EPOS WHITE PAPER DRAFT V18

Executive Summary

European countries own a mosaic of hundreds of state-of-the-art solid Earth science research infrastructures such as networks of seismic and geodetic stations, volcanic observatories, geophysical instrumentation pools, analytical laboratories and modelling facilities. The European Plate Observing System (EPOS) integrates these resources into a single, sustainable, permanent and distributed infrastructure, optimizing access to data and offering a wide variety of powerful modelling tools. This new environment will foster innovative research, taking full advantage of Big Data analytics, for a better understanding of the physical and chemical processes that control natural disasters – earthquakes, volcanic eruptions, landslides, tsunami – the formation of geo-resources, and Earth Systems dynamics in the context of global change.

EPOS is a collaborative framework with an ambitious mission, where many diverse communities of geoscientists and engineers are creating the conditions to exploit the power of Big Data in addressing the daunting challenges of sustainability. EPOS will provide open access to geophysical and geological data as well as visualization and modelling tools. In this way, EPOS will enable a step change for multidisciplinary, interdisciplinary and transdisciplinary research in fields of high societal impact, such as seismic and volcanic hazard and risk assessment, monitoring and mitigation of environmental impacts, or long-term sustainable supply of energy and critical raw materials.

EPOS integrates ~300 research institutions from 25 European countries, already developing substantial but scattered efforts at national level, mobilizing geoscientists around a three-pronged goal:

- To boost our understanding of the complex physical and chemical processes at play in the geosphere through data-driven science;
- to increase the resilience of Europe in the face of disaster threats posed by geologic hazards;
- to support a leading role of Europe in the sustainable, safe and equitable provision of geo-resources that are critical to human well-being.
European Plate Observing System (EPOS) – enabling Solid Earth science for a safe and sustainable society

Humankind dwells on the drifting plates of planet Earth, and taps into its resources for livelihood. The success of this enterprise is measured by a six-fold increase in global population during the 20th Century. The same figure starkly highlights the challenges ahead for the management of resources and mitigation of natural risks.

Coastal regions bear most of the brunt of demographic stress, a result of migratory fluxes dictated by the quest for material welfare. By the same token the vulnerability to geological hazards rises, as more people settle, and more property and infrastructure is built, within active tectonic plate boundary regions that are prone to earthquakes, tsunamis and volcanic eruptions. Alongside armed conflicts and pandemics, natural disasters rank high among the threats to our way of life that require mitigation and preparedness.

The modern state is charged with the protection of its citizens against potentially overwhelming threats. Sound land-use planning, well-informed building codes and real-time monitoring of the Earth systems are examples of effective measures to mitigate natural risks, contingent on the possession of in-depth knowledge of the adverse phenomena.

Our ability to harvest the geosphere in a sustained and equitable way is increasingly strategic. The exploitation of geo-resources has played a central role in the development of our civilization, from the earliest stone tools and arrow-heads to the hydrocarbons that fueled the industrial revolution to the critical metals that enable electronic miniaturization or low-carbon energy generation. Meeting the growing demand imposed by our technological societies while avoiding adverse environmental impacts requires leading-edge research. This is a prerequisite for sustainable, politically secure and environmentally sound exploitation, and for exploration of new finds of commodities to counteract future global and regional scarcity.


Once passive spectators of geological phenomena, humans are increasingly perceived as agents of change to the Earth processes. Expressions such as “fracking” or “greenhouse gases” entered the common parlance, and for some specialists the Holocene – the warm period that covered the last ten thousand years – is giving way to the Anthropocene\(^2\), a new geological era defined by the potential for human influence on the dynamics of the Earth. As a research field, the mitigation of environmental hazards induced by human activities has therefore become an area of increasing focus for scientists and decision-makers alike.

