Department of Geology research strategy 2014-2020

During the RQ08 Assessment the Department of Geology research groups received the grades 'very strong' to 'outstanding' by the evaluation panel. The first and most significant change in our internal research landscape since that time is the recruitment of high-level researchers from outside institutions that have expanded our research beyond the classical core subjects. Among the very strong emerging fields are *Biogeochemical Cycles*, *Solar and Geomagnetic Dynamics*, and *Molecular Palaeobiology*. In this regard, the department as a whole has approached the research performed in Biology (Ecology), Center for Environmental and Climate Research (CEC) and Department of Physical Geography and Ecosystem Science (INES). The volume of this new research is significant, the leaders attract large sums of external grants, and the themes are expected to continue to grow. A second important development is that *Marine Geology* and *Applied Geology* now can be identified as strong research fields with clear connections to in-house teaching programs and to industry (*Applied Geology*). The diversification has been vitalizing our entire research environment and increased the competitiveness of the department. The important core subjects *Bedrock Geology*, *Palaeontology*, *Glacial Geology* and *Palaeoecology*, which is fundamental for geologists and for our basic education, still stand very strong in international comparison and are positively influenced by the new emerging fields.

The Department of Geology has expanded the volume of staff in a growing economy since 2008 with the major increase being from PhD student positions and non-permanent research positions. Since the RQ08 evaluation the Department has hosted two KVA researchers and one Wallenberg researcher. These positions have been critical to build new internationally strong research groups in the emerging research themes *Biogeochemical Cycles*, *Solar and Geomagnetic Dynamics*, and in our research about Mass Extinction Events. This development clearly shows the strategic necessity to attract and recruit strong researchers from external environments. The demography of the Department is positively skewed with a mean age of 50 years among the permanent lecturers. Department management has proactively recruited young researchers at the positions where retirements have occurred. The gender equality is very good at the PhD and Post-doc levels (ca 50-50), but heavily skewed at the lecturer and professor levels, where only 20-25 % of the staff is women.

The Department of Geology has a wide diversity of sources for external funding with the Swedish Research Council (VR) as a key source. We have over the last few years increased the number of published peer-reviewed articles per year, which is in contrast to the overall faculty trend. Citations per publication (CPP) for the Department are among the top five of all departments and subunits in the Faculty of Science.

Since RQ08 we have developed several research collaborations within the Science faculty, not least through strategic research areas such as BECC, MERGE and LUCCI. In Molecular Palaeobiology we work closely with researchers from both the Biology and Chemistry departments. Several of our researchers addressing palaeoecology further collaborate with Aquatic Ecology in the Department of Biology and INES. Within the research area Astrobiology we work with colleagues not only from the Science faculty but also with scientists from other faculties including social sciences. The Pufendorf institute has served as

the common platform. The new advanced LA-ICP-MS laboratory, set up in 2014 in collaboration between the departments of Geology and Biology, is a facility that is of great scientific value for a large number of research groups at the Faculty of Science (e.g. studies of aerosols, mineral-biota interaction, soil science, pollution, forensics, and material related sciences). In the Applied Geology theme close cooperation has developed the last year between Engineering Geology at LTH, as well as Århus University in Denmark and several Swedish Universities, within the Transparent Underground Structures, TRUST-project.

Researchers at the Department are frequently active within a range of major international collaboration programmes and several new partnerships have emerged since RQ08. We are currently active in International Geological Correlation Programmes supported by UNESCO, and have a leading role in IUGS/UNESCO International Geoscience Programme Project 591: *'Early to Middle Palaeozoic Revolution'* (430 researchers representing 41 countries), and in the recently approved Geoscience Programme *'Continental Crises of the Jurassic'*. Participation in these programmes substantially increases our contact surfaces with international research groups and also attracts researchers to come to Lund. Our department has also played a leading role in the planning and execution of the recently completed Baltic Sea coring expedition within the International Ocean Drilling Programme (IODP347), and we are involved in several ongoing and planned activities as part of the International Continental Drilling Programme.

