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History of Deep Seismic Soundings (DSS) Research in Poland and the Role of Professor Aleksander Guterch in its Development

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1. INTRODUCTION

Poland has a quite special location on the geological map of Europe. The Trans-European Suture Zone (TESZ) runs through the center of Poland. It is one of the most prominent tectonic units in Europe, a contact zone between the old, Precambrian, East European Craton (EEC), and the younger Paleozoic platform. Recognizing the deep structure of this zone is a great scientific challenge. The best research tools for this type of task are experimental seismic methods. Aleksander Guterch has taken up this challenge since the 1960s and created a strong research team I have been a member for 45 years. In his activities, he could initially count on the support of leading Polish geologists, Professors Jerzy Znosko, Władysław Pożaryski, Ryszard Dadlez and others, and also had good contacts with PGNiG (Polish Oil and Gas Company), Geofizyka Kraków, and Geofizyka Toruń enterprises. He can be called the "father" of DSS in Poland, although it must be admitted that Eng. Jan Uchman initiated this activity at the Department of Geophysics of the Polish Academy of Sciences in 1956.

Over the last few years, I have repeatedly tried to persuade Olek (Aleksander Guterch) to write down the history of the beginnings of deep seismic soundings (DSS) [GSS – głębokie sondowania sejsmiczne, in Polish] at the Institute of Geophysics of the Polish Academy of Sciences (IG PAS), previously, until 1971, the Department of Geophysics of the Polish Academy of Sciences. He usually replied that he had everything figured out and all that was left to put it down on paper. He flatly rejected offers of technical assistance. Unfortunately, he did not manage to fulfil this promise. Since I joined the team in 1978, I do not know the earliest period of DSS research from my own experience. After Olek's death, as the oldest employee, I was responsible for writing this story. I describe everything that concerns the years before 1978 on the basis of literature and fragmentary information obtained from former employees of the team or the Institute. They may be unreliable or incomplete, for which I apologize. At this point, I would like to thank many colleagues, former and current employees of the IG PAS, for supporting my knowledge of many details that I did not know or did not remember.

What does the name Deep Seismic Sounding mean? It is about researching the Earth's crust and upper mantle using experimental seismic methods, mainly active methods. In our case, these are refraction profiles with artificially generated seismic sources, usually detonations of chemical charges, made in holes drilled deep into the ground specifically for this purpose or at the bottom of shallow water reservoirs. We sometimes also use vibrators on land or air guns at sea as seismic energy sources. The latter are usually associated with reflective measurements. All such research requires huge, specialized technical and logistic support from geophysical companies specializing in seismic measurements. We usually cooperated with the PBG Geophysical Exploration Ltd., as well as with Geofizyka Kraków and Geofizyka Toruń.

The term "deep seismic soundings (DSS)", comes from the Russian (glubinnoye seismicheskoye zondirovania). In Western countries, the term "wide-angle reflection and refraction (WARR)", is more often used, which briefly defines which phases of seismic waves are used for interpretation.

This paper contains a brief description of projects in which the DSS research team of the IG PAS was the organizer and/or participant (Table 1); it is supplemented by four annexes published in electronic edition: Aleksander Guterch's Curriculum Vitae (Annex 1, https://pub.igf.edu.pl/files/Pdf/Arts/708.pdf?t=1732722512), Aleksander Guterch's Bibliography 1963–2023 (Annex 2, https://pub.igf.edu.pl/files/Pdf/Arts/709.pdf?t=1732722512), Measurement (Annex 3, https://pub.igf.edu.pl/files/Pdf/Arts/710.pdf?t=1732722512), and People (Annex 4, https://pub.igf.edu.pl/files/Pdf/Arts/711.pdf?t=1732722512). To enrich the otherwise plain text, Annexes 3 and 4 provide a collection of photos related to the development of measuring equipment and field experiments, as well as pictures of some members of the DSS team at work. The results of our extensive research have not been presented here, because this has been done in many other publications.

My intension was to present a condensed calendar of important, sometimes groundbreaking, events in the history of the Department of Lithospheric Research and Aleksander Guterch's participation in it. All our publications can be found on the website of the Department of Lithospheric Research, https://publikacje-zsbl.igf.edu.pl/.

Some data from our experiments can be obtained from the databases: EPOS-PL: https://cibsbl-platform.igf.edu.pl/ and IG PAS: https://dataportal.igf.edu.pl/organization/lithospheric-research. To obtain data that is not yet available in these databases, write to Department of Lithospheric Research IG PAS.

2. THE BEGINNINGS OF DSS RESEARCH

Preparations for the first DSS seismic experiment began at the Department of Geophysics of the Polish Academy of Sciences in 1956 under the supervision of Eng. Jan Uchman, who had already been involved in seismic exploration research in the Lviv region before the Second World War. Important problems to solve before the first measurements were testing solutions to ensure accurate measurement of the recording time and choosing the location of the first profile. The timing problem was solved by transmitting a standard time from the Central Office of Measures via the Warszawa I radio station, at a wavelength of 1320 m, which was received by seismic stations via ordinary transistor radio receivers. The first profile (A) was decided to be located between Racibórz (Radynia) and the Gulf of Gdańsk (around Stegna) with an additional shooting point near Konin. This profile location was chosen because it crossed the margin of the East European Craton. Measurements using 18 seismic devices, of course analogue, recording 6 channels on photographic paper, began along the profile in December 1960, and were continued, at 20 device spacings, in September and October of the following year. Measurements on the next profile (B) were carried out in 1963 and 1964, and on profile C in 1965 (Fig. 1). In 1963, a young graduate from the Faculty of Physics of the University of Warsaw (geophysicist), Aleksander Guterch, joined the small research team. The first publications presenting the interpretation of the data collected along the DSS profiles are signed with the names

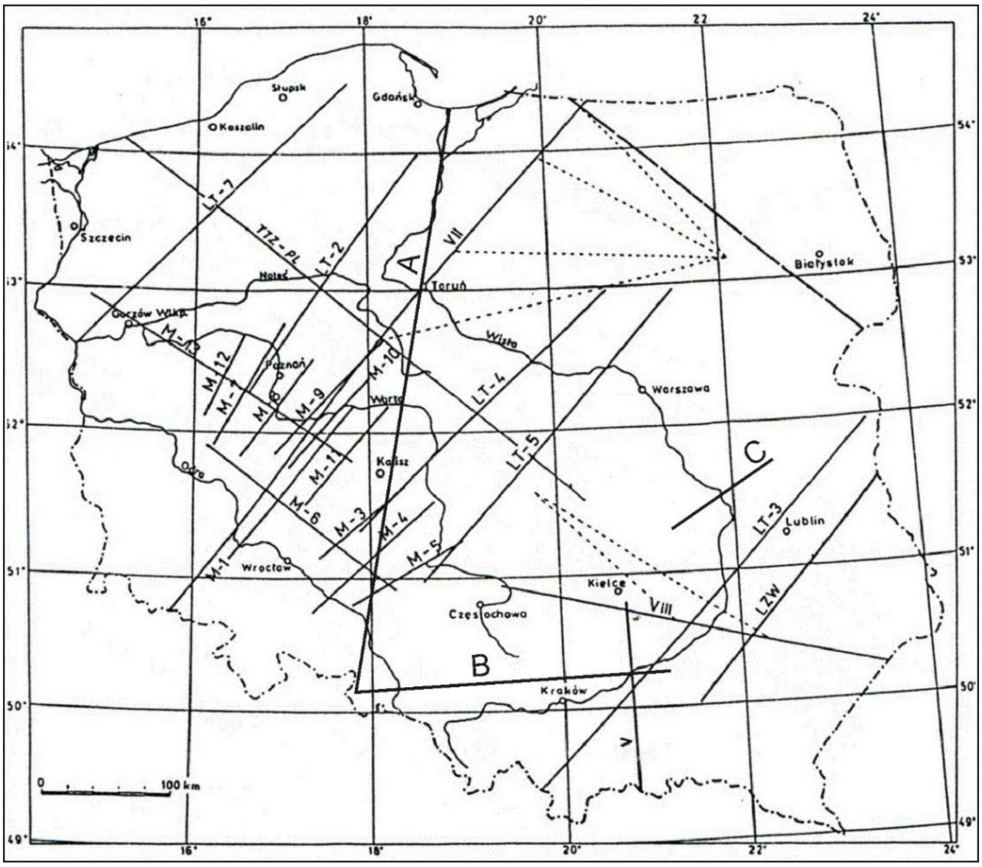


Fig. 1. Network of profiles of deep seismic soundings performed in the years 1960–1993 in Poland: first profiles, A, B, C; international profiles, V, VII, and VII; industrial profiles on the Fore-Sudetic Monocline, M-1 to M-13; profiles from the LT series: LT-2, LT-3, LT-4, LT-5, LT-7, and LZW (modified after Guterch et al. 1974; Guterch and Grad 1996).

of Bożenna Wojtczak-Gadomska, Aleksander Guterch, and Jan Uchman, in a different order of surnames, depending on the publication.

In 1969, the IG PAS DSS team joined the international DSS (research program conducted in Eastern European countries under the leadership of Prof. V.W. Sollogub from the Institute of Geophysics NANU in Kiev. As part of this cooperation, several international profiles were implemented. In Poland, measurements were made on profile V (Carpathian) in 1969, and on profiles VII and VIII in 1971–1973 (Fig. 1). In 1969, after defending his PhD, Aleksander Guterch took over the position of head of the Deep Seismic Sounding Laboratory. The team was also joined by geophysicists, Edward Perchuć (slightly earlier, from 1966, still as a technical employee), Jan Pajchel, and Eng. Rufin Materzok, M.Sc, with extensive experience in field work. A little later, in the 1970s, other colleagues joined us: technician Zbigniew Czerwiński, driver Zbigniew Gajewski, PhD student Marek Grad, who nominally worked at the Department of Geophysics, Faculty of Physics, University of Warsaw, but practically worked closely with the DSS team throughout his professional life, and in 1978 the team was joined by Tomasz Janik, graduate from the Faculty of Physical Oceanography of the University of Gdańsk. In the years 1971–1992, under the common name LT (LT-1 to LT-7), research work was carried out on a series of profiles crossing the edge of the East European Craton. The team also interpreted industrial profiles M-1 to M-13 made in 1967–1971 by Geofizyka Kraków on the Fore-Sudetic Monocline (Fig. 1). In the 1990s, other geophysicists joined the team: Edward Gaczyński, Piotr Środa, and Wojciech Czuba, and in the 2000s, Michał Malinowski and Mariusz Majdański, who later, in 2015, created the Geophysical Imaging Department.

