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5-YEAR MEDIUM-TERM PLAN (MTP)

DEEP-TIME DIGITAL EARTH (DDE) PROGRAM

Data-driven discovery in the Geosciences

INTRODUCTION

Deep-time Digital Earth (DDE) is a geological sciences program which, in the words of the Director of Science and Technology of the British Geological Survey (BGS), Prof. Michael H. Stephenson, who is also the Chair of the Governing Council of DDE, is dedicated to "lift" centuries old data held by museums, research institutes and individual scientists "from page to cyberspace"[1]. In December 2018, DDE won the backing of the International Union of Geological Sciences (IUGS), one of the world's largest scientific unions. DDE aims to enable and enhance data-driven discovery in the geosciences and create linked, interoperable big-data hubs that integrate unpublished data with existing databases in the public domain[2]. DDE will build a FAIR (findable, accessible, interoperable and reusable) data infrastructure that provides tailor-made products and services to academics, researchers, policy professionals and the public[3].

DDE was due to be formally launched at the 36th session of IUGS – the International Geological Congress (IGC) – which was scheduled for March 2020. But, like every such international event scheduled for 2020, IGC-36 was postponed due to COVID-19-pandemic imposed disruptions. IGC-36, is now being planned for March 2022 in New Delhi, India, in a format different from previous, quadrennial IUGS/IGC events. The formal launch of DDE may coincide with that March-2022 IGC; or it may be linked to an event in early autumn 2021 to commemorate the 60th anniversary of the IUGS.

Although it had not been formally launched, scientists who designed DDE have initiated actions and activities soon after it was endorsed by IUGS. DDE has developed a draft set of Statutes and Bylaws which are undergoing revision for finalization before the end of the first half of 2021. A draft White Paper (WP) entitled "Deep-time Digital Earth (DDE) 2019-2029: International Union of Geological Sciences recognized Big Science Program"[4], which includes a Science Plan of DDE, has undergone several revisions and is due to be finalized by March 2021.

This Medium-Term Plan (MTP) aims to translate the vision and mission of DDE as defined by the WP into goals, objectives, implementation processes, expected outcomes and deliverables for the five-year period beginning from the second half of 2021. It identifies risks to its implementation and ways and means of mitigating them; describes key performance indicators (KPIs) for mid- and end-of-term evaluations and outlines mechanisms for regular monitoring of progress. This is the 5th version of this MTP; so far, revisions have been based on inputs from scientists who have been guiding the development of DDE during 2019-2020. This version however, is being circulated to a broader range

of professional groups who have already engaged with DDE as Founding Members and Working and Task Groups (WTGs).

DDE: DEVELOPMENT DURING 2019-2020

DDE attracted funding and basic infrastructure support from China in 2018[1]. From 26 to 28 February 2019, 80 geoscientists from 40 different geosciences organizations, including IUGS, the British Geological Survey (BGS), the Russian Geological Research Institute and others came together in a "kick-off" meeting in Beijing, China. During that meeting, 12 Founding Members committed themselves to working with DDE. 5 more Members joined DDE during the 1st session (on-line) of the Governing Council of DDE convened on 21 October 2020. Since then, the Indian Geological Survey has joined.

Based on the proposals of the WP, Governance (a Governing Council (GC) and an Executive Committee (EC)), Advisory (Scientific Committee (SC)) and Operational (Steering Committee (StC)) organs have been established. China honored its commitment to provide infrastructure support by financing the establishment of the DDE Global Secretariat in Suzhou, China. In addition, China has initiated the construction of DDE's first Research Centre of Excellence (RCE) in Suzhou. Efforts to establish two more RCEs in UK and USA, respectively, are making progress.

19 Working Groups and 8 Task Groups have been established. Working Groups (WGs) provide DDE Program with operational scientific capacity to design, develop and implement individual projects within their own geoscience fields of expertise. Task Groups (TGs) will specifically explore databases through projects and/or workshops. A data-driven discovery symposium or expert dialogue is being planned for late 2021 or early 2022.

This MTP builds on current strengths of DDE to capture emerging opportunities for its continuing growth and development. It attempts to rectify some of the weaknesses pointed out by DDE Founding Members with regard to membership structure, rights and obligations of members, financial management procedures etc. These weaknesses are being addressed in the revision of the Statutes and Bylaws led by the Chair of the GC. Concerns expressed by some Founding Members of the tendency of some WTGs to work in their own silos are being addressed, partly through basic funding support given to WTGs, and some enabling projects due to be financed by resources mobilized by DDE/RCE, Suzhou in 2020.

