Poland: junction of the main geological provinces of Europe

INTRODUCTION

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This year, the *Geological Quarterly* celebrates its 50th anniversary. This journal was established in 1957 as the *Kwartalnik Geologiczny*. This Polish name and also the publication language of the journal, reflected its principal mission, namely to serve as a rapid publication vehicle for results of current geological research carried out in Poland, first of all by members of the Polish Geological Institute (PGI) that stands for the Geological Survey of Poland. Starting from the very first issue, however, brief summaries of papers published in Polish were also given in English and Russian. This reflects that the founders had the ambition to attract also the interest of a broader circle of international readers, mostly from neighbouring European countries. Since its establishment, the *Geological Quarterly* was published by the PGI, and its successive Editors-in-Chief were nominated from this institution. The conscientious efforts of Władysław Pożaryski (1957–1958), Antoni Łaszkiewicz and Jan Czermiński (1959–1962), Jan Czermiński (1963–1976), Ryszard Dadlez (1977–1997) and Leszek Marks (1998–2002) to establish and maintain the desired high scientific and editorial standards of this journal are here gratefully acknowledged.

Until 1990 the *Kwartalnik Geologiczny* essentially retained its original form and maintained its scope and thematic policy. Although since 1983 occasional articles were published in English, it was only in 1991 when most of the papers appeared in this modern scientific *lingua franca*. In the same year the journal started to be published under the bi-lingual title *Kwartalnik Geologiczny–Geological Quarterly*. It is certainly not a coincidence that these changes were implemented at the political turning point in the history of Poland and Central-Eastern Europe that followed the break down of the "iron curtain". This raised the will and hopes of Poland's Earth scientists to re-establish the co-operation with the international and particularly with the Western scientific community that had been interrupted by the World War II.

It was not until 1994 (volume 38), however, when for the first time the journal was exclusively published in English. Three years later, still under the editorship of Ryszard Dadlez, the *Geological Quarterly* changed its format to a more modern one. This change in its external image and improvements in the technical quality of the publication were soon followed by a revolution in the basic editing approach of the journal. This process started under the new Editor-in-Chief of the journal, Leszek Marks. Beginning in 1999, the Polish Editorial Advisory Board was complemented by a board of Consulting Editors to which several outstanding scientists representing international institutions were appointed. This was a clear message to the readers and contributors that from now on the journal was open also to international authors and that it aimed at a broader readership. At the same time the important peer review procedure started to be applied to all manuscripts submitted, while at the same time the Editors paid more attention to the quality of English texts in order to enhance the readability of papers published. In this context, thanks go to Dr. Jan Zalasiewicz (University of Leicester, UK) for his valuable on-going editorial and linguistic assistance.

All these efforts contributed much to raise the scientific level of this journal. In 2003 the Institute for Scientific Information in Philadelphia recognized this by including the *Geological Quarterly* in the Science Citation Index Expanded and in the Current Contents, as the second Polish journal from a broad category of periodic Earth Sciences publications. A positive feedback of this achievement was the growing in-flow of important manuscripts by international authors that

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still increases. Citation indexes and impact factors are likely to improve as the number of high quality papers by Polish and international authors grows. Examples of the by now truly international status of the *Geological Quarterly* are two of its Special Issues that were published during the last two years, partly with the assistance of guest editors. These are Volume 48 (3) 2004 that addresses "Multidisciplinary Event Approaches to the Devonian Stratigraphic Record" (co-edited by Grzegorz Racki and Marek Narkiewicz) and Volume 49 (2) 2005 that deals with "Stable isotope records of environmental change" (co-edited by Ana-Voica Bojar, Stanisław Hałas and Sławomir Oszczepalski).

Since its launching in 1957, this journal was devoted to the regional geology, firstly of Poland and later also of surrounding Central and East European countries. Until the 90's, it was the publication vehicle for new ideas pertaining to the geology of Poland that were put forward by such leading Polish geologists as Ryszard Dadlez, Marian Książkiewicz, Władysław Pożaryski, Edward Rühle, Jerzy Znosko, and many others. Regional geological papers covered broad aspects of tectonics, stratigraphy and palaeogeography, including the deeper basement, as well as Cenozoic and particularly Quaternary strata. Many papers focused on areas that were subject to regional and mineral resources studies by the Polish Geological Institute. Therefore, it is not surprising that, according to bibliographical studies by Grzegorz Racki, the most cited articles from these years are those that were devoted to aspects of the regional geology of Poland.