The first contribution of EPOS to innovation resides in its dimension, pan-European perspective, and ambition. EPOS integrates ~300 research institutions from 25 European countries, already developing substantial but scattered efforts at national level, mobilizing geoscientists around a three-pronged goal:

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Natural Risk mitigation: knowledge is protection

The natural phenomena that reshape the surface of the Earth and episodically challenge our notion of terra firma – earthquakes, volcanic eruptions, landslides – involve energies that fall far beyond human control. Yet, the disasters that ensue have a human dimension that allows for risk mitigation. Rousseau famously remarked on the damage caused by the great Lisbon earthquake that “it was not Nature that piled up there twenty thousand houses of six or seven floors each”. Yet, it has been observed for more than a century that “the desire inherent in most men to better themselves in material respects” \(^3\) drives migration dynamics, clearly superseding any environmental concerns. Self-regulation thus excluded, the negative toll of natural disasters can only be averted through legislation on land-use and construction standards, along with the implementation of early warning systems and modelling tools, and the preparedness of emergency response. The effectiveness of such measures relies critically on our ability to understand the dynamics of planet Earth.

Increased vulnerability to natural hazards is a facet of our modern way of life: more than 100000 flights were cancelled across Europe in 2010 due to a volcanic eruption in Iceland, causing economic losses of the order of 4 billion euros. Improved tools to model volcanic ash emissions and dispersion are key to the mitigation of this risk.\(^\text{©Alamy}\).

The deformations of the Earth’s surface over different time scales – the very slow motions of plate tectonics, the gradual swelling of the ground as magma is stored beneath a volcano, the earthflow in slow-moving landslides, the sudden failure of slopes, the shaking caused by seismic waves during an earthquake – are routinely monitored by multiple national agencies. This leads to data holdings that have risen to Petabyte sizes since the beginning of the digital era and increase by several Terabytes every month, making data storage and management increasingly challenging. It has become apparent over the last decades that the full integration of the resulting data sets is key to our understanding of the dynamics of solid Earth systems, while allowing optimum preservation of the data.

\(^3\) E.G. Ravenstein, *The Laws of Migration*, 1885
Satellite geodesy data are routinely acquired to maintain reference frames and support navigation, but can also be used to track tectonic plate motions, detect and measure the slow build-up of strain that cyclically charges seismogenic faults with elastic energy, or monitor the inflation of volcanic magma chambers. Slippage along a fault, or the internal dynamics of an erupting volcano, can be investigated with a combination of seismological, geodetic, and other geophysical data. Civil engineers use accelerometers to record the strong vibrations that shake the foundations of buildings and other man-made structures during earthquakes. The same data may be used by geoscientists to understand the amplifying effects of shallow soil layers, or the attenuation of ground motion intensity as the distance from the earthquake epicenter increases. Background noise recorded by earthquake seismologists, once regarded as an impediment, is now widely used by tomographers to probe the internal structure of the planet, in conjunction with gravity, magnetic and other geophysical observations, to shed light on the Earth’s internal dynamics. New ways of using solid Earth data continue to emerge, as technologies develop and new scientific discoveries are made.

Despite the cross-feeding potential of different Earth observation techniques, discipline-specific institutions – mapping agencies, geological surveys, geophysical observatories – often address specific purposes in isolation, leading to disconnected practices in data acquisition, formatting, and storage. The resulting lack of interoperability, combined with the sheer and ever increasing volume of the data sets, is a barrier for the progress of geosciences. Highly efficient means of data mining, visualization, validation and curation must be put in place to harness the full power of the accumulated seismic, geodetic and geophysical data in an integrated fashion, benefiting from the recent advances in big data research.

Natural hazards are not independent from each other. A volcanic eruption may induce a large-scale collapse of a flank of the volcanic edifice, which in a volcanic island may be followed by a large tsunami that impacts neighbor islands or distant coastal regions. Earthquakes may also trigger landslides or snow avalanches, when they occur on land, or tsunamis when the epicenter is offshore. Multi-hazard analysis must be more than just the summing-up of individual threats, and calls for a thorough understanding of the intricate relations between those adverse phenomena. This challenge requires innovative integration of data, data products, services and skills.