The development of the DSS work was accompanied by the efforts of the staff of the Equipment Design Department of the IG PAS, who created subsequent generations of more perfect seismic equipment (see the online Annex 3 Measurement, https://pub.igf.edu.pl/files/Pdf/Arts/710.pdf?t=1732722512). Initially, they were very heavy six-channel tube devices, made in the Soviet Union, later replaced by devices

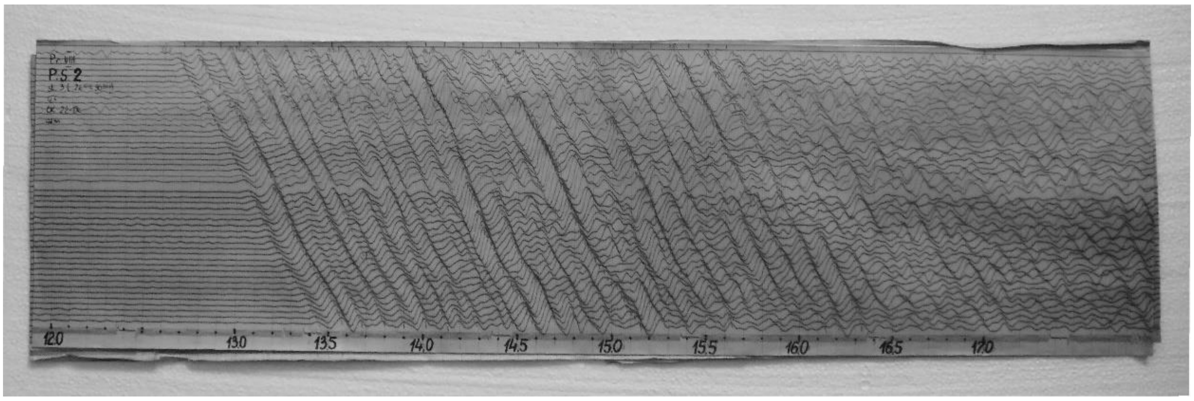


Fig. 2. Example of seismic recording from an industrial 48-channel equipment.

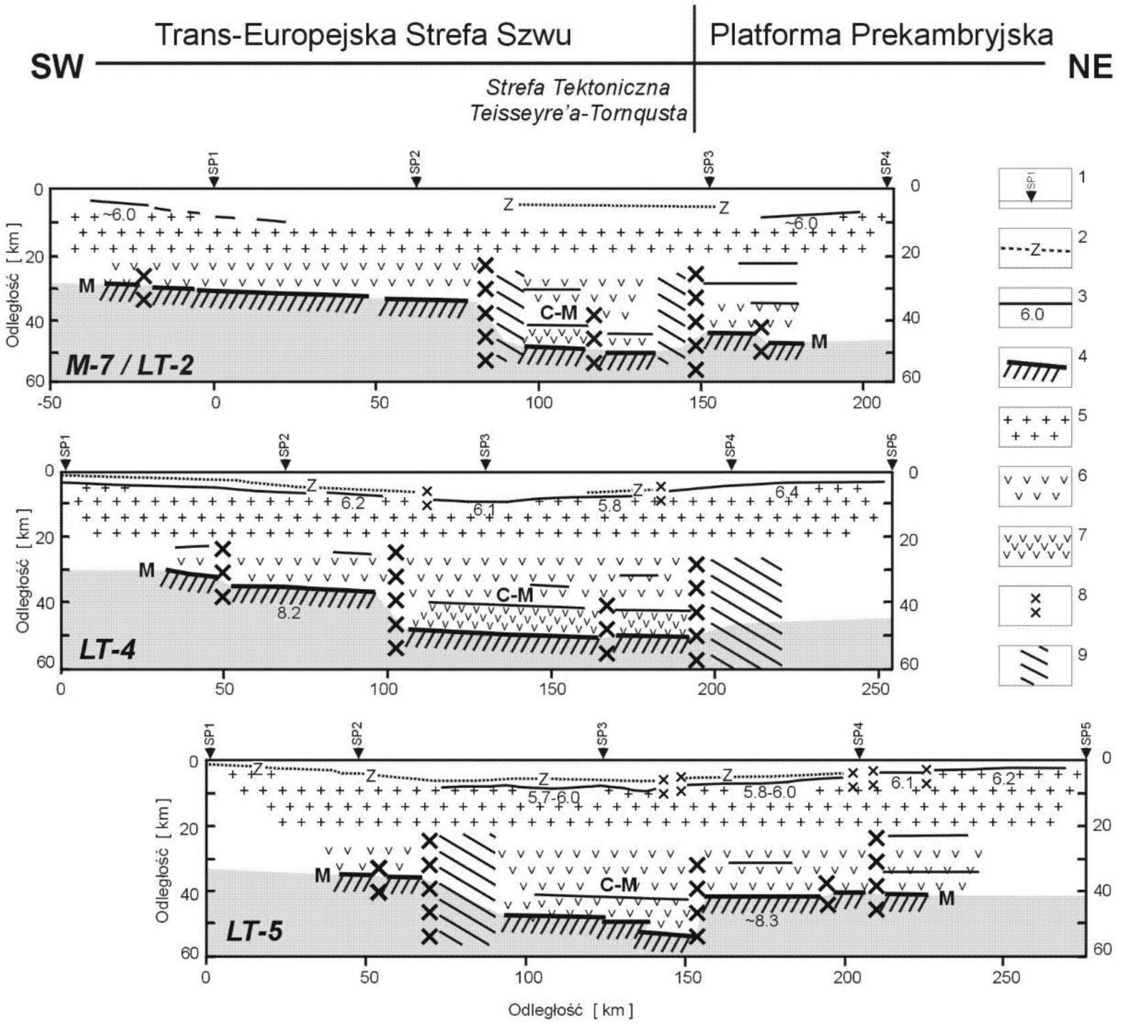


Fig. 3. Examples of seismic models from 1970 to1989 made using the 1D modeling technique. Cross-sections for profiles M-7/LT-2, LT-4, and LT-5 (modified after Grad et al. 2005).

of our own design, the H700, both with recording of seismic energy and timing on photosensitive paper. Six sensors connected to the equipment with cables were placed along the profile at distances of 100 or 200 m. Sometimes, in cooperation with industrial enterprises, 24- or 48-channel POISK devices were also used (Fig. 2). From the mid-1970s, in addition to recording on paper, analogue data began to be recorded on magnetic tapes, which were then digitized on a specially designed device. New designs of receivers for time signals transmitted from dedicated radio stations in Moscow and Bavaria (DCF) also came into use. However, measurements on subsequent profiles were still carried out extensively by using only a few or at most a dozen or so devices. This made it necessary to repeatedly move the equipment spacing along the profile and use the same shooting point locations to ensure appropriate registration density. This generated high work costs. The first experiment carried out with a larger number of seismic stations (over 100) was the TTZ-PL profile performed in 1993, in international cooperation (Universities of Hamburg, Uppsala, Helsinki, and Oulu). Only one sensor was connected to each of the devices, and most of them had the ability to operate automatically throughout the entire measurement night, without the need to manually press the start/stop button at each recording. However, this required a considerable amount of time to be devoted to digitizing these records at a later date. The use of a large number of equipment resulted in significant savings in blasting costs, which are always the largest expense. In the mid-1990s, seismic stations with digital recording and GPS time receivers became increasingly available. The digital revolution and political changes, as well as the opening to cooperation with Western partners in the late 1980s, allowed for a complete change in the philosophy of planning and conducting measurement works. At the same time, there have been major advances in seismic modeling methods and the use of computers. The previously common 1D modeling (Fig. 3) was replaced by 2D

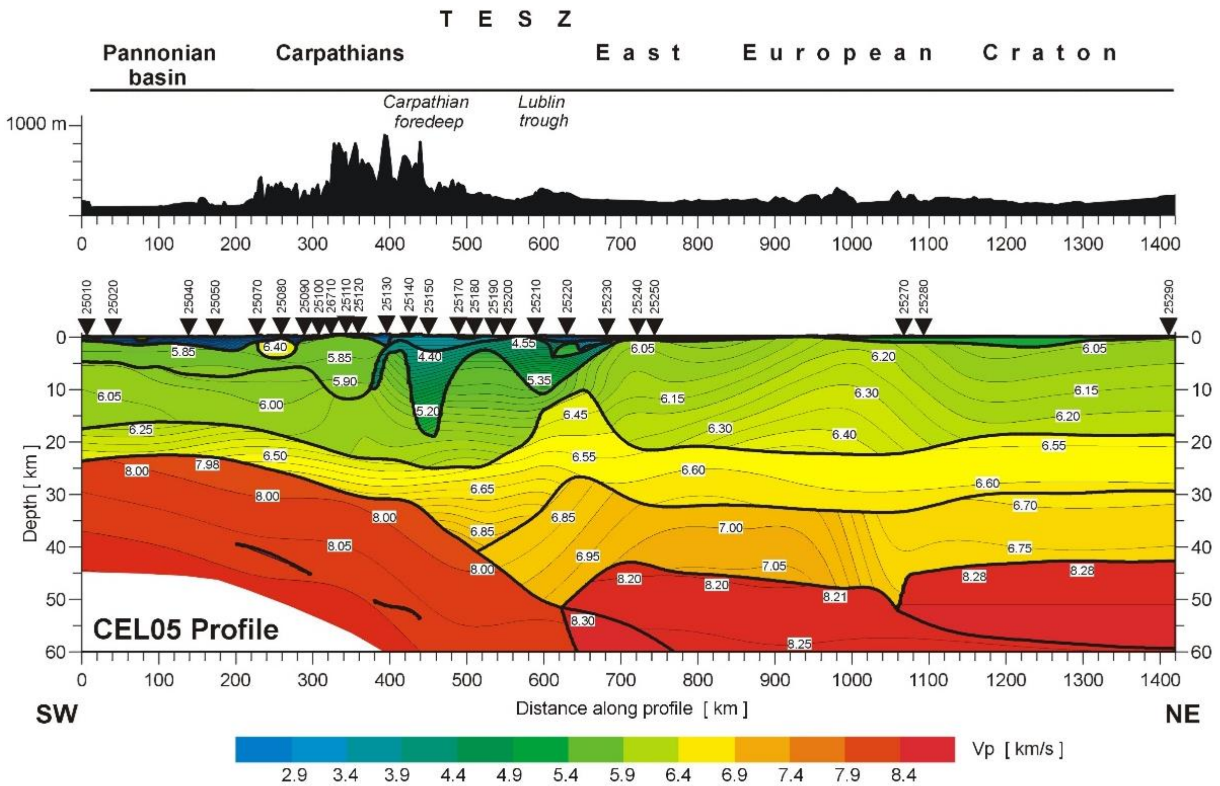


Fig. 4. Example of the two-dimensional P-wave velocity model for CELEBRATION 2000 profile CEL05 obtained by forward ray-tracing modeling using the SEIS83 package (Červený and Pšenčík 1984). The thick solid lines are layer boundaries and thin lines are isovelocity contours in km/s; numbered triangles refer to shot points. Vertical exaggeration for the model is ~6.8 (Grad et al. 2006).

