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Display materials

INVERSE AND FORWARD GRAVITY MODELING FOR REVEALING THE CRUSTAL STRUCTURE OF VOLGA-URALIAN SUBCRATON

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GD3.3 Geodynamics of continental crust and upper mantle, and the nature of mantle discontinuities

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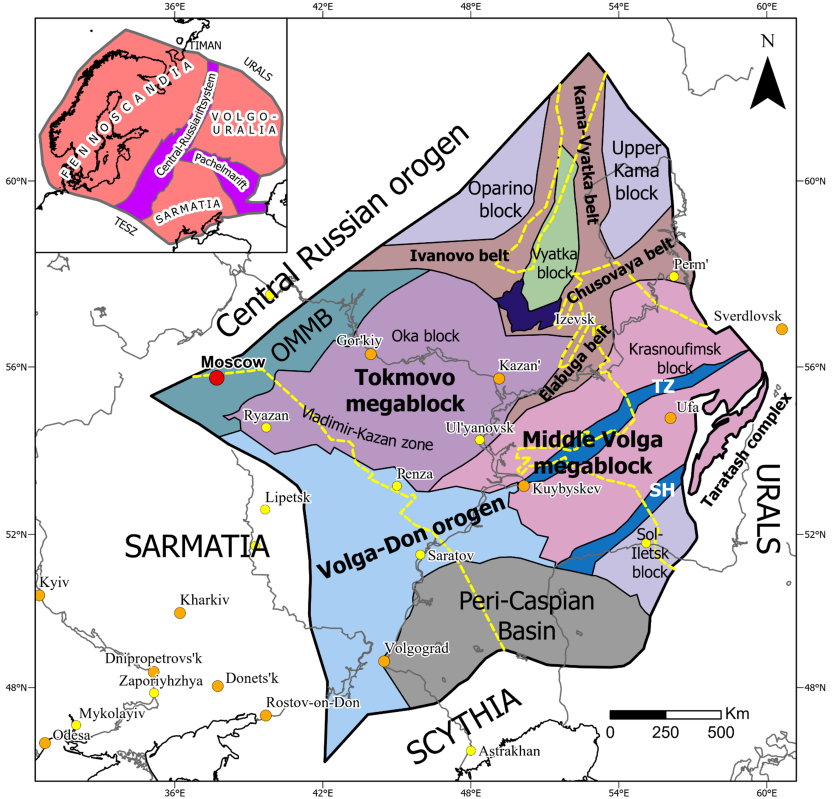
VOLGO-URALIA: TECTONIC SETTING



Tectonic setting of Volgo-Uralian subcraton (redrawn from Bogdanova et al., 2016)

Volgo-Uralia is a Neoarchean eastmost subcraton of the East European Craton. It is separated form the adjacent tectonic provinces by the large Proterozoic rift systems:

- Central-Russian rift system separates Volgo-Uralia from the Fennoscandian segment of the EEC
- Pachelma rift formed on the boundary between Volgo-Uralia and Sarmatia

On the East, Volgo-Uralia is detached from the Western Siberian plate by Phanerozoic Uralide orogeny.

a) b) c) Archean crust: a) 3.8-2.7 Ga, b) 3.2-2.7 Ga, c) Inferred Archean blocks

Archean and Paleoproterozoic crust reworked in deformation belts at 2.0-1.9 Ga

Tuymaza (TZ) and Sharlyk (SH) deformation zones

a) b) c) Paleoproterozoic crust: a) 2.3-2.1 Ga, b) 2.0-1.95 Ga, c) <2.1 Ga

Ultramafic and mafic intrusions of ca. 2.4-2.0 Ga

Peri-Caspian Basin which includes Mesoproterozoic to Phanerozoic successions

Volgo-Uralia boundary

Tectonic boundaries of Volgo-Uralian crustal blocks

Aulacogens' main boundaries (1.6-1.0 Ga)