Among recently concluded efforts are the International Polar Year (IPY 2007/2008) and related and subsequent polar-oriented research networks, such as Arctic Palaeoclimate and Its Extremes (APEX) and PASTGateways. We are involved in large international ice coring projects in Greenland, i.e. The North Greenland Eemian ice coring project (NEEM) focusing on radionuclide measurements with the focus of improving solar activity reconstructions, ice-core dating and to study Sun-climate linkages.

The societal value of the research within our research theme Applied Geology is directly applicable, and close cooperation with authorities as well as with the business community is well established (for example the Geological Survey of Sweden, the Swedish Geotechnical Institute, municipality boards, drilling companies, water suppliers and the mineral industry). Since 2010 we have a guest professor from the Swedish Geological Survey employed at 20 %. In addition, the Multistressors Strong Research Environment funded by FORMAS in the Department actively disseminates its research results to the management authorities concerned with Baltic Sea issues.

The Department has focused efforts on building infrastructure around core methods used in our research. One such area is *Geochronology*. The science of determining the age of geological materials is an extremely important tool within all research themes in the Department and can be seen as the backbone of our research. The Department has a multi-faceted array of modern instrumentation and expertise, which provides us with the direct temporal constraints necessary to study all aspects of planet Earth's history and evolution at time scales from Archean to recent. Early events and processes are dated with radiogenic isotopes such as the uranium-lead, lutetium-hafnium and potassium-argon systems, which are capable of recording ages ranging from several billions to a few millions of years. Slightly

younger events can be dated by palaeomagnetism or different types of luminescence, while radiocarbon dating, counting of annual increments (sedimentary varve chronology and dendro chronology) or lead and cesium radioisotope analysis can be used for dating in the range of tens of thousands of years to decades. We have a long tradition and experience of geochronology, and as a result of systematic infrastructure investments during recent decades (most recently the faculty funded LUGEOCLOCK) and we now have state-of-the-art analytical facilities for all the dating methods mentioned above. The new laboratory for laser-ablation inductively coupled plasma mass-spectrometry (LA-ICP-MS) is a new large investment from the faculty and a further step in this ambition. As an integrated complement to these absolute dating techniques, we also have facilities for relative dating of sediments based on microfossil analysis and correlation. This field, Biostratigraphy, provides a framework of fossil species successions for the last 542 million of years of Earth history, which enable us to date and correlate ancient sediments laid down in marine and terrestrial environments. The department hosts laboratories for processing of palynomorphs and has world-leading facilities for extracting vertebrate and other phosphatic microfossils.

Major research themes 2015-2020

The Department of Geology includes two sub-units organized around broad research themes; Bedrock Geology and Quaternary Geology. An important strategy is to increase collaboration across research themes. Below we present our eight research themes in short.

Continental crust – growth, collision and break-up

The Earth's crust is formed and continuously reworked by magmatic and metamorphic processes as a consequence of plate tectonics and by mantle plume activity. Our research is directed towards reconstructions of continental blocks (e.g. supercontinents), terrane analysis in time and space, and crustal growth through time. Our research is done in close collaboration with international research groups, in which our expertise comprises high-resolution geochemical and isotopic analysis of minerals and rocks. . Reconstruction of supercontinents is done by matching major coeval dyke swarms and other components of large igneous provinces, which are subsequently tested and refined by investigating the rocks' palaeomagnetic signatures. Metamorphic petrology is integrated with isotope geology and structural geology in order to constrain the dynamic evolution of continent collisional settings. All these studies use advanced chemical and geochronological analyses of minerals on the micro-scale. The main geochronological and petrogenetic tools we use are based on the U-Pb, Lu-Hf and Ar-Ar isotope systems, which provide information on the timing and the rate of processes involved in the evolution of Earth's continental crust.

