International Symposium on Deep Earth Exploration and Applications, DEEP-2021, causes a commotion

DEEP-2021 国际地球深部探测与应用学术研讨会掀起一片涟漪

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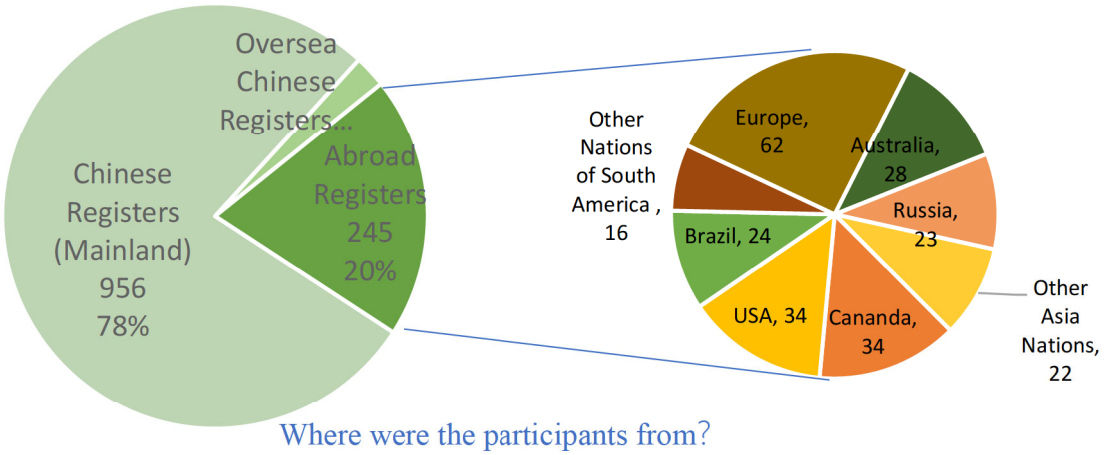
DEEP -2021

The 2021 International Symposium on Deep Earth Exploration and Practices (Deep 2021) was held on November 1-6, 2021. Originally planned for Nanjing, China, it was successfully transformed into a virtual international event due to COVID. This event was hosted by the China Geological Survey of the Ministry of Geology and Mineral Resources and the National Natural Science Foundation of China. Like its predecessors in 2011 and 2018, this symposium was an opportunity for geoscientists from around the world to share their latest results on lithospheric structure and evolution as viewed across a broad range of disciplines and with a special focus on mineral resources. Whereas previous meetings in this series included a focus on results from Phase 1 of the multidisciplinary SINOPROBE initiative in China, Deep 21 was influenced by developments related to Phase II of SINOPROBE. One such development, announced during

Deep 21, is the transformation of the SINOPROBE center into a new *China Deep Earth Science Laboratory and Program* within the Ministry of Natural Resources, which will extend until 2030. This laboratory will serve to attract collaborators from around the world and expand the range of disciplines and issues to be addressed. Another significant development was a new emphasis on future international collaborations, represented in part by the Earth CT initiative, a concept that was introduced during Deep 2018. A third important new development was the focus in many contributions on the importance of the lithosphere for mineral resources. In this sense, Deep 21 represents a major step forward in Chinese leadership in global lithospheric studies.

1231 scientists from 44 countries registered for DEEP-2021. There were 986 Chinese participants (including 30+ overseas Chinese) and 245 international participants, with the USA, Canada, Australia, Russia, Brazil, Germany, UK, Spain, Italy, France, Poland, Iran, Turkey, Denmark, South Africa, Nigeria, India, Japan, Mongolia, Vietnam, Indonesia represented. Deep 2021 was sponsored by the SinoProbe Deep Earth Science and Exploration Technology



Where were the participants from?

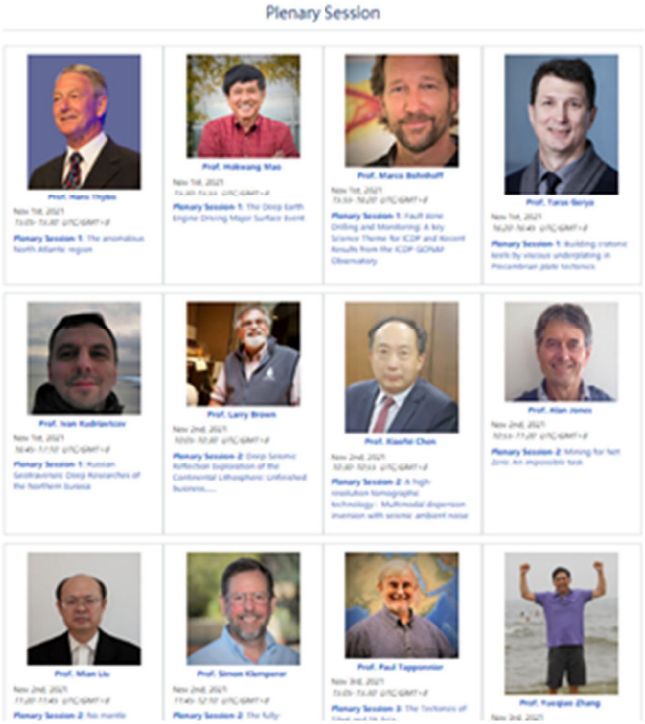
Laboratory of the Ministry of Natural Resources (formerly the SinoProbe Center), the c vInternational Union of Geological Sciences, the International Lithosphere Program, the International Continental Scientific Drilling Program, the Seismology Section of American Geophysical Union, and the Society of Economic Geologists, K.P.KARPINSKY Russian Geological Research (VESEGI), The Helmholtz Centre Potsdam - GFZ German Research Centre for Geosciences, Institute de Physique du Globe de Paris(IPGP), State Key Laboratory for Mineral Deposits Research of Nanjing University, China Seismic Experimental Site.