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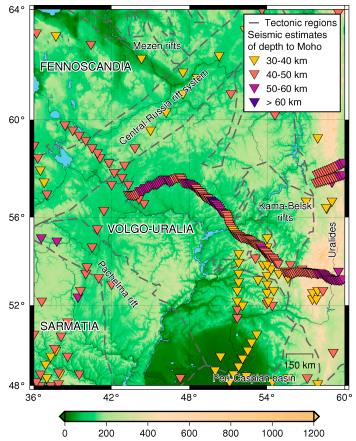
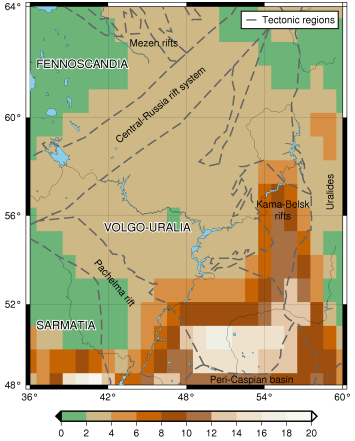
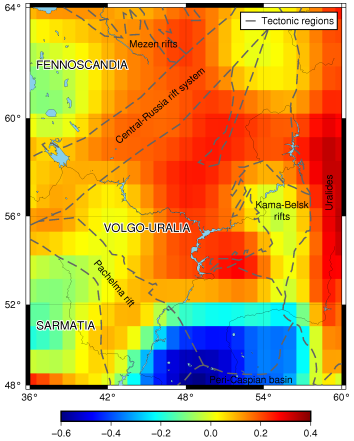
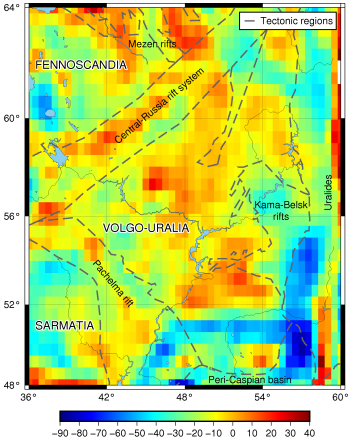
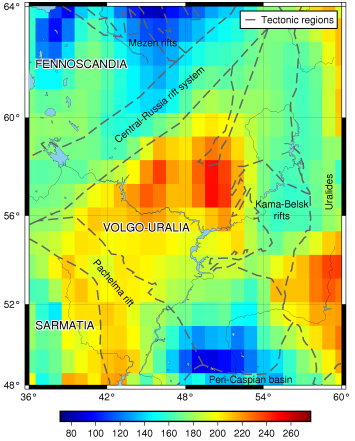
INPUT DATA AND MODELING WORKFLOW

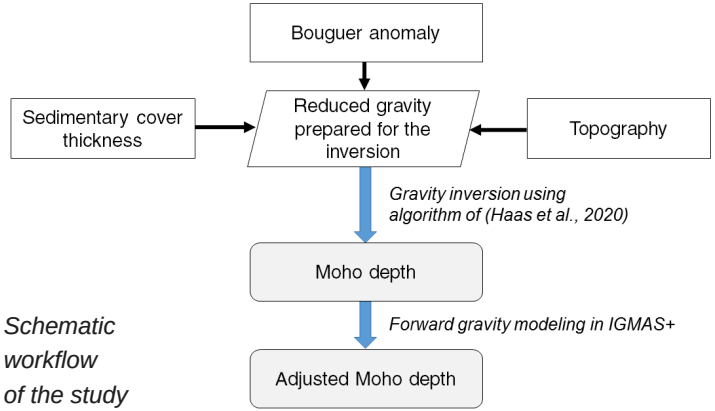












Schematic workflow of the study

Data used in the study:

Seismic data
- USGS global seismic catalog (Chulick et al., 2013)
- TATSEIS-2003, URSEIS-95, UWARS, ESRU reflection profiles (Trofimov, 2006;Tryggvason et al., 2001, Puchkov, 2010; Thouvenot et al., 1995; Brown et al., 2002, Rybalka et al., 2006)

Gravity data
- GOCE gravity gradients (Bouman et al., 2016)
- XGM2019e gravity field model (Zingerle et al., 2019)