Evolution of the biosphere

We focus on the evolution of life and sedimentary basins through Earth's history. The approach is multidisciplinary involving palaeontology, sedimentology, stratigraphy, and biogeochemistry, with the aim to decipher the evolution of the biosphere relative to environmental and palaeogeographical dynamics. Through petrographic and stratigraphic analysis of sedimentary rocks from around the world we reconstruct ancient marine and terrestrial environments and study their evolution in time and space. We also study various

fossil groups and their palaeobiology and palaeoecology to understand forcing and feed-back mechanisms and biodiversity changes in ancient environments. The research includes study of the history of the carbon cycle and its relation to biodiversity and climatic changes through deep time. The theme further includes an astronomical perspective whereby studies of extraterrestrial matter and impact craters provide information about the history of the solar system, and possible relationships between astronomical processes and the evolution of life. A new and innovative sub-discipline embraced within this theme is molecular palaeobiology, which concerns the investigation of fossil biomarkers and labile soft tissue structures, using cutting edge imaging, molecular and chemical techniques. This work is carried out in close collaboration with colleagues at the MAX-IV laboratory and the SP Technical Research Institute of Sweden. Given recent methodological advances, refined analytical techniques, and the ground-breaking discoveries made so far, we envisage this part of the theme to attract extensive international recognition.

Environmental dynamics

Within this research theme we explore natural archives such as sediment sequences from lakes and coastal waters, peat sequences and tree-ring records to extend the temporal range of different environmental parameters beyond the reach of monitoring series. The objective is to assess the development and extent of human impact on the environment in the perspective of natural variability and change. We use biological, physical or geochemical data obtained from carefully dated natural archives as proxies for past environmental change. By combining such time series with monitoring data and historical documents we aim at reconstructions across time scales of environmental governance and to increase awareness of the influence of humankind on the Earth system. Recent methodological advances within palaeoecology and geochemistry now enable quantitative or semi-quantitative reconstructions of a range of environmental parameters, such as land cover, land use, vegetation structure, soil development, permafrost distribution, water quality, aquatic ecosystem functioning and biodiversity. Statistical analysis and comparison with model simulations are important tools towards a process-based understanding. These research activities have well-established links to the Centre for Environmental and Climate Research (CEC) through joint funding of PhD projects and research education, particularly through the strategic research areas BECC (Biodiversity and Ecosystem Services in a Changing Climate) and Multistressors (Managing Multiple Stressors in the Baltic Sea). In addition, there are research connections to archaeology.

Palaeocology and palaeoclimatology

A coherent understanding of past climatic and environmental variability and their relationships to Earth system processes is essential to better understand Earth's climate and ecosystems, and to increase our ability to predict future impacts of human-induced climate change. Within the fields of palaeoecology and palaeoclimatology we primarily work throughout the Phanerozoic Eon, i.e. from the pre-Cambrian/Cambrian transition some 542 million years ago to the last geological epoch, the Holocene, in a range of terrestrial and marine environments and palaeoenvironments across the globe. We investigate the taxonomic composition of various organism groups and their stable isotope geochemistry in modern and fossil sediments. Integration of terrestrial and marine multi-proxy records allows reconstructions of key climatic parameters, such as temperature, moisture regime, sea level, and atmospheric/oceanic circulation patterns. There are three major research

directions within this theme; 1) proxy calibration and evaluation together with quantification of uncertainty estimates, 2) generation of records with very high temporal and spatial resolution, 3) intensified integration of terrestrial and marine proxy data with modelling experiments. This approach will lead to increased understanding of how climate change is expressed through global-scale teleconnections of the atmosphere and the ocean, and how climate dynamics are related to changes in the carbon cycle. Our research allows for the evaluation of hypotheses on mechanisms behind climatic and ecological turnovers and a better understanding of the processes involved.

Biogeochemical cycles

Biogeochemistry is the scientific discipline that involves the study of the chemical, physical, geological, and biological processes and the reactions that govern the composition and functioning of the Earth system. We are developing a predictive understanding of human-environment interactions for the future. Part of our research is focused on the human impact of inorganic and organic nutrient inputs to aquatic environments, especially the Baltic Sea. Particular emphasis is placed on the scientific basis of how we should understand the causes of the lack of oxygen in the bottom of the Baltic Sea and how we can best tackle this big problem and solve it as quickly as possible. We use paleoecological techniques and analysis of monitoring data to help understand long-term trends in aquatic ecosystems. In addition, we are making novel connections between the carbon and silicon cycles over the Phanerozoic to join two of Earth's main biogeochemical cycles through Earth's history. Within this research theme we are particularly interested in weathering and the linkages between the silica cycle and CO_2 concentrations in the atmosphere and the ocean. We are making significant advances in our understanding of the controls of long-term climate variations through the study of interactions between the globally important biogeochemical nutrient (N, P and Si) cycles and the carbon biogeochemical cycle.