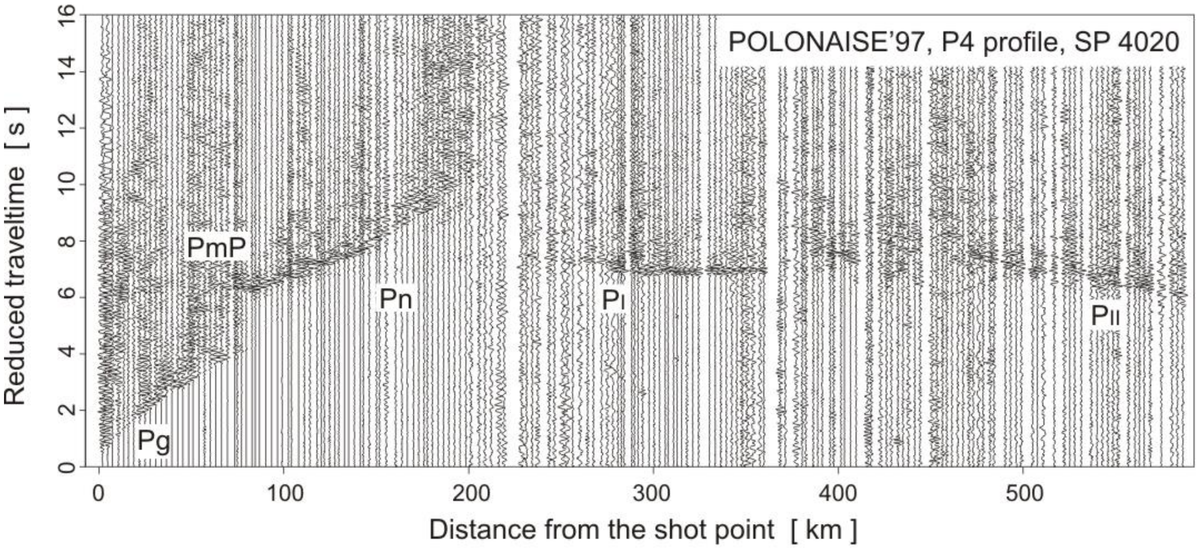


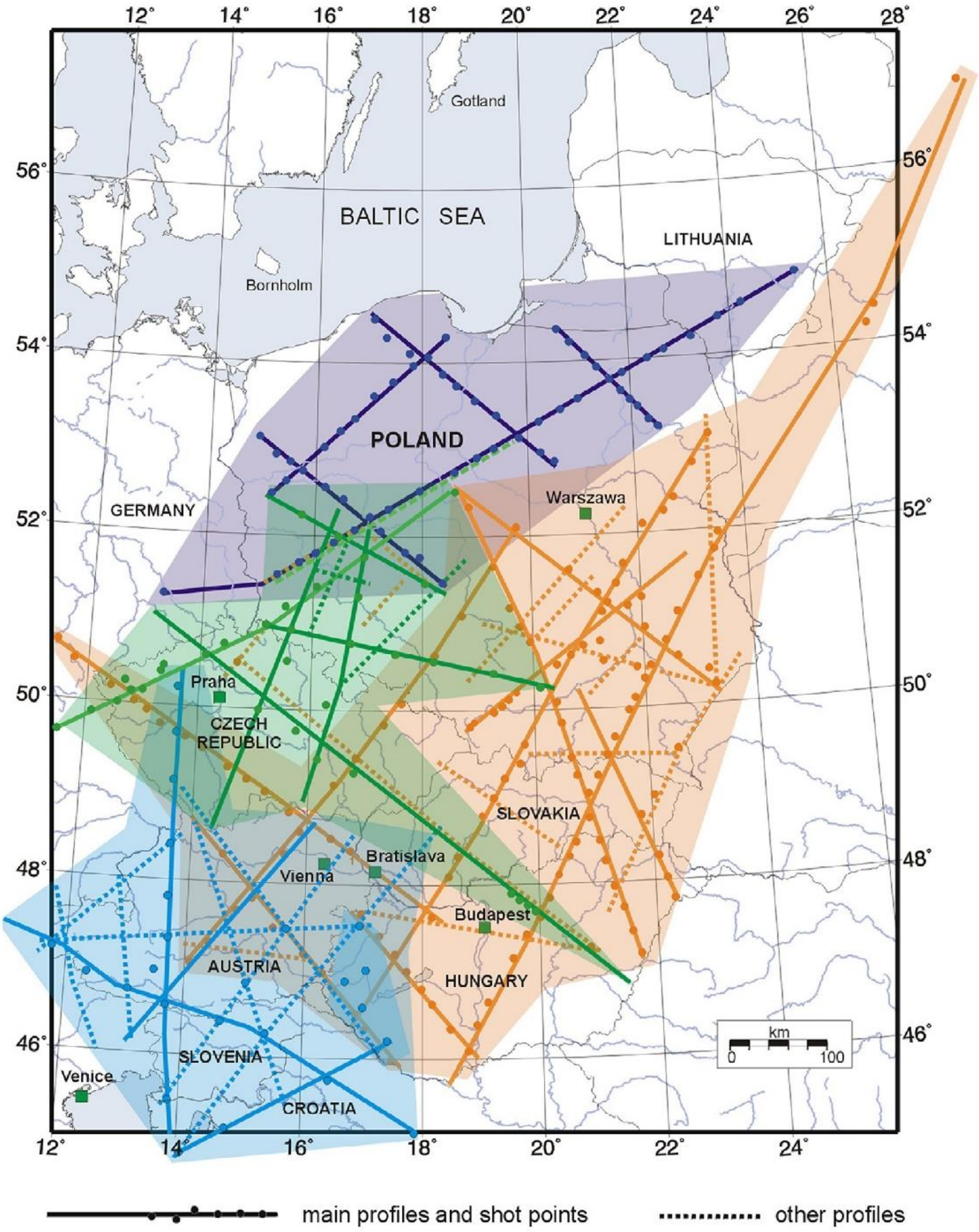
Fig. 5. Example of a shot gather recorded during POLONAISE'97 experiment. Observed seismic phases are: Pg – crustal refraction, Pn – mantle refraction, PmP – reflection from Moho, and P_I–P_{II} – mantle arrivals.

modeling (Fig. 4), and it was possible to work directly with seismic sections (Fig. 5) on a computer screen, and not, as before, with travel-times on paper and photocopies of registrations, spread out on a ping-pong table. These great changes opened up the possibility of organizing large active seismic experiments, first in Poland and later farther to southern Europe.

3. LARGE SEISMIC PROJECTS

In the years 1997–2003 Prof. Aleksander Guterch was the initiator and organizer or co-organizer of large seismic research projects on the deep structures of the Earth's crust and lower lithosphere in Central Europe, from the Baltic Sea to the Adriatic Sea (Fig. 6). These were the great refraction seismic experiments, commonly known as POLONAISE'97 (Polish Lithospheric Onsets – An International Seismic Experiment, 97), CELEBRATION 2000 (Central Lithospheric Experiment Based on Refraction), SUDETES 2003, GRUNDY 2003, ALP 2002 (implemented mainly in Austria on the initiative and with the participation of the Polish side). All main geological structures in the study area were covered by a system of modern seismic profiles with a total length of approximately 20,000 km. The research was conducted in cooperation with 35 scientific and industrial institutions from 15 European countries, the USA, and Canada. The interpretation of the research was presented in many important scientific journals, and a summary of the results was made by Guterch et al. (2015), in an article being a synthesis of the whole of geophysical research carried out so far in North-West and Central Europe. All the above-mentioned seismic experiments were carried out under the patronage of a specially established non-profit organization – Association for Deep Geological Investigations of Poland – founded and directed by Aleksander Guterch. Only this type of organization could receive research funding from extra-budgetary and foreign funds. In total, out of the multi-million costs of work only in Poland, the vast majority (over 70%), were covered from extra-budgetary and foreign funds.

Aleksander Guterch did not limit his scientific interests to the area of the Trans-European Suture Zone (TESZ) in Poland and Central Europe but extended them to other tectonic units of the East European Platform (Fennoscandia, Sarmatia). We have established long-term fruitful cooperation with the team of Prof. Urmas Luosto from the Institute of Seismology of the University of Helsinki and the University of Oulu, Finland. We participated not only in measure-



Experiment	Shots	Stations	Length
POLONAISE' 97	64	613	2000
CELEBRATION 2000	147	1240	8900
ALP 2002	32	1124	4500
SUDETES 2003	52	956	3450

Fig. 6. Location of seismic profiles in Central and Eastern Europe experiments: POLONAISE'97, CELEBRATION 2000, ALP 2002, SUDETES 2003; lines show seismic profiles of a total length of ca. 20,000 km, with ca. 7,000 seismic receiver positions; dots show 295 shot points (Guterch et al. 2004, 2015).