Structural data
- ETOPO1 relief (Amante and Eakins, 2009)
- EUNAseis sedimentary thickness (Artemieva and Thybo, 2013)
- LAB interface (Artemieva, 2019)

Petrophysical data
- Constraints on sedimentary, crustal, and mantle densities (Artemieva, 2007)

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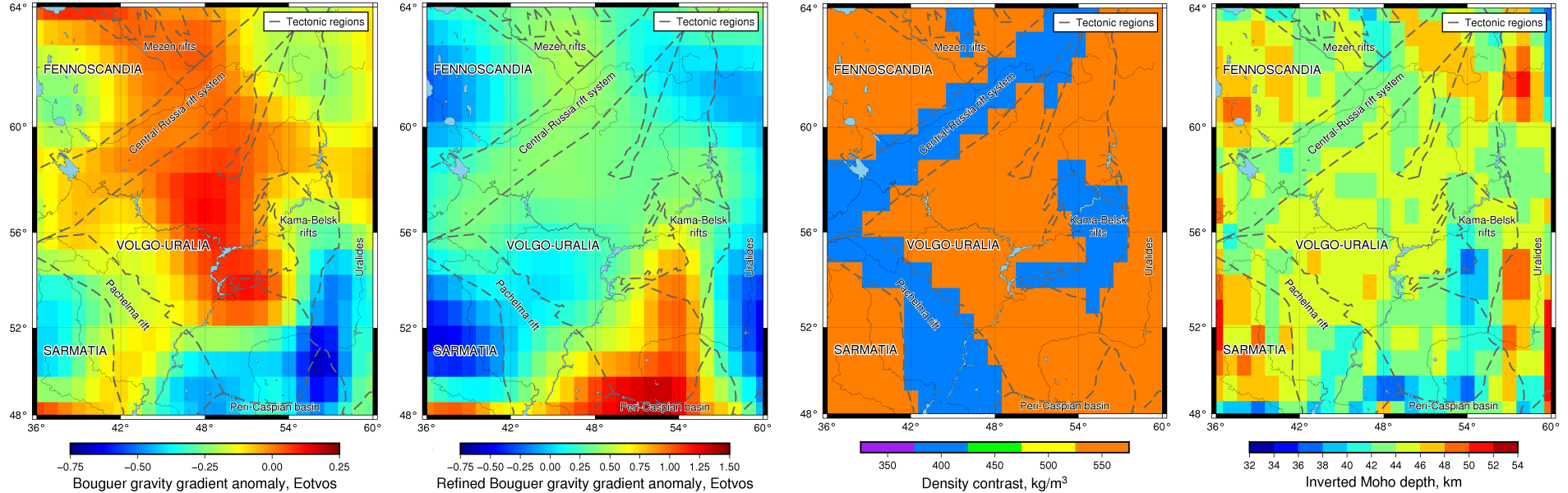
GRAVITY FIELD INVERSION



Gravity gradient field was prepared for the inversion by subtracting gravity effect of the sedimentary cover from the Bouguer gravity gradient anomaly:

$$G_{REFINED} = G_{BG} - G_{SED}$$

Gravitational effect of sediments was calculated using tesseroids (Uieda et al., 2016).

Input parameters for the gravity inversion:

- 3 tectonic regions: Cratons, Proterozoic rifts, Uralides
- Range of density contrasts: from 350 to 550 kg/m^3 with 50 kg/m^3 step
- Range of reference Moho depths: from 41 to 50 km with 1 km step

As a result reference depth of 46 km was used. Also, Proterozoic rifts were assigned a density contrast of 400 kg/m^3, and Cratons with the Uralides of 550 kg/m^3.

