## Description of the main research directions investigated by the institute

The Institute of Geology of the Czech Academy of Sciences is a public research institution with a broad scope of scientific activities. In general, it concentrates on the study of the structure, composition and history of the Earth's lithosphere (its interior and its surface) and the evolution of biosphere in the past. Although the Institute does not have the opportunity to cover all geological disciplines, it has a multidisciplinary character and its activities span a wide range of problems in geology, geochemistry, paleontology, paleomagnetism and rock mechanics. The Institute contributes to the understanding of general rules governing the evolutionary processes of the lithosphere and biosphere at regional as well as global scales. The Institute is also indispensable in the educational and science-promotion system at national scale (for details see below).

Although being a research institution of a multidisciplinary character, the Institute certainly cannot cover the full range of geosciences. Therefore, our researchers widely cooperate with colleagues from other geoscientific institutions and university faculties in the Czech Republic and abroad.

In the achievement of the postulated scientific goals, researchers of the Institute combine a variety of methods in different geoscientific disciplines, such as petrology and geochemistry of igneous and metamorphic rocks; lithostratigraphy of sedimentary and metamorphic complexes; volcanology and volcanostratigraphy; structural geology and tectonics; paleogeography and terrane identification; taxonomy and phylogeny of fossil organisms; paleobiogeography of Variscan Europe; paleoecology (incl. population dynamics, bioevents); paleoclimatology as evidenced by fossil organisms and communities; biostratigraphy and high-resolution stratigraphy; basin analysis and sequence stratigraphy; exogenic geochemistry; exogenic geology, geomorphology; Quaternary geology and landscape evolution; karstology and paleokarstology; paleomagnetism; magnetostratigraphy; rock magnetism and physical parameters of rocks. This approach resulted in a participation in numerous foreign and international cooperations and, as a consequence, in a publication of peer-reviewed papers in prestigious geological journals (more than 470 IF papers in years 2015–2019) and also in other publications (book chapters, books, conference proceedings) and unpublished outputs (reviews, industrial reports, etc.). The relatively wide range of specializations of the teams (and consequently also individual researchers) allows a cooperation in numerous joint projects supported by national and international grant agencies. Research conducted at the Institute can be generally classified into four main directions, representing the activities of separate teams. However, as mentioned above, this research incorporates a variety of inter-disciplinary problems and topics, many of which are solved within a tight cooperation among the teams.

The history of the Institute dates back to 1960. During time, a relatively compact and stable structure of scientific units was constituted in response to different scientific needs and administrative requirements. Today, six official departments with different fields of research are delimited with more or less overlapping or complementary fields of research, representing four evaluated teams: (1) Department of Geological Processes; (2) Department of Paleobiology and Paleoecology; (3) Department of Environmental Geology and Geochemistry, and (4) joint Department of Analytical Methods, Geotechnics and Paleomagnetism.

**Team 1** (**Department of Geological Processes**) focuses on three main research areas: (1) complex studies that link geochronology with specific rock-forming processes and their physical-chemical conditions (petrochronology, elemental and isotope geochemistry, geodynamics). Routine use of a wide range of geochronological and geochemical methods (e.g., laser ablation ICP-MS and TIMS mass spectrometers) in Team 1 laboratories, combining petrology and geochemistry with chronometric analyses, allows to disclose the processes in the Earth crust and upper mantle lithosphere in sufficient detail; (2) study of the past processes on the Earth surface, characterized by interdisciplinary approach (geoarcheology, sedimentology and stratigraphy, Quaternary processes and

paleoclimatology); (3) other research, conducted in collaboration with other teams of the Institute and with other research institutions. Topics beyond the scope of research areas (1) and (2) are mostly linked with the operation of the ICP-MS and clean lab facilities, which contributed to the publication of several joint-team IF papers and monographs. For details see Appendix 3.4 of Team 1.

The research focus of **Team 2** (**Department of Paleobiology and Paleoecology**) is the biosphere and its changes during geological history, with five main research areas: (1) Paleozoic biostratigraphy and paleoenvironments (high-resolution biostratigraphy and relative dating of sedimentary rocks, development of biozonal scales, and complex biotic response to paleoenvironmental changes and global events, especially using graptolite and conodont faunas); (2) Paleozoic–Cenozoic plants and palynology (systematic positions of spores and plant taxa and paleoecological intepretations and syntheses of data from Carboniferous tropical forests); (3) vertebrate paleontology (study of fish-like vertebrates, amphibians and mammals from different stratigraphic intervals, their anatomy, morphology, phylogeny, paleobiology and paleoecology, together with a description of new taxa); (4) Cretaceous research (study of Cretaceous biostratigraphy, micro and macrofauna, paleoenvironments, paleoecology and sedimentary environments). Area (5) stands for “other research” – rather interdisciplinary-oriented and dealing with specific fossil groups and rarely studied phenomena. Important is also the cooperation of the team with neontologists. For details see Appendix 3.4 of Team 2.

The activities of **Team 3** (**Department of Environmental Geology and Geochemistry**) lie in seven main research areas: (1) study of processes shaping sandstone landforms (the so-called “sandstone phenomenon” at various size scales); (2) karst-related research (complex research of karst areas in various soluble but also insoluble rocks); (3) tektite geochemistry; (4) environmental geochemistry of toxic elements (study of environmental contamination with potentially hazardous elements such as arsenic, mercury, thallium and others); (5) monitoring of fluxes in the environment (monitoring and studies dealing with the dynamics of elements in the environment, together with monitoring of atmospheric deposition); (6) repositories of radioactive waste material, and (7) development and innovation of analytical methods. For details see Appendix 3.4 of Team 3.

**Team 4** (**Department of Analytical Methods, Geotechnics and Paleomagnetism**) is composed of small, similarly orientated research groups whose interests are centred around analyses of instrumentally measured data. The main research areas are: (1) integrated multi-proxy study of the Jurassic–Cretaceous boundary in marine sequences (as a contribution to global boundary definition); (2) paleomagnetism and magnetostratigraphy of karst sediments in central Europe; (3) a reference climate curve for the early Miocene climatic optimum in central Europe; (4) non-destructive determination of heated artefacts in Upper Palaeolithic assemblages; (5) Cretaceous–Paleogene boundary in the Carpathians – a multidisciplinary search for local variations in a global cataclysm event; (6) investigation and simulation of extraterrestrial materials and shock effects; (7) magnetic methods and mineral–material magnetism; (8) anisotropy of sedimentary and crystalline rocks; (9) alkali–silica reaction; (10) field and laboratory anisotropy study; (11) rock fracturing study; (12) tektites and impact glasses; (13) biomineralization; (14) historical glass; (15) mineralogy of meteorites; (16) sample provenance estimation for forensic applications; (17) analytical service for research projects. Analytical service for research projects is also a part of the duties within the Institute. For details see Appendix 3.4 of Team 4.

Laboratory equipment is being constantly modernized and supplemented. The most important acquisitions for Team 1 are represented by a brand new 193nm *excimer laser system (Cetac/Teledyne)* to the existing laser ablation ICP-MS lab (2016) and a novel generation of *thermal ionization mass spectrometer (TIMS) Triton Plus (Thermo)* in 2017. Installation of the TIMS led to the introduction of routine TIMS analyses (Nd, Sr, Pb, Os and Sm) with the focus on the development of a very precise CA-ID-TIMS U–Pb dating technique at the Institute. The planned expansion of the analytical methods was successful in establishing the precise Lu–Hf geochronology and *in situ* zircon Hf analysis, setup of double-spike technique protocols for non-traditional stable isotope analyses (Mo, Cd), high-precision

Cd elemental analyses using the isotopic dilution technique and extension of Re–Os analytical protocol to obtain Re–Os ages of arsenopyrite, pyrite as well as black shales. U–Pb zircon dating routine was established also for monazites. The important instrumental investments were also directed to laboratories of Team 4. *Raman micro-spectrometer S&I MonoVista CRS+* (purchased in 2015) allows a collection of Raman and photoluminescence spectra from a sample with spatial resolution of 1 μm laterally and 2 μm axially. The spectra can be collected within the range of 60–9300 $cm^{-1}$ with 488 nm and 532 nm excitation lasers and 60–3500 $cm^{-1}$ with a 785 nm excitation laser. Typical applications include both the identification and in-depth study of minerals, their inclusions as well as various synthetic materials like gemstone imitations or microplastics. In 2017, a Fourier-transform infra-red spectrometer (FTIR) *Thermo ScientificNicolet iS-50* was acquired with a built-in mid- and far-IR capable diamond attenuated total reflectance (ATR) accessory. In the transmission arrangement, the spectrometer covers the wavenumber range of 7800–350 $cm^{-1}$. In the ATR mode, the wavenumbers covered are 4.000–100 $cm^{-1}$ depending on the used beam-splitter. The instrument is used for the identification of powdered samples of minerals, rocks and solid-state synthetic substances. Cutting and grinding machine *Buehler PetroThin* was acquired in 2017 to expand the possibilities of manufacture of polished thin sections. In addition, a brand new *electron probe microanalyzer (JEOL JXA 8230)* was installed in November 2019. It provides quantitative chemical composition data for major and minor elements in polished solid state samples including a wide variety of materials covering minerals, rocks, archeological artefacts, glass fibres, catalysts and other synthetic products. For quantitative applications, it is equipped with five wave-dispersive spectrometers housing together 14 analytical crystals. a proprietary JEOL energy-dispersive spectrometer is installed in the instrument to collect overview spectra to determine major constituting elements. Imaging is possible *via* secondary or back-scattered electron detectors. Panchromatic cathodoluminescence detector allows to image fine details in microfabrics otherwise unseen with standard imagery.

This is not a complete list of instrumental investments which support all teams (and departments) and the Institute as a single unit but shows the most significant acquisitions (often with a significant financial support from the Czech Acad Sci). It is also necessary to mention an effort to expand or improve the spaces for detached workplaces of the Institute. These efforts took place during the period under review.

In the 2015–2019 period, the teams participated in many projects granted by the Czech Science Foundation (GAČR) and ministerial agencies and in international projects (for details see Appendix 3.2). Although the number of grant proposals is growing (mainly from providers Czech Science Foundation – GAČR and Technology Agency of the Czech Republic – TAČR), and the teams are somewhat more successful than in the previous evaluation period, the situation is not ideal. This results from the generally under-financed support of science (as a whole, including budgets of the main grant providers) in the Czech Republic, together with the fact that geosciences are not counted among the “top” science fields supported by the scientific policy of the Czech Republic.

Even though the Institute is under-financed in its research and loaded by numerous administrative requirements, the teams are able to produce high-quality results, comparable to those of international teams of similar size and focus. It is also necessary to note that all results achieved by the Institute are published as research reports in printed and on-line versions on an annual basis (for details see https://www.gli.cas.cz/en/annual-reports).

## Research activity and characterisation of the main scientific results

**Research Area 1 – Petrochronology, Elemental and Isotopic Geochemistry, Tectonic Processes and Progress in Relevant Analytical Methods**

Below is the characteristics of scientific outputs (111 papers in IF journals + 1 book) achieved by Team 1 within the framework of Research Area 1.

Petrochronology is a relatively new field within Earth sciences, in which the isotopic and/or elemental composition of a mineral chronometer is interpreted in combination with its age, thus yielding a more synergistic combination of petrology and chronology that can be used to interpret geologic processes. During the evaluated period, Team 1 routinely introduced several applications using laser-ablation ICP-MS and fission-track facilities as tools for studies conducted in various areas of the world. Routinely provided petrochronologic analyses by single-collector ICP-MS instruments connected with excimer laser ablation were used for isotopic analyses, such as U–Pb geochronology of zircons and monazites, Re–Os geochronology of sulphides, while conventional fission-track method was applied to apatites. A complex approach including petrographic description, isotope geochemistry and geochronology resulted in 32 papers dealing with petrochronological studies in high-rank Earth science journals. The U–Pb zircon geochronology paralleled by mineral petrography were used for the interpretation of high- to ultrahigh-P metamorphic protolith conditions that were followed by anatexis and syntectonic growth of granulites in the Podolsko complex (ID 47513) or granulite-facies rocks from the Kutná Hora Crystalline Complex (IDs 443594, 462061). In an attempt to evaluate how and when an active margin evolved to a passive margin in the Teplá–Barrandian Unit, Team 1 determined the age of key Cambrian to early Ordovician stratigraphic sections within the late Neoproterozoic to early Cambrian Blovice accretionary wedge of the Bohemian Massif (IDs 499733, 509408). The U–Pb zircon age data from magmatic and clastic rocks were used to reconstruct the evolution of the Bohemian Massif and related units from its formation at the active northern Gondwana margin in the Neoproterozoic (ID 478000) to a lower Paleozoic anatexis (ID 508957) and a later micro-continent formation (ID 488620). Another study on the evolution of the Bohemian Massif rocks focused on the Brno massif, which is the largest exposed part of the Brunovistulicum (eastern Bohemian Massif). A combination of new geological, geochemical and isotopic data, including U–Pb zircon dating obtained by Team 1, revealed two distinct Precambrian magmatic events within the Central Basic Belt preceding the Cadomian arc magmatism (ID 509342). The Teplice rhyolite intra-caldera deposits of the Altenberg-Teplice Caldera were investigated by lithofacies analysis, stratigraphy, and whole-rock chemistry as well as U–Pb zircon dating of Team 1. The U–Pb zircon dating yielded ages from 323 to 312 Ma, which indicate that the Teplice rhyolite was generated within a time span of ~325–317 Ma (ID 511532). The Variscan assembly of various terranes is recorded in sedimentary sequences studied in the Northern Rhenish Massif (ID 498620, 507887) and later tectonic processes on peneplaned Variscides in the Late Paleozoic and Mesozoic siliciclastics of the northern Bohemian Massif (ID 518673). Team 1 had a tight connection to a research group studying the correlation of geological units between South America and Africa with an ultimate goal to find a direct link between the geological units on both sides of the Atlantic (ID 459707). The U–Pb zircon dating of magmatic and detrital zircons as well as *in-situ* Hf analysis of zircon were utilized to characterize Paleo- to Mesoproterozoic magmatic rocks in Uruguay (ID 504223) as well as Neoproterozoic rifting (ID 490793) and flysch sedimentation (ID 477428) at the opposite (African) coast of the Atlantic. A number of studies deal with zircon provenance of sedimentary successions along Baltica. The Mesoproterozoic to Cambrian sedimentary cover of the East European Platform was studied in Belarus (ID 517234). Cambrian and Ordovician sediments in SW Scandinavia suggest an exotic origin of the detritus travelling from Early Palaeozoic Timanides in the NE (ID 454789, 465584). The youngest studied sedimentary sequences are the Mesozoic reservoir rocks of the Barents Sea (IDs 487420, 488624). Team 1 started an extensive collaboration with the researchers from the Polish Academy of Sciences dealing with fluid alteration of accessory minerals. Data from the LA ICP-MS lab of Team 1 were used to study the re-equilibration of

the U–Pb system in chronometers in naturally (ID 489501) as well as experimentally altered samples (ID 509442). The U–Pb zircon data of Team 1 were also used to study the provenance of Palaeozoic glacially influenced rocks in Bolivia (ID 504093). The U–Pb dating of zircon also helped to find evidence for Archaean, ca 3.3 Ga oceanic crust in the Barberton greenstone belt of South Africa (ID 477429) and defined constraints of arc-related basement during Mid Ordovician and Late Devonian magmatism of Western Mongolia (IDs 459681, 487425). Team 1 participated in trace-element characterization of apatites from Martian meteorites – nakhlites (ID 518665), which were used to infer their magmatic and fluid evolution. The use of apatite fission track analysis and vitrinite reflectance modelling revealed paleo-thermal and coalification history of Permo-Carboniferous sedimentary basins of Central and Western Bohemia of the Bohemian Massif (ID 511608).

