age in continental settings may be considered as proxy for expected

heat flow (Lucazeau 2019). The relationship of heat flow with tectonic age was studied for the Polish area in earlier works (Majorowicz 1973a, 1973b, 1976) and recently by Majorowicz et al (2019a). The variation of heat flow with age for continental regions, derived from data reported in Polyak and Smirnov (1968), Hamza and Verma (1969), Hamza (1979) and Pollack et al (1993). It was recently reviewed by Vieira and Hamza (2018).

In Poland the age of the consolidated crystalline basement varies from less than 100 Ma for the Carpathian forefront zone to $>1000 \text{ Ma}$ for the Precambrian basement of the East European Platform. The Alpine zone of the Carpathian is an external zone of the Carpathians overlying an older basement (Figure 1a and Figure 4 a, b). However, major lines dividing tectonic unites of different ages (like the TTL) are not always evident indicators of the boundary between regions of low Q in the east and high Q in the west. Low heat flow zone persists at all depth levels west of TTL. In general, it extends to southern margin of the Pomeranian Massif (Królikowski, 2006). In the south-east of TTL it extends partially into the Cadomian area in Southern Poland (Karnkowski, 2008; see also Figure 4a). The boundary depicting extension of the Carpathian foreland (see Figures 2 and 4) is not revealing itself as a Q boundary. Low Q zone extends from the eastern part of the Cadomian basement beneath Northern Carpathians and goes into high Q in the west across the E-W boundary of the Carpathian foreland zone (Figure 1). Thus, heat flow increases from the modest values in the foreland zone to higher ones in the internal Carpathians. The highest values occur in the Pannonian basin (see Figure 1b and Šimonová et al, 2019), where it reaches $>90 \text{ mWm}^{-2}$ on average, surpassing locally $>110 \text{ mWm}^{-2}$ (Figure 1b).

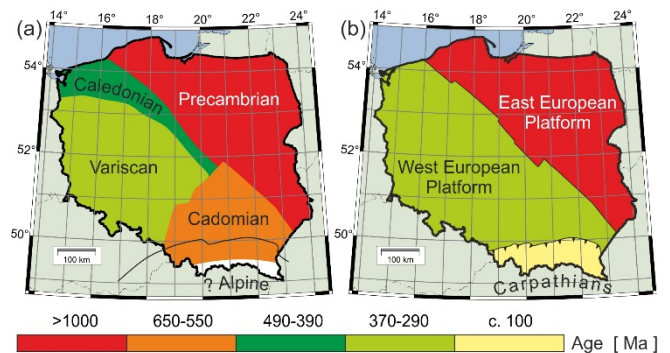


Figure 4 - Regional distributions of tectonic units in Poland according to (a) Karnkowski (2008) and (b) Żelazniewicz et al (2011). Original colors were modified in both maps for maintaining the common pattern.

Latest volcanism in southwestern Poland has rather minimal remaining impact upon heat flow, as revealed in results obtained in 3D modelling of thermal effects of intrusions (Puziewicz et al 2019). In this work, the Cenozoic volcanic lavas were considered as having migrated from the asthenosphere between 30 and 18 Ma and at temperatures of 1400°C (considered as compatible with asthenospheric basanite solidus; Puziewicz et al 2019). As the lithospheric mantle was infiltrated by lavas moving to the surface, we expect transient heat but 3D numerical modelling (Puziewicz et al 2019) shows that it explains only a relatively small ($< 4 \text{ mWm}^{-2}$) increase of heat flux at the current Moho depths and also in surface heat flow. We cannot exclude the suggestion by Puziewicz et al (2019) that Moho heat flow, which indicates

“warm” lithospheric mantle, can be an artefact, resulting from underestimation of radiogenic heat production. Note that we have not considered thermal effects of rhyolites/granites related to the Permian igneous province, the role of which is not known. Q in the Polish Carpathian foreland have low to moderate values, representing older basement units thrust beneath folded sedimentary successions. It increases towards inner Carpathians and Pannonian basin.