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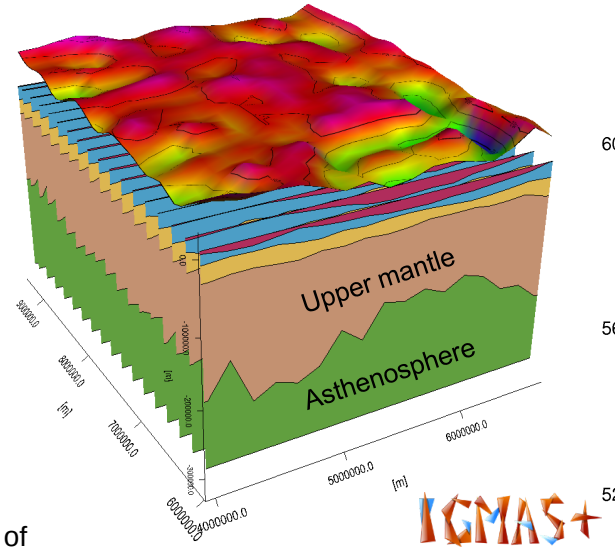
FORWARD GRAVITY MODELING - 1

Forward gravity modeling was performed in IGMAS+ software (Götze and Lahmeyer, 1988; Schmidt et al., 2020):

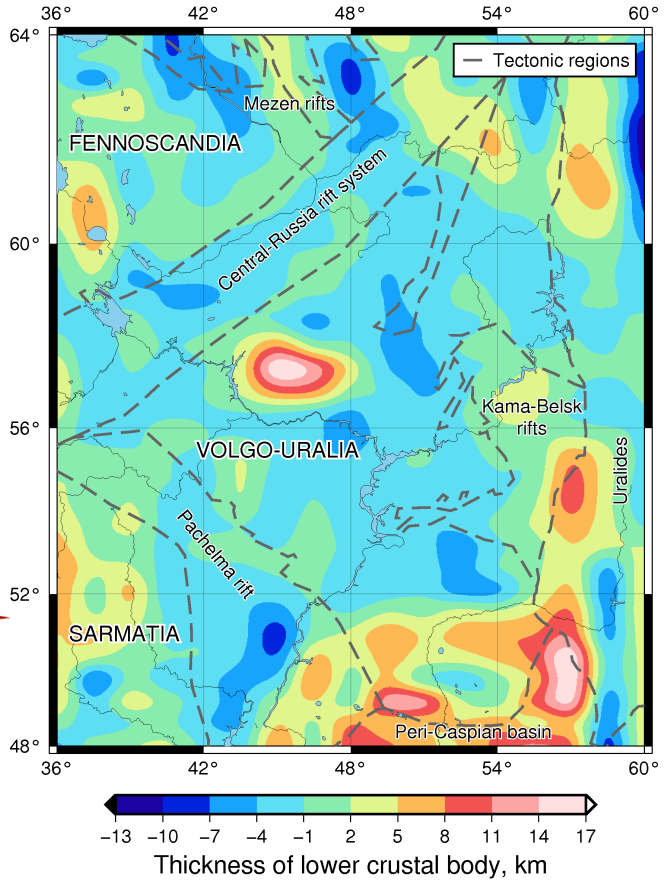
Initially the model contained five layers:

1) Sedimentary cover
2) Upper crust
3) Lower crust
4) Upper Mantle
5) Asthenosphere



IGMAS+ model

- During the adjustment of the model to seismic data, gravity misfit of ca. 100 mGal was found in the center of Volga-Uralian subcracton
- We attributed this misfit to underplated body of 3100 kg/m^3 density
- We confirmed our finding by the isostatic calculations
- It gave us average thickness of the underplated body of ca. 10 km.

