Autoreferat

1. First and family name.
Wojciech Czuba

2. Diplomas held, scientific/artistic degrees – with name, place and year of obtainment, and title of PhD thesis.

1994 – Master of Sciences, field: geophysics, specialization: physics of lithosphere, University of Warsaw, Faculty of Physics, Institute of Geophysics

2005 – PhD in Earth Sciences, dissertation tilte: „Sejsmiczne modelowanie struktury skorupy ziemskiej w rejonie północno-zachodniego Spitsbergenu" (ang. Seismic modelling of the Earth's crustal structure in the north-western Spitsbergen region), Institute of Geophysics in Warsaw, Polish Academy of Sciences

3. Information about history of employment in scientific/artistic institutions.

1994 – present – Institute of Geophysics in Warsaw, Polish Academy of Sciences, Seismology Department, then Independent Laboratory of Deep Structures, currently Department of the Lithospheric Research.

4. Indication of the achievement issued from the art. 16 par. 2 of the act from 14th March, 2003 about scientific degrees and scientific title, and about degrees and title in arts (Dz. U. 2016 r. poz. 882 ze zm. w Dz. U. z 2016 r. poz. 1311.):

a) Title of the scientific achievement

Three-dimensional seismic lithospheric structure of the western Svalbard particularly in the area of the continental passive margin

b) (author/authors, publication title/titles, year of issue, publisher's name)

Czuba W., Grad M., Guterch A., Majdański M., Malinowski M., Mjelde R., Moskalik M., Środa P., Wilde-Piórko M. and Nishimura Y., 2008. Seismic crustal structure along the deep transect Horsted'05, Svalbard, ***Polish Polar Research*** 29 (3), 279-290.

Czuba W., Grad M., Mjelde R., Guterch M., Libak A., Krüger F., Murai Y., Schweitzer J. and the IPY Project Group, 2011. Continent–ocean-transition across a trans-tensional margin segment: off Bear Island, Barents Sea, ***Geophys. J. Int.***, 184, 541-554, doi: 10.1111/j.1365-246X.2010.04873.x

Czuba W., 2013. Seismic View on the Svalbard Passive Continental Margin, ***Acta Geophysica***, 61 (5), 1088-1100, DOI: 10.2478/s11600-013-0126-0

Krysiński L., Grad M., Mjelde R., **Czuba W.** and Guterch A., 2013. Seismic and density structure of the lithosphere−asthenosphere system along transect Knipovich Ridge−Spitsbergen−Barents Sea – geological and petrophysical

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implications, ***Polish Polar Research***, 34 (2), 111–138, DOI: 10.2478/popore-2013-0011

Czuba W., 2017. 3-D seismic tomographic modelling of the crustal structure of northwestern Svalbard based on deep seismic soundings, ***Geophys. J. Int.***, 208, 508-520, doi: 10.1093/gji/ggw418

c) elaboration of the scientific target of the work/works listed above and elaboration of results together with evaluation of possible utilization.

Svalbard Archipelago is located at the north-western corner of the Barents Sea continental platform bordered to the west by passive continental margin. Spitsbergen is the main island of the archipelago. This region is an interesting and important area for understanding the evolution of the North Atlantic and Arctic Oceans. This is the youngest region of the Atlantic and Arctic Oceans giving a good source to study processes leading to their opening. Rifting and subsequent sea-floor spreading processes in the North Atlantic Ocean and the development of the passive sheared continental margin of Svalbard and the Barents Sea continental platform, these are the processes which form the today's face of the Earth. The development of this margin is strongly connected with the history of opening of the North Atlantic Ocean. (Czuba, 2013)

The geological history of Svalbard Archipelago is ranging in age from Precambrian to Cenozoic. Its structure reflects the relative activity of the Eurasian and the North American plates. The evolution of the North Atlantic Ocean can be divided into two main phases.