In the Earth's interior and surface, multiple processes are responsible for the evolution of the mantle and formation of the crust. The main focus of Team 1 is to understand the mechanism and consequences of partial melting and metasomatism in the Earth's mantle, to explain the composition of mantle-derived melts in terms of their sources and modification during the ascent, reveal what processes control and affect the composition of the Earth's crust, provide new constraints on the formation of rocks originated during high-speed velocity impacts of extra-terrestrial bodies and contribute to our understanding on the formation of mineral deposits. To accomplish all these objectives, Team 1 members apply multiple tools combining detailed field observations with petrography, bulk rock and *in situ* major/trace element geochemistry and radiogenic (Sr-Nd-Pb-Hf-Os) and stable (Cu-Zn-Cr-Mo-C-O) isotope geochemistry. During the 2015–2019 period, collaborative studies with several institutions from the Czech Republic and especially the intensive collaborative research with many scientists from abroad (USA, Japan, Germany, Austria, Russia, India, Canada, China, United Kingdom, Norway, Slovakia, Hungary, Turkey, Iran, Denmark, South Africa, Spain) resulted in the publication of 61 papers in IF journals. The nature and evolution of mantle-derived rocks (peridotite, pyroxenite, eclogite) were targeted by several studies. An external collaboration with colleagues from the University of Vienna resulted in two papers (IDs 438962, 460245) describing the properties of mantle xenoliths from Patagonia and discussing a possible connection between Africa and Antarctica continents in the past. A member of Team 1 provided analytical data and contributed to their interpretation. The nature, evolution and age of subcontinental lithospheric mantle beneath the Bohemian Massif was underpinned by three new studies focused on mantle xenoliths from Cenozoic volcanic rocks (IDs 443757, 443759, 459712) where Team 1 members played a key role in sampling, data collection and interpretation. Another paper (ID 457346), resulting from a collaboration with University of Wisconsin, described depletion and metasomatism of mantle rocks from the Saxothuringian Unit of the Bohemian Massif providing missing information on the Variscan evolution of this area. Here, a Team 1 member provided analytical data and largely contributed to the whole interpretation. Three papers (IDs 442927, 472991, 491911) provided new constraints on the formation of mantle-derived melts and metasomatism deduced from a detailed study of multiple-phase inclusions as a result of continuous co-operation with Japanese colleagues. In these studies, a Team 1 member led the fieldwork and contributed to the interpretation. Detailed studies on the age and petrogenesis of mantle pyroxenites from the Bohemian Massif were conducted (IDs 460854, 459673) in collaboration with colleagues from USA, Japan and Germany where Team 1 members initiated the research, performed sampling, gathered most analytical data and played a key role in their interpretation. In a similar manner, Team 1 members led a study (ID 444774) dealing with the nature of phlogopite pyroxenites in a close connection to durbachites in the Bohemian Massif. Another study where a Team 1 member provided analytical data and their interpretation reported on unusual spheroids discovered in eclogite from the Bohemian Massif (ID 459770), which argue for the presence of immiscible Fe-Ti melts in the upper mantle. The collaboration with Chinese colleagues resulted in a paper (ID 505049) providing new evidence for the upper mantle Zn isotopic heterogeneity as a result of intense melt–rock reactions. Here, a Team 1 member provided all samples for the study and largely contributed to the overall interpretation. Petrogenesis of Cenozoic volcanic rocks from the Bohemian Massif was targeted by several studies in close collaboration with colleagues

from Germany, Canada and Hungary. In all these studies, Team 1 members acted as leading persons of research pursuing sampling, gathering significant amount of data and providing a majority of data interpretation. A study dealing with the petrogenesis and age of phonolitic and trachytic rocks, intriguing and common rocks from the České Středohoří Volcanic Complex, was published (ID 443083) and paralleled by a complex study of Miocene alkaline volcanic rocks from Western Bohemia (ID 459103). Two papers were focused on two prominent features of Cenozoic volcanic rocks in the Bohemian Massif – the presence of tachylites (ID 478570) and amphibole phenocrysts, xenocrysts and cumulate xenoliths (ID 490486) providing new constraints on their origin. Two papers (IDs 476474, 503956) originated in a close co-operation with Saint Mary's University (Canada) and National Taiwan University summarizing all available geochemical data as well as providing new data for Cenozoic and Proterozoic volcanic rocks from the Bohemian Massif. In these papers, a new model on the origin and mantle sources of these rock suites was presented, and the impact of Variscan orogeny was explained. Another paper (ID 448549) described unique petrology and mineral chemistry of Upper Cretaceous to Pleistocene melilitic rocks from the Bohemian Massif. Besides the Cenozoic rocks, the origin of orogenic lamproites of Variscan age, representing a rare but intriguing type of rocks in the Bohemian Massif, was explained (ID 460319) in a close collaboration with a research team from University of Potsdam. In addition, a detailed geochemical study of Neoproterozoic volcanic rocks (ID 509766) revealed the nature of oceanic floor subducted beneath Gondwana during the late Neoproterozoic–Cambrian. Several studies were also undertaken on magmatic rocks from India, Iran, Faroe Islands and Antarctica by Team 1 members. Carbonatites from the Tamil Nadu region, India, were investigated in detail in terms of their major/trace element and isotopic geochemistry (ID 475325) and highly siderophile element geochemistry (ID 505893). Here, Team 1 members initiated these studies, gathered predominant amount of data and played a key role in data interpretation. A detailed study of basaltic rocks from NE Iran (ID 500254) benefitted from the Re–Os data and associated interpretation provided by a Team 1 member, bringing new evidence for a Middle Permian oceanic plateau fragment in the Paleo-Tethyan suture. Team 1 members also contributed to two studies (fieldwork and data interpretation) dealing with basaltic dykes with a specific texture from the Faroe Islands (ID 509628) and alkaline volcanic rocks from the James Ross Island in Antarctica (ID 443682). Finally, a Team 1 member provided analytical data for a study dealing with geochemistry of apatites from neovolcanic rocks in Slovakia (ID 499454). Granitic rocks, representing a prominent rock type of the Earth's crust, were the objective of several studies led and accomplished by Team 1 members who provided most analytical data and played a key role in their interpretation. *In situ* quartz, mica, tourmaline chemistry representing a unique tool in deciphering the evolution of granitic melts paralleled by detailed bulk rock geochemistry, mineralogy and petrology was applied to Sn–W-bearing granites from Cínovec/Zinnwald (IDs 480140, 479233, 480068, 503969), granite to aplite–pegmatite rocks from Cornwall (ID 488627) and Ta–Li-rich granites from Transbaikalia, Russia (ID 511042). The effects of low-temperature hydrothermal overprint on the composition of rare-element-bearing granites were studied in a close collaboration with colleagues from Slovakia (ID 443442). Compositional patterns of zircon and monazite and their effect on the bulk-rock budgets of Zr, Hf, Th, U, Y were investigated in granitic rocks from England and the Bohemian Massif (IDs 465588, 465674, 477204). A comprehensive study (ID 476328) summarized concentrations of Li and other trace elements in micas from granitic rocks and discussed mica potential as a marker of geochemical evolution of granitic melts. A Team 1 member also contributed to the complex study focused on the ore-formation processes at the Weilasituo tin-polymetallic deposit in China (ID 509551) interpreting *in situ* mica data. Similarly, a collaborative research with University of Wisconsin conducted on calc-alkaline granitic rocks from the USA (ID 509341) benefitted from the inclusion of Team 1 members who provided analytical data and contributed to their interpretation. Finally, two papers dealing with the petrogenesis of pegmatites from the Bohemian Massif (ID 475498) and chemistry of molybdenites from topaz-bearing granites (ID 449610) benefitted from the interpretations of geochemical data by a Team 1 member. Besides studies on granitic rocks, a Team 1 member also contributed (field work, help with data interpretation) to the study of Japanese colleagues

dealing with thermometry of the Bohemian Massif granulites (ID 480051) and the study focused on molybdenum isotope geochemistry (ID 504100) of Paleoproterozoic Mn-ores from Brazil (in collaboration with colleagues from Brazil and Germany) where Mo isotope data were provided and interpreted. Lastly, Team 1 members played a leading role (data interpretation) is a paper evaluating Cu-Zn-Cr stable and Os radiogenic isotope systematics of the black shales from the Bohemian Massif (ID 505892). Timing and evolution of several ore deposits from the Bohemian Massif including those hosting important Sn–W and Au mineral deposits were revealed by members of Team 1 providing crucial geochronological Re–Os data on molybdenite and arsenopyrite, U–Pb data on zircon and Ar–Ar data on mica and associated interpretations. Specifically, a large dataset of Re–Os ages for more than 20 ore mineralizations was gathered (ID 475311), chronology of Au deposit at Kašpeské Hory was revealed (ID 504080) and multiphase formation of the Obří důl base metal deposit was discussed (ID 489612). In collaboration with colleagues from South Africa, Team 1 members provided new constraints on strong economic potential of the Uitkomst Complex in South Africa (ID 488682). We revealed that the identification of different types of mineralization can be made using *in situ* trace element measurements of molybdenite in combination with detailed scanning electron microscopy (ID 460127) and provided analytical data for a detailed investigation led by colleagues from Spain and Austria on the occurrence of critical metals (REE, Sc, PGE) in laterites exemplified by rocks from the Dominican Republic (ID 459700). Members of Team 1 also contributed to the study of PGE and Au distributions in sulphides from Mo-rich black shales from China (ID 479341) gathering the crucial analytical dataset and contributing to the interpretation. Team 1 members were largely involved in geochemical investigations explaining the formation of tektites – silica-rich glasses formed during extra-terrestrial impacts. Two studies (IDs 475494, 504263) led by Team 1 members searched for an admixture of extra-terrestrial material in the Central European tektites (moldavites) and Australasian tektites, respectively. Besides that, we also largely contributed to the interpretation of the formation of impact melt glasses from the Zhamanshin impact structure in Kazakhstan (ID 461314), provided analytical data and associated interpretation for two papers focused on the formation of moldavites (IDs 458591, 460301) and one paper dealing with the chemistry of Australasian tektites (ID 504421). Finally, a member of Team 1 contributed to the interpretation of the occurrence of shenguanite, a rare Ni-Fe sulphide discovered in Australasian tektites (ID 507835).

Magmatic, metamorphic and tectonic processes form and shape the Earth's crust, the thin and uppermost layer of our planet. To contribute to our understanding of such dynamic system, Team 1 members employ a wide range of research methods based on detailed field mapping of selected magmatic and sedimentary rock formations in the Bohemian Massif (Czech Republic, Germany and Austria), Western Carpathians (Slovakia), Rocky Mountains (Colorado), Sierra Nevada (California) and Blue Mountains (Oregon). The most important methods include structural and paleostress analysis, petrography, geochemistry, radiometric dating, anisotropy of magnetic susceptibility (AMS), and rock magnetism. During the 2015–2019 period, Team 1 cooperated with specialists from domestic and foreign institutions, which resulted in 10 peer-reviewed publications with IF and one book monograph. In seven cases, our team led the research, and largely contributed to three other scientific papers. Four main research topics can be distinguished: (1) mechanical aspect of magma transfer and emplacement processes associated with collapse calderas. In particular, we investigated the dynamics of ring-dyke emplacement and extrusion of lava domes along ring faults (IDs 504671, 464899). The most important outcome is that these processes are largely coupled with caldera subsidence, and that the internal structures of lava domes and ring dykes may record different mechanism of caldera collapse. Further on, we explored magmatic intrusions associated with post-collapse evolution (IDs 519313, 480055). It was discovered that a shallow-level magmatic systems of collapsed calderas remain active for another few millions of years and produce multi-pulsed intrusions and complex dyke swarms. Contrary to previous models, such intrusions may record far-field tectonic deformation still in magmatic state, thus representing markers of stress field generated by lithospheric plate motions. (2) research of a deeper magmatic systems, especially large felsic plutons and composite batholiths

(IDs 448156, 448159, 480054). Here, we interpret their 3D shape, space-opening mechanisms, and link the timing of emplacement and their internal architecture with major orogenic events. Perhaps the most important result is that, based on spatial-compositional-temporal relations, we were able to reconstruct the motion of adjacent lithospheric plates. (3) similar results were acquired during the study of a foreland sedimentary basin (ID 507814). An extensive dataset of anisotropy of magnetic susceptibility (AMS) and structural data, together with paleomagnetic analysis performed at New Mexico Highlands University, allowed us to decipher complex sedimentary and polykinematic deformation patterns. These data were then linked with underthrusting of microcontinental plate movements along major strike-slip shear zones during late Variscan post-orogenic processes. (4) the Late Cretaceous to Pliocene succession of intra-plate tectonic stresses in the foreland of the Alpine–Carpathian orogen is the key to the understanding of faulting/rifting and distribution of magmatic activity. As yet, it has been only roughly estimated, with no precise timing available. Paleostress analysis along the Lusatian Fault in the Bohemian Massif allowed to refine the paleostress pattern scale for the Alpine foreland and set reliable time constrains (IDs 443496, 503079).

**Research Area 2 – Geoarchaeology, Sedimentology (Stratigraphy), Quaternary Processes and their Implications for Paleoclimatology**

Below is the chracteristics of scientific outputs (49 papers in IF journals + 18 chapters in books and 3 books) achieved by Team 1 related to the topics within Research Area 2.

In recent years, geoarchaeology has become a newly emerging inter-disciplinary field of science among geology, geomorphology, environmental archaeology and classic archaeology. It is especially its inter-disciplinary character that makes it a very attractive tool in archaeology. Yet, it has been applied by only relatively few specialists. A relatively small number of methodical handbooks exist in the Czech Republic to ensure proper methodical approaches. One of the most recent ones is the monograph Methods of study of garden-art monuments (ID 453419), which contributed from the inputs of Team 1 members. Team 1 is basically the only team in the Czech Republic running a functional geoarchaeological lab. This lab conducted research in the Czech Republic and beyond, being highly valued abroad (IDs 517518, 469906, 519081, 443420, 465853). The methods used by this laboratory include routine sedimentological, geomorphological and standard geochemical analyses combined with magnetic proxies (ID 446005) and grain-size analysis (IDs 443420, 465853). This information is subsequently extended by micromorphological characteristics, which is an integral part of geoarchaeological analysis. Micromorphology is a thin-section study of samples acquired in archaeological context. The geoarchaeological laboratory of Team 1, specifically its head Assoc. Prof. Lenka Lisá, was the first who applied successfully this method in the Czech territory and continues to teach this method at universities in Prague (Charles Univ.), Brno (Masaryk Univ.) and Plzeň (Univ. of West Bohemia). The know-how of the lab was conveyed also through the supervision of several BSc., MSc. and PhD students. This method was recently applied, among others, to the study of ditches (IDs 453419, 519081), including not only the means of their usage but also their backfilling reflecting the development of human societies in relation to climatic changes (ID 519496). Other topics included the study of human presence in utilizing alluvial plains of rivers (IDs 504106, 509732, 450066), the means and intensity of impacts on Subrecent (IDs 489768, 465853) or buried (IDs 469906, 443420) soil complexes. Another possible application of geoarchaeological tools is petroarchaeology (IDs 497229, 517518), which employs classical tools of mineralogy and petrography. The use of methodically more advanced tools, such as those related to geo-biochemistry (ID 481030), is promising for the future.