The Deep 2021 Program

The program for Deep 2021 began with Opening Remarks from Academician Hou Zengqian, Deputy Director of the National Science Foundation of China, Prof. Yan Guangsheng, Chief Engineer of the China Geological Survey, Prof. Shuwen Dong, PI of SinoProbe and Chairman of the Scientific Committee of DEEP-2021, Academician Hans Thybo, President of the International Lithosphere Program, Prof. John Ludden, President of the International Union of Geological Sciences, and Prof. Marco Bohnhoff of the International Continental Scientific

Drilling Program. The technical program included 4 Plenary Sessions, 12 Thematic Sessions and a Keynote Session on future work.

In this report we summarize highlights from these sessions as reported by their convenors and participants. It is not meant to be comprehensive, but merely to convey the range of geological issues addressed, the state of technology used to investigate them and the potential for future collaborations on these critical topics.



The index page of Plenary Speech of DEEP-2021

Plenary Session One

Chairs: Shuwen Dong, Rixian Zhu. Reporter: Larry Brown

Professor Dong, Shuwen gave an introductions, which was followed by five outstanding keynote presentations, given by Hans Thybo; Hokwang Mao; Marco Bohnhoff; Taras Gerya; and Ivan Kudriavtcev, followed by a general discussion led by Professor Rixiang Zhu.
Scope: The scope of this session was very broad, ranging from laboratory analysis of deep earth minerals to geophysical imagery of the crust, to monitoring of physical properties in boreholes, as well as reporting new geodynamic models of lithospheric evolution. This mix kept the session interesting to a diverse audience.
Scientific Highlights: The presentations covered a diverse range of topics: the geodynamics of the North Atlantic region, how the deep earth drives surficial processes, the importance of drilling into active faults, the generation of lithospheric keels, and the latest views of crust/ lithospheric structure from long range seismic reflection profiles in Russia.

Plenary Session Two

Chairs: Wang Chengshan, Walter Mooney. Reporters Walter Mooney and Chengshan Wang

Opening remarks were delivered by Academician Chengshan Wang from China University of Geology (Beijing). The co-host, Professor Walter Mooney from U.S. Geology Survey, gave a summary after the discussion section. Five speakers with five outstanding keynotes successfully attracted more than 260 individuals during this online meeting

Scope: This plenary session covered a wide scope of topics, from active- and passive-source seismic imaging of the lithosphere, to modeling studies and an assessment of future needs for minerals of all kinds.

Scientific Highlights: Gaps in global coverage of seismic reflection measurements of the continental lithosphere were detailed by Larry Brown, and opportunities and challenges for future deep earth exploration were identified. The practices and the power of passive-source seismology to image the S-wave structure of the crustal and mantle was demonstrated (Xioafei Chen), who described a new method of extracting higher modes from the ambient noise. The increase in consumption of mineral resources of all kinds, and the urgent need for the discovery and development of new resources was emphasized by Alan Jones. Jones also stressed the importance of attracting and training new young scientists to collect the data which will be needed to find these critical resources in the future. The application of rheological modeling of lithospheric structure to explain the evolution of continental lithosphere, particularly orogenic plateaux was illustrated by Mian Liu, who suggested that the primary driving mechanism is a weak mantle lithosphere in the overriding plate. The tectonic significance of lower crustal and upper mantle earthquakes beneath Tibet was demonstrated by Simon Klemperer, who presented a robust new method of determining whether earthquakes near the Moho were actually in the lower crust or the upper mantle.

Plenary Session Three

Chairs: Hou Zengqian, Irina Artimieva, Liu Dunyi. Reporter: Irina Artemieva

Scope: Plenary session 3 covered a broad range of topics related to structure and evolution of continental lithosphere based on geophysical and geochemical methods with implications for an assessment of ore mineral deposits.