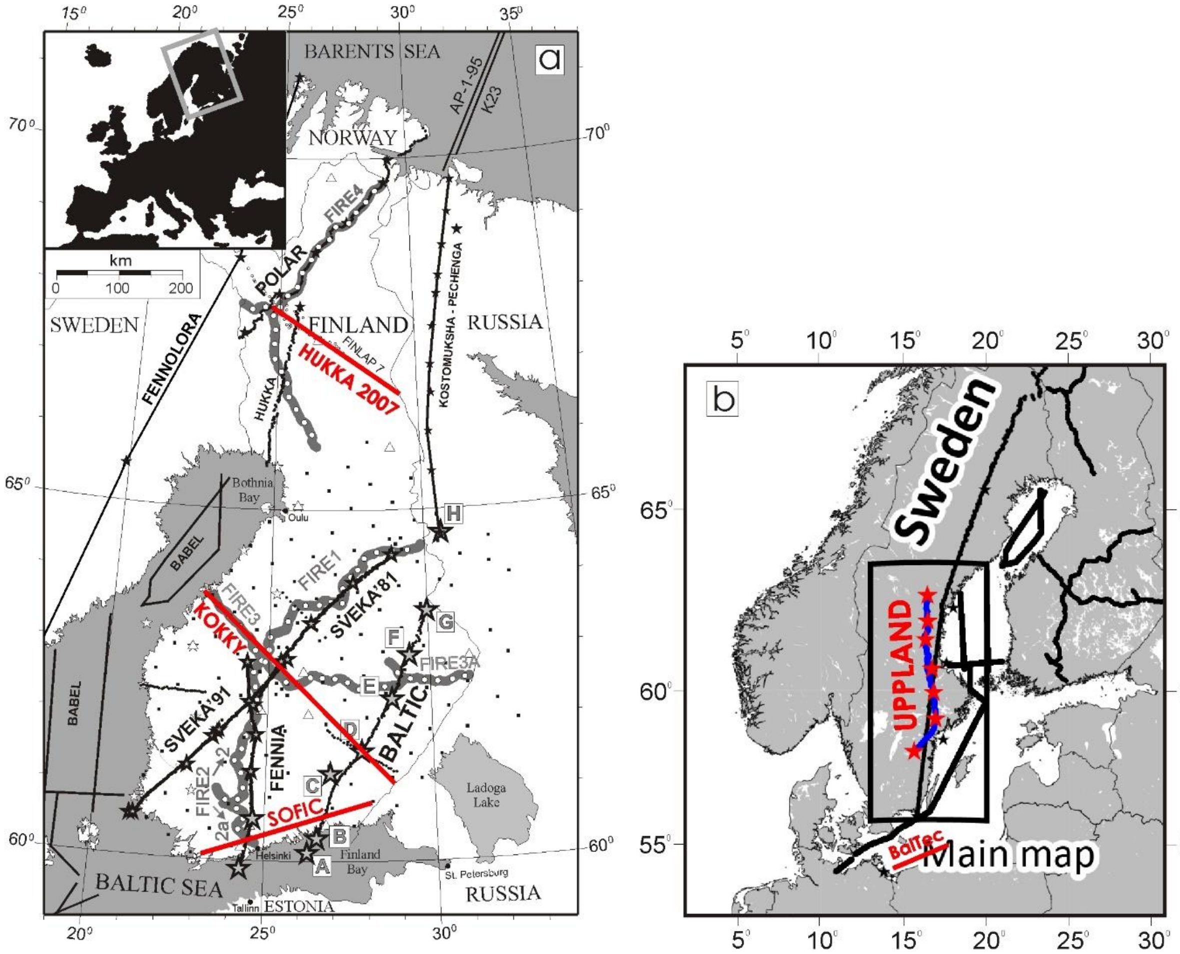


Fig. 7. Location of main onshore and offshore seismic experiments in the eastern part of the Fennoscandia: SVEKA transect (SVEKA'81 and SVEKA'91 profiles) BALTIC, POLAR, and FENNIA profiles, and deep reflection profiles FIRE 1–4 (modified after Janik et al. 2009). Stars represent the shot points of the profiles; black dots represent recording stations of the DSS experiment; grey dots represent receiver stations; and large white dots represent selected CDP points of the deep seismic reflection experiment FIRE. Positions of record stations of the SVEKALAPKO temporary passive array are denoted by rectangles (temporary broadband and short-period stations) and by triangles (permanent stations). The inset map shows the location of target area in Europe. Profiles conducted since 2007 are marked in red (HUKKA 2007, KOKKY, SOFIC, UPPLAND, and BalTec).

ments in their area, the SVEKA'81, FENNIA, SVEKA'91 profiles, but also in the interpretation of data from the BALTIC, POLAR, and many other projects (Fig. 7). Finns also often participated in our research. As part of the EUROPROBE project, we jointly participated in research on the DSS, EUROBRIDGE'95&96, EUROBRIDGE'97, and DOBRE'99 profiles on the territories of Lithuania, Belarus, and Ukraine. This research was conducted in broad international cooperation.

4. RESEARCH IN THE POLAR REGIONS

In addition to research in Poland, Aleksander Guterch initiated, in the 1970s, the marine DSS research in the polar regions.

In the years 1976–2008, he organized six geophysical expeditions to the Arctic (1976, 1978, 1985, 1999, 2005, 2008) to study the structure of the Mid-Atlantic Ridge and the edge of the Eurasian plate in the Svalbard area (Fig. 8).

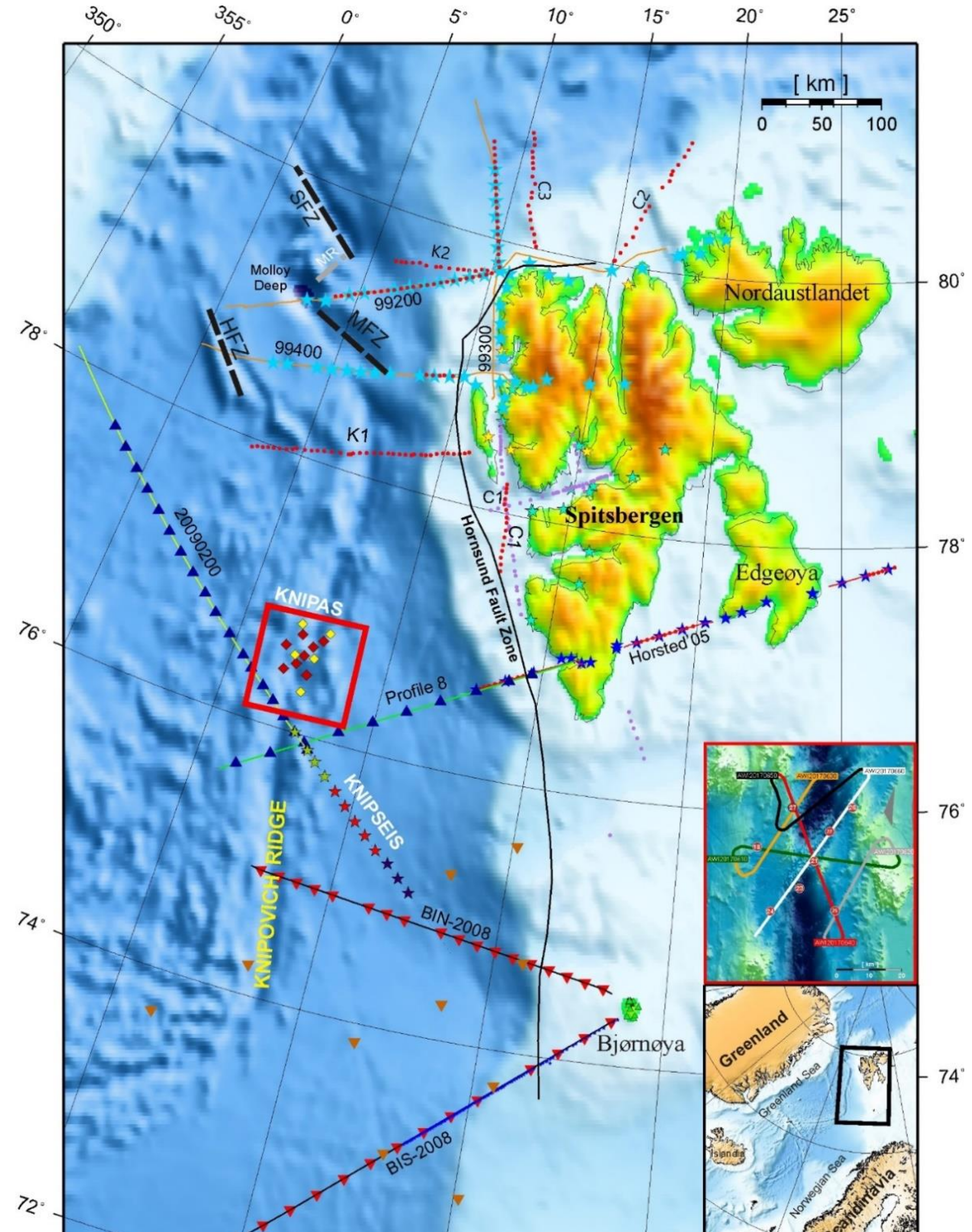


Fig. 8. Location map of the deep seismic profiles conducted by a Polish group in the years 1976–2017 in the ocean-continent transition zone in the western Svalbard and Barents Sea margin (modified after Czuba 2013) on the background of topography/bathymetry map (Jakobsson et al. 2000). Stars, diamonds, and triangles are receivers, thin lines and dots are airgun and chemical (TNT) shots, respectively. Green stars and pink dots are from projects of 1976 and 1978 years (profiles Isfjorden, Central and Coastal). Profiles C1, C2, C3, K1, and K2 are from the 1985 expedition, profiles 99200, 99300, and 99400 are from the 1999 expedition, profile Horsted'05 is from the 2005 expedition, and profiles BIN-2008 and BIS-2008 are from the 2008 project, our team took part in measurements along the BIS-2008 profile. The upper inset shows the map of seismic refraction lines of the active part of the KNIPAS project (2017) over the Logachev Seamount with OBS locations as red circles (red diamonds on the main map). Bathymetry is compiled of multibeam echo sounder data acquired during several cruises. The area is marked by the red frame on the main map. Lower inset – general map of the Arctic region.

In the years 1979–1991, four geodynamic expeditions (geophysics, geology, paleontology) were organized to West Antarctica (1979/80, 1984/85, 1987/88, 1990/1991). The seismic studies of the lithosphere conducted in the outer part of the Antarctic Peninsula (including the subduction zone of the former Phoenix Plate and the Pacific Plate below the South Shetland Islands), the Bransfield Strait and further south, up to Adelaide Island, allowed the presentation of a new geodynamic model of this part of West Antarctica. Some of the polar projects were carried out in cooperation with scientific institutions from Norway, Germany, Japan, and the USA.

Research in the polar regions, especially during the first expeditions, involved, of course, a lot of organizational effort, both before and during the expedition, for the entire team and the crews of the ships we used. These were different ships and different crews: ORP "Kopernik", a hydrographic ship with a Navy crew, and at the same time belonging to Geofizyka Toruń, whose staff operated seismic research equipment of the ship (Spitsbergen 1976, 1978, and West Antarctica 1979/1980); tugs of the Polish Ship Rescue Service, including the famous "Jantar" (West Antarctica 1984/1985, 1987/1988, and Spitsbergen 1985) and "Neptunia" (West Antarctica 1990/1991) (Fig. 9). Since we used manually operated seismic equipment during these expeditions, it required the stay of several (2–3) person measurement groups on land, in the few places where it was possible to locate the base and equipment. Mostly, these were abandoned huse (trapper cabins on Spitsbergen) or bases of polar explorers. Their technical condition varied greatly, from very bad to quite tolerable. However, adapting them to live for several weeks and conducting measurements always required a lot of effort from the entire team and the ship's crew. 2–3 tons of equipment and food had to be transported to the shore, four walls and a roof had to be secured for the measuring group, and a radio mast had to be erected. Sometimes, due to lack of other shelter, it was necessary to set up tents, and sometimes the "lucky" ones found accommodation near a functioning base. Later expeditions had a different character. Automatic recording devices were placed on land and did not require constant human service; alongside, we deployed bottom seismic stations (OBS) on the seabed. We used Japanese OBSs for the first time in Antarctica, in the Bransfield Strait, during the expedition at the turn of 1990/1991.