The variation of heat flow with age for continental regions, derived from continental data have been reported for various tectonic units (see for example, Vieira and Hamza, 2018). Here we compare relation of average Q with age for two Polish areas of Variscan and Precambrian ages. Average Q values derived from maps of Figures 2 and 3 are compared against those derived from the relationship in which age is considered proxy of expected Q from general continental heat flow versus tectono-thermal age. Note that Q – age pairs derived from Szewczyk and Gientka (2009) are off the scale of the relationship (Figure 5). This is especially evident for the Variscan age province (Geological Atlas of Poland 2017) and map of Figure 3.

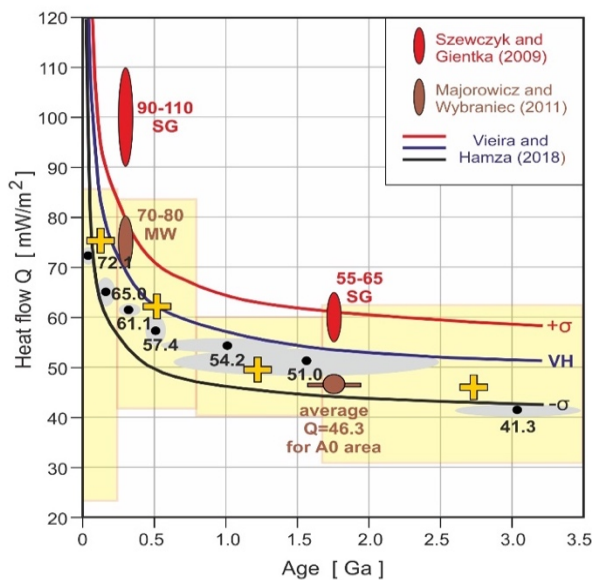


Figure 5 - Variation of continental heat flow with tectonic age, as proposed by Vieira and Hamza (2018). Averaged values considered by Grad et al (2018) for their area of „13 BB Star” array is shown as brown circle with line. Average heat flow - age groups from Szewczyk and Gientka (2009) are marked SG, while those of Majorowicz and Wybraniec (2011) are marked MW. Note that MW data fit the expected heat flow - age relationship much better (Compiled from Jessop et al, 1976; Majorowicz and Jessop, 1981; Majorowicz, 1984; Vieira and Hamza, 2018).

Most heat flow data in Poland come from wells drilled into sedimentary strata. Only a few wells reach crystalline rocks (Dowgiałło, 2002). Sedimentary fill in the Polish basins vary from just few hundred meters in North Eastern region to some 15 km thickness in the central-northern Poland, as indicated in results of 3D seismological modeling (Grad and Polkowski 2016) and numerous seismic profiles cutting across sedimentary basins. The thinnest sedimentary cover in the Mazury-Belarus anticline is only 0.3 to 1 km thick, which increases to 7 to 8 km along the East European Craton (EEC) margin. It reaches as much as 9 to 12 km in the TESZ (Grad and Polkowski 2016). The Variscan domain is characterized

by a 1 to 4 km thick sedimentary cover, while the Carpathians are characterized by very thick sedimentary layers, up to about 15 km. This is confirmed in high-resolution 3D model of entire crust and uppermost mantle down to depths of 60 km (Grad et al 2016).

This procedure allows calculation of heat flow at the base of sediments (designated as the consolidated basement) and at the Moho. The left panel of Figure 6 illustrate variations of heat production Rudna test site (see Figure 2 for location). Models of heat production A with depth z are from seismic P-wave velocity model of the crust extracted from the Grad et al (2016). The right panel of Figure 6 illustrate heat flow distribution with depth for surface heat flow of 80 mWm^{-2} . Moho heat flow is assumed to be $34 \pm 2 \text{ mWm}^{-2}$.