Sedimentary rocks were treated as the Earth's history archives which record environmental changes in geological past, however, with implications for the present as well. Team 1 applied various modern approaches and methods on these rock units worldwide as very effective tools to understand the timing of geological units, sequence stratigraphy, diagenetic processes, paleoenvironmental and paleoecological changes in different settings. A very successful co-leadership of our representatives of the joint UNESCO and IUGS Project (IGCP) 580 (2009–2013, 2014 O.E.T.) benefitted from the precise and unusual technical

practice through years. Besides, a summarizing book on magnetic susceptibility (MS) application to sedimentary rocks was published (ID 448522). The study on Silurian carbonate successions in the Barrandian area and time warping of the MS logs across the prominent Lau Event were revealed (ID 448516). But most of the studies focused on the Devonian period. A modern complex of magnetic susceptibility measurements, gamma-ray spectrometry logging and geochemical analyses (MS-GRS-GC) was established as a very effective tool for paleoclimatic, paleoenvironmental or tectonic reconstructions. Such multiple analyses of the Late Devonian to Lower Carboniferous boundary beds in Central Asian Orogenic Belt, which represent an open ocean island arc environment, revealed the precise position of the Hangenberg Event which has been usually manifested by the occurrence of black shales but was missing in this environment (ID 461368). The results are consistent with data on epicontinental margin sediments. This study also contributed to UNESCO and IUGS Project 596 (2011–2015). Our representatives were active members and contributors to this project during all four years. An illustrated book on the Devonian and Carboniferous geological stages introducing life and dynamic evolution of life on Earth was published under the auspices of IGCP 596 (IDs 458787, 458984). A conodont-based correlation of two peri-Gondwanan middle and upper Lochkovian carbonate stratal successions (Prague Synform and Central Pyrenees) suggested a refining of the interval into five major zones which can be used as tie points for high-resolution studies including MS-GRS-GC (ID 451024), e.g., Lochkovian–Pragian boundary beds in the Central Pyrenees (ID 458604). Another long-term puzzle is the lack of precise data on duration of Palaeozoic sedimentary units. A successive project IGCP 580 – IGCP 652 (2017–2021) – deals with age estimation using cyclostratigraphy and detection of Milankovitch cycles. The team members and their colleagues from Belgian team refined the duration of the Lochkovian and Pragian stages from MS data of the Lower Devonian limestone strata in the Barrandian area (ID 464292). Down deep into detail and further in the understanding of sub-Milankovitch cycles in such old Palaeozoic rocks goes the spectral analysis of Ti record which revealed a millennial-scale climate changes. These can be related to the Hallstatt cycle and close to the Dansgaard-Oeschger oscillation (IDs 503957, 511428). A sequence stratigraphic analysis of carbonate-dominated successions using a combination of GRS data and basin-wide facies correlation was performed across prominent Early and Middle Devonian bioevents in the Prague Synform. Sequences were integrated into a peri-Gondwana relative sea-level curve (ID 482899). Quantitative allochem composition analyses were used for a detailed reconstruction of facies stacking patterns and sea-level history across the Lochkovian–Pragian boundary (ID 476461). The origin of pigmentation of the red carbonates of the Pragian in the Prague Synform and their stratigraphic context were studied using GRS-GC, facies analysis, optical and electron microscopy and reflectance spectroscopy (ID 483848). Early diagenetic formation of nodules in Lower Devonian limestones in the Barrandian area is supported by the discovery of large star-like trace fossils which intersect the nodules (ID 444551). A selection of the new Global Stratotype Section and Point (GSSP) for the Aeronian stage has been targeted by the Subcommission on Silurian Stratigraphy. Team 2, together with a member of Team 1, performed a complex study of the GSSP candidate section (Hlasna Treban in the Barrandian area). Detailed biostratigraphy, geochemical data as well as MS-GRS records show no disconformity and meet all GSSP requirements (ID 490800). A study of a 2.7 km thick sequence of Lower Palaeozoic marine sediments of Ordovician to Middle Devonian age, using analyses of fluid inclusions, organic and mineral components, suggested high-grade diagenetic to anchimetamorphic conditions during the burial of the rocks. The team also closely cooperated within the study of Mesozoic (Lower Turonian) sandstone facies and paleobottom reconstruction and provided analytical methods for Team 2 (ID 446085). Another field of study of a Team 1 member is non-marine environment in a quite remote destination: Paleogene and Neogene volcaniclastic and coal-bearing sediments in Iceland and Faroe Islands. An endemic ichnoassemblage in a Miocene paleolake in SE Iceland within turbidite volcaniclastic beds and first trace fossils and pseudo-fossils from volcaniclastic sediments in Faroe Islands were identified (IDs 480379, 453417). The study of geochemical and petrochemical parameters of coal revealed limited alteration effects of the overlying basalt lava flows (ID 462147).

Quaternary processes represent an extremely varied set of problems, necessitating a multi-disciplinary approach. With their outstanding expertise in geology, geochemistry and mineralogy and their exceptional laboratory background, Team 1 members frequently assist other teams specializing in environmental geology and geochemistry (most notably Team 3), thereby contributing to papers in such areas as paleoclimatology, paleoecology, pedology and engineering geology. This does not mean, however, that Team 1 does not conduct independent research in Quaternary geology: its members take a leading edge in many aspects of Quaternary research. They study sedimentary record in a range of depositional environments (loess, paleosols, fluvial/lacustrine sediments, cave sediments, tsunamites). They also study lithological and climatic controls on sandstone weathering. The geographical areas of study range from arid regions (Egypt, Sudan, United Arab Emirates) across temperate regions (central Europe) to polar regions (Faroe Islands). Quaternary research was mostly funded by the Czech Science Foundation projects, to a lesser degree by the Czech Acad Sci and foreign universities, and is often combined with international cooperation programmes. Paleoclimatic implications for the Last Glacial period were based on the study fossil archives across central Europe: in fluvial/lacustrine sediments (IDs 480373, 480522) and in loess/paleosol sequences (ID 440531). These studies later concentrated on the MIS 3 paleoenvironment and on refinement of the Weichselian climatic curve (IDs 486226, 488629). A similar study proved a balanced lacustrine paleoenvironment in a Mid Holocene lake (ID 448975). Holocene environmental changes in NE Africa including flooding history of the River Nile were characterized based on the study of fluvial/lacustrine sediments in collaboration with Team 3 (IDs 467472, 467478, 467480). Holocene history of tsunami events in the Eastern Pacific was derived from sedimentary sections in Mexico (ID 459723). Sandstone weathering studies (partly in collaboration with Team 3) provided characteristics of weathering forms the temperate zone (IDs 460125–460126). Symmetrical cavities were found to be initiated by carbonate dissolution (ID 444261) and newly defined arcades are unconformity-controlled, shaped by irregular stress distribution in the rock massif (ID 489228). Some specific landforms were described as related rather to a hydrothermal process (IDs 444275, 481602). Studies in clay mineralogy significantly contributed to the explanation of soil formation on various substrates in central Europe (collaboration with Team 3, IDs 498576, 445936, 481159) and of active landslide dynamics in Ethiopia (ID 450963). Other mineralogical and sedimentological studies helped to explain the origin of cave sediments in United Arab Emirates (collaboration with Team 4, IDs 473049, 475834) and the deposition of Pleistocene lacustrine sediments and Holocene soils on the Faroe Islands (IDs 496939 and 506812, respectively). The U–Th dating of calcite speleothems allowed to unveil depositional histories in different European caves (IDs 498612, 509423 and, in collaboration with Team 3, ID 500577). In order to assess extreme marine inundation events, long-term instrumental and historic records on the magnitude and frequency together with other proxies were tested to distinguish and reconstruct evidence of ancient inundation events at the Mexican Pacific coast (ID 458587).

**Research Area 3 – Other Research**

Collaboration with other teams of the Institute as well as with other scientific institutions is a vital part of Team 1 activities. In the evaluated time interval, it resulted in the publications of several IF papers and monographs, which are beyond the scope of the above outlined research areas/subareas. Below is the characteristics of scientific outputs (11 papers in IF journals + 2 books + 1 chapter in book) achieved by Team 1 and colleagues from other Teams related with topic of Research Area 1.

The common interest in atmospheric dust deposition with Team 4 yielded a description of the “clumping mechanism” for dust deposition in the Arctic, which has climatic implications in view of global warming (ID 443041). Environmental consequences of volcanogenic dust deposition were tested and modelled with respect to mercury levels (IDs 494020/496919). Data from Team 1 laboratories proved invaluable in the assessment of other environmental issues such as cadmium toxicity in plants (ID 459976) including those addressed jointly with Team 3 members: mercury contents in larch tree rings (ID 496017) or heavy metal accumulation in fungi (ID 507843). Mineralogical and petrographic analyses contributed to two

studies on soil formation with Team 3 (IDs 480125, 510709). Collaboration with Team 2 centred around paleoenvironmental problems in the Devonian of Moravia: the first find of skeletal remains of an osteolepiform tetrapodomorph (ID 465849) and the changes in shallow-water microfauna around the Kellwasser Crisis (ID 491908). In addition, Team 1 contributed with geochronology analyses to multi-disciplinary characteristics of Cambrian–Ordovician volcano-sedimentary rocks to be used as a research facility for deep repository studies (ID 505451) and published several regional-geological studies in monographs aimed at a wider public (IDs 489824, 504287, 455492).

## Research activity and characterisation of the main scientific results

During 2015–2019, members of the Department participated in various international projects (e.g., UNESCO/IGCP projects Nos. 575, 591, 596, 580, 609, 653, 679 and bilateral cooperations) and authored and co-authored a number of publications (100 papers in IF journals, ca. 33 papers in other journals, ca. 15 book chapters or books, and other publications). Members of the Department were active in organizing meetings and symposia, teaching, in popular-science activities and, also, were engaged with important international duties (e.g., within subcommissions of the International Commission on Stratigraphy IUGS).

During the five-year period all the main research areas were also successful in securing funding, and several long-term projects have been launched. The projects of the Czech Science Foundation completed in the period of 2015–2019 can be listed as follows: GA 17-06700S Přídolí Series in the Prague Synform – a proposal for chronostratigraphic subdivision; GA16-21523S Changes of the Paratethys fish fauna during Oligocene to Lower Miocene – evidence of selected groups from sites in Moravia (Czech Republic); GP13-19250P Palaeobiological study of marine fossil fishes from the Oligocene of the Hermanowa locality (Poland); GA14-16124S Refinement of lower Silurian chronostratigraphy: proposal of new GSSPs of the Aeronian and Homerian stages; GAP210/12/2053 High-resolution floristic changes as a response to climatic dynamics during the Late Paleozoic ice age recorded in the basins of the Bohemian Massif; GA17-10233S The oldest vascular land plants and palynomorphs from the Silurian–Lower Devonian of the Barrandian area, Czech Republic.

Apart from these, also projects from other sources have been accomplished: M100131201 (International cooperation project of the Czech Acad Sci) Hi-res correlation and dating of Mid-Paleozoic sedimentary sequences of Peri-Gondwana using integrated biostratigraphy and chemo-physical methods; CAS-17-06 (International cooperation project of the Czech Acad Sci) From East to West and Back Again: evolutionary history, migration patterns and paleoecological context of North Eurasian carnivores during the Quaternary; No. 16302 (Research Grant of the Nanjing Institute of Geology and Palaeontology, China) Graptolite marker species of Rhuddanian/Aeronian boundary interval of the Czech Republic and China; GAUK 704216 (Grant Agency of the Charles University) The revision of some sphenopterid types of ferns from Carboniferous coal basins of the Bohemian Massif, Czech Republic; GAUK 922216 (Grant Agency of the Charles University) Family Spathognathodontidae (Conodonta) from the Silurian/Devonian boundary and its biostratigraphic correlation (Na Požárech and Praha-Radotín sections; Prague Synform); GAUK 222214 (Grant Agency of the Charles University) Geochemical markers from foraminiferal tests as a key to paleoenvironmental interpretations in the epeiric sea; 2016/21/B/NZ8/02443 (Project of the National Science Centre, Poland) The Late Cretaceous flowering plants in the context of the transgression of the Central European Sea.

Five projects supported by the Czech Science Foundation are running at present: GA18-05935S From past to present: fossil vs. recent marine shelled organisms as a substrate for colonization and bioerosion; GA19-06728S How precisely can we reconstruct Carboniferous tropical forests? Examples from the Czech Republic and China, including three projects that have just been started: 20-23550Y Evolution of fossil arthropods during Cambrian explosion and GOBE events; 20-06134S Palaeoecology of early angiosperms during the mid-Cretaceous, a case study of material from Iberian Peninsula and central Europe; 20-23363S Biostratigraphy and faunal dynamics of the Silurian pelagic biota of the Prague Basin in the context of major environmental changes and perturbations. The ongoing project GAUK 1698119 (Grant Agency of the Charles University) *Zieglerodina petrea* sp. nov. and *Zieglerodina paucidentata*: phylogenetic models and their application in the global stratigraphy of the Silurian/Devonian boudary, will be accomplished this year.

One of the most prestigious and scientifically demanding activities is the organization of international conferences. In this aspect, members of the Department of Paleobiology nad Paleoecology were very active in the period under survey. This is an overview of the major events:

1. International Subcommission on Silurian Stratigraphy (ISSS) GSSP Workshop – Prague 2015: GSSPs of the Silurian stages revisited, Prague, July 29–30, 2015. Organized by Institute of Geology and Czech Geological Survey, Prague, Czech Republic. Organizing committee: Štorch P. (Team 2), Melchin, M.J., Manda, Š., Tasáryová, Z.

The primary focus of the ISSS GSSP Workshop was on candidate sections for the Aeronian, Telychian and (prospective) Homerian GSSPs. The meeting was attended by 16 participants from 5 countries – titular and corresponding members of the ISSS and additional members of the stratigraphic community interested in current agenda and research devoted to the re-study of the GSSPs of some Silurian stages and series. Post-conference field trip brought the participants to important reference sections of the Silurian stratigraphy, including potential candidates for the Aeronian and Homerian GSSPs situated near Prague.

2. 4th International Conodont Symposium ICOS4: Progress on Conodont Investigation. Jointly with the International Subcommission on Devonian Stratigraphy (SDS) and the International Subcommission on Silurian Stratigraphy (ISSS) of the ICS/IUGS, Valencia, Spain, June 20 – July 5, 2017. Organized by University of Valencia and Cagliari, Inst Geol of the Czech Acad Sci and University of Graz. Organizing committee: Valenzuela Ríos J.I., Liao J.-Ch Martínez-Pérez C., Corradini C., Slavík L. (Team 2), Suttner T.

The Institute of Geology was among the principal organizers of this event focused on progress in the investigation of enigmatic conodont organisms that are considered direct ancestors of vertebrates. Participants from five continents took part in the follow-up Post-Symposium Excursion to the Prague Synform and Carnic Alps that was co-organized by L. Slavík and A. Hušková (Team 2).

3. 19$^{th}$ Czech-Slovak-Polish Palaeontological Conference & 11$^{th}$ Micropalaeontological Workshop MIKRO 2018, Prague, Czech Republic, October 18–20, 2018. Organized by the Inst Geol of the Czech Acad Sci, Department of Paleobiology and Paleoecology, and the West Bohemian Museum in Pilsen. Organizing committee: Svobodová A., Votočková Frojdová J., Dašková J., Scheiner F., Weiner T., Weinerová H. (all from Team 2), Pšenička J., Kaminski M.A.

The conference focused on a wide variety of paleontological topics. Its aim was to bring together researchers from Central Europe, and to present their research interests. It was attended by 102 researchers from 5 countries. There were representatives of a wide range of interests including paleobotany, paleozoology, micropaleontology and also anthropology. The last day was reserved for a guided field excursion dealing with the stratigraphy and tectonics of the Prague Basin, led by František Vacek of the National Museum.

4. XV$^{th}$ International Ichnofabric Workshop. Prague, April 27 – May 3, 2019. Organized by Inst Geol of the Czech Acad Sci.

Organizing structure: Convenor: Radek Mikuláš (Team 2), Convenor Assistant: Martina Kočová Veselská (Team 2). International Advisory Board: Gabriela Mángano and Luis Buatois (University of Saskatchewan, Canada), Andrew K. Rindsberg (Alabama State University, USA), Lothar H. Vallon (Geomuseum Faxe, Denmark).

The series of International Ichnofabric Workshops represents the longest-lasting event in the scope of the modern ichnology, taking place every two years since 1991. Soon, it became a prestigious occasion to present regional geological units and their ichnological content to the most significant and influential group of world ichnologists. The Prague workshop was visited by 32 participants with 30 scientists from abroad. “Ichnofabrics from the aeolian systems” (Buatois, L.A.; SCOPUS H-index=42); and “Ichnofabric” (Knaust, D.; SCOPUS H-index=20) shall be noted as the key talks of the workshop. The main topic selected for discussion was the use of computed tomography of bioturbated substrates at present and in the future.

Besides organization of conferences, P. Štorch and L. Slavík as officers of International stratigraphic subcommissions, were convening several thematic sections at IGCP meetings, International Congresses on Stratigraphy: Strati Graz 2015 and Strati Milano 2019, IPC Paris 2018 (International Palaeontological Congress), ICOS 2017 Valencia, etc.