During the last eight years the editors attempted to maintain this regional focus of the journal, however, at the same time trying to reach beyond strictly local Polish Earth Science problems. To this end, authors from neighbouring countries were attracted, that share areas of regional geological interest. Moreover, all authors, both Polish and international, were encouraged to present their findings in a broader regional context crossing national boundaries. Such an approach took into account that Poland straddles several important European geological boundaries and realms, a fact of which the Earth Science community at large became increasingly aware.

Poland covers the boundary between the stable East European Craton and the metastable Phanerozoic platform of Western and Central Europe that is built up by crustal domains consolidated during the Caledonian and Variscan orogenies, and which is bounded to the south by the Alpine Orogen. In the area of Poland the Caledonides (Pomerania), the Variscides (Sudetic margin of the Bohemian Massif) and the still active Alpine Orogen (Western Carpathians) meet, and abut the East European Craton along the Trans-European Suture Zone. After the Late Carboniferous consolidation of the Variscan Orogen, the Western and Central European Palaeozoic Platform and its boundary towards the East European Craton were affected by a sequence of complex tectonic processes controlling the development of the Permian Basin and, more generally, the Central European Basin System. The Permian-Mesozoic Mid-Polish Trough is a polyphase basin that essentially recorded all important tectonic events and processes affecting Central Europe, starting with the latest Carboniferous and Permian pulse of wrench tectonics, Mesozoic rifting, and ending with the Late Cretaceous-Paleocene build-up of collision-related compressional intraplate stresses emanating from the evolving Carpathians. Inversion of the Mid-Polish Trough and upthrusting of basement blocks forming the Bohemian Massif at the Cretaceous/Cenozoic transition was followed by the development of the flexural Carpathian foreland basin and its partial destruction during the emplacement of the Carpathian nappe systems. The Cenozoic history of the Polish Lowlands is to a large degree representative for Central Europe, whilst their Pleistocene glacial record is among the most complete and best studied of Europe.

CONTENTS OF THE ANNIVERSARY VOLUME

The Anniversary Volume presented here, is the latest expression of the long-standing tradition to report in the *Geological Quarterly* salient results of recent regional studies on the geology of Poland and its neighbouring countries. It also summarizes the last achievements resulting from the application of new methods and concepts to regional studies. These include deep refraction- and shallower high-resolution reflection-seismic studies, potential field analyses, radiometric dating, geochemical indicators of plate-tectonic settings, quantitative basin analysis, and the assessment of dynamic processes controlling intraplate tectonics and the evolution of orogenic belts, including the involvement of exotic terranes. International cooperation, particularly under the ESF sponsored EUROPROBE and the EU-funded TMR PACE projects played an important role in introducing these new approaches to regional studies. This fulfilled the hopes and intentions of the *Geological Quarterly* editors that re-directed in the early 90's the journal's scope away from purely national requirements to those of an international "European" publication.

This Anniversary Volume aims at presenting, within the limited space of the journal, an as thorough as possible overview of the crustal configuration and geological evolution of Poland and neighbouring territories during Phanerozoic times, highlighting the most important stages.

The first two papers present the interpretation results of refraction- and wide-angle reflection-seismic experiments conducted by **Aleksander Guterch** and **Marek Grad** and their Polish and international collaborators. The following paper by **Czesław Królikowski** summarizes the results of seismic research coupled with modelling of potential field data that support the new concept that the crust of the East European Craton extends westward beyond the long-known Teisseyre-Tornquist Line. The next paper by **Ryszard Dadlez** aims at better defining the course of concealed orogenic fronts and major faults and at enhancing the understanding of their importance on the location of geological boundaries and depocentres in the Late Palaeozoic and Mesozoic sedimentary cover.

These crustal-scale interpretations added much information on the complex Trans-European Suture Zone (TESZ) that is of particular importance to the understanding of the geological evolution of Poland. The TESZ component of the highly successful EUROPROBE Project was devoted to this very zone that was the main subject of the succeeding PACE Project. Between 2001 and 2004 the Polish national project "Palaeozoic Accretion of Poland" (with some international co-operation)

was carried out in order to further pursue the reconstruction of Late Proterozoic-Early Palaeozoic scenarios for the development of the Polish part of the TESZ. The paper by **Jerzy Nawrocki** and **Paweł Poprawa** that is mainly based on combined petrological, geochronological, palaeomagnetic and sedimentologic-stratigraphic studies summarizes salient results of this project. This overview paper is supplemented by the more focused presentation by **Krzysztof Jaworowski** and **Magdalena Sikorska** that explores the Early Palaeozoic relationship between the Łysogóry Block and the East European Craton, mainly based on sedimentological and facies criteria.