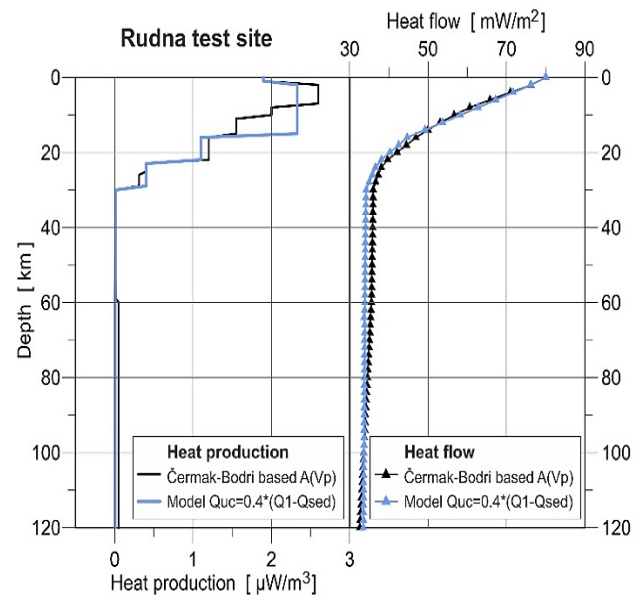


Figure 6 - Vertical variations of heat production and heat flow, inferred for the Rudna test site (see Figure 2 for location). Models of heat production A with depth z are from seismic P-wave velocity model of the crust extracted from the Grad et al (2016). Heat flow distribution with depth is shown for surface heat flow of 80 mWm^{-2} . Moho heat flow is assumed to be $34 \pm 2 \text{ mWm}^{-2}$.

Heat flow at the base of sedimentary succession of consolidated basement and at Moho are compared below in maps of Figures 7 and 8. In both cases the heat flow patterns at basement and at Moho are like those found for the surface (Figure 2). The sedimentary rocks contribute significantly to radiogenic heat production. The difference between surface heat flow and the contribution of sedimentary cover is up to 20 mWm^{-2} with the largest reduction just west of TTL in the Mid-Polish Swell, where thickness of sedimentary cover is $>10 \text{ km}$.

However, comparison of all three heat flow maps shows that general patterns agree despite large decrease in Q from 80 mWm^{-2} at the surface down to 35 mWm^{-2} at Moho. The Q patterns generally fit major tectonic division and tectonic lines. Tectonic lines like the position of TTL in Poland (Narkiewicz et al, 2011), magnetic line depicting southern margin of Pomeranian Massif (Królikowski, 2006) and basement borders (Karnkowski, 2008) fit changes in heat flow at all three Q levels. The highest Q values are in south western part of Variscides (West European platform and western Sudetes).

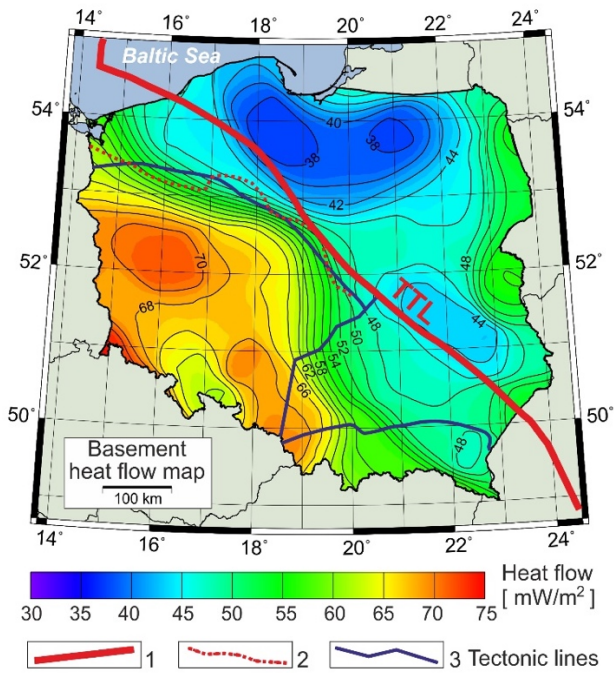


Figure 7 - Crystalline basement heat flow map of Poland. Tectonic lines as in Figure 2. Note differences in color scales.