During four geodynamic expeditions in West Antarctica in 1979–1991, an extensive program of lithospheric research using explosive seismic methods was carried out along over 1,000 km of the shelf of the Antarctic Peninsula and the Shetland Trench, from the Elephant Island to the Adelaide Island (Fig. 9). Seismic measurements were carried out on 20 refractive marine profiles with recordings on land or using bottom seismometers (OBS). The Bransfield Strait is a back-arc basin between the South Shetland Islands and the Antarctic Peninsula. The still active subduction of the Antarctic plate beneath the peninsula is bounded by the Shackleton Fracture Zone (SFZ) to the north and the Hero Fracture Zone (HFZ) to the south. Further south, there is an inactive subduction zone. The occurrence of such diverse tectonics and the proximity of the Drake Plate make it one of the most attractive areas in terms of research, one of the tectonic nodes of the globe. During the first expedition, over 1,000 km of seismic reflection profiles were made in the area of the Bransfield Strait and the South Shetland Islands, using a streamer and air-gun seismic sources from the ORP "Kopernik" deck (Fig. 10).

In 1999, during an expedition to the North Atlantic, our team, in cooperation with German colleagues, used the "Polarstern" icebreaker. The receivers were German land stations, OBSs and bottom hydrophones (OBH). Air guns from the "Polarstern" deck and chemical explosions from the Polish yacht "Eltanin" were used as energy sources. The measurements on the Horsted profile were made in 2005 from the ship of the Gdynia Maritime University "Horyzont II" in cooperation with researchers from the University of Bergen and the Hokkaido University (Fig. 8). In 2008, research was carried out in the area of Bear Island using two ships, Polish

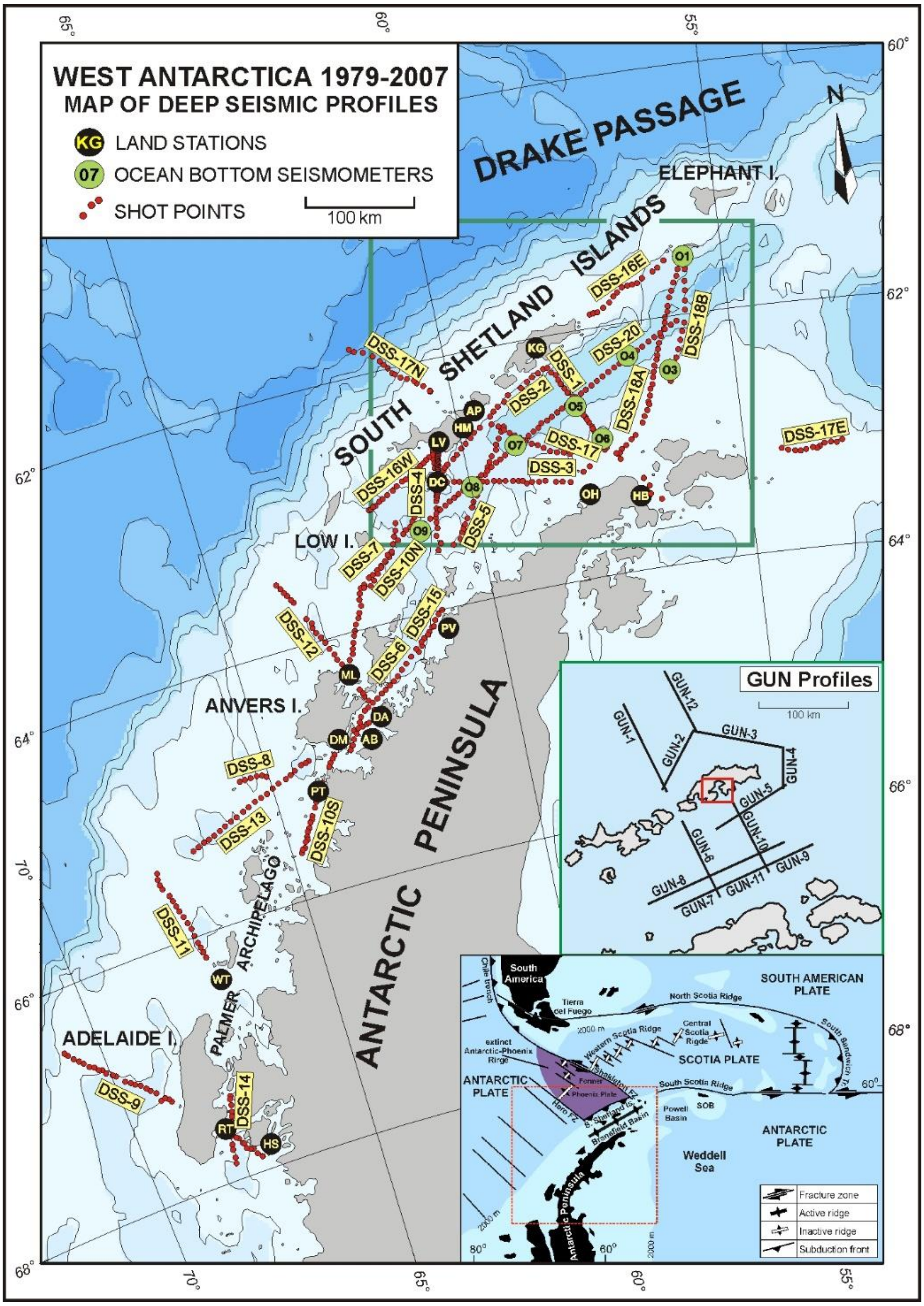


Fig. 9. Location of profiles of deep seismic soundings in West Antarctica carried out by Polish geodynamic expeditions in 1979–1991 (modified after Janik et al. 2014). Land seismic stations: AB – Almirante Brown; AP – Arturo Prat; DA – Danco; DC – Deception Island; DM – Damoy; HB – Hope Bay; HM – Half Moon Island; HS – Horse Shoe; KG – King George Island; LV – Livingston Island; ML – Melchior; OH – O'Higgins; PT – Petermann; PV – Primavera; RT – Rothera; WT – Watkins; 01–09 – underwater seismic stations (OBS). Bathymetric map with isobaths every 500 m (ETOPO5 database used, NOAA's NGDC), using the GMT program (Wessel and Smith 1995). Insets: Map of multi-channel seismic profiles (GUN) conducted by Polish Academy of Sciences during the Polish Geophysical Expedition in 1979/1980 and the tectonic map of the area. The red square marks the area of research during the 2007 expedition to the Admiralty Bay.

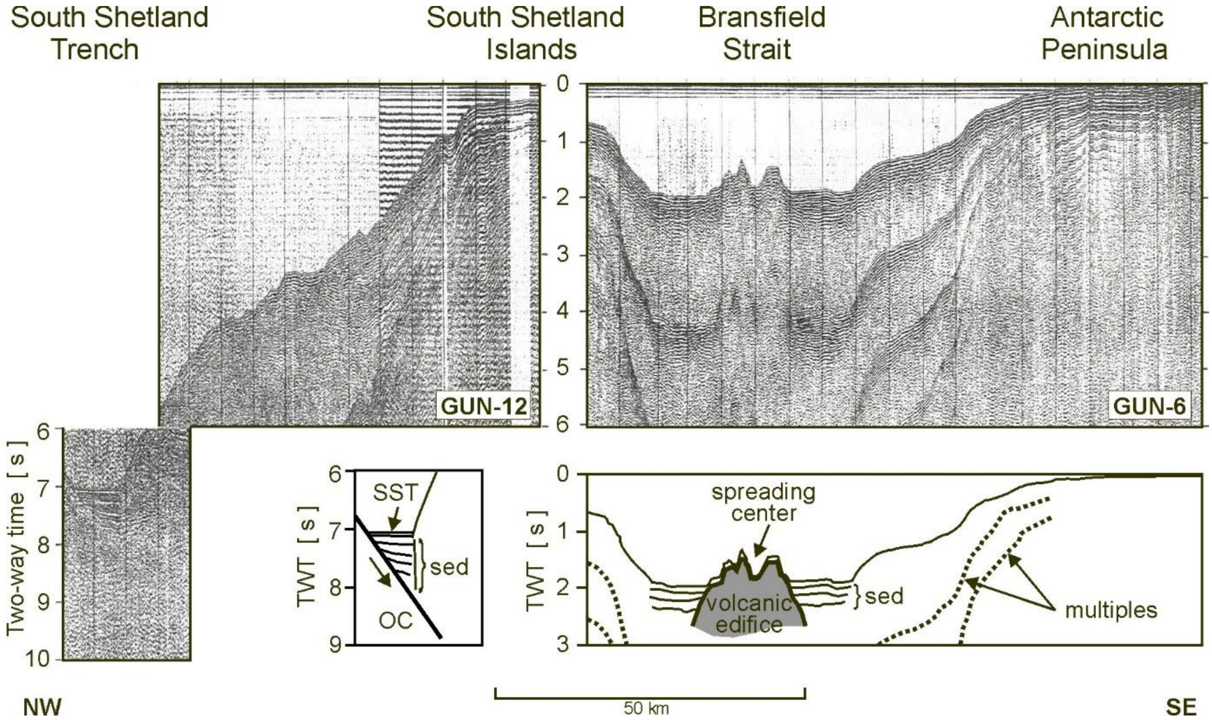


Fig. 10. Seismic reflection profiles and interpretative lines showing the trench sediment fill and structure of the oceanic crust (OC) in profile GUN-12 perpendicular to the South Shetland Trench (SST), and across the spreading centre of the volcanic edifice in the Bransfield Strait (GUN-6) (Janik et al. 2014).

"Horyzont II" and Norwegian "Håkon Mosby", in cooperation with Japan and Germany, using land and bottom seismic stations (OBS) and air-gun sources and chemical explosions.

In 2007, shallow 3D research was carried out in Admiralty Bay (King George Island) using the Russian ship "Polar Pioneer" (Fig. 9).

As part of the passive seismic project KNIPAS, in cooperation with AWI Bremerhaven, the Department's team deployed 5 broadband OBS Güralp stations on the bottom of the Greenland Sea (depth > 3 km), west of Svalbard (Fig. 8). The aim of the project was to study the structure and processes occurring in the mid-ocean Knipovich Ridge. These stations, together with similar German devices, recorded seismic events from September 2016 to July 2017. The Polish side of the project involved the ships "Horyzont II" and "Oceania".

In the summer of 2019, in Polish–Norwegian–Japanese cooperation, measurements were performed by the Norwegian scientific vessel "G.O. Sars" on the extension of the previously completed German profile 20090200, as part of the KNIPSEIS project. The aim of the expedition was to conduct deep refraction seismic studies in the Knipovich Ridge area (Fig. 8).