Below, the most significant achievements are presented for each of the focal research areas.

**Research Area 1 – Paleozoic biostratigraphy and paleoenvironment**

The studies were focused on high-resolution biostratigraphy and relative dating of sedimentary rocks, development of biozonal scales, and complex biotic response to paleoenvironmental changes and global events, especially using graptolite and conodont faunas. Projects: M100131201 (ASCR); GA17-06700S; GA14-16124S (GA ČR), and 16302 (NIGPAS, China). Results of the completed project (M100131201) include a detailed correlation of two peri-Gondwanan regions, based on conodont sequences between middle and upper Lochkovian carbonate successions. Such themes were addressed for the first time and resulted in a considerable refinement of the biozonal chart at this stratigraphic level (ID 451024). This correlation facilitates the definition of tie points for further multidisciplinary studies that seek to establish high-resolution temporal subdivision and global correlation. Some intervals have a precision of less than 0.5 Myr, which is significantly better than in previous studies. The estimated elapsed time considered herein is about 3.2 Myr and is subdivided into five major biozones of global scope. By providing tie points and globally applicable criteria, this research contributes to international cooperative effort to subdivide the Devonian standard stages into globally recognized substages. The original aim of this Czech–Spanish project (Inst Geol of the Czech Acad Sci and University of Valencia) “Hi-Res correlation and dating of Mid-Palaeozoic sedimentary sequences of Peri-Gondwana using integrated biostratigraphy and chemo-physical methods” was to apply auxiliary correlation tools in intervals where the density of biostratigraphic time-marks is low. The correlation was then based on the application of several methods in the sections: the detailed biostratigraphical framework is supplemented by multiple chemo-physical measurements (i.e., gamma-ray spectrometry and magnetic susceptibility) in order to avoid discrepancies in correlation of the peri-Gondwanan successions. The interpretation of obtained petrophysical data from two key peri-Gondwanan regions point to the following conclusions (ID 458604): 1. The progressive condensation and shallowing-up tendency observed in the end-Lochkovian limestones, both in the Spanish Central Pyrenees and Barrandian area, indicate a major paleoenvironmental phenomenon that may be connected with an enormous sea-level fall and a rapid cooling of sea water masses. 2. The Pragian time is characterized by relatively well oxygenated sediments, where dysoxic conditions in the water column and stratification of oceanic waters were strongly suppressed. Possible frequent mixing of sea water in conditions of relatively depressed sea level resulted in the formation of equivalents of oceanic red beds. Elevated contents of chemically weathered components in the Pragian carbonates indicate still hot but relatively humid climate conditions, governing the mid-latitude landmasses adjacent to peri-Gondwanan seas. 3. With no evidence of polar ice sheets or alpine glaciers in Iapetus-collision mountain ridges, the Pragian must be considered a very “hot” period, even though it was possibly cooler compared to the Lochkovian. 4. Sedimentation of the middle to upper Pragian rocks is characterized by the alternation of highly contrasting rocks with an increased delivery of siliciclastics and extremely elevated and highly fluctuating GRS–MS patterns. This reflects a period of great climatic instability that could have been possible in conditions of sufficiently hot and humid climate. 5. The subsequent stabilization of the climatic system and partial cooling can be seen in the late Pragian to early Emsian when the amounts of non-carbonate impurities decrease considerably. The project on a subdivision of the Pridoli Series (GA17-06700S) brought a refinement of conodont biozonation and formal establishment of the first multi-zonal conodont scale for the Přídolí in its stratotype area (ID 496845). The most important achievement is an integration of published and newly obtained biostratigraphic data and integration of conodont and graptolite biozones with data on biotic changes in other marine faunas, geochemical ($\delta^{13}C$ and $\delta^{18}O$ isotopes) and petro-physical data (established magnetic susceptibility and gamma-ray spectrometry logs from the Přídolí strata) into the generalized correlation chart. This led to the proposal of subdivision of the Přídolí Series into two stages based on integrated studies of selected sections in the Prague Synform (lithology, sedimentology, biostratigraphy, faunal content, geochemistry and petro-physical data): three options for the subdivision have been presented and offered to the International Subcommission on Silurian Stratigraphy (ISSS/ICS) at the International Congress on

Stratigraphy (2019). The most significant faunal change coincided with the base of the *bouceki* Biozone.

Updated biostratigraphic data on conodonts were presented in several studies, e.g., refining the Early Devonian time scale using Milankovitch cyclicity in cooperation with Université de Liège and other colleagues of the Inst Geol, Czech Acad Sci (ID 464292, ID 503957) and contributed to some other Silurian and Devonian studies (ID 448516, ID 483848, ID 479395 and ID 496852).

One of the main tasks of the project Refinement of lower Silurian chronostratigraphy: proposal of new GSSPs of the Aeronian and Homerian stages (GA14-16124S) was to prepare fundamental data for ongoing redefinition of the base of the Aeronian and the base of the Homerian global stratotypes (GSSPs) within the Silurian System. This belongs among current research priorities of the International Subcommission on Silurian Stratigraphy (ISSS of the ICS) because the existing global stratotype sections of the respective boundaries have been found inadequate with respect to modern high-resolution tools of stratigraphic correlation and even standard biostratigraphy. In response to the ISSS initiatives, a new Global Stratotype Section and Point (GSSP) has been proposed for the Aeronian Stage (Llandovery Series, Silurian System) to replace the current stratotype section in the Llandovery area of Wales. Particular attention was given to a proposed marker species of the base of the Aeronian Stage and related species (ID 499800). Patterns of gradual morphological change within the species were interpreted as anagenetic changes whereas apparent patterns of morphological divergence were interpreted to represent speciation events. Apart from biostratigraphic markers, geochemical and petrophysical data have been employed in cooperation with the Department of Geological Processes of the Inst Geol of the Czech Acad Sci, the Czech Geological Survey and St Francis Xavier University, Antigonish, Canada. Multi-proxy study on the richly fossiliferous section at Hlásná Třebaň (ID 490800) proved that it meets all formal requirements for the stratotype of a chronostratigraphical unit.

Homerian succession studied in the abandoned Kosov quarry near Beroun revealed the anatomy of the mid-Homerian mass faunal extinction (Lundgreni Event), survival, and subsequent recovery in hemipelagic offshore facies of the Motol Formation (ID 504740, ID 508372). Significant changes in graptolite community structure and species dominance inferred from both qualitative and quantitative data analysis pre-dated major species extinctions and changes in benthic fauna. A correlation with the Nesvačily and Všeradice sections suggests that well-balanced environment returned and new adaptive radiation developed as late as in the latest Homerian in the Prague Synform. High-resolution graptolite and $\delta^{13}C_{org}$ data brought first robust evidence that the mid-Homerian graptolite mass extinction was coeval with onset of the first peak of the late Homerian carbon isotope excursion and moderate changes in other pelagic and benthic faunal assemblages. Sedimentary succession and benthic fauna account for enhanced bottom ventilation and sea-level drawdown assigned to global cooling and glacial pulse. Nevertheless, our data suggest that the graptolite mass extinction and the onset of the positive carbon isotope excursion slightly pre-dated the maximum sea-level fall. Unfortunately, the Sheinwoodian/Homerian boundary interval itself remained inaccessible in the middle of a steep and unstable face of the 5$^{th}$ level of the Kosov Quarry until a mechanical excavation provided by the quarry keeper in November 2017. Detailed systematic sampling carried out in 2018–2019 will be completed in the field season 2020.

In addition, a new section through the Homerian/Gorstian (i.e., Wenlock/Ludlow) boundary interval was studied near Nesvačily (ID 464893). The offshore shale-dominated succession comprised upper *ludensis* and lower and middle *nilssoni* biozones. This interval is notorious for its rather low diversity of graptolite fauna. Despite this precaution, 16 species were identified including new and long-time missing taxa. The published results qualified the Nesvačily section for one of the most important reference sections worldwide in the ongoing search for new GSSP of the Ludlow Series (and Gorstian Stage).

Principal objectives of the Czech–Chinese cooperation (Nanjing Institute grant No. 16302) were to test the supposed paleobiogeographical affinities of lower and middle Aeronian graptolite faunas world-wide based on species distribution exemplified by strictly

taxonomically revised early and mid Aeronian species of the cosmopolitan genera *Rastrites* and *Petalolithus* along with paleogeographically more restricted *Stavrites.* A taxonomic revision coupled with a paleobiogeographical cluster analysis revealed a distinct paleogeographical distribution indicating that two provinces existed in the early and mid Aeronian pelagic realm: low-latitude Northern Hemisphere Province of South China, Siberia and northern North America, and largely mid-latitude Southern Hemisphere Province comprising Avalonian British Isles, southern Baltic area, central Europe, western and southern Europe, and North Africa. Contrary to the existing stereotypes, none of the examined species exhibits cosmopolitan distribution. Environmental and faunal changes across the Ordovician/Silurian boundary interval were reviewed in collaboration with an international research team (ID 461649). Faunal succession with a number of seemingly exotic taxa was studied in collaboration with Instituto de Geociencias (CSIC, UCM), Facultad Ciencias Geológicas, Madrid, in an uninterrupted and richly fossiliferous section in the Spanish Pyrenees. New data indicate that some boundary strata are missing in the majority of to date preserved Ordovician/Silurian boundary sections elsewhere in the peri-Gondwanan Europe. Sediment starvation or omission in other sections is coeval with the culmination of the latest Ordovician post-glacial rise in sea-level (ID 505046). Noteworthy results were obtained in co-operation with the Centre of Advanced Study in Geology, Panjab University, India. The co-operation consists of inviting R. Mikuláš as a specialist in ichnology to the broad team studying the basic tectonic and paleogeographic aspect of the Lesser Himalaya (from the Czech side, covered by the Czech Science Foundation grant No. 18-05935S and the IGCP of UNESCO & IUGS, Project Code No. 653: The onset of the Great Ordovician Biodiversification Event). Finds of ichnofossils in siliciclastic sequences (namely those from the *Cruziana rugosa* Group) in the Koti Dahman Formation document a partial transgression of the Ordovician Epeiric Sea on the Indian tectonic plate during the latest Cambrian to Early Ordovician. This discovery changes substantially the present views of tectonic development of the Himalaya (ID 519322). Also, several studies on ichnology from diferent regions were published (e.g., IDs 441658; 444551; 478555; 482907; 484059; 499822).

The members of the team also took part in project GA 14-18183S focused mainly on Devonian eustatic oscillations and climate changes. One of the subtopics of this project included the study of the Frasnian–Famennian interval in the Moravo-Silesian Basin marked by the Kellwasser Crisis representing one of the most severe mass extinctions in the Phanerozoic. This interval is connected with the spread of calcimicrobes as bioconstuctors which reflect a global demise of metazoan reef-builders caused by environmental changes in the upper Frasnian. The study focused on this phenomenon in carbonate ramp environment of the Šumbera section near Brno (ID 491908) was published in cooperation with the Department of Geological Sciences, Faculty of Science, Masaryk University, Brno. The recorded Moravian association of calcimicrobes, calcareous algae and microbialites is well calibrated by conodont biostratigraphic data and reflects global trends in this interval. The association is relatively taxonomically diverse especially in the upper Frasnian and shows similarities with approximately coeval associations from other areas, especially Australia, Canada, China, Russia, and Belgium. Another paper dealing with the origin of red carbonates was published (ID 483848). The presentation of these results was partly supported by IGCP project 652.

The main results of the Paleozoic arthropod research comprise the description of developmental patterns in Cambrian trilobites (ID 499752) and larval stages and possible eggs from the Ordovician of Spain (ID 504955). Result ID 499752 is highly relevant to our understanding of the evolution of Early Paleozoic arthropods, and to revealing phylogenetic relationships of Cambrian trilobites. Currently, four other manuscripts are in various stages of submission (one submitted, three resubmitted after review). Of particular importance are especially the following: 1, a manuscript describing ancestral morphology of trilobite early developmental stages based on rich material from Newfoundland; 2, a comprehensive quantitative analysis of taphonomic bias in exceptionally preserved biotas based on exceptionally preserved fossils from the Burgess Shale, Fezouata Shale and Chengjang lagerstätten; and 3, description of a new species of Ordovician arthropod from Morocco.

**Research Area 2 – Paleozoic-Cenozoic plants and palynology**

Palynological and paleobotanical research was focused on systematic positions of spores and plant taxa (IDs 500460, 484066, 480461, 465655, 444775, 517433) and paleoecological intepretations and syntheses of data from Carboniferous tropical forests (ID 487069). The team collaborated with several collagues from Czech institutions (National Museum, Charles University, Czech Geological Survey, West Bohemian Museum, Pilsen) and from the UK, Germany, USA and Canada. A special type of collaboration was supported by the Czech and Chinese Academy of Sciences and by the University of Yunnan. The results are a part of project GA19-06728S. Important aspects of the research include the classification, morphology, anatomy and paleoecology of various types of ferns (IDs 484066, 480461, 465655, 518193). Another important group is represented by lycopsid plants (IDs 444775, 500460, 484060) which were the most important contributors to biomass in tropical forests and a crucial plant type in coal swamps. Reconstruction of plant cover in the Intra-Sudetic Basin (ID 487069) brought important data about the history and development of tropical forests during a 25 Myr interval. Plant diversity recorded in the rock record throughout the studied interval was mainly controlled by climatically-driven potential for preservation of plant material, which was the highest in poorly drained/waterlogged habitats (wetlands, lakes) concentrating in basinal lowlands and representing major windows of preservation. A new and the oldest species of the genus *Cooksonia* – *Cooksonia barrandei* – was described in the prestigious journal Nature Plants (IF 13.297, ID 489467). The paper made it clear that the find of *C. barrandei* rewrites textbooks; it shifts the earliest record of land plants to 432 Ma and represents the oldest vascular plant globally. Its robustness undermined the hypothesis that first plants were not able to reach photosynthesis because of their small size. Using the example of *C. barrandei* the hypothesis can be ruled out. Our additional studies on early land plants broadened our knowledge about the first polysporangiate plants occurring in the Barrandian area. Further details on *C. barrandei* and associated flora including dispersed spores occurring at the Loděnice locality were published in a Czech journal (ID 499811). These are the oldest sculptured trilete spores in the world. The plant colonization in the studied region implies a significant role for islands in plant and spore dispersion. Prague Basin is apparently among those playing a key role in this process of colonization, strongly influenced by local environment dynamics as well as global climatic and sea level changes. Thus, the key events of plant evolution are now completed in the unique Central European area providing a very rich fossil record through the whole history of plant evolution. This conclusion will strongly influence the view on early plant colonization of the terrestrial environment worldwide.

**Research Area 3 – Vertebrate Paleontology**

The vertebrate paleontology team of the Department works on several faunal groups at different stratigraphic intervals.