Applied geology

Modern society is highly dependent on natural resources. Their handling and use affect occurrence, fate, behaviour and transport of contaminants in the environment, and are of great concern for ecosystems and human health. In order to sustainably utilize and secure drinking water, industrial minerals and rock resources, thereby achieving the national Swedish environmental objectives, society requires knowledge about the resources for their protection and management. Applied geology is a multidisciplinary theme, which encompasses the sciences of chemistry, geology, physics and biology, as well as social sciences. Our hydrogeology/environmental geology research focusses on fate, occurrence and transport of harmful substances within the groundwater system and associated risks, age determination and monitoring of groundwater, natural attenuation of contaminants and geophysical determination of their transport patterns. The research on industrial minerals aims at finding ways, based on chemical and physical properties of carbonate rocks, to optimize the industrial processing of the rocks and thereby minimize production losses, CO_2 emission and other environmental effects. Our research area includes carbon capture and storage with the overall aim is to localize sedimentary sequences suitable for sustainable storage of CO_2.

Glacial geology

The Scandinavian landscape is to a large extent the result of repeated glaciations during the Quaternary period. The Quaternary sediment cover is thus the foundation on and into which we build our infrastructure, from which most of our groundwater is extracted, and that forms the substrate for agriculture and more or less natural ecosystems. It is thus vital for society to build knowledge of glaciated landscape structure, distribution and formation. Our research focuses on glacial and periglacial sediments and landforms, and reconstruction and understanding of the processes that formed them. Based on stratigraphic and chronological work we also reconstruct glacial history on a range of spatial and temporal scales: from ice sheets to ice caps, and from the present back to the last deglaciation, including the two last glacial-interglacial cycles. This work is highly dependent on precise and accurate dating methods using radiocarbon (^{14}C), optically stimulated luminescence and cosmogenic exposure dating. Glacial geology is a classical core area of Quaternary sciences, the research in Lund judged to be outstanding in the RQ08 assessment. For the coming period our research will centre on four major topics; 1) South Scandinavian stratigraphy, 2) aeolian activity in Scandinavia during the last deglaciation, 3) glacial processes at present Icelandic ice caps, and 4) Arctic glacial history. Southern Scandinavia has stratigraphic records that can address the presently debated glacial history prior to the last glacial maximum; these studies will be linked to the Swedish Scientific Drilling Programme. The study of aeolian deposits is a new research avenue that exploits the underused aeolian records as a palaeoenvironmental archive, particularly for the latest glacial and early Holocene. Our research on Iceland focusses on understanding of present glacial processes. Our Arctic research, which has a long tradition at the Department, will be continued on Greenland, Iceland, Svalbard and Siberia and aims to reconstruct past ice-sheet dynamics and chronology.

Solar and geomagnetic dynamics

Our research within cosmogenic radionuclides (e.g. ^{14}C and ^{10}Be) encompasses many different aspects of solar system and Earth sciences that range from heliospheric and geomagnetic modulation of cosmic rays, solar eruptions and solar variability to sun-climate interactions, carbon cycle investigations and climate studies. We perform world-leading research on cosmogenic radionuclide records through broad national and international collaboration, and this theme can be expected to prosper over the coming years following a large six-year grant from the Swedish Research Council. This will allow us to start new and innovative studies on solar activity reconstructions and their extension back in time. Another focus will be investigations of the relationship between solar activity and climate change. This will lead to a better understanding of a possibly underestimated factor in climate change, and could lead to enhanced predictions of future climate change. In addition, we are involved in cosmogenic radionuclide-based dating of sediments and other geological archives, e.g. estimating the age of the Greenland ice sheet. Our research is embedded in the Linnaeus Centre LUCCI, which focusses on carbon cycle-climate interactions and the strategic research initiative MERGE on climate modelling. Furthermore, it will benefit from the recent strengthening of the climate modelling competence and it exploits the potential of the ^{14}C dating laboratory at the Department. The research on geomagnetic field changes in connection to our palaeomagnetic laboratory is an important key to the future success of this research area.