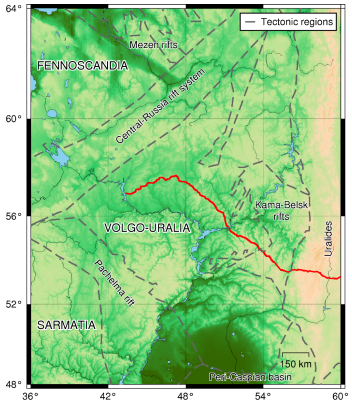


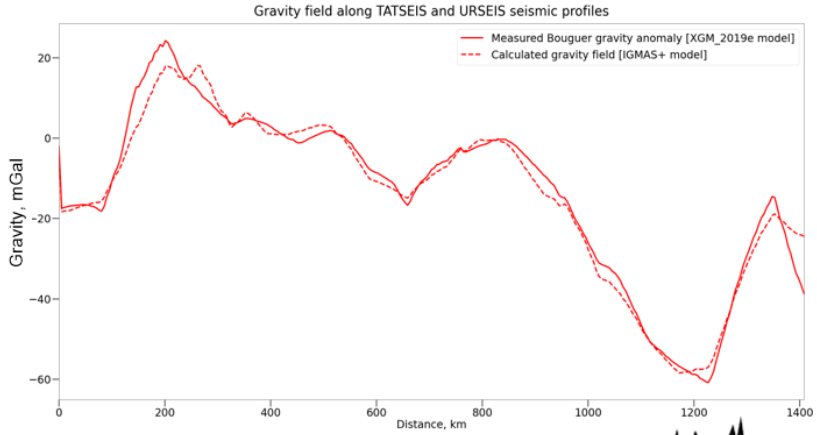
FORWARD GRAVITY MODELING - 2

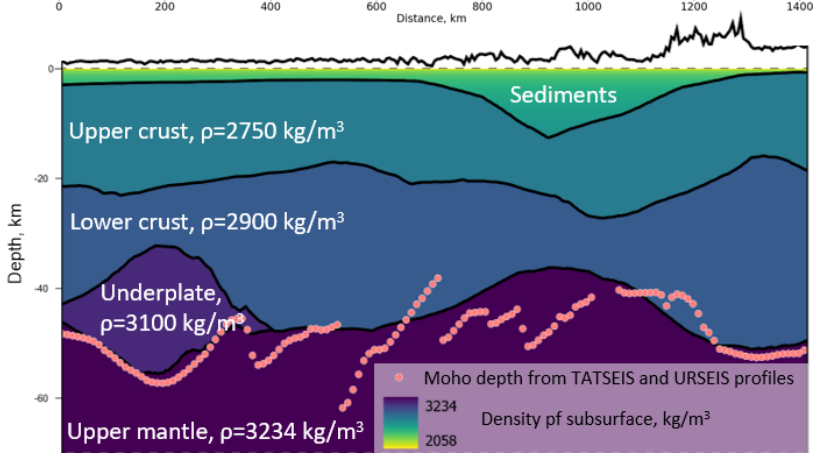
Density model used in the study

Layer	Density, kg/m³
Sedimentary cover	2430×z^0.045*
Upper crust	2750
Lower crust	2900
Upper mantle	3234
Asthenosphere	3224

** z – ½ of the depth of sedimentary strata in km*







Model cross-section along TATSEIS-2003 and URSEIS seismic profiles

In order to fit the gravity signal calculated from the 3D model to the observed gravity data, Bouguer gravity anomaly from XGM2019e global gravity field model was used:

- Standard deviation of measured gravity from the calculated gravity is 5.7 mGal;
- Correlation coefficient of measured and calculated gravity is 0.952;

✓ Finally, both seismic and gravity constraints were respected with the sufficient fit of measured and calculated gravity data.