Scientific highlights: The evolution of SE Asia since the Paleo-Tethys and critical assessment of various geodynamic models for the formation of Tibet were reviewed by Paul Tapponnier. The effect of the Mesozoic Pacific subduction on modification and reworking of the cratonic lithosphere below Eastern China was analyzed in the overview by Yigang XU. Heterogeneity of the lithosphere structure of Eastern Asia in relation to various collisional events and formation of the associated magmatic ore-deposits was discussed by Yueqiao Zhang. The overviews of Suzanne O'Reilly and Graham Begg focused on application of geochemical and geophysical methods to studies of the evolution of the cratonic lithosphere and magmatic processes that control mineralization in the cratons.

Plenary Session Four

Chairs: Liu Mian, Liu Lijun; Reporter: Qin Wang

Scope: Global.
Scientific highlights: An Yin introduced a new method he has developed, and showed that, in field where brittle and ductile deformation coexist, we can use paleopiezometry and paleobarametry to estimate pore-pressure and lithostatic pressure and their ratios. Zhigang Peng gave an overview of tectonic tremors in the world, thought to occur in brittle-ductile transition where pore-pressure is near lithostatic pressure, so they are sensitive to stress perturbations caused by surface waves of distant earthquakes. Xiaodong Song presented a comparison of different 3D seismic tomography of the lithospheric structures in continental China, highlighting the caution needed for using and interpreting seismic tomographic models, and the need to develop unified community models. Richard Ernst provided an overview of recent advances in large igneous provinces (LIP), and its relationships to mantle plumes, mantle and crustal structure, lithosphere-asthenosphere interactions.

Keynote Session: Earth CT: Quo Vadis? Identifying critical areas of the Earth that are still unexplored by deep lithospheric techniques

Chairs: Larry Brown, Shuwen Dong, Hans Thybo

Scope: This session welcomed researchers from all over the world to share their research achievements in the field of deep lithospheric studies using such techniques as deep seismic reflection and refraction profiling, broadband seismic observations, and magnetotelluric sounding (MT). The session provided a very optimistic stimulation for future lithospheric research by discussion of critical tectonic zones that have not yet been probed by modern deep exploration techniques. The session made a major step forward to facilitate new initiatives in the global deep exploration cooperation (Earth CT) program.
Scientific Highlights: The session provided a comprehensive overview of previous large scale regional programs for integrated interpretation of lithospheric structure and evolution. It included a historical view of the earlier very successful Global Geoscience Transects program of the International Lithosphere program. The presentations provided clear overview of the challenges and opportunities that the Earth CT (Global geoscience Transects) program may entertain.

The session provided important advice to the program leaders for successfully developing the new program. Some main conclusions are:

- The program must be inclusive regarding participation of all interested scientists.
- The program must build on the most modern methodology and should make use of satellite data in addition to surface observation.
- The global "profiles" should include a 3D/4D coverage around the profiles.
- Old/Vintage data should be included as far as possible and digital up-to-date reprocessing should be applied.
- The program should have a "slim structure" being led by a small group of dedicated participants.

- The program should ensure visibility and inclusivity, e.g. by. town hall meetings at all major international conferences as well as virtual meetings.
- Industry is a possible major sponsor both for economic contributions and for providing new data.
- The program may build on the general political understanding that massive new mineral resources will be required for the development of Carbon Zero society, as e.g. emphasized by the recent COP26 meeting.

Thematic Session 2: Deep structure and dynamics of the Himalaya-Tibet orogen and global collision zones

Chairs: KLEMPERER Simon; YIN An; NIU Fenglin; YUAN Xiaohui; LI ZhongHai
Scope: The Himalaya and Tibetan Plateau are the most spectacular manifestations of continent-continent collisional orogens and forms one of the most prominent geologic features on the Earth's surface. This session highlights recent progress on the structure and dynamics of Tibetan Plateau and other continental collision zones around the world, through diverse geologic, geochemical, geophysical and modeling studies.
Summary: During this session, twelve oral presentations have been conducted, focusing on the new results of Tibetan structures and continental collisional dynamics, which cover the whole Himalayan–Tibetan system from south to north. Presentations included: Complex tectonic deformation within the crust of the Himalaya and southernmost Tibetan Plateau with different methods; new interpretations of the crustal structure in the central–western Tibetan plateau; demonstration of lithospheric delamination beneath the Pamir from a seismic nodal array across the Main Pamir Thrust; competing crustal deformation models in the northeastern Tibet and differential physical mechanism for the expansion of the plateau; the overall evolution of western Tibetan system was further discussed using the large-scale numerical models, which shed new light on the far-field effects of India–Asia collision and the mechanism of Tian Shan uplift. Presentations on the general Tibetan dynamics and large-scale tectonic background included: the potential internal relationship of deformation pattern of the Cenozoic Himalayan–Tibetan orogen with the pre-Cenozoic suture zones and Permian mantle plumes and a discussion of the thermal-/lithospheric-structure and the underlying tectonics of East–Southeast Asia.