(a) Mammals: The studies were focused particularly on taxonomic and phylogenetic analyses of selected mammal groups with the aim to better understand: (i) phenotypic changes on the background of global paleoenvironmental events; (ii) intercontinental relationships of selected taxa and their dispersals within Eurasia; (iii) phylogenetic roots of main lineages of Eurasian lagomorphs; and (iv) adaptations in insular conditions. The main results can be grouped as follows. ● Small mammal studies: (1) The unique findings of ancient ochotonines and leporines (i.e., main lagomorph clades) from the upper Miocene of eastern Europe changed a view on the earliest evolution and Eurasian dispersal of basal species leading to modern lagomorph taxa (IDs 443423, 464296). The proven presence of the genera *Ochotona* and *Alilepus* indicates important paleoecological changes and faunistic rearrangements in the late Miocene and provides a tool for stratigraphic correlation of European paleontological localities. (2) Detailed analyses of *Prolagus* findings from the upper Miocene of the Pannonian Basin resulted in a description of two new fossil species and contributed significantly to general understanding of *Prolagus* evolution and

paleobiogeography in the late Miocene of central Europe (ID 443640). (3) The Asia Minor represents an important cross-roads region of intercontinental mammalian migrations. Unfortunately, the fossil record of Pliocene leporids in that important area was extremely rare and taxonomy of available finds remained unclear for a long time. The extraordinary fossil record from the new lower Pliocene locality of Turkey filled this gap and revealed an unknown dispersal history of leporids within Eurasia (ID 517254). (4) Studies on mammalian evolution in insular conditions were focused particularly on enigmatic finds of an ancient rabbit from the lower Pleistocene of Sardinia. This insular endemic form, described as the new genus *Sardolagus* (ID 489473), revealed a surprising tooth morphology indicating yet unknown evolutionary changes in leporid teeth. A detailed analysis of insular lagomorphs of Sardinia and other records from the Mediterranean area allowed to clarify phylogenetic relationships between insular and continental taxa, and hypothesize scenarios of lagomorph colonization of Sardinia (IDs 479220, 446779, 489473). (5) The long-term cooperation with the National Museum in Prague on research of Czech fossil-bearing localities resulted in a study dealing with taphonomical aspects of the early Miocene mammalian assemblage from the Ahníkov locality (ID 473029 ). ● Large mammal studies: Taxonomy and distribution pattern in selected Chinese carnivores from the Pliocene to Quaternary were revised and compared with related European taxa. For the first time the unambiguous record of speleoid bears in China was confirmed (ID 495945). It represents the first record in this southeastern, more humid area and clearly proves a broader ecological valence for Asiatic forms of this lineage. The comparison of large early mid Pleistocene *Canis* species from Europe and northeastern China gave evidence for their conspecifity (ID 490802). Contrary to previously published opinions, we demostrated that *C. mosbachensis* was distributed from Europe to East Asia and that there were no principal migration barriers for this large carnivores. The revision of Pliocene to early Pleistocene badgers from China resulted in a description of a new species and evidence of higher early Pleistocene *Meles* diversity than previously supposed (ID 490801). A taphonomic situation of a hyena den with uniquely preseved skeletons was interpreted (ID 453445).

(b) Frogs (Anurans): Studies of fossil anurans were focused not only on formal descriptions of new taxa and assessment of their role in whole fossil assemblages, but also on anatomical aspects which allow comparisons of fossil frogs with extant taxa. For this reason, an international team of specialists was constituted on an ad hoc basis, which made it possible to use laboratory facilities not available at the Institute of Geology of the Czech Acad. Sci.(e.g., micro CT scans, 3D computer reconstruction software), comparative fossil material deposited in other institutions, and knowledge of experts from other fields of paleontology. For the first time, the histological structure of the frontoparietal bone, which is one of the most significant skeletal parts of the *Palaeobatrachus*, was investigated by non-invasive methods (ID 457767). The inner anatomy of the head of an ancient frog *Barbourula* from Philippines yielded data necessary for anatomical interpretations of Lower Cretaceous anurans from the Liaoning Province, China (ID 464118). Studies of fossil assemblages from the lower Eocene of China (ID 489815), middle Miocene of Turkey (ID 519347), upper Miocene of Russia (ID 517181), and middle Pleistocene of the Netherlands (ID 465850) introduced new taxa, which are important additions to general knowledge of early evolution of the anuran amphibians and their paleobiogeography. Abundant fossil material from the middle Miocene locality of Gritsev (ID 519344) provided data on some amphibians and squamate lizards before they disappeared from Europe in the Pleistocene, now persisting in southeastern Asia (e.g., *Chelotriton*, *Mioproteus*, *Andrias*). It should be added that in 2015, the Department organized a commemorative meeting at the occasion of 100th anniversary of Zdeněk V. Špinar, a renowned paleoherpetologist, and that a special volume of Fossil Imprint journal was published in co-operation with the Paleontology Department of the National Museum in Prague (ID 460589; ID 462813; ID 462819; ID 462836; ID 462837; ID 452843). An obituary was also published honouring French paleoherpetologist Jean-Claude Rage, who was our close collaborator for about 40 years, at the occasion of his death in 2017.

(c) Fishes: Fossil fish fauna was studied at different stratigraphic levels and in different regions. The studies on modern teleosts (with marginal comments on elasmobranchs too)

were based on material from several Cenozoic sites representing different types of environments: Oligocene and Miocene marine fishes of the Paratethys region were studied and provided new perspective on the systematics, diversity and paleoecology of several groups (such as stomiiforms, myctophiforms, gadiforms, and many others), including descriptions of several new taxa (IDs 452075, 459691, 464128, 473048, 473704, 473710, 475096, 476469, 480671, 486206, 488890, 496012, 499767, 503952); Paleocene-Eocene fish remains preserved within deposits of the Boltysh impact structure (ID 486205); and freshwater fish fauna of the Pliocene deposits of Catalonia (ID 443659). In all results, members of the team studied fish specimens, prepared figures, main texts, and discussed the results. Joint publications were prepared with several cooperating scientists from other Czech institutes (Charles University, Masaryk University, Moravian Museum) and with scientists from Italy (Torino University), Germany (Ludwig-Maximilians-Universität in Munich, Museum in Darmstadt), Spain (Fundació Instititut Català de Paleoecologia Humana i Evolució Social in Tarragona), Poland (Polish Academy of Sciences in Krakow), and Romania (Natural Science Museum in Piatra Neamt). Numerous outputs were obtained as results of projects supported by the Czech Science Foundation (GP13-19250P in 2015; GP16-21523S during 2016 to 2018). The previously described and/or evaluated Late Carboniferous and early Permian non-marine fish taxa (sharks, actinopterygians, sarcopterygians) were used for solving stratigraphic problems. The defined fish paleocommunities helped during geological maping with the description of geological units and with the specification of the non-marine Carboniferous/Permian boundary. Reconstructions of the food-webs for the successive lake levels were important for the evaluation of paleoecological and paleoclimatological changes and paleogeographic development. The above listed results represent contribution to the IGCP/UNESCO Project No. 575: Pennsylvanian terrestrial habitats and biotas of southeastern Euramerica.

**Research Area 4 – Cretaceous research**

(a) Cretaceous microfossil biostratigraphy and paleoenvironment: A detailed multi-proxy study of the Jurassic/Cretaceous (J/K) boundary interval provided new data that are valuable and important for fixing of this boundary. Microfossil studies concentrated on palynomorphs (spores, pollen grains, calcareous and non-calcareous dinoflagellate cysts), calcareous nannofossils and calpionellids. We focused especially on the biostratigraphy and paleoenvironmental changes of selected sections across the Tethyan area, namely Puerto Escaño (southeastern Spain, ID 460320), Kurovice, Vigantice, Štramberk (Czech Republic, Outer Western Carpathians, IDs 504498, 490442), Strapková (Slovakia, Pieniny Klippen Belt, ID 461649) or Dorset (England). Finally, the Vocontian Basin sites (St Bertand, ID 490485; Beaume Belvedere, Charens, Tré Maroua), located in southeastern France, were recommended as the best candidates for the Global Boundary Stratotype Section and Point (GSSP). Our biostratigraphic results are keyed to the Global Polarity Time Scale and all these stratigraphic data can be mutually and globally correlated. Lower Cretaceous studies were carried out in cooperation with the University of Bristol (W.A.P. Wimbledon), Charles University, Faculty of Science (M. Košťák), Comenius University in Bratislava (D. Reháková), Slovak Academy of Sciences (J. Michalík), Czech Geological Survey (L. Švábenická) and Technical University of Ostrava (P. Skupien). These results are a contribution to the work of the Berriasian Working Group of the International Subcommission on Cretaceous Stratigraphy of the ICS. The second part of Cretaceous studies concentrates on the Upper Cretaceous of the Bohemian Cretaceous Basin and coeval deposits in Austria (Northern Calcareous Alps), Germany and Poland. An integrated biostratigraphic and paleoecological analysis using palynomorphs, foraminifers and calcareous nannofossils was carried out in cooperation with the Czech Geological Survey (L. Švábenická) and Technical University of Ostrava (P. Skupien). These studies present a new insight into bioevents and document sea-level changes.

Paleobotanical and palynological research was focused on Late Cretaceous plants from the North Sudetic Basin of Lower Silesia, southwestern Poland (Project of the National

Science Centre, Poland "The Late Cretaceous flowering plants in the context of the transgression of the Central European Sea" 2016/21/B/NZ8/02443). Late Cretaceous plants from the North Sudetic area were reviewed on the basis of megaflora from 17 localities, mesoflora from 2 localities and microflora from 4 localities. Paleocommunities include back swamp forest with abundant ferns, riparian forest in alluvial plains and fern savanna with pine forest. The age of the studied deposits corresponds to the Coniacian–Santonian based on angiosperm pollen of the Normapolles group. The study was carried out in cooperation of the Institute of Paleobiology of the Polish Academy of Sciences, Warszawa, Faculty of Geology, Warszawa, National Museum, Prague and Institute of Geology of the Czech Acad. Sci., Prague. Other integrated biostratigraphic analyses were made using palynomorphs, foraminifers and calcareous nannofossils both in Lower and Upper Cretaceous of the Gosau Formation in the Northern Calcareous Alps (Austria) and resulted in several papers and mapsheet explanations (IDs 349919, 349929, 349931, 436070). This project was carried out in cooperation with the Czech Geological Survey. Sedimentological, coal-petrographic and palynological investigations of bituminous coal discovery from the Upper Cretaceous sandstones (Turonian/Coniacian) of Waltersdorf in the Zittauer Gebirge (Saxony, Germany) revealed that allochtonous coals originated by redeposition of peat sheds in a delta under marginal marine conditions (cooperation with the Senckenberg Museum für Naturkunde Görlitz).

(b) Macrofauna, paleoecology, sedimentary environments: Studies of biostratigraphy, faunal communities, paleoecology and migration patterns were conducted in the Coniacian hemipelagic facies in the Bohemian Cretaceous Basin. The paper (ID 490310) provided new data on palaeocorystid crab *Ferroranina fritschi* from the Lower–Middle Coniacian at Březno, northwestern Bohemia. *Ferroranina* has been formerly recorded from the Upper Cretaceous of southern India, Madagascar and the southern United States (Texas). The Czech species thus constitutes the fourth known member of the genus and simultaneously the first record of *Ferroranina* from Europe, thereby considerably extending the previously known geographical distribution of the genus in the Cretaceous. The key role of the Czech species in the interpretation of potential migration routes of these crabs in the Late Cretaceous is discussed. The research was realized within international cooperation with Oertijdmuseum in the Netherlands (B.W.M. van Bakel) and Natuurhistorisch Museum Maastricht in the Netherlands (J.W.M. Jagt). The paper (ID 509577) introduced a reconstruction of the paleoenvironment and biostratigraphy of the Svinary deposits in the eastern Bohemian Cretaceous Basin. The outcrop provided a continuous biotic record of numerous stratigraphically significant fossils, such as calcareous nannofossils, foraminifers, inoceramid bivalves, and rare ammonites including a new record of a tridenticerid heteromorph ammonite *Tridenticeras tridens* in the Bohemian Cretaceous Basin. These faunal assemblages provided evidence for the late mid Coniacian age of the entire exposure at Svinary and documented the youngest preserved deposits of the muddy facies of the eastern part of the Bohemian Cretaceous Basin. The team cooperated with the National Museum, Charles University, Czech Geological Survey and with colleagues fromFrance.

**Other interdisciplinary topics**

Among other studies in the Cenozoic, international collaboration was focused on crustacean research from different regions and stratigraphic levels – especially from the Eocene of Seymour Island, Antarctica (ID 496937), Miocene of Vienna and the Czech Republic (ID 496135), and the Recent cirripedes from New Caledonian waters (ID 518678). Within the study of diverse fossil assemblages from the La Meseta Formation on Seymour Island, the rare middle Eocene balanomorph cirripede *Hexaminius venerai* attached to a conifer trunk was described. *Hexaminius venerai* is the earliest known record of the genus in Antarctica, the first occurrence of *Hexaminius* from outside Australian waters and the first record of a fossil cirripede attached to the substrate from Antarctica. The study was carried out in cooperation with the Czech Geological Survey and the RMIT University of Melbourne. The research of decapod crustaceans from the middle Miocene of the northern Vienna Basin

and southeastern Carpathian Foreland Basin in the Czech Republic resulted in a description of numerous isolated cheliped fingers belonging to alpheid shrimps from subtropical Paratethyan Sea. Their occurrence is comparable with the modern aplheid shrimps inhabiting mainly subtropical and tropical reefal environments. The study was carried out in cooperation with the Comenius University in Bratislava and Naturhistorisches Museum in Vienna. The study on cirripede epibionts on nautiloid cephalopod shells, collected from deep water off New Caledonia in the Southwest Pacific (ID 518678) has useful applications in unravelling the dispersal and post-mortem fates of shells in the fossil record and can be informative about the length of residence time on the sea bottom. The research was realized in cooperation with the RMIT University of Melbourne, the Comenius University and the Slovak Academy of Sciences in Bratislava. One of the topics focused on the paleoceanography and paleoecology of a Mesozoic epicontinental sea – the Central Paratethys. The papers (IDs 488668, 503959, 507825) were published in collaboration with Charles University, Masaryk University, Palacký University, National Museum and with experts from Slovakia and Germany. The results (IDs 488668, 503959, 507825) were a part of project GAUK 222214. The research dealt with geochemical proxies on foraminifera as a tool enabling to reconstruct particular water masses and define them using their physico-chemical attributes. One of the aims was to test, validate and “transfer” methodologies commonly used in a modern oceanographic research, and to determine their possible weaknesses with regards to the specificity of the studied environment (ID 488668). Further, the key findings were used to develop simplified models of circulation patterns and their evolution throughout the mid Miocene together with numerous local paleoenvironmental and paleoecological interpretations (IDs 488668, 503959, 507825). Moreover, a rather unusual combination of proxies was used (organic geochemistry together with geochemical proxies on foraminifera) to assess the problem of population dynamics of benthic foraminiferal communities in response to paleoecological changes in the studied area of the Central Paratethys (ID 507825). Overall, the key research outputs enabled an insight into regional aspects of the Paratethys-Mediterranean marine system, which is still not fully understood although this marine system greatly affected the evolution of European climate and ecosystems. Studies in the Paleogene and Neogene focused on fossils preserved in sediments of the Boltysh impact structure (Ukraine). Paleocene/Eocene age and lacustrine environment were confirmed by palynological data and remains of fishes, amphibians, gastropods and ostracodes (ID 486205). Published palynodata from the Paleocene/Eocene localities were collected, and a comprehensive database was prepared for further studies. One of these studies (ID 491791) is focused on the latitudinal diversity gradient and migration during the Paleogene “greenhouse” interval. Findings in tropical and extratropical flora suggest that they may have functioned independently at that time. The type specimen of *Comptonia difformis* from the Most Basin (Miocene) was re-investigated to obtain more accurate data on its morphology and to summarize the occurences and distribution of Myricaceae pollen in the Bohemian Cenozoic (ID 480048). The identification of this taxon in pollen record was found to be very uncertain in contrast to macroflora.

## Research activity and characterisation of the main scientific results

### Research Area 1 – Study of Processes Shaping Sandstone Landforms

Sandstone areas represent a common type of landscape in the Czech Republic but also in many other countries worldwide. Interesting sandstone landforms have become a subject of nature protection and conservation in numerous national parks worldwide (e.g., in the USA, Australia, China, Germany, UK, Czech Republic, etc.). National parks visited by millions of people each year have natural and economic importance for the society. Sandstone was also important building material for millennia, as well as basic material for sculptural arts. Therefore, its weathering and erosion are of high interest among scientist either from applied or basic research. Sandstone weathering leading to diverse morphological features covering a wide range of macro- to micro-scales was studied by the team members, and several important contributions to the understanding of such phenomena were delivered.

A new weathering form called arcades was identified in sandstone (ID 489228). Arcades differ from the previously defined cavernous forms (honeycombs/tafoni) in their clear association to discontinuities, in their shape and origin. As demonstrated by numerical modelling and physical experiments, arcades are the product of rock stress redistribution. This finding fundamentally changes the view on the formation of many weathering forms in granular rocks, but it is also important for weathering of monuments.