The continental break-up occurred and sea floor spreading started along the Reykjanes, Aegir and Mohns Ridges during the first phase in the Early Eocene. The shearing along faults between northeast Greenland and Svalbard has created the Spitsbergen fold and thrust belt to the north. Dense mantle material was intruded most significantly at the Vestbakken Volcanic Province after thinning and weakening of the crust. (Czuba *et al.*, 2011)

The second phase of North Atlantic evolution was marked by a change in the spreading direction from NNW-SSE to NW-SE. This has begun in Early Oligocene when spreading in the Labrador Sea stopped. The beginning of the phase has unlocked the northward development of the Mid Atlantic Ridge. The spreading axis has developed into the Spitsbergen Shear Zone creating the asymmetric, ultraslow and obliquely-spreading Knipovich Ridge. Around 23 Ma ago spreading started further, along the Molloy Ridge, and around 10 Ma ago continental break-up occurred along the Fram Strait. This has established connection between the Arctic and the Northern Atlantic ridges. (Czuba, 2013)

Good quality records of refracted and reflected P waves were obtained along the entire seismic profiles lengths during several international Arctic expeditions. They are an excellent data base for following seismic modelling along the profiles as well as 3-D seismic modelling. (Czuba *et al.*, 2008, 2011; Czuba, 2013, 2016)

A minimal depth of about 6 km of the Moho discontinuity was determined east of the Molloy Deep. There, the upper mantle exhibits P-wave velocity of about 7.9 km/s, and the crustal thickness does not exceed 4 km. It is associated with the Molloy Transform Fault Zone or with the Molloy Ridge connecting the Molloy Transform Fault Zone with the Spitsbergen Transform Fault Zone. (Czuba, 2013, 2016)

The Moho discontinuity dips down to 28 km beneath the continental part of the 99200 (northernmost profile) and K1 profiles and down to maximum 32 km beneath the other profiles. The P-wave velocity below the Moho interface increases generally up to 8.2 km/s, reaching maximal 8.6 km/s beneath the continental part of the profile located in the central part of the west coast of Spitsbergen. The continental crust consists of two or three crystalline layers. The lowermost crustal continental layer with the P-wave velocity in the order of 7 km/s does not exist in the continental crust along three of the profiles. It is completely missing (BIN-2008) (Czuba, 2013) or it exists in the transition zone only (99200, Horsted '05) (Czuba *et al.*, 2008; Czuba 2013). These layers or even high velocity bodies are connected with serpentinizing or partial melting in the magma-reach region. A layer characterised by P-wave velocities significantly above 7 km/s is found along the continental part of the BIS-2008 profile but it is very thin and it is hard to define as a normal continental lower crust. Profiles 99400 and K1 show clear continental lower crustal layer characterised by P-wave velocities 6.7-7.0 km/s and 7.1-7.2 km/s, respectively (Czuba, 2013).

The oceanic crust is generally similar in terms of thickness along all the profiles studied but it is composed of more layers in those three southern profiles, where opening of Northern Atlantic happened earlier. Differences in crustal thickness are the result of different spreading rate in the tectonic history. The thickness is minimal in the vicinity of mid-oceanic ridge. There, the P-wave upper mantle velocities are lowest along these profiles, being even lower than 7.9 km/s. The sedimentary part of the continent–ocean transition zone is characterised by a complex basin structure, known in the Spitsbergen region as west Spitsbergen foreland basin. The P-wave velocity at the topmost layers is very low, being even 1.8-1.9 km/s (BIS-2008, 99200), what indicates high water saturation of the rock body. (Czuba *et al.*, 2011; Czuba, 2013)

Margins crossing by several of the profiles have the character of sheared margin with rather short continent-ocean transition and abrupt change of the crustal thickness (99400, K1, Horsted '05). The shearing took place mostly along the Hornsund Fault Zone. Margins crossing by the other profiles have more complex history and their transition zone structure indicate the transform character in the past, but in the present they can be classified rather as rifted margins with ultra-slow spreading. (Czuba, 2013)

Seismic modelling for K1 profile and C3/C1 transect (profiles C1 and C3) was conducted to coincide parameters at the crossing area. Remodelling of the C1 profile was done to fit better the recorded seismic data. It has resulted in changing of the seismic model. The difference is obtained in the lower crustal layer, where P-wave velocities are in the corrected model 0.15 km/s in an average higher, than those along K1 profile in the same place. Moreover, the Moho depth agrees better in both models. According to accuracy discussion in several papers with the same seismic modelling method used this velocity difference is significant. (Czuba, 2013)