Thematic Session 3: The structure and evolution of the Eurasia continent and its margins

Convenors: Evgenia Milstein, Paul Tapponnier, Ramon Carbonell, Walter D Mooney, Wenjiao Xiao, Lijun Liu. Reporter: Zhang Yueqiao

Scope: The scope of this session focuses on the deep structure of Eurasia, including a variety of geologic, geochemical and geophysical investigations, and numerous active and passive seismic explorations as well as non-seismic methods. A total 13 talks presented new results on the deep structure of Eurasia and its margins. These results are multi-disciplinary and combine multiple data sets.

Scientific Highlights: Seismic crustal and upper mantle structures across the eastern domain of the Central Asia Orogenic Belt, Trans-Baikal orogen and far-east Russia of eastern Eurasia are clearly shown by long distance reflection and refraction seismic profiling. The seismic structure of the Iberian lithosphere was reported based on a large number of control-source seismic transects across the Pyrenees. These seismic data provide strong evidence for orogen-scale discontinuities in the crust and complex reflective crust of the central Asia accretionary orogens. The lithosphere of Eurasia shows heterogenous structure with variable thickness, as shown by thermal model of the lithosphere in Greenland, the East European and the Siberian craton and by density structural model of the lithosphere mantle in the European-Anatolian Tethys belt. These deep geophysical observations have important implication for the tectonic evolution of the Eurasia continent. Crustal and upper mantle structure of North and NE China has been a subject of vivid debate. New results have been reported from multi-seismological observations across the Solonker-Xar Moron suture of northeast China, from receiver function study across the NW Ordos block, and from natural drilling and geophysical combination of the North China Craton. These results provide a new insight into the complexity of crustal and upper mantle structure associated either with the destruction process of the NCC, or with the Mongol-Okhotsk suturing in late Mesozoic, or with westward subduction of the paleo-Pacific Plate in late Mesozoic. One important talk concerns the nature of cratonic lithosphere worldwide. Two-layer density profilez of cratonic mantle lithosphere were proposed based on calculation of global topography and geoid, which suggests the conditional stability of a dense cratonic root.

Thematic Session 4: Dynamics of intracontinental deformation

Chairs: Taras Gerya, Junfeng Zhang, Ling Chen, and Qin Wang.

Scope: This session invited contributions from various disciplines in geophysics, geodynamics, structural geology and geochemistry that focus on the structure and evolution of the continental lithosphere and on geodynamic processes within the continental interior.
Scientific Highlights: The first part on seismology was chaired by Profs. Zhouchuan Huang and Liang Zhou. Presentations addressed an overview of unified Vp and Vs models for China's continental lithosphere from joint inversion of seismic surface and body wave data. These velocity models reveal significant changes between different tectonic units and yield a solid basis for future investigation in the continental composition and deformation; the relationship between 3-D crustal azimuthal anisotropy and multi-stage deformation processes in the Sichuan Basin and its adjacent area, SW China. The following talks demonstrated how seismic anisotropy and SKS spitting can be used to trace continental deformation, ranging from coupled crust-mantle evolution for >2 Gy in southern Africa, sub-lithospheric mantle flow beneath East Africa, tectonic boundary-controlled lithospheric deformation in the Iranian plateau, to deformation in Central East China. In addition, shear attenuation beneath the southeastern margin of the Tibetan Plateau and spatial patterns of seismogenic faulting in northeastern Asia highlight other methods that can be used to infer deformation of the continental lithosphere.

The second part included dynamic modelling, rock physics and rheology and was chaired by Profs. Junfeng Zhang and Qin Wang. The rpesentations included continental marginal break-up and evaluated various processes in the geodynamic evolution of continents; heat-pipe models for the deep earth in deep time, as well as in other rocky planets. According to dynamic modelling,

craton lithospheric thinning can be caused by the connection between a subcontinental plume and the mid-lithospheric discontinuity. Deformation in collisional margins, i.e., NW Himalaya and Iran, are compared. The predominance of amphibolites in the lower crust of the southern Tibet raised a debate, based on experimental study of natural samples and seismic observations.

Thematic Session 5: Lithosphere structure and its control on Mineral System (Jointly sponsored by ILP TF I - Lithosphere structure and mineral resources)

Chairs: ARTEMIEVA Irina; LÜ Qingtian; ERNST Richard; HOU Zengqian; LI Yaoguo

Session Scope: The geological processes in the lithosphere are closely related to deposition of minerals, many of which occur only in specific lithospheric settings. This session included contributions from geology, geophysics, geodynamics, geochemistry and petrology with focus on the links between the crustal structure, lithosphere evolution, plate tectonics, deep mantle processes (including LIPs), and the origin of various mineral deposits in different geodynamic and tectonic settings. Multidisciplinary contributions had focus on Precambrian cratons, continental collisional belts, modern and paleo-subduction systems, and large igneous provinces.