**EPOS** brings together a large number of European institutions from multiple disciplines that continuously monitor the surface of the crust at 7224 observation points (as of December 2016) with a variety of observation techniques, and promotes a seamless integration of their data holdings. EPOS will work with the European Space Agency to supplement these *in situ* data with remote sensing products, unravelling the full power of Earth Observation for natural hazard research.
Addò lo fuoco coce, ma sì fuje, te lassa stà. In view of the staggering density population of the Neapolitan Metropolitan Area (>2500 inhabitants per square kilometer), civil protection preparedness for an impending volcanic eruption must rely on real-time data-intensive monitoring, along with an augmented understanding of the internal plumbing and workings of the volcanic edifice. [from https://www.charmingitaly.net/area/-naples_6/excursions-tours/pompeii-herculaneum-vesuvius-tour-from-naples-private-full-day-tour-_50_152_50_0.html, don’t know if copyright applies]

Alongside data and data products, EPOS will provide state-of-the-art tools for data mining, visualization and analysis, boosting the research potential of European geoscientists. Volcano Observatories from Iceland, Italy, Greece, Portugal and France will be connected through EPOS to share harmonised data, data products, tools and knowledge within volcanological research groups and with the wider Earth sciences community. Cutting-edge results from Near-Fault Observatories will also be made accessible through EPOS, enabling European geoscientists to push the frontiers of our understanding of the physical and chemical processes that take place at seismogenic faults. EPOS will close the loop by serving as a platform for each individual geoscientist or group to share its research – maps, models, simulations – thus enabling researchers to become also providers of data products to a wide stakeholder community.

Natural disasters arise from the interaction between nature and the built environment. As the demographic trend and the growing complexity of modern societies steadily render the human enterprise more vulnerable to geological hazards, sustainability becomes increasingly intertwined with risk mitigation. Although this challenge is beyond the scope of a straightforward technological fix, any successful strategy to face it – e.g., through the regulation of land-use and building standards or the operation of early warning systems – must be underpinned by sound scientific knowledge of the natural threats. To enable protection through knowledge is a central goal of EPOS; the path to this goal is the empowerment of European geoscientists as agents of risk mitigation.

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4 “Were the fire burns but, if you run away, it lets you in peace”. From popular Neapolitan song Funiculi Funiculà, (Turco / Denza, 1880).
Enabling the sustainable exploitation of Earth’s resources

Over the last few decades, space travel ingrained in the collective mind the finiteness of our planet. After centuries of western civilization’s despotism over the Earth’s resources – a practice based on the premise that Nature is at its best when it serves human needs – the tide turned and a new belief structure is being adopted. The pledge “to ensure that all human beings can fulfil their potential in dignity and equality” now extends “to protect the planet from degradation, including through sustainable consumption and production, sustainably managing its natural resources and taking urgent actions on climate change, so that it can support the needs of the present and future generations”\(^7\). In this quest for sustainability, a wide and clear consensus exists on ensuring “that policies are developed, assessed and implemented on the basis of the best available knowledge”\(^8\). Therein lies a clear mandate for researchers, and EPOS is a collective response of European geoscientists to this call.

Despite technological advances leading to more efficient use and re-use, the demand for geological resources is steadily increasing, a trend that will continue far into the future as global population grows and standards of living raise. In addition, most European countries’ dependency on imports brings with it major economic and political risks. As a result, Europe is currently seeing a renewed focus on mineral exploration. Prospects include many historical mining camps, now reassessed using new exploration technologies such as geophysical imaging, geological modelling and data visualization. Exploitation of resources previously considered not viable or not acceptable may now be possible through eco-efficient mineral processing or environmentally sensitive mining techniques. Examples of promising targets are the mountain belts of Eastern Europe and deposits in Scandinavia and Greenland. In addition, the concern about access to critical minerals has resulted in increased European focus on the exploration of Arctic geo-resources\(^9\).

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\(^6\) For Thomas Aquinas (1225-1274), intellect makes humans an instrument of the perfection of Nature.