Cavernous weathering is a global phenomenon in forming honeycombs (ID 486216). The two commonly assumed formation hypotheses – hydraulic and case hardening – were tested to elucidate its origin. Mechanical and hydraulic tests and innovative fluorescein dye visualization revealed that the spatial distribution of capillary and vapour zones controls the pit formation or rock surface smoothening. This finding represents a new progressive approach for geomorphologists.

A pioneer research in the field of sandstone weathering is represented by the mineralogical and DNA study of biologically-initiated rock crust (BIRC) described in (ID 475873). On sandstone surfaces, the BIRC is formed mostly by various fungi and contains no secondary minerals. As determined by a set of mechanical and hydraulic tests, the BIRC develops on freshly exposed surfaces within 2 years and that it protects the underlying material from erosion. This finding opens new view to the understanding of sandstone erosion.

Another globally important research was performed in Petra (Jordan), where gravity-induced stress was studied as a factor reducing the decay of sandstone monuments (ID 460239). The purpose of this investigation was to evaluate the negative feedback between stress and weathering of sandstone monuments at the Petra World Heritage Site in Jordan *via* field observations and salt weathering experiments supported by physical and numerical modelling. This novel approach to investigate weathering clearly demonstrates that elevated stress lowered the decay rate of the Petra monuments. To properly delineate the endangered zones of the monuments, potential damage caused by weathering agents should be combined with stress modelling and verified by documentation of a real damage.

Although the team of Environmental Geology and Geochemistry consists of chemists, mineralogists and geomorphologists, the aforementioned complex results were achieved in co-operation with other internal or external teams (e.g., Brigham Young University, Utah; Charles University, Prague; Bohemian Switzerland National Park, Institute of Rock Structure and Mechanics of the Czech Acad Sci). The fruitful cooperation was beneficial with respect to combination of field observations, geophysical methods and measurements as well as mathematical modelling.

### Research Area 2 – Karst-related Research

A traditional topic of the team of Environmental Geology and Geochemistry is the research of karst areas in various soluble rocks (primarily limestone and salt). This research integrates mineralogical, geochemical and geological approaches, increasingly employing techniques of stable isotope geochemistry and dating. The research activities were spread over carbonate karst of several European areas including the international co-operation with Slovenian, German, Romanian, Polish and Slovak research partners.

The team member M. Filippi gained worldwide credit in research of salt karst regions in Iran. Based on his expert knowledge, comparative study (ID 476183) of salt karst hydrogeology under different cap soils and climates (Persian Gulf and Zagros Mts., Iran) was performed in collaboration with partner researchers from Shiraz University, Brigham Young University and Charles University. A similar study (ID 480740) was performed by the same team in the Jahani salt diapir, Iran. Both studies bring an insight into the relationships among climate, soil formation and composition, and salt karst system development. A representative work in carbonate karst is the publication (ID 500577), focusing on a special type of cave speleothem of cryogenic origin. The so-called cave pearls, which were established as a new type of speleothem by a member of the team, K. Žák, were accepted by the speleological community and recently became a subject of study of several research teams in Germany, Spain and Russia. Further research in this field by the team members discovered and described a new locality of coarse-grained cryogenic cave carbonates in the Za Hajovnou Cave (Javoříčko Karst, central Moravia, Czech Republic). Crystals and crystal aggregates form typical loose accumulations on the surface of large fallen limestone blocks in the cave. Cryogenic origin of the carbonates has been supported by their mode of occurrence, specific crystal and aggregate morphology, and C and O stable isotope data. Furthermore, U-series dating of one sample of cryogenic carbonates indicated that a period of karst water freezing occurred in marine isotope stage (MIS) 3.

Professionals from the evaluated team also cooperate with amateur speleologists. Within this work, rather orientated towards the general public and local authorities, hydrology of the deepest underwater cave in the world – the Hranice Abyss, Czechia – was examined by advanced techniques of geochemistry and isotope geology (ID 510557). In this hypogene karst, water mixing was studied. Water in the abyss was found to be a mixture of shallow and thermal groundwater with a modest content of modern water. Water mixing is controlled by density-driven flows.

**Research Area 3 – Tektite Geochemistry**

Tektite geochemistry has always been a promising research area, which was developed widely in the evaluated period by the team members, also in cooperation with other teams of the Institute. Its development was facilitated by advances in instrumental and laboratory techniques as well as by granting research projects. World famous tektite material – moldavite – is still enigmatic and its study may lead to the solution of several geochemical issues. To further understand moldavite genesis, element abundances and isotope compositions, team researchers studied chemistry of Tertiary sediments in the surroundings of the Ries impact structure (Germany), traditionally connected with the South Bohemian moldavites and the tektite glass composition. The tektites were formed by complex processes including melting, vaporization and condensation. Majority of their matter was found to be derived from the target, not from the impactor. By comparison of moldavites element chemistry and target sediments in the Ries, it was possible to get a more detailed insight into the process of moldavite formation and to formulate a new conceptual model. This multistage process included fragmentation of overheated melt by escaping volatiles and vaporization and back-condensation of a part of the matter (ID 458591).

Profound changes in the chemical composition of melt occurred due to loss and fractionation of volatile elements during hypervelocity impacts of large extraterrestrial bodies on the Earth's surface, leading to ejection of terrestrial material and its re-melting into the tektite. However, the fate of less volatile elements remained uncertain. We studied the behaviour of volatile elements (Zn, Cu) during impacts (ID 479288) and the relation of Ries sediments and central European tektites on the basis of lithium (ID 466967). Moldavites were found to be slightly depleted in Zn and distinctly depleted in Cu, and enriched in heavy Zn, Cu isotopes relative to their supposed sedimentary precursors. Lithium concentrations and isotopic patterns pointed to a limited Li loss during the impact and a striking homogenization of Li in the tektites, which is consistent with the present models. Our results replenished the chemical composition dataset for central European tektites (moldavites).

**Research Area 4 – Environmental Geochemistry of Toxic Elements**

Environmental geochemistry of potentially toxic elements is a traditional study subject of the Team. In recent years, the main contaminant under investigation was mercury, accompanied by arsenic, cadmium and thallium. Our endeavour was targeted towards understanding of geochemical relations in the several compartments of the environment. We studied various ways of element inputs, mobility, pools and its release. The toxic elements are frequently retained and accumulated by living organisms. Therefore, a significant part of our research was aimed onto tree and mushroom/mycelia uptakes. Some tree species were found to be attractive as biogeochemical archives due to their longevity, while fungi were found to be remarkable bioindicators due to their (hyper)accumulation properties, intensively collecting toxic elements from the environment.

The publications dealing with mercury represent an important, wide group of papers. Team members arranged all related activities including experiment /activity /work planning and design, sample collection and pre-analytical workup, complex analyses as well as data evaluation and preparation of papers. Data quality and knowledge gained by the team is at a highly advanced level, thus several comparative studies and methodical papers were published. The important relation between toxic elements used as indicators of environment contamination was established in the paper (ID 465360) dealing with the comparison of mercury geochemical archives and geochemical records registered in lead. Frequently cited methodical article discussing the influence of sample-drying procedures on mercury concentrations analysed in soils and sediments (ID 443264) described optimized procedures for solid samples workup before ultra-trace mercury analysis. Another recognized article written on demand of international community dealt with the stability of mercury concentrations in archived soil and peat samples (ID 491047), opening a possibility of reliable mercury quantification in properly archived solid samples.

In the evaluated period, a steady development in the approach to the study subject is apparent, the focus is shifted from a descriptive concept to the study of mercury distribution and speciation and factors governing it. Special attention was given to mercury concentrations in stream water at several Czech catchments across a Hg and S deposition gradient (ID 446917) in international collaboration with hydrologists from the United States Geological Survey. The second half of works was focused onto biogeochemical archives because the records of temporal changes in historical contamination are important for future risk assessments. Larch tree rings were identified as a tool for the reconstruction of past atmospheric mercury levels (ID 496017) and further established as a valid archive giving reliable evidence for historical mercury contamination (ID 472707). These works were accepted by international community and included into recent relevant critical reviews. The whole procedure ranging from appropriate tree core acquisition, workup and archive Hg concentrations reading to the evaluation, interpretation and publication was fully developed and performed by the Team members.

Besides basic research, the Team concerns with the applied geochemistry topics in connection with environmental protection issues. Long-term monitoring of gaseous mercury in the vicinity of presently closing Spolana chlor-alkali plant in Neratovice, Czech Republic, offers a unique possibility to monitor the evolution of toxic element concentrations in the environment immediately after the interruption of pollutant emission. The history of mercury pollution near the Spolana chlor-alkali plant is known from records in Scots pine tree rings and other bioindicators. Further work of the Team members evaluated the decreasing input of Hg to the central European forest ecosystems in litterfall and the effects of bark beetle infestation on Hg deposition with respect to the bark beetle calamity/disaster in the Czech Republic in the early decades of 21$^{st}$ century (ID 505047).

In the period under survey, several special multidisciplinary issues were solved together with teams from other institutes of the CAS. Preconcentration and detection of mercury with bioluminescent bioreporter E. coli ARL1 (ID 453525) represents an example of fruitful collaboration with biotechnology specialists from the Institute of Chemical Process Fundamentals of the Czech Acad Sci. In this work, application of genetically modified organisms was tested as a sensitive mercury reporter.

Arsenic geochemistry constitutes the second important study area of the team. The ability of spreading of arsenic (As) contamination in the Czech Republic presents a potential threat especially in connection with the arsenic-rich historical mine waste dump. This topic was studied both in the field and in the lab with respect to chemical composition and mineralogy (ID 446768) of waste. Arsenic mobility in the mine dump was discussed, also in connection to (ID 460472) describing mobility and attenuation of arsenic in sulphide-rich mining wastes from the Czech Republic in detail. Results significant for local authorities including bioaccessibility of As, Cu, Pb, and Zn in mine waste, urban soil, and road dust were obtained at the locality of historical mining at Kaňk, Czech Republic (ID 491961) near the famous historical silver mines in Kutná Hora. Members of the team of the Department of Environmental Geology and Geochemistry M. Filippi and J. Rohovec contributed to the publications above by laboratory analyses and data interpretation.

Environmental geochemistry aspects of toxic element problematics are emphasized in geomycological studies, which complement our projects focusing on toxic elements in soils, mine dumps and alluvial plains. The toxic elements enter mycelia from the soil and reflect local contamination. Team member J. Borovička is a team leader in this field: he formulates research targets and acts as the principal investigator of several Czech Science Foundation projects. His activities have been further supported by internationally recognized professionals in molecular biology, advanced analytical separation techniques (HPLC-MS etc.), mycology etc. A typical example of environmental-geological outputs is the paper describing bioaccumulation of heavy metals and toxic metalloids in ectomycorrhizae from a smelter-polluted area (ID 462845). Multidisciplinary overlaps allowed the identification of transporter genes AsCTR2 and AsCTR3 playing role in Cu and Ag uptake and accumulation of Ag and Cu in *Amanita strobiliformis* (ID 458603). Another work with strong public impact led to the discovery of arsenic hyperaccumulation in the edible ink stain bolete *Cyanoboletus pulverulentus* (ID 478561). This publication, in connection with (ID 503074), pointed to the significance of arsenic speciation knowledge and paved the way to the discovery of homoarsenocholine as a novel arsenic compound detected for the first time in nature (ID 490100).

At the end of the period under survey, an employment of T. Nováková expanded the research interests of the Team by the study of geochemistry of toxic elements (Hg, Cd, U, Th) in floodplains and river sediments. In a short time interval, three papers were published dealing with sedimentary archive of contamination in a confined channel of the Ohře River (ID 477503), migration of risk elements within the floodplain of the Litavka River (ID 500190) and the effects of dam reservoirs acting as an efficient trap for historical pollution by Hg and Pb (ID 492584). These papers originated in collaboration with the Institute of Inorganic Chemistry of the Czech Acad Sci.

**Research Area 5 – Monitoring of Fluxes in the Environment**

The research activity with the longest time span is monitoring of environmental fluxes and studies dealing with the dynamics of elements in the environment. The team of the Department Environmental Geology and Geochemistry is well established in this research field, with a dense network of collaborations to other institutions (Institute of Hydrobiology, Biology Centre of the Czech Acad Sci, Institute of Hydrodynamics of the Czech Acad Sci, Global Change Research Institute of the Czech Acad Sci, Czech Geological Survey, Charles University etc.). Our contribution to the efforts of the scientific community lies in the management and realization of monitoring at the experimental catchment of Lesní potok. This small watershed is a part of the country-wide GEOMON network. The dataset covering fluxes of macroelements as well as trace elements gained at the Lesní potok is unique with respect to its completeness, standardized sampling methodology and long sampling period (30 years of monthly monitoring will be reached in year 2020). This research was supported by institutional grants, Czech Science Foundation projects as well as grants obtained within the Natural Hazards Programme AV21 (Innovative monitoring and modelling techniques for hydroecological analysis in a small catchment, Project No. 9223).

Our further monitoring activities are connected with localities in the Bohemian Switzerland National Park (NPCS), where we perform monitoring of the atmospheric

deposition. This monitoring was active through the whole evaluated period and is planned to continue. The obtained results are annually published in the form of scientific reports. (NPCS Administration, Krásná Lípa: Monitoring of Atmospheric Precipitation in the Bohemian Switzerland National Park, Project No. 7407).

Monitoring activities of the team of the Department of Environmental Geology and Geochemistry are contributed by colleagues from the Institute of Hydrobiology, Biology Centre of the Czech Acad Sci, Faculty of Science, University of South Bohemia, and with limnologists from the University of Maine, USA (over a period of 20 years). Common outputs of this international cooperation can be represented by paper dealing with issues of climate change accelerating recovery of the Slovak Tatra Mountains lakes from acidification (ID 510074, 20%). This publication was further supported by cooperation with authorities of the Tatra National Parks (TANAP in Slovakia and TPN in Poland), State Forests of TANAP and the Earth Science Institute, Slovak Academy of Sciences.

In the period under survey, several short-term monitoring projects were carried out. These were dealing with contamination of forest and aquatic ecosystems within the Brdy Protected Landscape Area with mercury and speciation of aluminium in the surface waters, mobility of ecotoxic elements in the Litavka River ecosystem and evaluation of the environmental legacy contamination within the Litavka River sediments. Financial support was provided by the Nature Conservation Agency of the Czech Republic and Strategy AV 21 Natural Hazards Programme. The results were published in local scientific journals and popular science journals (IDs 488785; 490494; 517431).

**Research Area 6 – Repositories of Radioactive Waste Materials**

Fluorescent salts have been generally understood as valuable tracers for monitoring of groundwater flow in fractured and porous environments. Groundwater-aided migration of contaminants in the rock environment can be studied and modelled using a non-sorbent fluorescent tracer with selected parameters. The information gained is valuable for an exact description of geological formations used for the disposal of high-level radioactive wastes. This topic was elaborated by the team of the Department Environmental Geology and Geochemistry within a Technology Agency of the Czech Republic grant with a consortium of private-owned companies (ISATech s.r.o., ProGeo s.r.o., Geotechnika s.r.o.) and Czech Technical University in Prague, which are long-term cooperating partners. The fruitful project was finished by production of type N results: Certified methodology No. 84404/ENV/16 (Evaluation of migration parameters of tracers in real environment in rocks with fracture permeability using fluorescent tracers, certified by Ministry of Environment of the Czech Republic, ID 473246) and Z type results: Verified technology (describing technology of tracer application).

In the course of subsequent project granted by the Ministry of Industry and Trade (project No. CZ.01.1.02/0.0/0.0/15_019/0004643 MPO), the same research partners applied strongly sorbent fluorescent tracers as easily identifiable fluorescent labels capable of strong binding and marking of freshly opened surfaces of fractured structures. Application of several colour tracers subsequently applied into hydrogeologically communicating structures enabled the identification of higher-order generations of fractures. Further optimization of conditions for efficient application and verification of functionality upon *in situ* conditions gave multigenerational non-active tracer set applicable up to the third generation of fractures. This tracer set was defended as a result of type L: Functional sample (ID 511811). Further results of applied research for industrial partners included 5 reports in total.