5. COOPERATION WITH THE INSTITUTE OF GEOPHYSICS, FACULTY OF PHYSICS, UNIVERSITY OF WARSAW

Already since his student days, in the mid-1970s, Marek Grad, later the professor and long-time director of the Institute of Geophysics of the University of Warsaw, collaborated with the DSS team, and later the Department of Lithospheric Research, in most seismic projects. He was Aleksander Guterch's "right hand" in many projects and co-author of publications. He was supported in several endeavors by his younger colleagues: Lech Krysiński, Monika Wilde-Piórko, and Marcin Polkowski.

6. PASSIVE SEISMIC INVESTIGATIONS

Professor Guterch was also engaged in research using experimental seismic methods other than deep refraction. The DSS research team under his supervision took part in large international passive seismic research projects in Europe: TOR (1996–1997) (Fig. 11a), SVEKALAPKO (1998–1999) (Fig. 7) in Scandinavia, and the PASSEQ project organized mainly in Poland (2006–2008) (Fig. 11b), which was led by Dr. Monika Wilde-Piórko from the Institute of Geophysics, University of Warsaw. This method allows recognizing the structure of the Earth's crust and upper mantle down to a depth of several hundred kilometers, i.e. to much greater depths than the usually interpreted DSS refraction profiles. It can reach below the lithosphere-asthenosphere boundary. By participating in these experiments, we gained experience in conducting this type of research.

a) b)

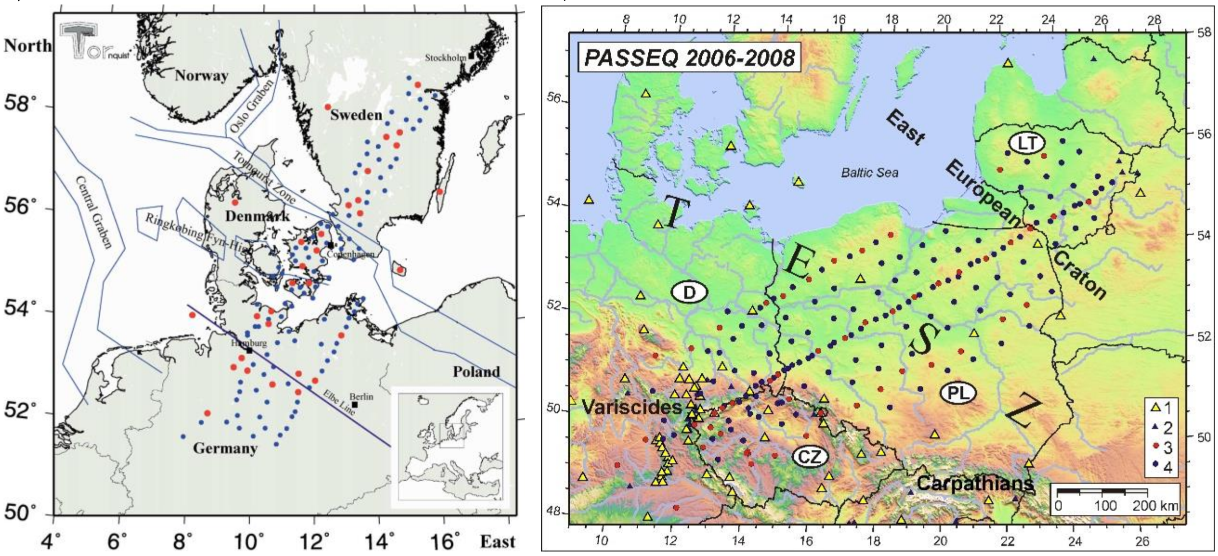


Fig. 11: a) The location of seismometers during the field work of the TOR project 1996–1997. The small blue dots indicate short-period seismometers and the large red dots indicate broad-band seismometers. The tectonically important features are also depicted (Gregersen et al. 2002); b) Location of PASSEQ 2006–2008 seismic experiment around the Trans-European Suture Zone (TESZ): 1, 2 – permanent broad-band and short-period seismic stations of national and regional observatories; 3, 4 – temporary broad-band stations and temporary short-period stations (Wilde-Piórko et al. 2008).

7. DEEP REFLECTION SEISMIC SURVEYS

Another seismic research method, complementary to the previously mentioned ones, is deep seismic reflection research. Sections made of reflective profiles allow you to obtain an accurate image of geological structures, but they are many times more expensive. After long efforts to obtain funds, thanks to the support of the Ministry of the Environment and PGNiG, Prof. Guterch also managed to conduct deep reflection soundings (Figs. 12 and 13) in south-eastern Poland on a 210 km long profile, project POLCRUST-01 (2010).

8. ACTIVITY AFTER 2012

Aleksander Guterch led DSS research at the IG PAS for over 40 years. From 1969, he was the head of the Deep Seismic Sounding Laboratory, renamed as the Independent Deep Structures Laboratory, and later the Department of Seismic Lithospheric Research. He held this position until 2012, when he handed it over to Tomasz Janik, the author of this text. Since then, he has

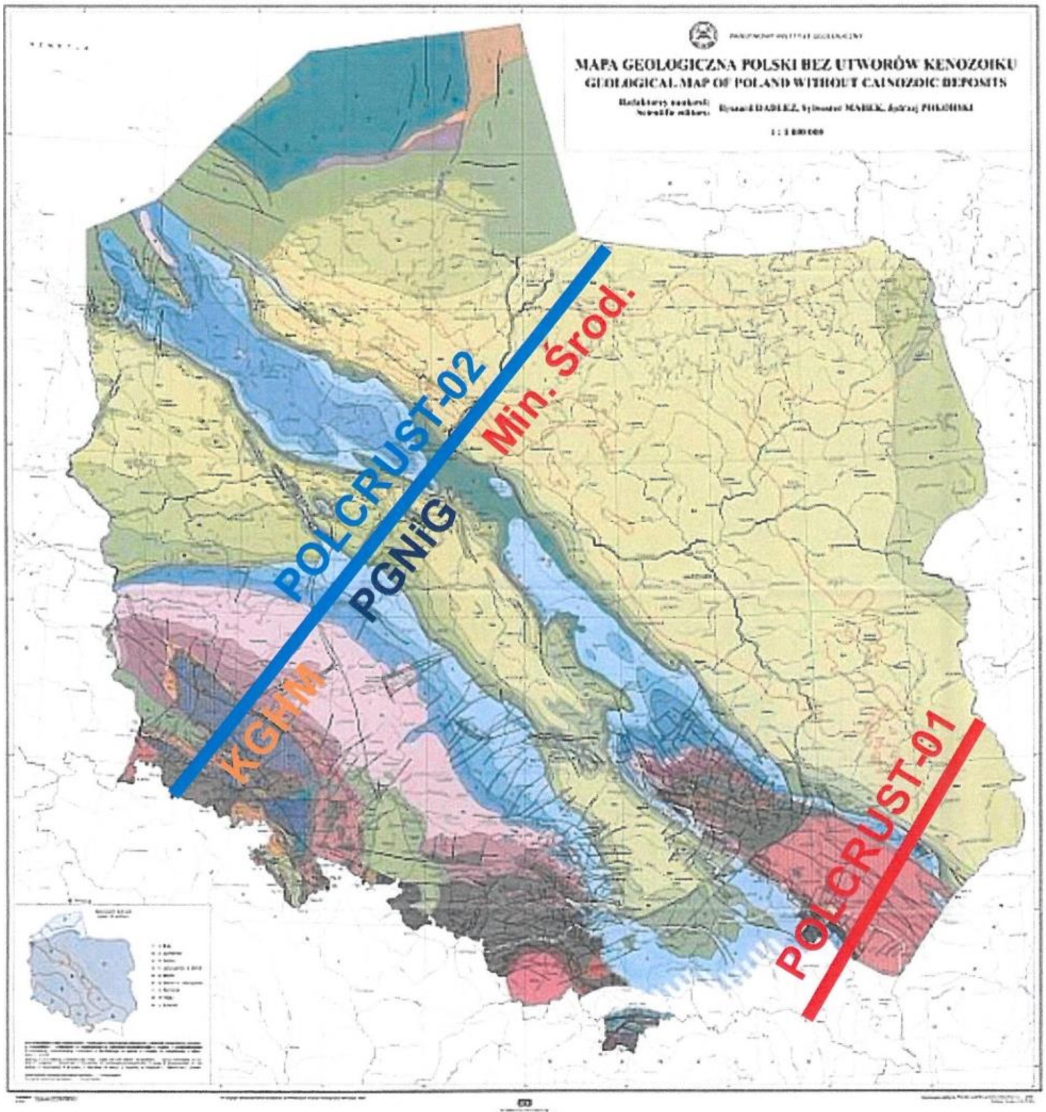


Fig. 12. Location of profiles of deep reflection seismic soundings POLCRUST-01 carried out in 2010 and the planned profile, with three potential sponsors (KGHM, PGNiG, and the Ministry of the Environment) POLCRUST-02, unfortunately not implemented. In the background, a geological map of Poland (Dadlez et al. 2000).

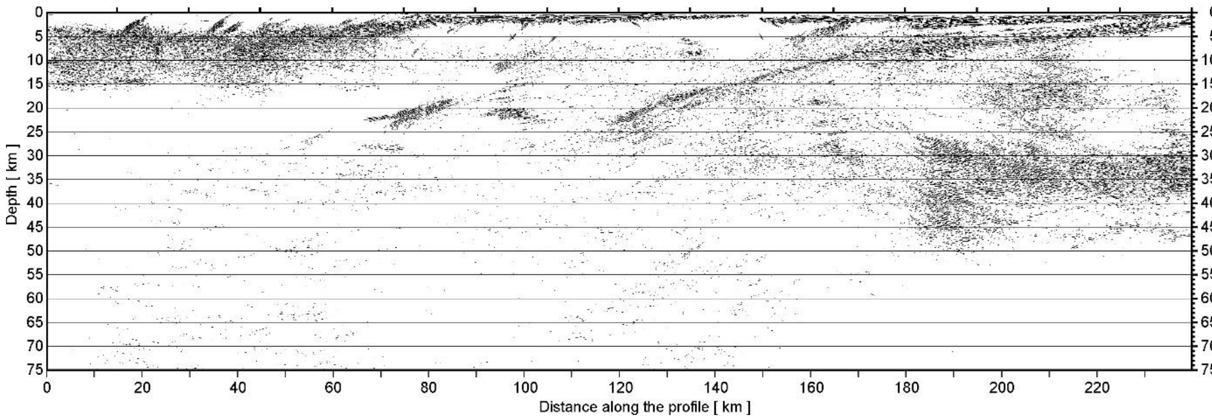


Fig. 13. The POLCRUST-01 profile, post-stack migrated final time seismic reflection section after curvelet denoising (Malinowski et al. 2015).

worked on a nominally part-time basis. He focused his activity mainly on efforts to gain support and funds for conducting research on another deep reflection seismic profile, POLCRUST-02. This profile, approximately 500 km long, was planned to cross all the most important tectonic units from the Sudetes on the SW to the East European Craton (around Braniewo) on the NE. These activities were extremely difficult. Such a long profile, which should reach the structures of the upper mantle and pass through the deep Polish basin, had to be made to the highest technical standards for this type of research. Of course, this required obtaining sufficiently high funds. Professor Guterch was the initiator of the creation of a consortium for the implementation of this project, which included potential sponsors of individual parts of the profile, KGHM, PGNiG, the Ministry of the Environment, and potential organizers and units responsible for interpretation, IG PAS, IGF UW, and PIG PIB. The project went through many “ups” and “downs” (see M. Narkiewicz, this volume). Olek was not discouraged by the failures and fought for the project, in the thicket of necessary consents and acceptances, until the pandemic in 2020. Twice it seemed that the success was literally within reach. However, at crucial moments the support from the geological community was not strong enough. This failure had a heavy impact on Olek. There were also health problems. However, as much as he could, he tried to be active in the scientific community until his last days.