\(^7\) UN (2015), Transforming our world: the 2030 Agenda for Sustainable development. UN Report A/RES/70/1

\(^8\) EC (2006), Renewed EU Sustainable Development Strategy, Council of the European Union Note 10117/06.


New frontiers: the increased interest in mineral exploitation in the Arctic is potentially a major economic and political issue for the coming decades, involving several European countries (Denmark, Finland, Iceland, Norway, Sweden). It presents sensitive environmental challenges which will require intensive research to develop appropriate extractive techniques. Depicted: Diavik diamond mine, Northwestern Territories, Canada. Source: www.riotinto.com/media. Accessed 14 March 2017.
Security of supply of rare earth elements, which are used in a range of modern technologies, is a concern for the European Community. Over 95% of the global supply is controlled by China. Source: United States Department of Agriculture (photo by Peggy Greb), https://www.ars.usda.gov/oc/images/photos. Accessed 14 March 2017

Geoscientists are tasked with providing the needed knowledge and expertise to access minerals and raw materials in Europe, adjusting industrial practice to evolving societal requirements. Public resistance to large open-pit mines is leading to the development of mining methods that have minimal impact, such as fully-mechanical underground mines or in-situ leaching. This requires the development of integrated monitoring systems, data capture from underground sensors, data assimilation and open exchange of knowledge with the public.

Meeting the energy demands of future generations

The coming decades will see a gradual transition from fossil to renewable energy sources, as a result of the commitment by many nations to reduce CO₂ emissions to the atmosphere. At present, conventional fuels still account for ~90% of the primary energy trade¹⁰, and a smooth transition demands new research towards the continued exploration and sustainable exploitation of hydrocarbons for the years to come. An example of the contribution of geoscientists on this front is the development of enhanced hydrocarbon recovery techniques in tandem with carbon capture and storage (CCS) through CO₂ sequestration, potentially an important mitigation and adaptation measure to face the challenges of climate change. Our ability to continue tapping the Earth’s resources without disrupting the ecosystems depends on understanding subsurface processes and interactions.

The rapid expansion of the shale-gas sector globally - and the associated environmental issues - are another topic requiring the contribution of geoscientists. Urgent research and technological development for the environmentally responsible extraction of this valuable resource is therefore a high priority if it is to be societally acceptable in Europe. Exploitation of shale gas reserves in Europe and globally will require careful geological and geophysical characterization of the underground to find and map potentially suitable areas, assess the commercially viable reserves and monitor for potential environmental problems including groundwater pollution and induced seismicity. The sheer potential economic significance of the sector will be a key driver for both basic and applied Earth sciences research over the coming decades, and will

require the integrated access to multidisciplinary data and facilities of many different types. This is well in line with the EPOS concept.

Household and industry heating and cooling, accounting for roughly half of Europe’s energy bill, rely heavily (75%) on fossil fuels\(^1\). In order to reach its goal of 27% power production from renewable sources by 2030\(^2\), Europe needs to improve the harnessing of underground thermal energy, and to mitigate the associated anthropogenic risk. Depicted: Hellisheidi Geothermal Power Project, Hengill, Iceland. Image source: http://www.renewable-technology.com/projects/hellisheidi-geothermal-power-project-hengill/, accessed 14 March 2017.

District heating and cooling currently represent around 10% of energy use in the EU. There is a vast untapped potential for the adoption of industrial-scale heat pumps in district heating and it is estimated that over 25% of the EU population live in areas suitable for district geothermal heating applications, enabling higher shares of renewable energy in the EU energy system. Europe has a large potential for medium- to high-enthalpy geothermal energy in a variety of geodynamic settings – from sedimentary basins to active volcanic regions\(^3\) – both for direct heating or cooling applications and for electricity generation. The full assessment and optimal exploitation of this resource depends on our understanding of the underground conditions, which will require detailed geophysical data. There remains a strong role for the geosciences in harnessing geothermal energy in a densely populated and infrastructure-rich environment such as Europe, particularly in what concerns enhanced geothermal systems where the optimization of production and the mitigation of environmental concerns require detailed monitoring and modelling of the reservoir environment.