Scientific highlights:

Invited and keynote lectures presented overviews of the state-of-the art research of various problems related to the links between the lithosphere dynamics and magmatic ore deposits. Prof. LIU Lijun presented a concise summary of the geodynamic evolution of Eastern China with focus on magmatism, lithosphere reworking, cooling and subsidence history in response to the Pacific subduction. The multidisciplinary study combined seismic, geological and geochemical information with numerical modeling and the results led to a broad discussion. Prof. LÜ Qingtian presented an excellent overview of the strength of integrated application of geophysical methods (seismic, MT) to study the Yangtze River Metallogenic Belt, where an extensive Fe-Cu (Au) mineralization is clearly associated with an unusual crustal structure. This observation and the strength of combining seismic and MT methods led to a broad discussion. Prof. ARTEMIEVA Irina presented an overview of thermo-chemical heterogeneity of the cratonic lithospheric mantle based on the integrated application of geophysical methods (thermal, seismic, and gravity) in combination with geochemical models. The examples from the North China, Siberia, Baltica and Kaapvaal cratons demonstrated the kimberlite sampling is biased towards magmatically modified lithospheric mantle. The results for the North China Craton led to a broad discussion.

Short presentations and posters covered a broad range of topics related to formation and identification of magmatic ore deposits. Geographically, they focused on the Neo-Tethys belt of Turkey and Iran, Eastern and South China, South Africa, Central Mongolia, and the Baltic Shield. Methodologically, they included studies based on thermo-barometry and geochemistry, gravity and magnetic inversion, thermal and numerical modeling, seismic reflection, seismic tomography, and seismic receiver functions. Therefore, the session was highly interdisciplinary with a broad representation of various geophysical and geochemical approaches, and many presentations emphasized the necessity to combine various datasets in integrated interpretations.

Thematic Session 6: Crust-mantle interaction and deep recycling

Chairs: Xu Yigang, Jingsui Yang, Esteban Gazel, Jianping Zheng, Lihui Chen, William Griffin, and Suzanne Y. O'Reilly.

Scope: Melting of the mantle transports material from the deep earth to the surface and builds the crust. Conversely, crustal material returns to the mantle through subduction, subduction erosion and/or delamination. Such a cycling process plays a key role on the habitability of our planet. The recycling of the crustal materials, including volatiles, not only affects the net growth of the crust, but also modifies the composition and the physical property of the mantle. In recent decades, the crustal growth, the crustal recycling process and the fate of the recycled crust have been investigated not only through petrological/geochemical observations of natural rocks, e.g. oceanic/continental basalts, mantle xenoliths/xenocrysts, ophiolitic mantle rocks, ultra-high pressure metamorphic rocks, ultra-deep diamonds and their inclusions, but also through high-pressure experiments and geodynamic modelling.
Scientific highlights: Presentations covered major topics like mechanisms of magma generation, compositional variation of the deep mantle, and their linkage with geophysical results, new tools and progress of analytical techniques. All these have significant implications for our understanding about deep earth processes: the definition and importance of mantle metasomatism, demonstrated the power of 4D Lithosphere mapping and its application in metallogenic exploration; volatile content in the mantle; and a talk on control of lithosphere thickness on basalt generation is very provocative and stimulated many discussions.

Thematic Session 7: Lithospheric architecture and deep material probing (Co-sponsored by IGCP 662)

Chairs: HOU Zengqian, WANG Tao, O' REILLY Suzanne Y., SELTMANN, Reimar, XIAO Wenjiao, GLADKOCHUB Dmitry, VANSTAAL Cees, SAFONOVA Inna

Scope: The session focused on probing on deep materials and lithosphere architecture, one of the important tasks of solid-Earth science.
Scientific highlights: Several presentations addressed powerful integration of geochemical and geophysical as well as geothermal methods to probe mantle compositions and architecture. In Tibet, mantle flow in a collisional setting was discussed in detail. Orogen-scale isotopic mapping demonstrates crustal architecture of orogens and characterize different-type orogens in term of deep compositions.

Thematic Session 8: Downhole monitoring of geodynamic processes: opportunities and challenges

Chairs: Wiersberg Thomas and Dong Hailiang

Scope: Downhole monitoring is becoming an important way to directly acquire in-situ data about geodynamic processes, including seismic wave, slow deformation, tilts. The developments of instrument suitable for borehole conditions are key for such monitoring.
Scientific highlights: The session aimed to provide an overview about state-of-the-art in the field of scientific drilling with a focus on borehole monitoring and instrument developments. The topics included developments of logging and monitoring instruments and experiences in borehole monitoring; an experiment about the wireline logging in Omen and the confidential data of source rock mineralogies and physical properties; the results of continuous monitoring using self-developed SOVs and DAS; observations of slow to aseismic deformation in the Marmara region from ICDP-GONAF borehole observatory; on-line and long-term fault zone gas monitoring in boreholes of deep South African gold mines; the seismogenic zones in the Witwatersrand basin based on an ICDP project; new developments in in-situ logging experiments, MEMS gravity sensor and time domain electromagnetic remote boundary detection method toward well-logging or borehole applications, respectively; and developments in algorithm lithological pore types and wall-rock formation, respectively.