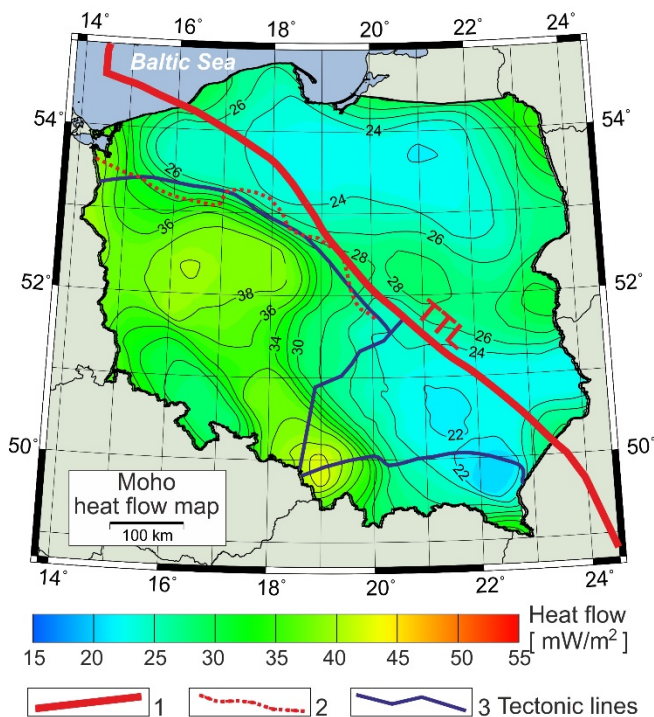


Figure 8 - Moho heat flow map of Poland (modified from Majorowicz et al 2019). Tectonic lines as in Figure 2.

4. Seismic LAB vs thermal LAB

Observed 20 mWm^{-2} difference of the average Q is seen from map according to Geological Atlas of Poland (2017), based on Szcwzyk and Gientka (2009). This is reproduced in Figure 3. It may be compared with maps of Majorowicz and Wybraniec (2011) and Majorowicz et al (2019a), reproduced in Figure 2. As surface heat flow is the main boundary condition that determines geotherms, mantle heat flow and thermal lithosphere-asthenosphere boundary (Pollack and Chapman 1977; Artemieva 2011; Artemieva and Mooney

2001; Jaupart and Mareschal 2003; Jaupart et al 1998) we tested lithospheric geotherms for South-Western Poland for estimating thermal LAB. Two models were considered, differing by 20 mWm^{-2} (80 mWm^{-2} vs 100 mWm^{-2}). We used one-dimensional steady state case ‘boot strapping’ method described by Hasterok and Chapman (2011) and the model of heat generation and thermal conductivity by Majorowicz et al (2019a). In addition, use was made of 3D seismic model (Grad et al 2016; Grad and Polkowski 2016). Local data available for thermal conductivity and heat production for sediments and crystalline rocks, has been described by Majorowicz et al (2019a). Changes of λ due to increase of pressure and temperature with depth were calculated using the equation with empirical constants (Chapman and Furlong 1992; Correia and Šafanda 2002; Čermák and Bodri 1986; Čermák et al 1989). The vertical distributions of temperatures are illustrated in Figure 9.