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\(^1\) EC (2016), An EU Strategy on Heating and Cooling; European Commission, Brussels.

\(^2\) EC (2014), A policy framework for climate and energy in the period from 2020 to 2030; European Commission, Brussels.

\(^3\) ETP (2012), Strategic Research Priorities for Geothermal Technology, European Technology Platform for Renewable Heating and Cooling, European Communities, Brussels.
Bin, sink, bury? Failure to understand and account for the dynamics of geo-systems while planning the disposal of dangerous waste can lead to extremely unmanageable situations. In the picture: radioactive waste leaking into the groundwater (near Brunswick, Germany). Image source: Helmholtz Zentrum München. [I got the image via New Scientist, who credit them]

Large scale underground storage is often the best solution for resources such as natural gas, water or thermal energy. In addition, several industries produce hazardous waste that requires safe long-term storage below the Earth’s surface. The requirements are particularly strict for the nuclear industry, whose waste – spent fuel rods as well as mine tailings – must be disposed of in underground facilities with the highest standards of safety. Adequate planning of underground repositories to meet all potential long-term threats, including natural hazards – a current concern in several countries – demands geological information in an unprecedented level of detail.

**Unravelling the dynamics of the Earth and its critical thresholds in the Petabyte era.**

EPOS will put at the fingertips of European researchers an unprecedented wealth of multidisciplinary data from seismic and geodetic stations, satellite Earth Observation, model simulations, laboratory measurements, near-fault observatories, geomagnetic observatories, etc. Alongside data analytics supported by high-power computing, this level of access to data has the potential to impact deeply the pursuit of knowledge, in a way that some specialists describe as an epistemic revolution\(^ {14} \). In contrast with conventional knowledge-driven science

whereby experiments are designed to test the predictions of a theory and data are generated and analysed with a specific question in mind, data-driven science searches abductively\(^\text{15}\) for patterns that emerge from the datasets, in order to steer the theoretical development without the constraints of an \textit{a priori} conceptual framework. The intricate correlations between the multiple components of the Earth systems are among the complex topics that benefit the most from this new process of inquiry. EPOS is tailored to enable the full implementation of this approach to boost our understanding of the Solid Earth.

\[\text{Data-driven research will allow European geoscientists to unravel the intricate complexities of solid Earth systems, enabling a more effective mitigation of geological risks, a more sustainable exploitation of geo-resources and a deeper understanding of how the Earth works. © British Geological Survey.}\]

\(^{15}\)Abduction is a type of logical inference whereby an observation amplifies a theoretical premise raising new questions worthy of testing, whereas induction simply confirms or falsifies a hypothesis.
How EPOS works

EPOS is a distributed research infrastructure, with four categories of key elements:

- National Research Infrastructures;
- Thematic Core Services;
- Integrated Core Services;
- EPOS-ERIC Executive Coordination Office.

The EPOS architecture

National Research Infrastructures are the data providers, and guarantee access to data and products. Owned and managed at national level, these infrastructures have a significant economic value both in terms of construction and yearly operational costs. The EPOS architecture ensures that their value is maximized and their data is made available to a transnational community. New elements can be integrated as they become operational.

Thematic Core Services (TCS’s) are transnational governance frameworks that enable community-specific integration, designed to take into account the requirements of the different EPOS communities. Besides addressing the specific scientific questions, these platforms foster the discussion of best practices for data harmonization and interoperability, as well as sustainability, legal and ethical issues.
The **Integrated Core Services** will constitute a new e-infrastructure that ensures seamless access to multidisciplinary data and products. Its key element will be the central hub (jointly operated by the UK, France and Denmark), hosting the EPOS portal, the application programming interface (API), the metadata catalogue, and the system manager. This is where the users can discover and access data and products offered by the Thematic Core Services and National Research Institutions, along with services for integrating and analysing multidisciplinary data. The **compatibility layer** will interface the central hub with the different thematic services, guaranteeing communication and interoperability. The central hub is complemented by distributed resources – **Integrated Core Services - Distributed** – that provide supercomputing tools for data processing, modelling and visualization, as well as additional storage and backup.