It appears that after a period of provocative hypotheses invoking continental-scale transcurrent faulting and long-distance terrane travelling, such as those by Pożaryski, Brochwicz-Lewiński, Lewandowski, we return now to more stabilistic concepts for the evolution of the TESZ that were heralded already in the important paper of Dadlez *et al*. (1994; Geol. Quart., v. 38, no. 2). Nevertheless, we are still far from the "ultimate truth" and a detailed scenario for the Early Palaeozoic events that controlled the assembly of crustal blocks involved in the TESZ. Major strike-slip displacements are for the time being still a viable proposition.

Stanisław Mazur *et al*. review the evolution of the Sudetic part of the Variscan Orogen. They clearly demonstrate that considerable progress has been made in understanding the very complex tectonic puzzle of the Sudetes, by acquiring new stratigraphic data (including biostratigraphy of metamorphic sequences and radiometric ages), new petrological fingerprints of igneous and metamorphic rocks, and a wealth of modern data on the structural evolution of this area. The painstaking process of fitting the Sudetes into the Kossmat's regional scheme for the European Variscan Orogen appears to be closer than ever to its successful completion. Yet, at the same time, the Sudetic Foreland outboard of the Dolsk Fault, a possible counterpart of the Rheno-Hercynian Zone, cannot be readily fitted between the German "type area" and the Moravian-Silesian area. This is mostly due to the lack of data below the thick Permian-Mesozoic successions of the western Polish Lowlands in the Wielkopolska area. As a result, the presently observed relationship between the West-Central Sudetes and the Eastern Sudetes is not yet adequately understood in terms of the evolutionary stages of this orogen.

Hubert Kiersnowski and **Arkadiusz Buniak** describe the development of the Permian Rotliegend Basin based on detailed studies of well data from north-west Poland, neighbouring Germany and the Baltic offshore area. They demonstrate that latest Carboniferous and Early Permian wrench movements along the Teisseyre-Tornquist and Sorgenfrei-Tornquist zones controlled the subcrop pattern of Carboniferous and older strata beneath the Permian deposits, and that these waned only gradually during the accumulation of the Rotliegend clastic series. This study describes how differential movements between individual fault-bounded blocks, forming a complex mosaic, controlled the development of localized Rotliegend depocentres. The sequential facies maps, retracing the early evolutionary stages of the Polish part of the Southern Permian Basin, draw the attention of the Petroleum Industry that explores for gas accumulations in Pomerania. Tentative across-border correlations of the Rotliegend series are advanced, on the base of which differences in the evolution of the Polish and German sub-basins are addressed.

Piotr Krzywiec reassessed the Mesozoic evolution of the Mid-Polish Trough on the base of modern reflection-seismic data calibrated by boreholes. Results of his studies improved the understanding of dynamic processes that controlled the development of the Mid-Polish Trough and that are also relevant for entire Central European Basin System. This pertains to such important issues as the role of basement discontinuities during extensional basin subsidence and transpressional inversion, the mechanical decoupling effect of the Zechstein salts during extensional and transpressional deformations, controls on the evolution of salt structures, and, lastly, the structural and stratigraphic record of the Late Cretaceous-Paleocene basin inversion. The study of inversion processes documents that they commenced during the Turonian and that the subsequent uplift stages of the Mid-Polish Swell correlate with inversion pulses evident in the North-Danish and North-German Basins. All these aspects are among the main topics of the recently initiated international SPBA Project ("Petroleum Geological Atlas of the Southern Permian Basin Area").

According to modern concepts (see e.g. Ziegler, 1988, 1990), dynamic processes affecting in the Tethys realm the southern margin of the European Platform exerted a strong control on the Mesozoic evolution of the Polish Lowlands. Tensional reactivation of the TESZ during Triassic to Early Cretaceous times, controlling subsidence of the Mid-Polish Trough, is related to rifting processes that resulted in the opening of Tethyan oceanic basins. The build-up of intraplate compressional stresses, controlling Turonian to Paleocene inversion of the Mid-Polish Trough and upthrusting of basement blocks forming the Bohemian Massif, can be attributed to increasing collisional mechanical coupling of the evolving Alpine-Carpathian orogen with its European foreland.

Nestor Oszczypko addresses amongst others these issues in his comprehensive review of the tectono-stratigraphic evolution of the Polish part of the external Western Carpathians and their foredeep basin. His model for the geodynamic development of the Western Carpathians incorporates the results of recent structural and stratigraphic studies and new data on clastic source areas, as well as new quantitative sedimentation rate and subsidence analyses. Palaeogeographic concepts and palinspastic reconstructions are discussed in the context of the entire Alpine-Carpathian orogenic system. Significantly, compression-induced partial inversion of the Outer Carpathian sedimentary basins commenced during the Turonian, in tandem with the earliest inversion movements documented from the Mid-Polish Trough. Special attention was given to the evolution of the Carpathian foredeep basin. Interestingly, its subsidence increased sharply during the last thrusting pulse that preceded detachment of the subducted lithospheric slab, but ended abruptly upon detachment of the latter around 10.5 Ma when uplift and erosion of this basin commenced.