The C1 profile runs along the Spitsbergen coast and it is approximately parallel to main geological structures, while the K1 profile crosses these structures (e.g. Knipovich Ridge and Hornsund Fault Zone) and the C1 profile almost perpendicularly. It could mean therefore that the P-wave velocity difference is the result of a P-wave velocity anisotropy. It is rather small anisotropy, in the order of 2 %. The anisotropy is rather not connected with cracks and faults existing closer to the surface. It could be connected with extensional regime acting in the lower crust during spreading processes in the Knipovich Ridge. (Czuba, 2013)

It was possible to model very accurately the seismic crustal structure along profiles located in the western Svalbard and Barents Sea continental passive margin. There were found sedimentary basins (probably of Cenozoic sequence) with a low seismic velocity and the thinned continental crust in the continent-ocean transition zone. The detailed DSS model along the Horsted '05 profile supplemented by results of other seismic interpretations allowed to perform lithospheric gravity modelling. This helped to expand the tectonic interpretation (Krysiński *et al.*, 2013).

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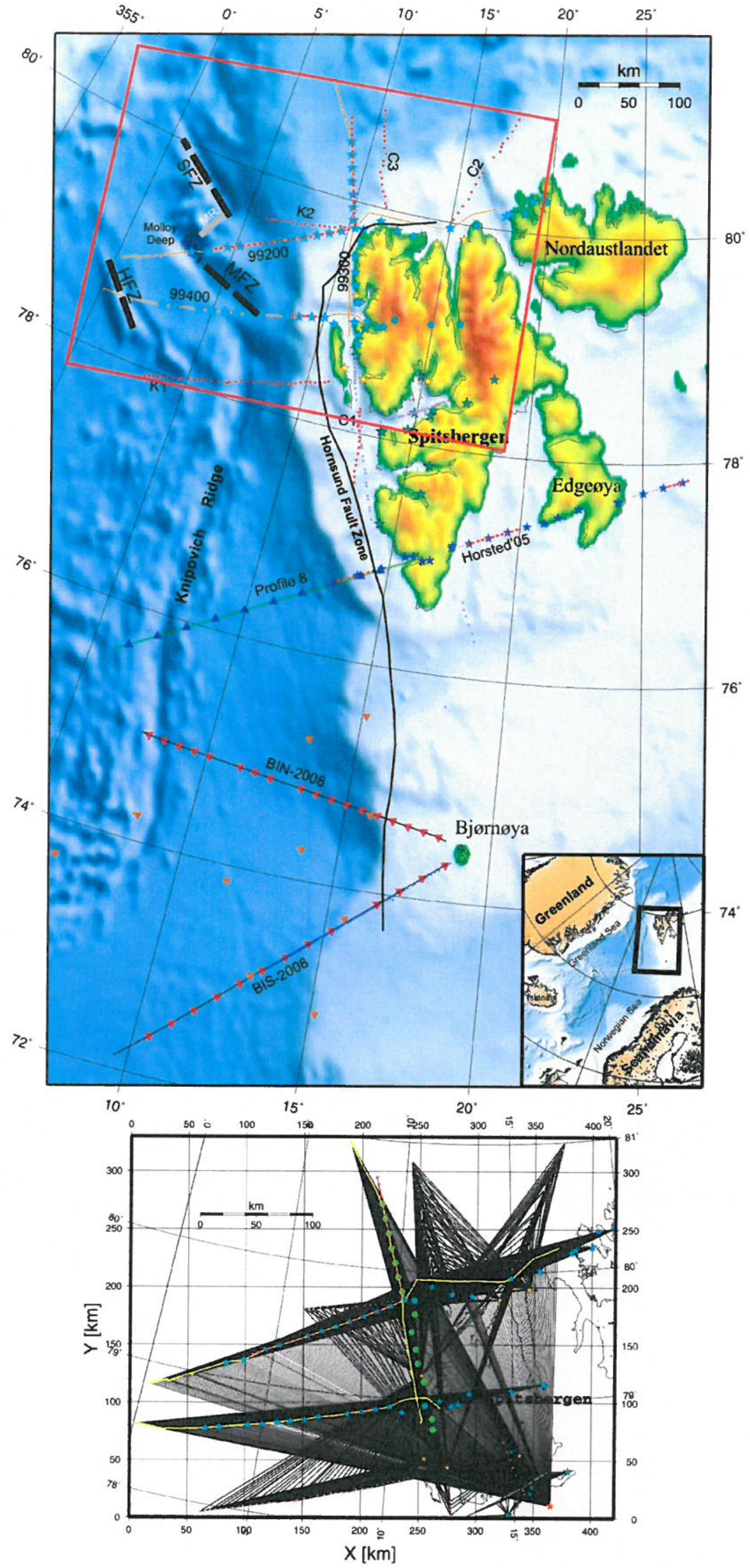