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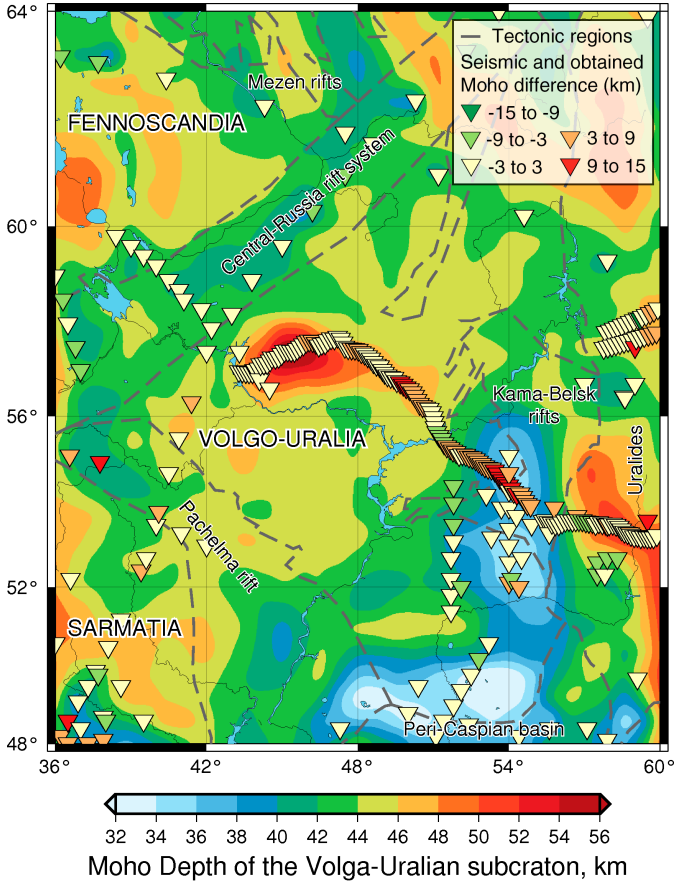
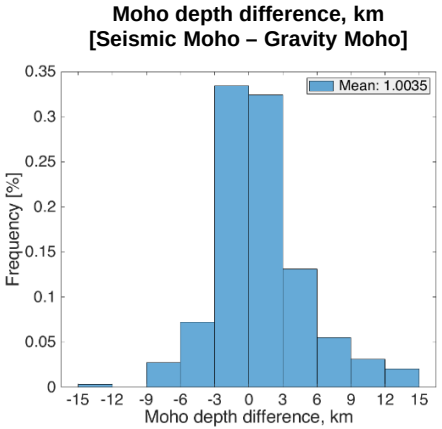
RESULTS



As a result, crustal model of the Volga-Uralian subcraton was obtained:

- The model showed crustal thickness variation from 32 to more than 55 km in some areas;
- The thinnest crust with the thickness below 40 km appeared on the Pericaspian basin which corresponds to the thickest sedimentary column;
- A relatively thin crust was found along the central Russia rift system;
- The thickest crust is located underneath Ural Mountains as well as in the center of the Volga-Uralian subcraton. In both domains it exceeds 50 km.



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CONCLUSIONS

- New crustal model of the Volga-Uralian subcraton was obtained using gravity inversion and thorough forward gravity modeling with seismic constrains. It respects all the main geological features of the Volga-Uralian subcraton and its surroundings;
- The 3D forward gravity modeling reveals a considerable gravity misfit in the central part of the study area which supports the hypotheses of underpladed body located on the top of the Moho (Artemieva and Thybo, 2013);

Future work:

Geothermal modeling of the area using the obtained crustal model as a basis.

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- The work has performed within the cooperation between two universities: Kiel University, Germany and Kazan Federal University, Russia.

Further questions:

GD3.3

Geodynamics of continental crust and upper mantle, and the nature of mantle discontinuities