**Research Area 7 – Development and Innovation of Analytical Methods**

Ultra-trace chemical as well as isotopic analyses are vital tools to obtain reliable geochemical research results. The team of the Department of Environmental Geology and Geochemistry was giving extraordinary attention to this instrumentally- and skill-demanding activity. Majority of the development and innovation of analytical methods is hidden in the publications mentioned in Research Areas above.

A prominent advance was achieved in the development of a new analytical protocol for high-precision Cd isotopic analyses in biological materials using thermal ionization mass

spectrometry (TIMS) at the Inst Geol of the Czech Acad Sci. This includes decomposition of samples in the presence of a newly prepared $^{116}Cd$ – $^{106}Cd$ double spike, ion exchange chromatography for Cd isolation, and TIMS analyses. The outcome of these procedures relies in gathering high-precision Cd concentration data (calculated through the isotopic dilution technique). The veracity of the whole procedure was thoroughly tested on biogenic and geological certified reference materials with different compositions including soil, Mn nodules, oyster/mussel tissue, and plant tissues (needles, leaves). This progressive protocol was developed in progress of the Czech Science Foundation (GAČR) grant No. 19-06759S, and is presently prepared for publication.

Economic vitality of the Department of Environmental Geology and Geochemistry in the period under survey can be documented by successful grant applications and funded projects of other types. The financially most beneficial projects originated from the main public grant agencies, i.e., the Czech Science Foundation (GAČR), the Technology Agency of the Czech Republic (TAČR) and the Ministry of Industry and Trade of the Czech Republic (MPO). These projects are listed in the appendix 3.2.

The personnel of the Department of Environmental Geology and Geochemistry largely contributed to other research grants held by principal investigators from other departments across the whole Institute of Geology of the Czech Acad Sci in the roles of project team members.

Department activities were funded also by resources from state offices (government funding contract project with the Administration of the Bohemian Switzerland National Park or Nature Conservation Agency of the Czech Republic) and private organizations (e.g., Velkolom Čertovy schody, Inc.). Further funding was obtained from Programmes of Strategy AV21. We appreciate these projects not only for financial support, but they are of special importance owing to the possibility of access to interesting localities and creating/maintaining a network of professionals in environmental and other scientific fields. A representative overview of such projects is given below.

In the near future, funding of the research activities of the team of the Department of Environmental Geology and Geochemistry is well secured. In the year 2020, we have already started with two research projects supported by the Czech Science Foundation.

**Instrumental Equipment**

The team of the Department of Environmental Geology and Geochemistry is appropriately equipped with instrumental techniques for current and future research tasks. In most cases, the department is self-sufficient with respect to sample preparation (drying, homogenization, workup under anaerobic conditions in a glovebox), analyses of major elemental components and trace elements (ICP EOS 5100 SVDV, Agilent), analyses of anions (HPLC with conductivity detector Knauer). We are sharing sector field ICP MS Element II (Thermo) with other GEO departments for our analyses of ultra trace elements, and also IR (Nicolet) for solid materials studies. The team members manage highly specialized laboratory devoted exclusively for mercury analyses. In this unit, two instruments AMA 254 are employed for mercury analyses in solid samples (soils, biomass, tree cores etc.), while liquid samples (natural water type) are analysed on CV-AFS fluorimeter (PSAnalytical). In the period under survey, this lab was further equipped by a combined unit Merx (BrooksRand Inc.) for fully automated THg/MeHg analyses, which is a crucial instrument for highly precise quantification of ultra trace Hg concentrations in liquid samples and allow further support for contamination-related projects. Sub-nanogram speciation analyses for quantification of extraordinary toxic methylmercury are the secondary application of this instrument.

Besides the BrooksRand instrument, we acquired also the RA-915 M field mercurymeter (Lumex, Canada) for the quantification of gaseous mercury in the air in the period under survey. This was the missing part of mercury geochemical cycle, which we were not able to follow yet. Due to its versatility, this instrument was subsequently upgraded by

acquisition of a burning oven and external cuvette for Hg quantification in solid samples, enabling flexible analyses during longer field expeditions.

Our equipment of general interest was extended also by the acquisition of a differential thermal analyzer producing both thermogravimetric and differential calorimetric record up to 1100 °C.

In the near future, we plan to extend our instrumental park by a CHNS analyzer (Elemental Inc.). This instrument will be helpful to study the composition of solid materials such as soils and sediments with respect to organic material. Besides other metals such as Pb and Cd, organic compounds in soils and sediments are especially relevant to mercury speciation because of the tight relation between mercury and organically bound sulphur. With respect to the plans of the Department of Geological Processes on extension of laser ablation technique on the current sector field ICP mass spectrometer, we might consider the acquisition of a smaller quadrupole ICP mass spectrometer for the liquid sample analysis in far future.

**Conclusion**

Generally, the situation in the team of the Department of Environmental Geology and Geochemistry can be considered as stabilized in all respects. The team members are successful in acquiring support for research projects from several grant agencies as well as from government and private sources, which makes the team financially secured. The work on research project proceeds with high standard, keeping the production of peer-reviewed papers steady. At the same time, the quality of results produced has an increasing trend, with papers published in highly respected journals with considerable IFs. Several cooperations, at national and international level, were established and are kept active. The Team was strengthened by a new scientist with outstanding ability to conduct research and publish in the field of environmental science.

## Research activity and characterisation of the main scientific results

As stated above, for the purpose of the Institute evaluation, three departments were merged together to constitute a single team referred to as the Department of Analytical Methods, Geotechnics and Paleomagnetism. All three departments of the Team 4 are involved in independent scientific work and produce scientific publications yet they are also partly responsible for providing data on a service basis.

In the period of 2015–2019, scientists of the Team 4 published, either as first authors or contributing authors, over 100 papers in journals with impact factor (IF), many papers in peer-reviewed journals without IF, several chapters in books as well as numerous abstracts in conference proceedings.

The research of the **Department of Paleomagnetism** covered a wide range of research areas (e.g., magnetism of stratigraphic system boundaries, karst sediments, and terrestrial and meteoritic materials), which resulted in publishing 59 papers in journals with IF, and 5 books or chapters in books, as well as several papers in other scientific journals. Of the 59 IF papers, the Department members were first authors in 15. Rankings of journals in these 15 cases are as follows: Q1 – 5 papers; Q2 – 4 papers; Q3 – 4 papers; Q4 – 2 papers.

Researchers of the **Department of Physical Properties of Rocks** published 18 papers in journals with IF: Q1 category– 6 papers, Q2 – 9 papers and Q4 – 3 papers. Our research was focused on elastic anisotropy study under high hydrostatic pressure, rock fracturing process, interpretation of acoustic emission and ultrasonic monitoring and alkali–silica reaction of mortar bars. In addition to that, about 15 extended abstracts were published at international conferences.

Researchers of the **Department of Analytical Methods** (co)-authored 49 papers in journals with IF, being the first or corresponding authors in 10 of them. Rankings of journals in these 10 cases are as follows: Q1 – 5 papers; Q2 – 2 papers; Q3 – 3 papers. In addition to that, five chapters in books, several papers in journals without IF and a field-trip guide were co-authored by members of the Department. The topics covered chemistry of impact glasses (central European and Australasian tektites and tektite-like bodies from the Zhamanshin impact structure), microstructure and mechanical nanoproperties of mammalian tooth enamel, crystal chemistry of sulphide minerals in enstatite meteorites, chemical composition of historic glass and developing a procedure to unveil the provenance of garnets using Raman and photoluminescence spectroscopy.

### Research Area 1 – Integrated multi-proxy study of the Jurassic–Cretaceous boundary in marine sequences: contribution to global boundary definition

The Jurassic–Cretaceous (J/K) boundary is the last stratigraphic system boundary without its GSSP (Global Stratotype Section and Point). The Team successfully applied rock magnetic and paleomagnetic methods at several J/K localities (e.g., Kurovice and Štramberk – Czech Republic; Tre Maroua and St Bertrand – France; Veliky Kamenets – Ukraine; GACR 16-09979S) and determined their magnetostratigraphy. The Team, in close collaboration with the Berriasian Working Group (BWG) of the International Commission on Stratigraphy, strongly contributed to the definition of the J/K boundary (base of the calpionellid Alpina Subzone within M19n2n magnetozone) and led to the selection of a potential J/K boundary section for GSSP. The BWG proposal for the GSSP has been submitted to the Cretaceous Subcommission. In this research area the team did sampling, conducted measurements, performed interpretation and wrote scientific publications (IDs 457329, 462062, 464293, 490442, 490485, 504498, 509565, 509570, 519466, 519474).

### Research Area 2 – Paleomagnetism and magnetostratigraphy of karst sediments in central Europe

The research focused on reconstructions of karstogenetic and speleogenetic evolutions in different karst regions in various geological and geomorphological settings (a.o., platform of the Bohemian Massif, orogenic areas of Western Carpathians, Northern and Southern Alps, Oman Mountains, active orogenic areas of the Dinarides). The research combined a number

of dating methods of karst sediments deposited in active, relict and unroofed caves, e.g., paleomagnetism and magnetostratigraphy, MS U-series, AFTA, LA-ICP-MS zircon dating, cosmogenic isotope dating, zoo- and phytopaleontology, oxygen isotope stratigraphy. Sulphuric acid speleogenesis was described as a new type of cave-forming process in the Western Carpathians (ID 517249). Evolution of relief was reconstructed (IDs 447787; 449261; 461156; 464669; 504049; 520611). Unusual minerals were described in some cave deposits (IDs 475834; 500530; 500583). Depositional phases of cave sediments since ca 5.2 Ma were defined in the Classical Karst of Slovenia (IDs 447787; 487364). In this research area, the team participated in sampling activities, conducted the measurements, and interpreted and published the results. The team collaborated with grant projects VEGA (SK) Nos. 1/0030/12, 1/0430/15, 1/0146/19; AAPV (SK) No. 0325, and EU CZ.05.4.27/0.0/0.0/15-009/0004533. (IDs 445161, 445759, 447787, 449261, 453364, 453365, 459931, 460074, 461156, 464669, 473049, 475834, 482458, 487364, 500583, 504049, 509801, 517249, 520611, 520879)

**Research Area 3 – Reference climate curve for the beginning of the Miocene Climatic Optimum in central Europe**

Project GACR 16-00800S concentrated on chemostratigraphy, magnetostratigraphy and cyclostratigraphy of Miocene Climatic Optimum recorded in lake sediments of coal-bearing Most Basin (Eger/Ohře Rift). The chemostratigraphic scheme was verified across the whole basin. Magnetic polarities were analysed in a 1.8 Myr long time interval within the Burdigalian. The composite section was correlated with the reconstructed extent of the East Antarctic Ice Sheet and with ocean (global) $\delta^{13}C$ and $\delta^{18}O$ records. The target interval in the Most Basin records several distinct paleoenvironmental (especially paleoclimatic) periods or thresholds. In this research area, the team participated in sampling activities, conducted the magnetic measurements and interpretations, and participated in publications (IDs 477504, 481473, 496960).

**Research Area 4 – Non-destructive determination of heated artefacts in Upper Palaeolithic assemblages**

The research (GACR 18-02606S) aims to identify stone industry technique in Magdalenian period (15000–11500 uncal BP) in Moravia, where the Olomučany-type chert and real flint (source from Upper Jurassic in the Blansko Graben) was used. A combination of several techniques was used to identify heat treatment and enhancing knapping properties of the raw material: Fourier Transform Infrared Spectroscopy (FTIR), Mass Magnetic Susceptibility, and Isothermal Remanent Magnetization measurement. FTIR is suitable for the identification of heat-treated cherts that have been exposed to temperature increase up to 300 °C. Iron oxides hydrate approximately between temperatures 200 and 400 °C due to water released from chalcedony. Above 500 °C the newly formed magnetic minerals dehydrate again in a reducing environment that causes new hematite and magnetite to form. In this research area, the team conducted magnetic measurements and interpretations, and participated in publications (IDs 483206, 509626, 519483).

**Research Area 5 – Cretaceous–Paleogene boundary in the Carpathians - multidisciplinary search for local variations in global cataclysm event**

To systematically record and evaluate local magnetic and biotic changes during global Cretaceous–Paleogene boundary (KPB) cataclysm event, the team launched a new research (GACR 19-07516S) at localities within the central European part of the Carpathians. The team concentrated on detailed rock magnetic studies of samples from the Žilina drill core, Slovakia, and pilot paleomagnetic and rock magnetic studies of Uzgruň section, Czech Republic. The research revealed pronounced changes in magnetic properties at the KPB related to paleoenvironmental variations at Žilina. In this research area, the team conducted sampling, carried out measurements, and interpreted and published first pilot results (ID 519478).

**Research Area 6 – Investigations and simulations of extraterrestrial materials and shock effects**

The research focused on three main subjects: (i) impact effects of Tunguska and Younger Dryas boundary events; (ii) meteorites, and (iii) space weathering. Mineralogy, physical and magnetic properties on several meteorites, such as Annama, Chelyabinsk and Allende as well as shock metamorphism and shock-darkening of ordinary chondrites were extensively studied. The imaging of reflectance spectra of space weathering products, such as Lunar regoliths, as well as modelling of space weathering were carried out. Furthermore, the team member T. Kohout is involved in AIDA (Asteroid Impact & Deflection Assessment) mission activities. In this research area, the team participated in measurements and interpretations of data, and was involved in publishing activities (IDs 444565, 445116, 447798, 448088, 458598, 479296, 481022, 481577, 487580, 488673, 488675, 490441, 490562, 493827, 498870, 500391, 500402, 509585, 509621, 520240).

**Research Area 7 – Magnetic methods and mineral–material magnetism**

The research focused on two general areas: (i) development and testing of magnetic methods to improve magnetic granulometry research, a.o., and (ii) experiments of various materials and minerals and their magnetic fabrics. Magnetic methods, including out-of-phase susceptibility, cryomagnetic experiments, were applied to various materials and minerals – volcanic and sub-volcanic bodies, terrestrial ferromagnetic minerals, ultrafine superparamagnetic particles, carbon nanotubes, gadolinium metal, halotolerant bacteria, etc. In this research area, the team conducted magnetic measurements and interpretations, and participated in publications (IDs 443040, 443084, 443329, 444568, 445111, 448076, 458596, 476861, 479386, 479081, 481730, 490560, 490845, 500530, 501241, 503155, 503954, 504064).

**Research Area 8 – Anisotropy of sedimentary and crystalline rocks**

The fundamental result of this research (KONTAKT II LH13102) was a design of a unique new high-pressure measuring head enabling simultaneous ultrasonic sounding by longitudinal and transversal sounding up to 100 MPa of hydrostatic pressure. Determined P and fast and slow shear wave 3D velocity components enabled the calculation of full stiffness tensor. The knowledge of shear wave velocities in loaded rocks is important in describing elastic anisotropy. This head enabled to study microstructure and texture of serpentinite by means of synchrotron, neutron diffraction and P, S wave velocity anisotropy under isotropic pressure loading. It was confirmed that both methods provide similar results. From velocity measurements on spheres, elastic properties can be determined without making any assumptions about sample symmetry. Elastic properties can also be inferred by averaging over crystallites and their orientations. Both approaches provide similar results, within margins of error. Similar methods can now be applied to more complex geological materials where anisotropy is significant. The team of T. Lokajíček designed the new measuring head and performed all 3D ultrasonic measurements, H.R. Wenk carried out synchrotron measurements and H. Kern made high-pressure studies on cube samples (IDs 480056, 475323, 473593, 461533, 450997, 445717, 435076).