Fig. Location map of the seismic study area in the Svalbard region with the 2-D seismic profiles. The red rectangular frame marks the 3-D modelling area. Below the scheme of the 3-D modelling area in geographical and Cartesian (km) coordinates. Thin black lines – 10% of airgun and all the TNT seismic ray paths connecting the sources and receivers.

Realized number of seismic WARR profiles together with additional off-line recordings allowed to constrain a 3-D image of the crustal structure of the northwestern Svalbard region by a real 3-D seismic modelling scheme, not only based on interpolation and extrapolation of 2-D profiles (Czuba, 2016). The seismic sources from 1999 experiment were additionally recorded by the Isfjorden NORSAR permanent seismic station (SPITS) and incorporated to this modelling. This is the first attempt of such crustal modelling in this region.

The geometry setup of the seismic measurements in the study area was not planned as 3-D acquisition, however, a compilation of the records from several projects gives a 3-D coverage of the study area. The ray coverage is not as dense as it would be in a truly 3-D planned experiment; nevertheless, it allows to use a 3-D seismic modelling approach.

The resulted model gives general overview of the crustal velocity structure in the large, tectonically significant region. It gives also new information from areas outside the original seismic lines. The model (Czuba, 2016) can be compiled with gravity and geomagnetic anomalies. The model shows crustal thinning to the north but it is rather hard to distinguish the transition to the oceanic crust. It could be determined north of Spitsbergen along a southern limit of the low gravity anomalies.

A variation of the structure of the passive margin of Svalbard is clearly visible. The thickness of continental crust decreases to the north from about 35 km to 25 km. Such trend coincides with magnetic anomalies. The continent-ocean transition is characterized by significant shallowing of Moho interface of about 20 km or more, and the existence of quite large sedimentary basin with P-wave velocity even less than 2 km/s. This basin is less visible in the southern part of the margin where the mid-oceanic ridge is closer to the island. The transition zone is also characterized by clear change of the gravity anomalies from high to low to the west. The minimal crustal thickness of about 4 km is determined in the Knipovich Ridge and in the vicinity of the Molloy Deep. A low magnetic anomaly in its vicinity is observed, together with the lowest gravity anomalies. (Czuba, 2016)

The evolution of this region appears to be within a shear-rift tectonic setting. The continent–ocean transition zone along the northernmost profile is mostly dominated by extension, therefore the last stage of the development of the margin is classified as rifting. It can be interpreted as the result of an extensional regime, which probably has hidden previous shear structure of the margin crossed by the 99200 profile. The margin of the southern Spitsbergen is rather of sheared character, while the margin of the western Barents Sea is of slow to ultraslow spreading type. It could be explained by the tectonic history of the region. The most advanced spreading processes occur in the southern part of the study region, where the opening of the North Atlantic has started. Then new spreading processes have appeared in the north (Molloy Deep, Molloy Ridge), and the central part of the region (profiles 99400, K1, Horsted '05) has been keeping the transform regime for longer time. (Czuba *et al.*, 2008; Czuba, 2013, 2016)

The 3-D seismic model (Czuba, 2016) shows regional tectonic structure of the northwestern Svalbard region, which is characterized by passive margin features close to an active ultra-slow mid-oceanic ridge. It gives a general review of crustal structure variability of the continent-ocean transition zone along the west coast of Svalbard.

The understanding of crustal and upper mantle processes and structure is important not only just because of increasing of the knowledge about our planet Earth but it will be helpful for further economic exploration of the region.

5. Elaboration of the other research achievements.

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Working Groups connected to particular experiments appear in the author's lists of the published papers listed below. I belong to the Working Groups as a co-author.