Thematic Session 9: Geohazards and Crust Deformation: Deep-Earth Underground Science and Earthquake Science

Chairs: Zhongliang Wu, James Mori, Li Li, Paramesh Banerjee, Ying Li, and Johannes Schweitzer.

Scope: Research on the connection between the lithosphere and geohazards.
Scientific highlights: Seismic hazard assessment and earthquake forecast being the highlights was the theme of the first section. In an invited presentation, Giuliano F. Panza, presented state-of-the-art scientific knowledge on earthquakes and related risks and called for a transition of basic concepts in seismic hazard assessment. In another invited talk, James Mori presented a systematic investigation of the foreshock – mainshock relation for onshore Japan earthquakes from 2001 to 2021. Contributed presentations dealt with the China Seismic Experimental Site (CSES), source parameters of earthquakes in the Indian-Arabian-Eurasian plate collision zones, seismic anisotropy beneath the west-central North China Craton, and seismic hazard assessment in Armenia, among others.
The second section was mainly about observed crustal deformation and geo-hazard. In the invited talks, Yonggang Lishared the results and ideas of the characterization of subsurface fault damage structures associated with the strong earthquakes at Parkfield and eastern California shear zone by fault-zone trapped waves; Haibing Li presented the shallow crustal deformation, deep structure and seismogenic environment of the Xianshuihe fault, eastern Tibet. Contributed presentations included the pop-up ranges and partitioned oblique convergence in the southern Qilian Mountains of NE Tibet, the present-day crustal deformation in the northeast margin of the Tibetan plateau as revealed by GNSS observations, and the time-dependency of inter-seismic deformation at subduction zones in the Nankai trough of Japan; and the ongoing Nepal Airborne Lidar Project. Johannes Schweitzer commented that the development of GNSS has been impressive and the merge of seismology with geodesy in studying geodynamics and seismic hazard is promising.

The third section mainly focused on the interdisciplinary problems of geo-hazard. In his invited presentation Antonio Caracausi discussed the degassing, tectonics and seismicity based on recent geochemical investigations in Italy.Presentations in this section included the scientific field investigation of the recent 22 May 2021, Maduo, Qinghai, *M*s7.4 earthquake, the systematic study on the groundwater radon precursory anomalies in deep water wells in CSES, geo-fluids hosted in the deep crust and their significance, crustal structure of the Pakistan region, neo-deterministic seismic hazard assessment (NDSHA) for Pakistan and adjoining regions, and seismic resilience evaluation in the study of earthquake disaster response.

Thematic Session 10: Geological and surface processes in response to deep earth dynamics

Chairs: Jing LIU, Yann KLINGER, Haibing LI, Jean BRAUN, Kate HUNTINGTON.

Scope: Surface processes in response to deep earth dynamics with focus on Tibet.
Scientific highlights: Three invited talks given by Prof. Shaofeng Liu (CUGB, China), Ting Yang (SUSTECH, China), and Shaozhuo Liu (KAUST, Saudi Arabia) on the deformation in and around Tibetan plateau from the depth to surface. Other contributions concerned deformation in and around Tibetan plateau from the depth to surface, and the observation and modelling of the drainage integration of SE Tibet, seismic activity in Tibet, Tibetan surface deformation and the modelling of the segmented ruptures.
Surface processes are significantly related to the dynamics in the deep earth. The session focused on the analysis of the deformation we observe from the surface, to derive models of the physical deformation at depth. Geophysical observations, such as seismic cross-sections provide important information, and surface change provide information on the history of the deformation.

Thematic Session 11: New techniques and applications in dense array seismology

Chairs: Huajian Yao, Haijiang Zhang, Xiaobo Tian

Scope: To attract new techniques and new applications using dense seismic arrays (e.g., geophone array, DAS) to image Earth's interior structure (velocity, interface, etc).
Scientific highlights: The emerging DAS (Distributed Acoustic Sensing) technology has the great potential for subsurface structure imaging and seismicity monitoring. Its ultra-dense observation provides new opportunities to image high-resolution near surface to mid-crust structures and Moho depths.
The densely distributed geophone arrays or short period seismometers have provided new opportunities for high-resolution crustal and upper mantle velocity structure tomography and interface imaging from passive and active sources (e.g., ambient noise, earthquake waveforms, methane active sources) in regions of different scales, such as cities, fault zones, metallogenic belts, Sichuan Basin, the Tibetan Plateau, north Japan, central California, etc.
Advanced and new seismic imaging and data analysis methods have been used to image crust and upper mantle velocity and interface structures, such as adjoint or full wave tomography,

scattering imaging, Seismic Frequency Resonance Technique (SFRT), body-wave amplitude ratio inversion, array-based receiver function imaging or inversion, high-modes surface-wave dispersion inversion based on the F-J method, waveform similarity and graph analytics, coda auto-correlation, etc.
The spatial and temporal variation of subsurface velocity structures can be monitored by the ambient noise correlation method (seismic interferometry) to reveal groundwater fluctuations in the basins, consistent with surface deformation from InSAR.
The session showed that the combination of dense or ultra-dense observation systems together with the emerging new imaging techniques will enable more detailed seismic images, which can better understand dynamic processes of the Earth from the shallow surface to deep interior.