Visions for 2015-2020

The Department of Geology has a comparably young permanent staff (mean 50 years old). Young researchers (BUL) have already been recruited to replace staff that will retire within the next few years. This means that retirements predicted for the period 2015-2020 *will not* lead to the opening of new positions. The primary mechanism for the Department to grow in the next several years is through recruitment funded by external resources. Our future research growth will rely on our ability to attract young, externally funded researchers to perform their research at our department. Therefore, from a strategic point of view our most important task is to explore new research areas and avenues of funding. However, we must also fully develop our existing in-house research staff to their fullest potential. An important strategy in order to challenge and *grow our own people* is to provide leadership courses and give possibilities for continued education in their research fields. We will also establish recurrent in-house platforms for internal peer review of grants and mentoring.

We want to continue refining our dating techniques and infrastructure for precise dating of geological materials on all time-scales. This is crucial for the vast majority of our research and therefore highly prioritized. An overall, long-term strategy is to secure a stable future of our laboratories with independent but closely connected research groups and to further advance our collaboration with synchrotron light facilities at the MAX IV lab and form the fundaments for future collaboration with ESS. Of particular importance in the shorter term is to build on the momentum of the large infrastructure grant from the Faculty of Science in 2013 to acquire a joint LA-ICP-MS (laser-ablation inductively coupled mass-spectrometer) with the Biology Department (installed in 2014). Such infrastructure also strengthens research activities at the National Swedish Laboratory for Wood Anatomy and Dendrochronology, hosted by the Department. Our palaeomagnetic laboratory is a world leading facility with large recent investments and need to maintain a strong leadership. We further wish to refine our Scanning Electron Microscopy facility as well as our in-house instrumentation for precise dating through ^{210}Pb and ^{137}Cs gamma spectrometry of sediments from our newly acquired freeze corer. This is infrastructure of wider importance, and partly basic instrumentation, in the Faculty of Science and we anticipate good chances to receive infrastructure funds for these important facilities. Infrastructure for dating by ^{14}C and optically stimulated luminescence (OSL) are currently available, however we wish to increase the capacity of the Lund Luminescence Laboratory by acquiring another OSL machine and to secure its technical staff.

There are recently established research areas that are promising for the future that we judge to have a very high potential for attracting larger research funds, prestigious grants and external researchers. Such a promising interdisciplinary research field is *Molecular Palaeobiology*. We have recently initiated a process to expand this field by acquiring a world-leading guest-professor, partly through support by the Lund University Hedda Andersson fund. We early identified this field as one that most likely can receive large grants and molecular palaeontology should, in the longer time perspective, be firmly established as one of the major disciplines in palaeontology and evolutionary biology. A second strong research field is that of *Solar and Geomagnetic Dynamics*, using innovative studies on solar activity reconstructions and their extension back in time. This research group encompasses the full chain of methods from data acquisition to climate modeling and is a developing area of science excellence. Finally, the emergence of *Biogeochemistry* to understand the

complexities of the Earth system has quickly developed into a world-leading group in the last five years with several prestigious research grants.

In order to anchor and be able to follow up and evaluate strategic work, a strategy should be short and clear. We have identified four main strategy areas for strengthening our research in 2015-2020:

1) *To work purposefully to attract external excellent young researchers to our Department*. This requires identifying and recruiting potential up-and-coming candidates on the international scene and strategic work to entice them move to the Department of Geology.
2) *Develop our in-house research staff, especially the young staff*. Grow our people through leadership courses and continued education. Continue the development and implementation of new ideas in research and education.
3) *Through creativity and study of the external grant landscape increase our level of external funding.* In addition, to improve the grant writing capabilities of existing staff through internal peer review and mentoring.
4) *Maintain and strengthen our instrument and laboratory infrastructure through infrastructure funds and external grants.* This includes improving the utilization of our lab facilities with our collaborators, in our networks and in the wider community. Employ technicians to facilitate staff in developing research.