The **Executive Coordination Office** is the legal seat, located at the *Istituto Nazionale di Geofisica e Vulcanologia* (Rome, Italy). Its central role is the coordination of the entire infrastructure, including the operation of the integrated and thematic services.

**EPOS Thematic Core Services**

There are currently 10 thematic communities within the EPOS infrastructure, outlined below.

**TCS Seismology** provides and coordinates services for archiving, curating and making accessible seismological data, products, software and other tools, and computational seismology workflows. Building on existing organizations (ORFEUS, EMSC, EFEHR)\(^\text{16}\), TCS Seismology provides:

- seismic waveforms (including strong-motion) and metadata from permanent or temporary station networks, including ocean-bottom seismometers;
- derived parametric data (e.g. acceleration parameters for engineering) and metadata;
- station information, temporary deployment coordination and data handling support.
- epicentral locations, depths, magnitudes and other parametric earthquake information, including authoritativeness assessments;
- moment-tensors, seismic source models, and shaking or damage estimates;
- a community platform for product staging and evaluation;
- access to hazard maps, risk maps and scenarios;
- access to underlying data like tectonic fault maps and models, ground motion data and models, geotechnical, geological and site conditions inventories;
- tools to process exposure and vulnerability data for risk analysis.

Computational Seismology services include computational workflow definition, CPU-intensive processing, massive data mining and visualization.

**TCS Near Fault Observatories** operates networks of multi-parametric sensors located at sites of particular scientific interest, continuously recording high-resolution data on faulting and earthquake generation processes. Services include:

\(^{16}\text{Observatories and Research Facilities for European Seismology (ORFEUS, www.orfeus-eu.org) including European Integrated Data Archive (EIDA); European-Mediterranean Seismological Centre (EMSC, www.emsc-csem.org); European Facilities for Earthquake Hazard and Risk (EFEHR, www.efehr.org)}\)
access to near-fault seismic, geodetic, electromagnetic, magneto-telluric, geochemical, geological, gravity, strain and other near-fault multidisciplinary data, including borehole data;

a Virtual Laboratory environment for online engagement and knowledge-sharing initiatives concerning the anatomy of active faults and the causative physical processes generating earthquakes.

TCS **Global Navigation Satellite System**, in close cooperation with existing pan-European organizations such as EUREF\(^\text{17}\), provides:

- quality-controlled GNSS data processed with standardized algorithms;
- derived products such as coordinate time-series and velocity or strain rate maps;
- software and processing tools.

TCS **Volcano Observations** relies on a structured network of volcano observatories and other volcanological research institutions, including permanent GEO supersites MEDSUV and FUTURVOLC\(^\text{18}\) to provide virtual access to data, products and computational platforms, as well as physical access to volcanological resources. In particular, the service provides:

- seismic, geodetic, geochemical, petrological, and environmental data and products, as well as metadata, from volcanic sites;
- chemical/physical data on volcanic rocks, ashes, and fluids;
- eruptive parameters, thermal characteristics of lavas, eruption rates, satellite-derived high-level products;
- Volcanic reports, hazard and risk maps.
- computational tools for volcanological modelling (lava flow scenarios, ash plume emission, etc).
- transnational access to volcano observatories for scientists;
- support to temporary deployments of mobile multi-disciplinary instruments.

TCS **Satellite Data** builds on existing infrastructures such as EPOSAR, GDM, 3D-Def, MOD or COMET\(^\text{19}\) and on the platforms made available by the European Space Agency and other national space agencies, to provide:

- Synthetic Aperture RADAR (SAR) displacement time series and maps and for the analysis of tectonic or volcanic activity and geo-resource exploitation areas;
- 3D co-seismic displacement maps for the characterization of earthquake source mechanisms;
- virtual access to on-line processing of satellite data for surface deformation analysis;
- access to Earth Observation services managed by ESA and other national space agencies.