Thematic Session 12: Illuminating the Deep Earth with EM Geophysics

Chairs: Jin Sheng, Adam Schultz , Lü Qingtian

Scope: Provide overview of how electromagnetic studies may image Earth's interior from the near-surface to a global induction model with satellite and tidal data.
Scientific highlights: New datasets from the frontier of the EM methods, like the marine data from the western Pacific, the satellite data from SWARM and the MT profile from Mongolia, received most heated discussions. The cutting-edge EM techniques, like the joint inversions and 3D probabilistic simulations, are also under spotlight. Experts from all over the world showcase a diverse array of studies ranging from the near-surface applications in Scandinavia, all the way to the global induction model with satellite and tidal data.

Experiences and lessons learned from organizing Deep 2021

The DEEP-2021 conference style is a novel attempt at academic communication for most Asian participants, adopting a model of completing the whole process online, which included registration, abstract submission, convener monitoring, program scheduling, and all in one meeting platform. The organization working group organized four road shows in accordance with the organization's plans, as well as eight live testing activities for both domestic and international participants and conveners, created two guidebooks and a step-by-step chart for easy training.

Under the circumstances of the worldwide COVID-19 outbreak, the DEEP-2021 International Symposium was held entirely online. Due to the fact that conference attendees could not gather in person, the DEEP-2021 meeting structure was organized in three stages for streaming. The first stage was a webpage for pre-recording entire oral presentations and iPosters online, which began one week before and terminated one week after the live sessions. The second component was a live presentation and Q&A session. Third, the pre-recorded presentations and iPosters were available for review during the time of the live sessions.

The number of abstract submissions increased slowly at first, but with the proclamation of the conference model and the joint efforts of the conveners, by August 1, 2021 more than 380

abstracts had been submitted by 350 registered scientists, with 302 abstracts passing peer-review, including 180 abstracts by Chinese authors and more than 120 abstracts from abroad authors. The pre-recorded presentations were offered to the public for free from October 26 to November 12, 2021. International abstracts were still being solicited for extra submissions as of October 26. Before October 26, there were around 370 registrations, with almost equal numbers of Chinese and international registrants, including 200 Chinese registrants (China and Hong Kong) and more than 170 other nationality delegates. Since the commencement of live sessions on November 1, the number of registrants has significantly increased, particularly among Chinese registrants. There were 986 Chinese delegates and 245 international delegates from 44 countries registered by November 6, the deadline for registration. The majority of them were official delegates. The number of student registers was just 9% of the total.

The scientific program included 213 oral presentations, 116 poster presentations, and 19 plenary invited addresses. Following the online boarding of the meeting platform, 218 pre-recorded oral presentations and 100 online iPosters were received. Each pre-recorded oral presentation lasts around 15-30 seconds.

Because the physical meeting was canceled due to the COVID-19 outbreak, DEEP-2021 has served as an excellent academic exchange and communication platform for the bulk of deep-earth scientists, and has received widespread international acclaim. Academician Hou Zengqian, Deputy Director of Nature Science Foundation of China, Academicians Zhu Rixiang and Xu Yigang of Chinese Academy of Sciences, Academician Wang Chengshan of China University of Geosciences (Beijing), Academician Suszan O'Reilly, Prof. of Australian Academy of Sciences, Deputy Director of NSF-Australia, Academician Hans Thybo, Chairman of International Lithosphere Program, Academician Irina Artemieva of Royal Danish Academy of Sciences, Prof. Larry Brown of Cornell University, Prof. Katherine Boggs, Mount Royal University of Canada, Prof. Ivan Kudriavtcev, head of the Geophysical Department of VESEGI, and more than 20 other scientists attended the DEEP-2021 conference.

<u>The advantages of DEEP-2021 meeting format</u>

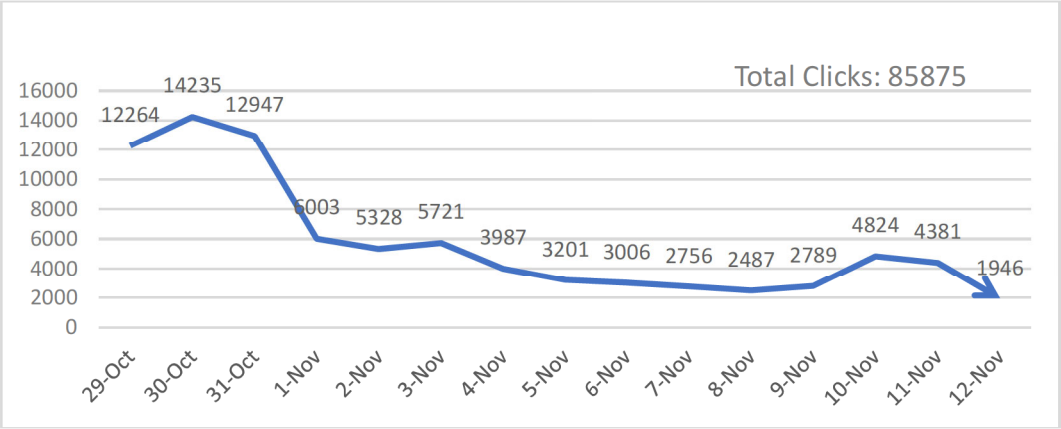
- Gave participants opportunities to participate in Q&A on different sessions,
- Made it possible to listen to more presentations than at in-person meetings
- Provided broad access to a diversity of topics.
- Enabled good preparation for in-depth, online discussions.
- Minimized international travel.