**Research Area 9 – Alkali–silica reaction study**

Project GACR P104/12/0915, studying how quartz deformation affects the alkali–silica reaction in concrete, resulted in the design of a new temperature-controlled heating chamber. This solution was later patented under Patent No. 306055. The chamber also enables a placement of two mortar bars at a time. Also, a unique methodology of the semi-continuous ultrasonic sounding of mortar bars under alkaline conditions and elevated temperatures was developed. Moreover, the technical solution of the chamber enables acoustic emission monitoring of experimental deterioration of mortar bars. The results show that ultrasonic sounding seems to be more sensitive to microstructural changes due to ongoing deterioration of concrete microstructure by the alkali–silica reaction than the standardized measurement of dimensional change. This study was carried out in collaboration with Charles University, Faculty of Science. Researchers from the University prepared experimental mortar bars for ultrasonic study and helped us with controlling proper alkali solution concentration. They also

prepared a second set of bars for classical expansion studies in their lab. The chamber design, construction, patenting, ultrasonic measurement and data processing were done by the team of T. Lokajíček (IDs 475320, 464894, 461533).

**Research Area 10 – Field and laboratory anisotropy study**

Anisotropy of seismic waves was estimated based on the comparison of P and S velocities determined in the field (peridotite) with laboratory high-frequency seismic measurements on spherical samples. It was found that peridotite rocks exhibit weak anisotropy and a good directional correspondence for different seismic waves (field/laboratory) and neutron diffraction velocity modelling. The presented results are based on the collaboration of three institutes. The team of T. Lokajíček authored the idea, organized and collaborated with field experiments, and performed high-pressure ultrasonic measurements on spherical samples. They also conducted field experiments and processed field data and wrote his part of the text including interpretation. T.I. Ivankina wrote their part of the text together with data interpretation, discussion and conclusion. J. Vilhelm contributed with made and processed texture measurement on identical spherical samples (IDs – 461533, 475323).

Laboratory measurement of P wave attenuation on spherical samples is unique in the world and enables the study of rocks in complex 3D coverage. Synthetic and experimental data of velocity, attenuation and Q-factor evaluate the quality of the proposed processing method. The published results will improve the knowledge of rock behaviour under high-pressure conditions and may find use in the study of deep earth structures or in the evaluation of demanding subsurface projects such as gas reservoirs or radioactive waste repositories. T. Lokajíček, T. Svitek and M. Petruzalek carried out all laboratory measurements and data processing and prepared majority of the manuscript, V. Vavrycuk supplied the theory of attenuation calculation (IDs – 473593, 475899, 479393).

We also continued in the utilization of the newly designed high-pressure head under international collaboration by the study of the Tambo gneiss from Promontogno, Switzerland. Numerous laboratory methods (optical microscopy, time-of-flight neutron diffraction, neutron and X-ray tomography) were applied to quantify mineral composition and microstructures and to construct self-consistent models of elastic properties. The data were compared with the results of three-directional ultrasonic measurements on a cube sample in a multi-anvil apparatus and on a spherical sample to determine 3D velocities. The study provides a basis to determine anisotropic elastic properties of rocks either by ultrasonic experiments or quantitative models based on microstructures. The interpretation of seismic data of the crust was based on obtained information. A comparison of symmetries of measured and modelled velocity distributions led to the conclusion that two systems of cracks should be present in the model at a pressure of 100 MPa to match the measured velocity distributions. It was proved that systems of low aspect ratio cracks or pores could still be present in metamorphic rocks in the Earth's crust at depths corresponding to ~3–4 km (project Dubna No. 04-4-1121-2015/2020). Contributions of individual authors: R. Vasin – neutron diffraction measurement and modelling, H. Kern – triaxial cube measurements, T. Lokajíček and T. Svitek – ultrasonic sphere measurements, processing and interpretation, E. Lehmann and D. Mannes – X-ray tomography, M. Couche – neutron tomography and R.H. Wenk – old measurements supplier (IDs 490796, 480961, 480056, 461462, 450997, 445717, 444374, 435076, 464992).

**Research Area 11 – Rock fracturing study**

The Department of Physical Properties of Rocks also conducts the study of acoustic emission during brittle fracturing of rocks. The shear-tensile crack (STC) model was designed as suitable for acoustic emission (AE) events generated by uniaxial compression loading of Westerly granite. The advantages of STC over the conventional moment tensor (MT) are as follows: (i) contrary to the MT, the STC is a physical source since it describes the straight and simple fracture modes anticipated inside a loaded sample, namely the shear-slip and both the open and closed tensile cracks; and (ii) the STC is simpler as it is described by fewer parameters (five instead of six required for an unconstrained MT), an essential feature for

stabilizing the inverse problem. The results indicate a more certain determination for the mechanism of orientation and improved reliability for the decomposition components. In addition, the use of the STC model allowed a better distinction between tension and shear type for AE events, which may be crucial for recognizing an approaching failure. For our experiment, the application of the STC model proved to be useful for recognizing the threshold of unstable microcracking and indicative for determining the failure plane orientation (GACR 13-13967S, GACR 16-03950S, GACR 18-08826S). Cooperation institutes: Institute of Geology – laboratory experiments, acoustic emission data processing and interpretation of results, Institute of Geophysics – STC theory application. Faculty of Science, Charles University – petrophysical analysis, geological studies (IDs 494576, 493426, 490923, 490796, 480056, 479393, 479672).

**Research Area 12 – Tektites and impact glasses**

In 2015–2016, members of the Department of Analytical Methods (R. Skála and Š. Křížová, née Jonášová) continued in the study of moldavites, irghizites and potential moldavite source sediments (GACR 13-22351S). This study resulted in a large set of chemical data, which was statistically evaluated and compared with published data to (i) characterize the behaviour of elements during hyper-velocity impacts, (ii) provide a new model for formation of tektites, and (iii) dispute the theory of significant component of ashes from local Ries vegetation in the moldavite melts (ID 458591). A moldavite from a newly discovered tektite sub-strewn field in Poland was characterized in detail for major and trace element concentrations. The results were compared with data for moldavites from other sub-strewn fields (ID 460301). A detailed investigation of microstructures of selected impact glasses from the Zhamanshin crater, Kazakhstan, paralleled by a detailed high-resolution chemical mapping, HSE and Os isotope data, in tandem with Cr, Co, and Ni concentrations, allowed to constrain the projectile type to a carbonaceous chondrite. New data also introduced a new model of formation of Zhamanshin impact glasses in the aftermath of the collision (ID 461314). A new large data set of Li abundances and isotope compositions for selected moldavites and a range of sediments from Ries was collected to provide further clues on the likely source materials of moldavites (ID 466967). Stable isotope systematics of Cu and Zn were investigated in selected moldavites and sediments from Ries. Zn was found to behave in a much more refractory manner than Cu despite reversed geochemical behaviour (ID 479288). Triple-oxygen isotope data in parallel to conventional $^{18}O$ analyses supplemented by high-precision Cr isotope measurements for samples of moldavites and impact glasses of the Zhamanshin crater enabled to qualify the impactor type for Zhamanshin as a rare CI chondrite and suggested a possibility of partial exchange with ambient air during the impact. The same procedure indicated no trace of an impactor in moldavites (ID 477523). The HSE and Os isotope data were collected for a suite of moldavites and sediments from Ries in an attempt to seek for impactor component in the Ries event. The complex material exchange/mixing prevented a more precise characterization of the impactor for Ries (ID 475494).

A topical continuation of the research was the project aiming to find a potential signature of extraterrestrial component in Australasian tektites (AAT) from the centremost region of occurrence of Muong Nong-type tektites in Laos, to constrain probable tektite parent rocks, and to localize the site of the potential parent impact crater through a study of chemical composition of AAT and country rocks that might represent tektite precursors (GACR 17-27099S). The studied sample set included both Muong Nong-type (MNAAT) and splash-form type (SFAAT) specimens. In addition, a suite of sediments from Laos representing potential tektite parent materials was available. The samples were characterized in thin sections, and bulk chemical data were acquired for the sediments. AAT were analysed by EPMA and LA-ICP-MS. Triple oxygen isotope analyses of AAT provided an indication that the tektites were not modified either by a substantial projectile matter admixture or by an interaction with the atmosphere (ID 504241). In a few MNAAT, a unique assemblage of sulphide globules <10 μm across was encountered. Rare mineral shenzhuangite, $NiFeS_2$, was identified among other sulphides, which may indicate a meteoritic component (ID 507835). The HSE contents and Re–Os isotopic compositions in MNAAT suggest mingling of crustal-derived and

extraterrestrial materials. Fractionation of HSE as well as extremely low content of Os in MNAAT require an impact targeted to a shallow sea to form these tektites. The contents of HSE and values of $^{187}Os/^{188}Os$ ratio indicate less than 0.005% addition of a chondritic impactor in this type of AAT (ID 504263).

For both projects, our team provided basic characteristics of the samples in terms of optical microscopy, manufactured and optically documented polished thin sections, imaged thin sections and analysed the tektite glass with SEM and EPMA, and statistically processed chemical data. The contribution of the team members varied from paper to paper, ranging from ~20 to ~80 %.

**Research Area 13 – Biomineralization**

A prime example of interdisciplinary research is the study of an enamel structure in mammalian teeth carried out in collaboration with the Department of Zoology, Charles University in Prague by A. Kallistová and R. Skála. At the beginning of the study it appeared that a special attention has to be given to the proper sample preparation technique for X-ray powder diffraction analysis. It was demonstrated that an inappropriate treatment of specimens causes a formation of extra phases. Moreover, the used preparation technique might affect microstructural properties of the hydroxyapatite crystals, especially the length of crystallites. Consequently, a special protocol was developed to prepare the specimens (ID 444550). Then, micro- and macro-structural changes were correlated with variations in mechanical properties during the maturation stage of amelogenesis in selected parts of a pig's tooth. The results showed that a delayed formation of interprismatic enamel is an essential adaptive pattern of a swine developmental dynamics (ID 475508). Qualitative characteristics of swine dental enamel (i.e., the degree of surface wear, chemical composition variations, and microstructural and mechanical properties) were correlated with the duration of crystallization developmental process and the age. The inner structure of the crystals seems to be immutable with the age of the animal (ID 489110). The research was initiated by A. Kallistová and the Dept Anal Methods provided essential instrumentation to perform the critical experiments (X-ray diffractometer, scanning electron microscope, grinding shop). The results provided grounds for the PhD thesis of A. Kallistová. Our contribution was mostly targeted to sample acquisition and handling, experimental data collection and processing. Final correlation of information on enamel structure parameters with biological, physiological and phylogenetic aspects resulted from cooperative data interpretation with the team from Charles University.

**Research Area 14 – Historical glass**

Another interdisciplinary research is represented by collaboration with the Inst Archaeol, Czech Acad Sci in Prague. It is focused on the chemical composition of historical glasses and on the use of these parameters to constrain source materials and hence possible history of the artefacts.

Fragments of glass beakers, goblets, different types of bottles, a mug, a bowl, a jar and lamps acquired in the excavations of cesspits at the Prague Castle were characterized by SEM, EPMA and LA-ICP-MS analyses. These archaeological glass specimens are dated to the period of 1650–1800. Chemical analyses demonstrated a temporal shift from wood ash glass through potash glass to potassium crystal-clear glass. A single sample from the set possesses the characteristics of high-lime low-alkali (HLLA) glass and can be therefore considered an imported object. Glasses found at the Prague Castle and those excavated in Lisbon are similar to the extent that a speculation can be made that the glasses from Portugal may represent imported items from Bohemia (ID 491143).

The morphology of the glass finds and the contents of major and minor elements were determined also in fragments from archaeological excavations at the Salm Palace. A construction-historical survey revealed that the two cesspits were actually used by inhabitants of the neighbouring Schwarzenberg Palace. The finds are dated between 1550 and 1800. All of them are made of transparent glass yet some display light colouring in yellow, green, blue, violet or grey hues. Two main groups were defined based on the major element contents: potash glasses and wood-ash glasses. Although the cesspits were used by the nobility, the

chemical composition of the recovered glasses indicates prevailing local production. Several samples represent attempts to imitate the glass developed and produced in Venice (ID 500069).

The Department provided instrumentation as well as expertise in optimization of analytical procedures while Inst Archaeol in Prague supplied samples with relevant archaeological background. The interpretation of data was a collaborative task.

**Research Area 15 – Mineralogy of enstatite meteorites**

During early phases of the study of chromium- and titanium-bearing troilites in enstatite-rich meteorites, mutual relationships between individual minerals in samples of meteorites Eagle, Pillistfer, Bustee, Bishopville and Mayo Belwa were characterized by SEM (GAUK No. 1090119). Chemical compositions of selected minerals were measured by EPMA. Concentrations of trace elements in the minerals were determined by LA-ICP-MS. During the SEM characterization of the Eagle meteorite, an unknown Fe-rich ZnS phase was discovered. To distinguish between two potential crystal structures (minerals buseckite or rudashevskyite), EBSD and single-crystal X-ray diffraction were conducted. Unfortunately, none of the methods provided an ultimate identification of the mineral. Determination of mutual crystallographic orientations of exsolution lamellae of daubréelite in a troilite host by EBSD were attempted. This study is a part of the PhD project of N. Mészárosová under supervision of R. Skála.

**Research Area 16 – Sample provenance estimation for forensic applications**

Raman spectra of garnets from various localities in the wider area of the České středohoří Mts. were obtained by the Department of Analytical Methods in an attempt to develop an instrumental protocol for the characteristics of selected mineral phases with a link to specific geographic origin (Ministry of Interior of the CR VI3VS/780). Position of the vibration bands and the proportions of their intensities are in good agreement with data published in the literature. Also, the directional dependence of vibrations in polarized spectra corresponds to the spectra given in the literature. Some of the inclusions in garnets contain only one mineral, others contain up to four different minerals. The minerals found in the inclusions include quartz, mica, amphibole, olivine, rutile, minerals of the spinel group. Laser-induced luminescence peaks are an important part of the observed garnet spectra, and their positions and relative intensities would probably allow to define individual types of garnets specific for their provenance. The Raman study of garnets is a part of MSc project of B. Píšová (employed with the Institute under a contract), a student of R. Skála.

**Research Area 17 – Analytical service for research projects**

The primary responsibility of the Department of Analytical Methods is to provide service for academic research projects as well as commercial companies. A scanning electron microscope as an imaging tool or coupled with an EDS spectrometer as a source of qualitative or semiquantitative data and electron probe microanalyzer providing quantitative chemical compositional data were used within many projects. In particular, these methods found their use in the study of, e.g., composition of central European tektites (GACR 13-22351S), composition of phases in burnt out coal mine waste dumps (GACR 15-11674S), phase relations in chalcogenides of PGE (GACR 18-15390S), chalcogenide mineralogy of the Kutná Hora ore district (GACR 15-18917S), historical amber (GACR 16-14855S), touchstone assaying tools (GACR 16-22207S), composition of historic and prehistoric glass (GACR 14-25396S, 19-23566S), materials for photonic applications (GACR 17-20049S, 17-06479S, 14-35256S, 13-37368P; TACR TH01010997, COST MP1401, COFILA LD15122, MPO - Trio FV30151). X-ray diffraction was applied in study of, e.g., processes in sandstone outcrops (GACR 13-28040S), stratigraphy of Devonian bioevents (GACR 14-18183S), composition of potential source sediments of central European tektites (GACR 13-22351S), sandstone erosion due to gravitational strain (GACR 16-19459S), Cretaceous–Paleogene boundary (GACR 19-07516S), weathering of granular rocks (GACR 19-14082S) or the 13$^{th}$ century houses (GACR 17-23836S). In cases where the Department staff was deeply involved in the process of data acquisition and processing as well as interpretation, the analysts were adopted

as co-authors of papers resulting from the research (IDs 443048, 443050, 446768, 453553, 455147, 455461, 459687, 460472, 465010, 467978, 473049, 473358, 475834, 476328, 476555, 478570, 479233, 480068, 485960, 488627, 490486, 503969, 506819, 509552, 476327, 517249, 443041, 489660, 490319, 520611, 495483, 507954, 465853, 497229, 442933, 500069, 501763, 447836, 471032, 489768, 502182, 493542). Besides the listed papers, members of the Department were also first authors of (listed only those in journals with IF not included in the text above): IDs 507830, 499454, 448549 and 491143. In addition to the publications, also 8 research reports were issued by the Department of Analytical Methods, covering such topics as asbestos content in building stones, composition of dust, determination of rock samples and chemical composition of various historical artefacts (IDs 520744, 476063, 463848, 463852, 463853, 463860, 475307, 476059).