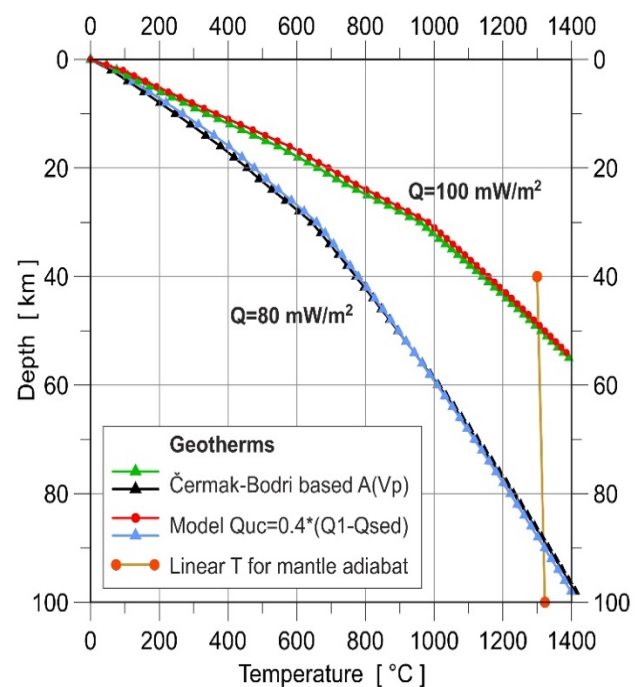


Figure 9 - Vertical distributions of temperatures at Rudna test site (see Figure 4 for location), for surface heat flow values of 80 mWm^{-2} and 100 mWm^{-2} . The brown line shows enriched peridotite solidus (MacKenzie and Canil, 1999; Hirschmann, 2000). Its intersection with geotherms occur at 90 km and 50 km, respectively.

The above-mentioned test (Figure 9) indicates that the assumption of low surface heat flow of 80 mWm^{-2} from Majorowicz and Wybraniec (2011) as maximum considered for the Variscan in southwestern Poland results in LAB of 100 km in reasonable agreement with seismic data interpretation (Wilde-Piórko et al 2010). Increasing heat flow in South-Western Poland to higher values of 100 mWm^{-2} as proposed by Szcwzyk and Gientka (2009) results in LAB depth decreasing to unrealistic shallow LAB of 50 km.

Comparison of thermal LAB estimates for Q of 80 mWm^{-2} is in broad agreement with results of independent seismological experiments as well as gravity and magneto-telluric evidences (Majorowicz et al (2019a). Seismic model of the crust and uppermost mantle beneath Poland from north-east to south-west point to thin crust and lithosphere beneath Paleozoic Platform, and thick crust and lithosphere beneath

East European Craton. Seismic LAB depth was determined from relative P-residuals of tele seismic events (Wilde-Piórko et al 2010). Average seismic LAB depths are about 90 to 100 km for south-western Poland, about 120 km for Polish Basin, and about 190 km for EEC. Such values are in reasonable agreements with thermal LAB estimated using heat flow variations in Figure 2. Assumption of higher heat flow 100mWm^{-2} would result in thermal LAB at unrealistic shallow depth of 50 km at Variscan Platform in south-western Poland. This estimate is much lower than seismological LAB depth. While thermal and seismological LAB are not the same (Pollack and Chapman 1977; Artemieva 2011; Artemieva and Mooney 2001; Jaupart and Mareschal 2003; Jaupart et al 1998) the difference of 50 km seems unlikely.

5. Discussion and conclusions

According to results of the present work there are differences of about 20mWm^{-2} between Q map of Poland (see Figure 4) and the Q map proposed by Szewczyk and Gientka (2009), illustrated in Figure 3. We proceed to examine the reason of such differences.

Q maps of Europe by Majorowicz and Wybraniec (2011) and in Central Europe (Majorowicz et al 2019b and Figure 1b) do not reveal any significant discontinuity in regional thermal fields of basins in Germany and Poland. This is not the case for the Q map of western Poland and eastern Germany compiled by Szuman et al (2018) for which Szewczyk and Gientka (2009) heat flow map was used. We suspect that the such changes in Q is mainly due to differences in thermal conductivity models used.

Paleoclimate is unlikely the reason for the differences in heat flow between maps based on Majorowicz and Wybraniec (2011) and Szewczyk and Gientka (2009), as both used paleoclimatic corrections.

The maps for which λ was measured in laboratory (used by Majorowicz and Wybraniec, 2011 and Majorowicz et al, 2019) show lower Q values when compared with those for which geophysical well log-based estimates are used. The latter is based on mineralogical component of rocks and their porosity with table-based world averages of thermal conductivity (Table 4.3 in Barker, 1996; Griffiths and Brereton 1992; Brigaud et al 1990).