<u>The disadvantages of DEEP-2021 meeting format</u>:

- International time differences complicated attendance
- Some of the online presentations and Q&A sessions received insufficient time to be fully effective
- Online discussions can be less effective than face-to-face in-person exchanges
- Few opportunities for continued communications and exchanges after the live sessions.

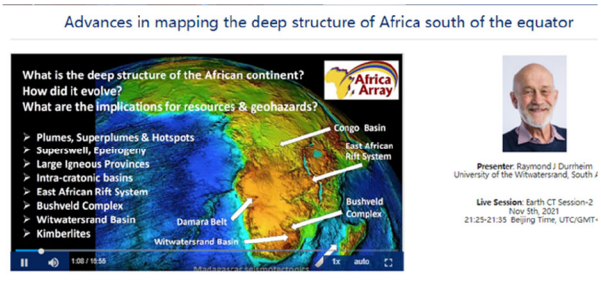
In spite of the challenges of moving such a complex symposium fully online in a relatively short time, the result was generally well received. Here are some of the comments from participants:

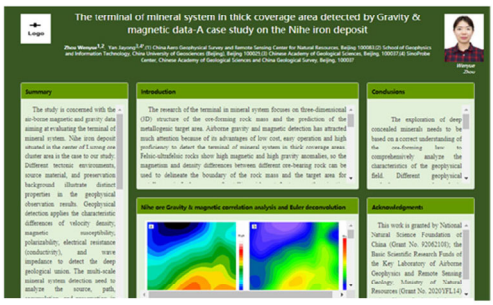
- "DEEP-2021 was organized very successfully and built an effective academic platform for communication"
- "We originally thought that the online conference would be not a good way to communicate, but DEEP-2021 allows us to communicate more than physical meetings and lively
- "This is a good example and a good direction for future meetings organization"
- "DEEP-2021 gives us the opportunity to participate in more forums and learn more about the progress of international geological work"
- "This is a real live workshop and I am very lucky to participate in DEEP-2021"
- "We hope that the DEEP-2021 platform will be retained for a longer time. We hope the DEEP-2021 platform will be retained for a long time."



Day-by-day visits to the Pre-recording Presentation personal page

The number of individual academic page hits was tracked from October 29. The number of clicks on the personal page of the pre-recorded presentations surpassed 85,000 by midday on November 12, 2021. (Multiple clicks by the same personal page or record within 30 minutes were counted as 1 click). The statistical days with the greatest rise in clicks from foreign nations were October 29-31, when the number of clicks from foreign countries was 1.2 times that of domestic clicks. The number of international clicks topped 14,000 from 10 p.m. on October 29 to 8 a.m. on October 30. The data reveal that local delegates are more inclined to participate in live





On-line pre-recording oral report and poster of DEEP-2021

conversations, whilst international delegates are more interested in abstracts and pre-recorded talks.

Screen shot of Live-Discussion of DEEP-2021

The picture wall of speakers of DEEP-2021

Summary

Deep 2021 was a great learning experience for organizers and participants alike, both in terms of managing and delivering an effective online experience and in terms of the science that was presented. Several aspects of this symposium stand out:

1. The world will need to find and extract huge quantities of new mineral resources in the near future if it is to mitigate future climate change. Much of the science reported at Deep 2021 has an important role to play in meeting this challenge.

2. Integration of new geophysical and geological observations is providing dramatically new perspectives on the deep lithosphere.

3. Much of the existing data on the lithosphere is poorly archived and difficult, approaching impossible, to access. Initiatives like Earth CT is a good first step in remedying this situation.

4. Much of the world, especially South America and Africa, remains largely unexplored by the full suite of modern deep investigative tools. A new approach is needed to focus resources toward properly exploring these regions. The involvement of scientists from these regions was a major asset to Deep 2021. That involvement of local geoscientists from underrepresented parts of the world should be expanded in future versions of the Deep 20XX series.

5. The newly organized *China Deep Earth Science Laboratory and Program* has the potential to play a leading role in organizing international collaborations for the future research on deep lithospheric structure, evolution and mineral deposits to address these challenges.