Under the new management, the Department continued research on the structure of the Earth’s crust and upper mantle using experimental seismic methods carried out in two statutory research topics, focused on land measurements NSL1: “Structure and evolution of the lithosphere of Central Europe with particular emphasis on the area of Poland” and on marine measurements NSL2: “Structure and evolution of the North Atlantic lithosphere in the contact zone of the Eurasian and North American plates in the Arctic and selected areas of West Antarctica”.

Active seismic research

Thanks to the increase in the pool of short-period field devices to over 200 and our existing interpretation experience, we have become an even more significant partner in DSS research. In land research, we have established close cooperation with Prof. Vitaly Starostenko and his team from the Institute of Geophysics NANU in Kiev. These were not large, spectacular projects like those carried out in earlier years, but systematically prepared DSS profiles, usually aimed at determining the structure of the margin of the East European Craton south of Poland, up to Crimea and the Azov Sea, or concerning the Prypiat’-Dnieper-Donets Basin and the structures of the Ukrainian shield. Measurements and interpretation in these projects were usually performed in various international collaborations, but our team always played a significant role. Profiles made (Fig. 14): DOBRE-2 (2007), PANCAKE (DOBRE-3) (2008), DOBRE-4 (2009), DOBRE-5 (2011), GEORIFT 2013 (2013), RomUkrSeis (2014), TTZ-South (2018), SHIELD’21 (2021), with a total length of approximately 5,000 km, jointly constitute the second largest uniform DSS measurement system in Europe after the CELEBRATION 2000 project. The only profile that we initiated, partly implemented in SE Poland and partly in Ukraine, was the TTZ-South profile, an extension of the previous TTZ and CEL03 profiles, running along the TTZ. This is due to great difficulties in obtaining appropriate financial resources for this research. We also continued cooperation with the Universities of Helsinki and Uppsala in researching the structure of Fennoscandia. The KOKKY, ESO2 (Finland), and UPPLAND (BASIC) (Sweden) projects were implemented on the Baltic shield.

Passive seismic research

Due to increasingly restrictive ecological regulations regarding shooting works in Western Europe, interest in active refraction seismic experiments is systematically decreasing. Finding partners to run such projects is difficult. However, passive seismic research is developing rap-

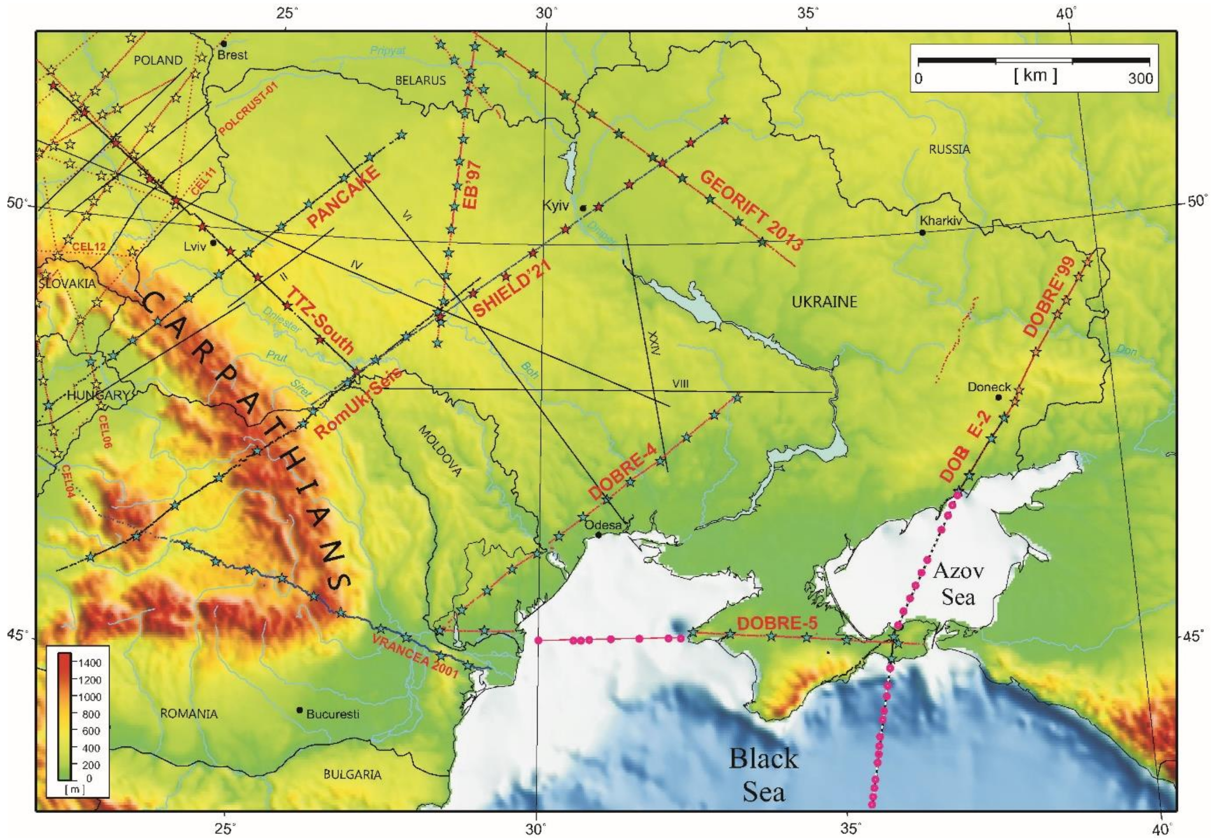


Fig. 14. Location of the deep seismic sounding (DSS) profiles in Ukraine and neighboring countries. Stars refer to locations of shot points along the profiles but large red dots show OBS's location at the bottom of the Azov and Black Seas. The profiles EB'97, DOBRE'99, DOBRE-2, PANCAKE, DOBRE-4, DOBRE-5, GEORIFT 2013, RomUkrSeis, TTZ-South, and SHIELD'21 were made to new (digital) standards unlike the previously made (in analog standards) profiles II, IV, VI, VIII, XXIV.

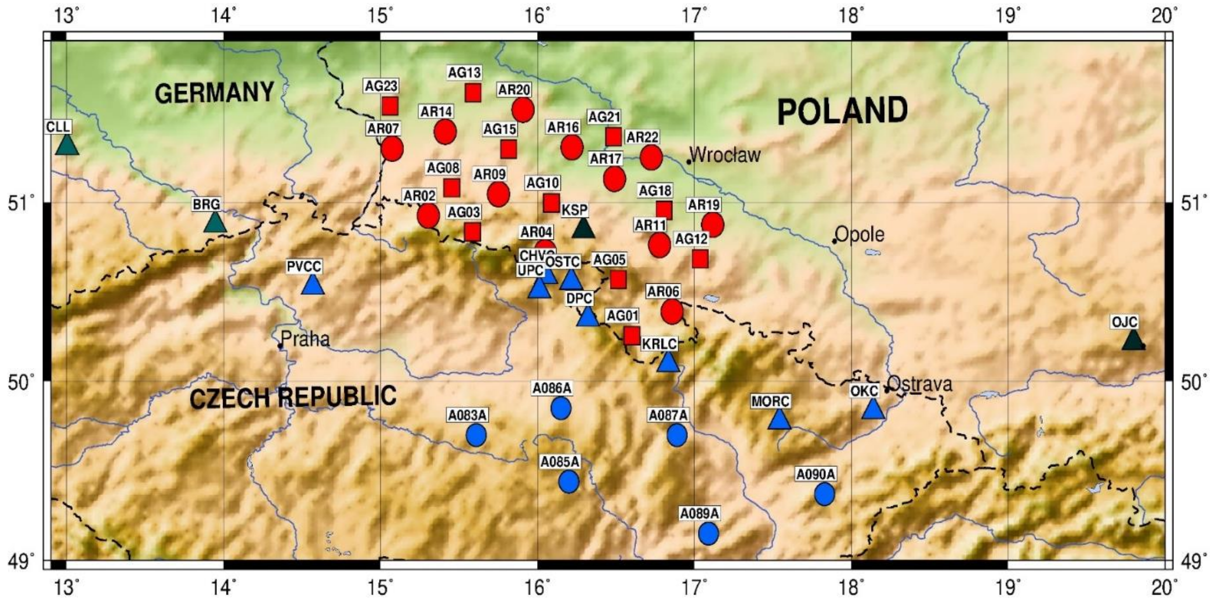


Fig. 15. Seismic stations of the passive experiment AniMaLS (modified after Bociarska et al. 2021). Temporary broadband stations with 120 s sensors are shown as red circles, stations with 30 s sensors as red squares and permanent stations of the Czech Regional Seismic Network and Polish Seismological Network with 120 s sensors as blue triangles. Elevation map based on GTOPO30 dataset (US Geological Survey 2018).