Although the main body of this volume is devoted to subsurface geology, it should not be forgotten that glaciogenic

Pleistocene deposits attaining thicknesses of up to 300 metres cover most of Poland and northern Central Europe. Polish geologists have been involved since many years in developing a precise stratigraphy and palaeogeography for the European Pleistocene. Currently, these studies aim at establishing correlations between glaciated and periglacial areas in which climate changes are recorded by interlayered humid soils and aeolian loess-type sediments. This is one of main subjects addressed by the paper of **Leszek Lindner *et al***. who present a wider correlation with the isotope stratigraphy of oceanic sediments that may eventually lead to establishing more exact comparisons of various records of climatic changes worldwide.

CONCLUSIONS AND OUTLOOK

Papers contained in this 50th Anniversary Volume of the *Geological Quarterly* present salient examples of progress made in the understanding of the configuration and evolution of Poland's crust, sedimentary basins and orogenic belts. Authors contributing to this volume come from the Polish Geological Institute a well as from Polish Universities and the Polish Academy of Sciences. As such, they represent large parts of the Polish geological and geophysical communities that jointly pursue their research efforts.

From the papers presented in this volume, it is evident that the thrust of ongoing research is not only directed towards a descriptive inventory of the regional geology of Poland but increasingly also towards the analysis and understanding of dynamic processes, inherent to the interior of the Earth and its surface, that controlled the geological evolution of Poland during Late Proterozoic to recent times. In this respect great progress has been made since open communications with Western scientists were re-established in the early 1990'ies and new technologies became available to Polish geologists and geophysicists who could now participate freely in international research projects and networks. Indeed, with the *Geological Quarterly* attaining an international status, the results of Polish Earth Science research became increasingly available to international readers, further stimulating transnational cooperation. At the same time, more Polish researchers began to publish their papers also in international journals, thus drawing increasing attention to the geology of Poland. Furthermore, opening of Poland to the international Petroleum Industry stimulated applied geo-research, particularly in terms of the acquisition high-resolution 2D and 3D reflection-seismic data, permitting a closer analysis of its complex subsurface.

Peter A. Ziegler has repeatedly pointed out that Poland is one of the geologically best-documented countries of Europe, and that Poland is a key area for the understanding of Europe's geological evolution. Polish literature generously provided to him by W. Pożaryski, J. Znosko, R. Dadlez, W. Brochwicz-Lewiński, J. Kutek and others allowed him to develop his Geological Atlas of Western and Central Europe (1982, 1990). This and related compilations have greatly stimulated research activities, including the TESZ and GeoRift components of the ESF-EUROPROBE Project, the EU-TMR PACE (Palaeozoic Amalgamation of Central Europe) and PCR (Permo-Carboniferous Rifting) networks, and the IGCP Project 369 (PeriTethyan Rift/Wrench and Passive Margins), to all of which Polish researchers made major contributions.

Poland, owing to its position with respect to the Caledonian, Variscan and Alpine orogens, may serve as natural laboratory for investigating repeated re-activation of crustal discontinuities in response to successive pulses of collision-related compression, subsequent uplift and erosion, followed by extensional processes.

For example, the TESZ, which represents a major crustal boundary, was repeatedly reactivated during Late Palaeozoic and Mesozoic times under changing regional stress fields after the Caledonian suturing of the East Avalonia Terrane to the East European Craton, involving a number of intervening suspected terranes of still disputed derivation. This contributed to the complexity of its crustal structure that is revealed by an unprecedented dense grid of seismic refraction-wide angle reflection profiles. Further progress in the understanding of the TESZ depends on the recording one or more deep near-vertical reflection-seismic lines across it, providing insight into the fabric of the crust that can be interpreted in terms of accretionary and subsequent overprinting processes.