Hrubcová P., Środa P. and CELEBRATION 2000 Working Group (Guterch A., Grad M., Janik T., **Czuba W.**, ...), 2008. Crustal structure at the easternmost termination of the Variscan belt based on CELEBRATION 2000 and ALP 2002 data, *Tectonophysics,* 460 (1-4), 55-75, doi:10.1016/j.tecto.2008.07.009

Malinowski M., Grad M., Guterch A. and CELEBRATION 2000 Working Group (Środa P., **Czuba W.**, Janik T., Gaczyński E., Keller G.R.), 2008. Three-dimensional seismic modeling of the crustal structure between East-European Craton and the Carpathians in SE Poland based on CELEBRATION 2000 data, *Geophys. J. Int.,* 173, 546-565, doi: 10.1111/j.1365-246X.2008.03742.x

Grad M., Tiira T. and ESC Working Group (**Czuba W.**, Gaczyński E., Grad M., Guterch A., Janik T, Majdański M., Malinowski M., Środa P., Wide-Piórko M.), 2008. The Moho depth map of the European Plate, *Geophys. J. Int.*, 176 (1), 279-292, doi: 10.1111/j.1365-246X.2008.03919.x

Grad M., Brückl E., Majdański M., Behm M., Guterch A. and CELEBRATION 2000 and ALP 2002 Working Groups (... **Czuba W.**, ...), 2009. Crustal structure of the Eastern Alps and their foreland: seismic model beneath the CEL10/Alp04 profile and tectonic implications, *Geophys. J. Int.*, 177, 279-295, doi: 10.1111/j.1365-246X.2008.04074.x

Janik T., Grad M., Guterch A. and CELEBRATION 2000 Working Group (... **Czuba W.**, ...), 2009. Seismic structure of the lithosphere between the East European Craton and the Carpathians from the net of CELEBRATION 2000 profiles in SE Poland, *Geological Quarterly*, 53 (1), 141–158.

Malinowski M., Środa P., Grad M., Guterch A. and CELEBRATION 2000 Working Group (... **Czuba W.**, ...), 2009. Testing robust inversion strategies for three-dimensional Moho topography based on CELEBRATION 2000 data, *Geophys. J. Int.,* 179, 1093–1104.

Papers listed above are the results of my work in many, mainly international, projects of seismic investigations using WARR technique (called DSS, too). I was also involved in the passive seismic project called PASSEQ, where many seismic stations observed teleseismic events (Wilde-Piórko *et al.*, 2008). Determination of Earth's crustal and upper mantle structure in one of the most interesting Europe's region like Trans European Suture Zone (TESZ), also called Teisseyre-Tornquist Zone (TTZ), and Carpathians with adjacent tectonic units allowing better understanding of tectonic processes creating our continent was the purpose of these projects. I was involved in several projects on the Ukrainian territory and its

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vicinity (Starostenko *et al.*, 2013, 2013, 2015, 2016). The eastern part of Ukraine is one of the most interesting places in Europe, where geological structures of different age with very dynamic origin are located within small area (Starostenko *et al.*, 2015, 2016). The other studies carried out with Ukrainian co-operation covered Carpathians and adjacent tectonic units like Pannonian Basin, East European Craton and Trans European Suture Zone (TESZ) (Starostenko *et al.*, 2013). These investigations have allowed to determine of the tectonic structure of Europe from the Palaeozoic Platform to East European Craton and from the Baltic Sea to the Adriatic and Black Seas. Obtained results have brought new look at geological evolution of Central Europe and Carpathians which has allowed progress of scientific discussion in Earth sciences community. Many of these results are applicable to the hydrocarbons exploration especially on Polish territory.

Two papers from those listed above describe application of the seismic modelling techniques to determination of ocean water features (temperature and salinity) and bottom oceanic sediment layers seismic features based on the example of an Arctic experiment. (Grad *et al.*, 2011, 2012)

One of the publications is the result of research made on the basis of a dense system of seismic profiles performed in Admiralty Bay (Antarctic) in the vicinity of the Arctowski Polish Polar Station. The research has allowed to determine deep geological structure of that region, especially in the sea part which is inaccessible for geologists. (Majdański *et al.*, 2008)

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