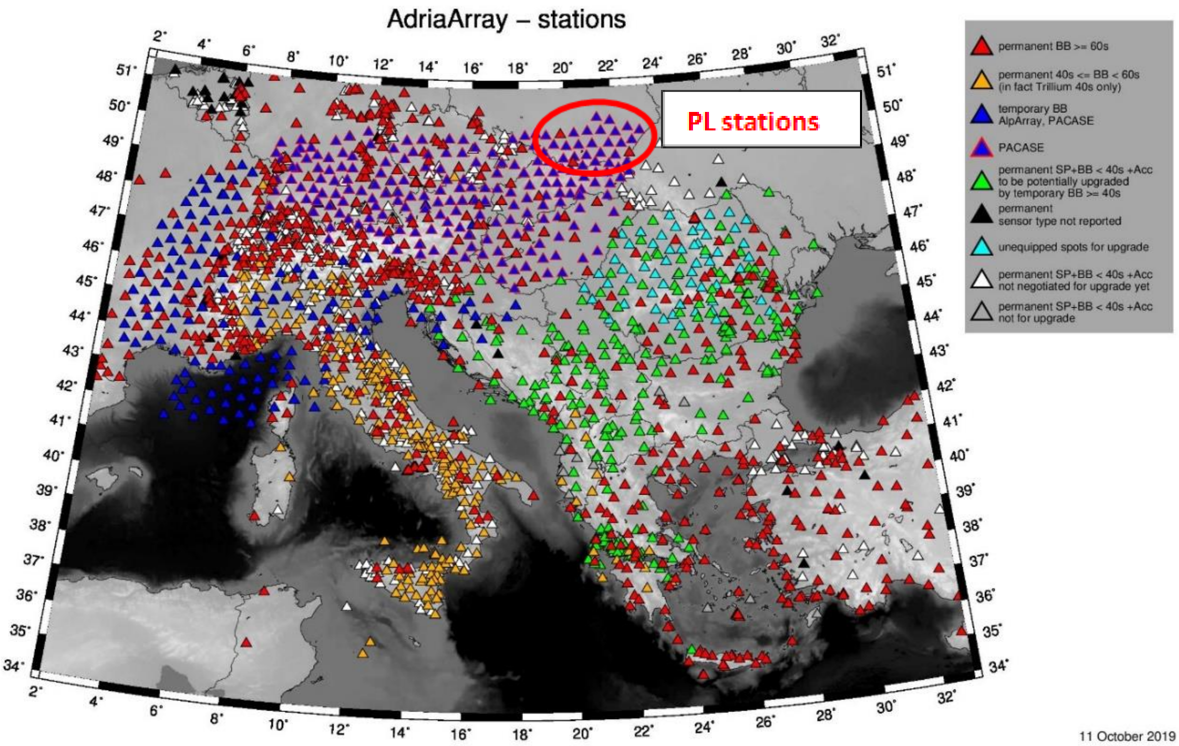


Fig. 16. AdriaArray project (units around Adria plate – from Carpathians to Mediterranean). The red ellipse marks the area where Polish seismic stations were located in the AdriaArray experiment, and previously in the PACASE experiment (modified after AdriaArray 2023).

idly. Having some experience in this respect, after obtaining 11 broadband devices of our own and 12 broadband devices from the University of Warsaw (Prof. M. Grad's pool), we started a research project aimed at determining the deep structures of the Earth's mantle, including the seismic anisotropy of the lithosphere, under the Sudetes (AniMaLS, 2017–2019) (Fig. 15), and later expanding the pool with 7 devices from the University of Silesia, under the Polish Carpathians, as part of the large international projects PACASE (2019–2023) and AdriaArray (2023–2026?), covering the area from the Carpathians to the Mediterranean Sea and from the Alps to the Black Sea (Fig. 16).

Offshore investigations

After purchasing six broadband OBSs, we were able to participate even more actively in marine research. Together with researchers from Hamburg University, we conducted active research (air-gun seismic sources) from the deck of the ship "Maria S. Merian" along the profile crossing TESZ, located along the Polish coast (BalTec 2016) (Fig. 7). Registrations were conducted by 15 OBSs and 3 land stations. Then, for almost a year, our OBSs were located at the bottom of the North Atlantic, at a depth > 3 km, in the area of the Knipovich Ridge, which is part of the Mid-Atlantic Ridge, west of Spitsbergen. This rift is unique, attracting the attention of researchers, one of the few rifts of the so-called "ultra-slow" type. This was the KNIPAS passive research project (2016–2017) of researchers from the Alfred Wegener Institute in Bremerhaven, with a small additional active program using air-guns from the ship "Maria S. Merian" (Fig. 8). Another active experiment in the same area was performed in 2019 in cooperation with the University of Bergen (ship "G.O. Sars") and Hokkaido University (operating some of the OBSs) along approximately 200 km long KNIPSEIS profile (Fig. 8). Our contribution to the project was the participation of the scientific team, including the expedition leader (Wojciech Czuba) and several OBSs.

9. SUMMARY

The Department of Lithospheric Research, mainly under the supervision of Prof. A. Guterch over several decades of his activity, has developed standards for seismic field measurements, preparation of seismic record sections and their interpretation, which are among the highest in the world. The analysis of the obtained experimental data, carried out using proven modern interpretation methods, is the basis for accurately determining the structure of not only the Earth's crust, but also the lower lithosphere. Our team's research covered the entire range of tectonic units distinguished by plate tectonics: continental plates, including old Precambrian platforms and younger Paleozoic plates cut by rift zones; areas related to the Alpine orogen; ocean plates; subduction zones with island arc and back-arc basin; and mid-ocean ridges with spreading centers.

The seismic studies of the Earth's lithosphere in Europe and the polar regions of the Earth, carried out by teams from the Institute of Geophysics of the Polish Academy of Sciences and the Institute of Geophysics of the University of Warsaw under the supervision of Prof. A. Guterch and Prof. M. Grad, are among the largest research projects of this type in the world. In particular, they provided results of key importance for understanding the structure and evolution of the Earth's crust in the geological heart of Europe, which is undoubtedly the area of Poland. Their result was the development of new seismic models of the Earth's crust, identifying and precisely defining drastic changes in physical properties in the area from the Variscan structures of western Poland, through the TESZ zone, to the Precambrian structures of NE Poland, and the creation of a tectonophysical framework for the three-dimensional interpretation of the geophysical and geological lithosphere of the entire area of Poland.

The POLONAISE'97, CELEBRATION 2000, and SUDETES 2003 seismic experiments conducted in Central and Northeastern Europe, each with a grid of multiple profiles, were international experiments organized and directed by the Polish side. These experiments were considered among the largest research projects of this type in the history of world geophysics. 35 scientific and industrial institutions from 15 European countries, Canada, and the USA participated in them.

The list of seismic experiments in which the team of the Lithospheric Research Department participated in the period 1960–2024 is presented in Table 1.

Table 1

Field seismic experiments in which the Department of Lithospheric Research participated, as the organizer and/or participant. The gray background experiments were carried out when Aleksander Guterch was in charge of the deep seismic sounding team.

Profile/experiment name	Years	Country/areas
A (Radynia – Zatoka Gdańska)	1960–1961	Poland
B (Radynia – Rodogoszcz)	1963	Poland
C (Starachowice – Radzyń Podlaski)	1965	Poland
V (Carpathians)	1969	Poland, Czechoslovakia
M1–M13 (Fore-Sudetic monocline)	1967–1971	Poland
VII International	1970–1973	Germany, Czechoslovakia, Poland, USSR
LT-2 (Stęszew – Starogard Gdański)	1971	Poland
VIII (Staszów – Tarnopol)	1973	Poland, Ukraine
LT-3 (Orava Lake – Brześć)	1976	Poland
SPITSBERGEN	1976	North Atlantic, Spitsbergen

LT-4 (Syców – Raciąż)	1977–1979	Poland
LT-5 (Pajęczno – Pułtusk)	1977–1979	Poland
LZW (Włodawa – Dębica)	1978	Poland
SPITSBERGEN	1978	North Atlantic, Spitsbergen
Lithosphere	1979	Poland, Ukraine
West Antarctica (I)	1979/1980	South Shetland Islands, Bransfield Strait
LZW (continuation)	1980–1981	Poland
SVEKA'81	1981	Finland
West Antarctica (II)	1984/1985	South Shetland Islands – Adelaide Island
SPITSBERGEN'85	1985	North Atlantic, Spitsbergen
LT-7	1987	Poland, DDR
West Antarctica (III)	1987/1988	South Shetland Islands, Bransfield Strait
West Antarctica (IV)	1990/1991	South Shetland Islands, Bransfield Strait
SVEKA'91	199	Finland
LT-7 (continuation)	1992	Poland
TTZ-PL	1993	Poland
FENNIA	1994	Finland
EUROBRIDGE'95	1995	Lithuania
GRANU'95	1995	Poland, Germany
EUROBRIDGE'96	1996	Lithuania, Belarus
TOR (passive)	1996–1997	Denmark, Germany, Sweden
POLONAISE'97	1997	Poland, Lithuania, Germany
EUROBRIDGE'97	1997	Belarus, Ukraine
SVEKALAPKO (passive)	1998–1999	Finland, Russia
SPITSBERGEN	1999	North Atlantic, Spitsbergen
DOBRE'99	1999	Ukraine
CELEBRATION 2000	2000	Poland, Belarus, Austria, Czech Republic, Hungary, Slovakia, Germany, Russia
VRANCEA 2001	2001	Hungary, Romania
ALP 2002	2002	Austria, Hungary, Slovenia, Croatia, Czech Republic, Slovakia
SUDETES 2003	2003	Poland, Austria, Czech Republic, Slovakia, Hungary, Germany
GRUNDY 2003	2003	Poland
SPITSBERGEN	2005	North Atlantic, Spitsbergen
ALPASS (passive)	2005–2006	Eastern Alps
PASSEQ (passive)	2006–2008	Poland, Germany, Lithuania, Czech Republic
West Antarctica	2007	Admiralty Bay
DOBRE-2	2007	Ukraine

HUKKA 2007	2007	Finland
SPITSBERGEN	2008	North Atlantic, Bear Island
PANCAKE (DOBRE-3)	2008	Ukraine, Hungary
DOBRE-4	2009	Ukraine
POLCRUST-01 (reflection)	2010	Poland
DOBRE-5	2011	Ukraine
GEORIFT 2013	2013	Belarus, Ukraine
RomUkrSeis	2014	Ukraine, Romania
KOKKY	2012–2014	Finland
P2 (extension)	2014–2015	Poland
SOFIC (ESO2)	2014	Finland
ARKO (LUMP)	2015	Sweden, Poland
BalTec	2016	Baltic Sea, Poland, Germany
KNIPAS (passive)	2016–2017	North Atlantic
UPPLAND (BASIC)	2017	Sweden
AniMaLS (passive)	2017–2019	Poland, Sudetes
TTZ-South	2018	Poland, Ukraine
KNIPSEIS	2019	North Atlantic
PACASE (passive)	2019–2023	Poland, Carpathians
SHIELD'21	2021	Ukraine
AdriaArray (passive)	2023–2025	Poland, Southern Europe

Some data from our experiments can be obtained from the databases: EPOS-PL: https://cibsbl-platform.igf.edu.pl/ and IG PAS: https://dataportal.igf.edu.pl/organization/lithospheric-research. To obtain data that is not yet available in these databases, write to Department of Lithospheric Research IG PAS.

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