Modelling and interpretation of deep seismic data has to be further integrated with the comprehensive evaluation of potential fields data that in the case of the Polish territory represent an exceptionally complete and detailed database (particularly gravity and magnetic and less so heat flow data). Yet, based on refraction-seismic and potential field data alone the definition of concealed crustal blocks boundaries (commonly vertical or sub-vertical discontinuities) is still difficult and leaves many questions open. In this respect, the analysis of outcrop and shallow subsurface data of southeastern Poland, indicating repeated Late Palaeozoic and Mesozoic re-activation of certain deep-seated structural discontinuities, such as the Holy Cross or Grójec faults, might be a promising complementing approach. For the central and northwestern segments of the Polish TESZ, extrapolation of such observations combined with the structural data at Permian and Mesozoic levels may permit to define the configuration of Early Palaeozoic crustal blocks or terranes (*cf*. Krzywiec and Dadlez papers, this volume). Confronting the results of such analyses with geophysical data is a basic requirement to arrive at viable models.

Although great progress has been made in unravelling the evolution of the Variscan Orogen in the area of the Sudetes, Moravia and Silesia, further efforts are, however, required to arrive at viable plate tectonic models. Moreover, development of the Variscan foreland basin and its partial destruction during the late phases of the Variscan orogeny and the subsequent Permo-Carboniferous wrench faulting and magmatism, requires further attention, not only to clarify its correlation with the evolution of its German counterpart that is superimposed on the Rhenohercynian Shelf, but also in terms of its hydrocarbon source-rock potential. The Polish part of the Variscan foreland area, that extends from the northern Koszalin-Chojnice Zone to the Holy Cross Mts. and Lublin areas in south-east, although not involved in the orogen itself, clearly responded to successive stages of Late Devonian–Early Carboniferous extension and subsequent late Viséan to Westphalian compression. Ongoing studies aim at constraining the temporal and kinematic

relationship between the orogen and its foreland, and will shed light on the role reactivation of pre-existing crustal discontinuities (crustal block boundaries) played during the development of Devonian and Carboniferous basins.

The Permian strata of the Polish Lowlands record the early evolutionary stages of the Southern Permian Basin. During the deposition of the Rotliegend clastics and the evaporites and carbonates of the Zechstein series, structural controls on their development appear to have been stronger in Poland than in adjacent Germany, reflecting persisting activity along the TTZ. This requires further quantification, particularly regarding structural controls on the subcrop pattern of pre-Permian series. In this respect, a major obstacle to further progress is the poor resolution of presently available reflection-seismic data at sub-Zechstein levels. This will hopefully be overcome by more advanced 3D seismic techniques and improved interpretation of well data.

The understanding of the Mesozoic evolution of the Mid-Polish Trough and the timing and mechanisms of its inversion into the Mid-Polish Swell has greatly advanced thanks to access to high-resolution industrial reflection-seismic lines. These efforts need to be pursued to lead to 2D and eventually 3D stepwise palinspastic reconstruction of the basin evolution that may provide insight into the development and preservation of hydrocarbon accumulations in Permian reservoirs. This requires closer stratigraphic controls on Late Cretaceous and Cenozoic strata than hitherto available, in order to unravel the exact timing and magnitude of inversion movements. Progress in this respect is also pertinent to resolving essential aspects of salt tectonics, such as the development of syn-inversion structures and their post-Paleocene reactivations. The latter is particularly important in view of the planned underground storage of fuels and radioactive waste in salt diapirs. Drilling of a fully cored research well that aims amongst others at a high-resolution stratigraphy and better calibration of the Late Cretaceous-Cenozoic seismic records in the Szczecin Trough area would be an essential step towards achieving these goals.

The deep structure of the Polish Carpathians still needs to be constrained by crustal-scale near-vertical reflection profiles permitting to assess their architecture at lithospheric scales. Collisional mechanical coupling of the Carpathian orogenic wedge with its foreland played an important role during the Late Cretaceous and Paleocene partial inversion of the Outer Carpathian Basin, the inversion of the Mid-Polish Trough and the upthrusting of basement blocks forming the Bohemian Massif. During the subsequent phases of Outer Carpathian nappe emplacement, relaxation of intraplate compressional stresses in the foreland, reflect its mechanical decoupling from the orogenic wedge, presumably owing to sediment subduction. Following Late Miocene detachment of the subducted lithospheric slab, compressional stresses built up again in the foreland, controlling reactivation of the Bohemian Massif.

Development and refinement of the Quaternary stratigraphy of Poland, and its calibration with the record of peri-glacial and oceanic domains has provided a powerful tool for monitoring past climatic changes. This tool can also be applied in the assessment of neotectonic deformation of the lithosphere, involving its isostatic adjustment to deglaciation and slab detachment, as well as its response to intraplate compressional stresses. In this respect geomorphologic studies, supported by geodetic data, could yield important information on the development of the present-day topography of Poland and its drainage systems. For such studies, the recently launched TOPOEUROPE Project provides an international platform.

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