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\(^{17}\) European Reference Frame sub-commission of the International Association of Geodesy (EUREF, [www.euref.eu](http://www.euref.eu))

\(^{18}\) Supersite projects: Mediterranean Supersite Volcanoes (med-suv.eu/); FUTURVOLC (futurevolc.hi.is/)

\(^{19}\) Operational infrastructures for processing Earth Observation data and combining satellite information of planet Earth with terrestrial measurements and modelling tools
TCS *Geomagnetic Observations* provides virtual access to data, data products and services of various level of taxonomy relying on existing organizations such as INTERMAGNET, WDCG, IMAGE, ISGI, and in particular:

- data from magnetic networks, airborne and shipborne magnetic surveys, auroral zone variometer networks as well as magneto-telluric data;
- geomagnetic activity indexes and lists of remarkable magnetic events;
- global and regional geomagnetic field and conductivity models;
- virtual access to computational platforms for compilation of lithospheric conductivity models.

TCS *Anthropogenic Hazards* provides virtual access to data, products and services associated with induced seismicity and other anthropogenic hazards associated with the exploration and exploitation of geo-resources. In particular, the service makes available:

- time series of data collected during episodes of geophysical processes induced or triggered by the exploration or exploitation of geo-resources;
- time series of data describing the causative activity (e.g. well head pressure, water level data);
- geological data describing the environment in which the technological activity takes place, and relevant metadata;
- tools for the analysis and discrimination of correlations between technological activity, geophysical processes and resulting geo-hazard.

TCS *Geological information and modelling* builds on existing platforms such as EuroGeoSurveys’ European Geological Data Infrastructure and OneGeologyEurope to provide virtual access to data, data products and services, namely:

- multi-scale geological data, including sample, borehole and geophysical data;
- Surface and subsurface maps (e.g. temperature, aquifers);
- landslide and other geo-hazard maps;
- virtual access to dissemination and exploitation platforms for borehole visualization.

TCS *Multi-scale Laboratories* provides virtual access to data, data products and services, and physical access to laboratories, for the use of analytical and experimental facilities. In particular, this service makes available:

- analytical and experimental data on volcanic ashes and magmatic rocks, experimental data on rock properties, paleomagnetic data, and data on analogue modelling materials;
- data products on volcanic ashes, magmatic rocks, magmas, rock/fault properties and rock systems, paleomagnetic data and analogue modelling repositories;
- transnational access to experimental and micro-analytical facilities such as high temperature/high pressure laboratories, electron microscopy, micro-beam, analogue modelling, and paleomagnetic laboratories.

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20 International Real-time Magnetic Observatory Network (INTERMAGNET, intermagnet.org/); World Data Centre for Geomagnetism (WDCG, wdc.bgs.ac.uk/); International Monitor for Auroral Geomagnetic Effects (IMAGE, space.fmi.fi/image/beta/?page=home); International Service of Geomagnetic Indices (ISGI, isgi.latmos.ipsl.fr/presenta.htm)
Finally, TCS Geo-energy Test Beds for Low Carbon Energy provides both physical and virtual access to academic and industry scientists to perform or participate in Geo-energy test bed experiments at multiple European geo-energy test beds. This will include:

- integrated delivery of data and models to underpin research and development of robust regulation;
- continuous monitoring data on emissions, gas and fluid flow and containment, well and seal integrity, etc.
- transnational access to deep geothermal facilities, conventional and unconventional gas recovery sites, and gas storage sites.

**Expected impacts**

- **A sound knowledge base in support of natural disaster risk mitigation**
  EPOS will empower European Earth scientists to characterize the physical and chemical processes at the root of natural and anthropogenic geohazards, laying a sound foundation for risk assessment and mitigation.

- **Secure and sustainable supply of geo-resources, with minimum environmental impact**
  EPOS will provide a research basis throughout the raw material and energy chains – from the geoscientific assessment of the feasibility and safety of exploration and exploitation of natural resources to the safe underground storage of the remains.