The difference is apparent when we compare mean measured thermal conductivity for deep Polish basin sediments on cores (mean of $2.3 \pm 0.4\text{Wm}^{-1}\text{K}^{-1}$ for wells in the Polish basin listed by Majorowicz and Plewa, 1979, their Tables 1-3), against those estimated from geophysical well logs (mean of $2.8 \pm 1\text{Wm}^{-1}\text{K}^{-1}$ in Szewczyk and Gientka (2009, their Figure 5c). Such changes in thermal conductivity explain the difference of 20mWm^{-2} between Q maps derived from the two methods. In western Poland where temperature gradient is 35mK^{-1} and thermal conductivity is 2.3W/mK , the value heat flow (Q_1) is 80mWm^{-2} for the first case. However, for thermal conductivity of $2.85 \pm 1\text{Wm}^{-1}\text{K}^{-1}$ heat flow (Q_2) turns out to be 100mWm^{-2} . Thus, a difference of 20mWm^{-2} is plausible. Suspected reason is poor calibration of well-log estimates for thermal conductivity data and poorly assumed literature values of average λ for the component minerals of rocks. These usually have a large range (Blackwell and Richards 2004; Blackwell and Steele 1989; Fuchs 2018). Such models work but need to be properly validated by

laboratory data, as recently demonstrated by Fuchs and Forster (2018).

Large parts of sedimentary clastics in the greater basins of Poland are shales. Their λ assumed by Szewczyk and Gientka (2009) $1.4\text{Wm}^{-1}\text{K}^{-1}$ is some $0.3\text{Wm}^{-1}\text{K}^{-1}$ higher than some of the measured λ on cores as evident from their Figures 5a, b. Thermal conductivity of shales analyzed by *in situ* experiments in deep wells for which precise *in situ* measurements are in reasonable agreement (Blackwell and Steele 1989; Blackwell et al 1999) indicate that λ for shales can be closer to $1\text{Wm}^{-1}\text{K}^{-1}$, e.g., which is approximately $0.4\text{Wm}^{-1}\text{K}^{-1}$ lower than the value assumed by Szewczyk and Gientka (2009) for their well log derived component of sediments. While Blackwell and Steele (1989) data are for shales across the Atlantic these may shed some light on overestimation of assumed values from world data-based tables of conductivity for shales.

It is apparent from our modelling (Figure 9), that the Q value of $70\text{--}80\text{mWm}^{-2}$ (after Majorowicz and Wybraniec, 2011, Majorowicz and Śafanda, 2018) imply lower mantle heat flux. The difference of 55mWm^{-2} vs 35mWm^{-2} , point to a difference in thermal LAB depth by approximately 50 km

Another argument stems from values of mantle heat flow of $50\text{--}60\text{mWm}^{-2}$, based on higher surface heat flow of 100mWm^{-2} . Such values are “extremely” unlikely (see Čermak 1993; Majorowicz et al 2019) and fit much younger thin lithosphere like the Pannonian basin and not an old Variscan platform in south-western Poland. Puziewicz et al (2019) who modelled input from Cenozoic alkaline volcanism at ca. 30–18 Ma in South Western platform of Poland showed that Q_M is in the range of $28\text{--}36\text{mWm}^{-2}$, which agrees with our estimate for Q_M of $26\text{--}38\text{mWm}^{-2}$. It locally may have been higher due to site-specific alkaline volcanic activity. It increased slightly the presently observed Q_0 and Q_M by ca. 4mWm^{-2} only. We see much lower LAB depth (56 km) assuming Q of 100mWm^{-2} for SW Poland from Figure 2 than assuming Q of 80mWm^{-2} . For the same site LAB depth is nearly 100 km for assumed heat production models. Such depth based on lower Q value is close to within 10 km of seismologically determined LAB (Wilde-Piórko et al 2010). Recent mapping of LAB depth from several seismological and thermal data show that the depth 90–100 km is typical for much larger area of south western Poland (Majorowicz et al 2019a) and agrees with seismological LAB determinations.

High surface heat flow of $60\text{--}80\text{mWm}^{-2}$ is a regional feature characteristic for the South-Western part of Poland and North-Western part of Eastern Germany. This enlarged Q zone (Figure 1b and Figure 2) occurs between the Middle Odra Horst to SW and the Variscan Deformation Front (Majorowicz and Wybraniec, 2011; Figure 2 in Majorowicz and Śafanda 2018; Puziewicz et al, 2019; and Figure 2 in this paper).

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1998) has been used to produce maps. This work benefited from suggestions and modifications by editorial staff of IJTHFA.

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