Co-organized by SM4, co-sponsored by ILP

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REFERENCES

- Amante, C., Eakins, B.W., 2009. 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. NOAA Technical Memorandum NESDIS, NGDC-National Geophysical Data Center, NOAA 24.
- Artemieva, I.M., 2019. Lithosphere structure in Europe from thermal isostasy. Earth-Science Reviews 188, 454–468. https://doi.org/10.1016/j.earscirev.2018.11.004
- Artemieva, I.M., 2007. Dynamic topography of the East European craton: Shedding light upon lithospheric structure, composition and mantle dynamics. Global and Planetary Change 58, 411–434. https://doi.org/10.1016/j.gloplacha.2007.02.013
- Artemieva, I.M., Thybo, H., 2013. EUNAseis: A seismic model for Moho and crustal structure in Europe, Greenland, and the North Atlantic region. Tectonophysics 609, 97–153. https://doi.org/10.1016/j.tecto.2013.08.004
- Bogdanova, S.V., Gorbatschev, R., Garetsky, R.G., 2016. EUROPE|East European Craton☆, in: Reference Module in Earth Systems and Environmental Sciences. Elsevier, p. B978012409548910020X. https://doi.org/10.1016/B978-0-12-409548-9.10020-X
- Bouman, J., Ebbing, J., Fuchs, M., Sebera, J., Lieb, V., Szwillus, W., Haagmans, R., Novak, P., 2016. Satellite gravity gradient grids for geophysics. Sci Rep 6, 21050. https://doi.org/10.1038/srep21050
- Brown, D., Juhlin, C., Tryggvason, A., Steer, D., Ayarza, P., Beckholmen, M., Rybalka, A., Bliznetsov, M., n.d. The crustal architecture of the Southern and Middle Urals from the URSEIS, ESRU, and Alapaev reflection seismic surveys 17.
- Chulick, G.S., Detweiler, S., Mooney, W.D., 2013. Seismic structure of the crust and uppermost mantle of South America and surrounding oceanic basins. Journal of South American Earth Sciences 42, 260–276. https://doi.org/10.1016/j.jsames.2012.06.002
- Götze, H.J., Lahmeyer, B., 1988. Application of three-dimensional interactive modeling in gravity and magnetics. Geophysics 53, 1096–1108.
- Haas, P., Ebbing, J., Szwillus, W., 2020. Sensitivity analysis of gravity gradient inversion of the Moho depth—a case example for the Amazonian Craton. Geophysical Journal International 221, 1896–1912. https://doi.org/10.1093/gji/ggaa122
- Laske, G., Masters, G., Ma, Z., Pasyanos, M., 2013. Update on CRUST1.0 - A 1-degree Global Model of Earth's Crust, in: Geophysical Research Abstracts. Presented at the EGU2013-2658.
- Mooney, W.D., 2015. Crust and Lithospheric Structure - Global Crustal Structure, in: Treatise on Geophysics. Elsevier, pp. 339–390. https://doi.org/10.1016/B978-0-444-53802-4.00010-5
- Puchkov, V.N., 2010. Geology of the Urals and Cisurals (topical issues of stratigraphy tectonics, geodynamics and metallogeny). DesignPoligrafService (in Russian).
- Rybalka, A.V., Petrov, G.A., Kashubin, S.N., Yukhlin, K., 2006. Middle Ural transect ESRU, in: Structure and Dynamics of the Lithosphere of Eastern Europe. Results of Studies under the EUROPROBE Programme (in Russian). GEOKART, GEOS, Moscow, pp. 390–402.
- Schmidt, S., Anikiev, D., Götze, H.-J., Gomez Garcia, À., Gomez Dacal, M.L., Meeßen, C., Plonka, C., Rodriguez Piceda, C., Spooner, C., Scheck-Wenderoth, M., 2020. IGMAS+ – a tool for interdisciplinary 3D potential field modelling of complex geological structures., in: EGU General Assembly Conference Abstracts. p. 8383. https://doi.org/10.5194/egusphere-egu2020-8383
- Thouvenot, F., Kashubin, S.N., Poupinet, G., Makovskiy, V.V., Kashubina, T.V., Matte, Ph., Jenatton, L., 1995. The root of the Urals: evidence from wide-angle reflection seismics. Tectonophysics 250, 1–13. https://doi.org/10.1016/0040-1951(95)00058-8
- Thybo, H., Artemieva, I.M., 2013. Moho and magmatic underplating in continental lithosphere. Tectonophysics 609, 605–619. https://doi.org/10.1016/j.tecto.2013.05.032
- Trofimov, V.A., 2006. Deep CMP seismic surveying along the Tatseis-2003 geotraverse across the Volga-Ural petroliferous province 40, 14.
- Tryggvason, A., Brown, D., Pérez-Estaún, A., 2001. Crustal architecture of the southern Uralides from true amplitude processing of the Urals Seismic Experiment and Integrated Studies (URSEIS) vibroseis profile. Tectonics 20, 1040–1052. https://doi.org/10.1029/2001TC900020
- Uieda, L., Barbosa, V.C.F., Braitenberg, C., 2016. Tesseroids: Forward-modeling gravitational fields in spherical coordinates. GEOPHYSICS 81, F41–F48. https://doi.org/10.1190/geo2015-0204.1
- Zingerle, P., Pail, R., Gruber, T., Oikonomidou, X., 2019. The experimental gravity field model XGM2019e. GFZ Data Services.