- **Training, education and professional development at the frontier of knowledge**
  EPOS provides an innovative environment for mentoring and training science and engineering students, enabling access to unique datasets and data analysis tools, and offering a solid platform for career development (workshops, specific courses, internships). EPOS will establish the basis for a new generation of Earth scientists, filling training gaps in interdisciplinarity and big data science.

- **Transdisciplinary reach**
  EPOS is attractive for users beyond scientists (including the private sector) as it will provide quality-controlled and standardized data relevant for developing new products and services for different stakeholders. Importantly, the use and re-use of multidisciplinary data and the harmonized access to services will foster the creation and offer of new scientific data products, unravelling the potential of this new scientific delivery system to address key societal challenges.
TEXT BOX

EPOS will ...

... provide a one-stop warehouse for convenient access to a broad swathe of quality-assessed Earth science data and metadata;

- boost fundamental solid Earth science in Europe through data-driven research;
- integrate the existing national and transnational Earth science research infrastructure;
- facilitate Earth science services to a broad community of users;
- facilitate temporary deployments of monitoring equipment, and access to geophysical instrument pools;
- coordinate access to relevant laboratory facilities;
- provide access to software and computing facilities for advanced modelling and analysis of multidisciplinary datasets;

fostering the enhanced understanding and mitigation of geo-hazards and environmental impacts, and the secure supply of critical geo-resources.

TEXT BOX ON EARTHQUAKE FORECASTING (W. SPAKMAN)

Natural disasters result from a chain of physical processes occurring in our planet’s interior that comprise huge spatial and temporal scales. Earthquakes, for example, are a seconds-to-minutes release of huge elastic deformation that was build up for years, decades, or centuries and was stored in the rock surrounding a locked fault zone. The hazardous fault can be hundreds of km long, of irregular geometry, and may locally be only centimeters wide.

When an earthquake nucleates, the fault rupture propagates along the fault surface with a speed of several km/s causing up to many meters of sudden fault slip for the largest earthquakes. The huge energy release is associated with enormous surface acceleration, often exceeding the gravitational attraction, leading to large destruction and human loss.

The start of an earthquake is still poorly understood but conceptually its nucleation occurs as a microphysical instability where locally the material stress build-up exceeds the material strength. Clearly, the material properties of a fault zone, including fault zone fluids, are key for understanding when and where earthquakes occur. Determining these properties, however, requires knowledge of the millions of years of geological evolution that determined the structure and properties of the fault zone.

Elastic deformation due to deep fault motion below the locked segment of a fault is kinematically monitored by geodetic observation, while seismological monitoring registers the short-term activity of a fault prior (and posterior) the major seismic energy release. Geodetic and
seismological monitoring thus leads to indirect observations of the local changes in the mechanical stress acting across the locked fault.

These observational efforts combined with experimental laboratory investigation of fault rock properties, fault friction, as well as fault-slip simulations, both experimentally and computationally, constitute the modern science-base for understanding earthquake activity on any magnitude scale, i.e. from human-induced seismicity to the disastrous mega-thrust earthquakes of the past decades (Sumatra, Japan, Chile). The missing crucial element for making a huge step toward earthquake forecasting, however, is knowledge of the magnitude of the absolute mechanical stress at the fault to which the local, fault related, stress changes add. This regional state of stress is unrelated to the fault and is caused by global material currents in the Earth’s mantle of which the plate tectonics of our planet’s outer “stiff” layer are an intrinsic part. The regional absolute stress level is therefore associated to physical processes that occur on spatial scales of hundreds to thousands of kilometers with motions of only several cm/year (1 cm/yr = 0.00000000032 m/s).

Conceptually, if we would know Earth in all its physical detail, including its planetary history, then estimating the regional absolute stress would be possible and forecasting earthquakes would be basically within our reach. Effectively, this requires very advanced computer simulation of our entire active planet on all its intricate dynamic scales, which is a game changing target expected to occur within the next decades.