The 6 MTP objectives focus on: (i) building the cyberinfrastructure; (ii) improving the design and content of the DDE website; (iii) creating a network of research centers of excellence (RCEs); prioritizing problems and questions for (iv) theoretical and (v) applied research and financing them; and for (vi) diversifying the budgetary and financial foundations of DDE which is currently dependent primarily on resources mobilized within China.

The MTP's mid-term evaluation, due at the end of 30 months of implementation will be conducted around the end of the year 2023. It will generate findings for the consideration of geoscientists worldwide as they prepare convene for their IUGS/IGC in South Korea in 2024. The performance of DDE from 2021 to 2023 will thus receive thorough scrutiny within the geosciences community in early 2024 and attract recommendations and suggestions for improving implementation MTP during the following 30-month period of this MTP and the remaining years until 2029 foreseen by the WP.

VISION AND MISSION

The WP defines vision and mission of the DDE Big Science Program as follows:

The long-term **VISION** of DDE is to transform the Earth Sciences by fostering a deep-time data driven research paradigm.

The overall **MISSION** of DDE is to harmonize and integrate deep-time earth data, share global geoscience knowledge and advance geoscience understanding and research.

With its 18 Founding Members and 27 WTGs (Working and Task Groups), DDE has brought together well over 100 scientists to work towards fulfilling its vision and mission of the WP. Work to establish a preliminary team structure, collate existing databases and create a global research network of centers of excellence has begun. As the implementation of this MTP moves forward experts from geo and data sciences will create a knowledge system framework under a common system of standards and data-sharing rules and procedures for data-driven research to address vital theoretical and applied science questions

DDE VALUES

DDE is a global, international partnership for promoting scientific cooperation for data driven discovery in geosciences. Its work will be carried out in an open and transparent manner, respecting rules, regulations, working methods and approaches as defined in its Statutes and Bylaws and of its member organizations and cooperating partners (both institutions and countries). It will follow the principle of non-interference in the internal affairs of cooperating countries and organizations. DDE will encourage geographical and gender diversity in representation in its Governance, Advisory and Managerial organs and leadership of its WTGs, members and partners. It will carry out its activities in a manner so as to benefit all regions of the world, in particular less developed countries. DDE will strive to attain the highest levels of professional competence and integrity in all research, data driven discovery and related initiatives. DDE will follow rules and procedures established via consensus for data-sharing and other aspects of international scientific cooperation critical for the success of DDE.

GOAL, OBJECTIVES, IMPLEMENTATION AND DELIVERABLES

The Goal of this 5-year plan is to:

“Develop DDE into a reputable, international research and development program for collaboration between data and geoscientists that generates and disseminates information, insights and knowledge of demonstrable significance to academic and scientific research, public policies on natural resources management and sustainable development and for raising awareness and appreciation of the public for deep-time geosciences phenomena”.

This goal will be reached through implementation of actions and activities to meet the 6 objectives and specific deliverables linked to each one of them.

Objective 1:

DDE cyberinfrastructure framework constructed based on existing knowledge base and data standards and is serving the global geosciences communities.

Implementation: The DDE cyberinfrastructure will include the following components: (i) data; (ii) knowledge; (iii) platform; and (iv) scholar[5].

Data: Deep time big-earth data covers all disciplines in the field of solid earth sciences. Different disciplines have their own data sources, characteristics, structures and standards. Depending on source channels and other dimensions, DDE will promote the construction of a full series of disciplinary, regional, project and other categories of databases. In view of the huge number of multi-dimensional scientific research data related to geosciences and their numerous sources, DDE will create an energy efficient technology system for obtaining research data and improving their reusability. It is necessary to build a high-quality literature database, and to study the multi-source heterogeneous geological data grabbing tools, including the development of "picture-literacy- data", multimodal data grabbing and other tools to interface with databases to improve the reusability of data.

Knowledge: Based on the powerful storage and computing capabilities of cloud platform and the security and privacy protection capabilities of edge computing as well as that of blockchain technology, DDE will develop a collaborative, sharing technology of distributed knowledge graphics based on geoscience characteristics. In order to obtain reliable geoscience knowledge from various resources, a reward incentive mechanism driven by knowledge quality is required. Based on individual behavior analysis and knowledge quality requirements, the construction of such incentive mechanism and interaction model among individuals are expected to ensure users long-term participation in structured geoscience knowledge generation. Finally, a collaborative knowledge addition and audit system for global scientists would be formed in order to jointly promote geoscience knowledge graphics construction.

Platform: The main challenges facing machine learning and artificial intelligence applications in earth sciences include coordinating and standardizing geoscience data, and developing specialized machine learning and artificial intelligence to solve complex geoscience problems. The DDE Enabling and Empowering Platform (DEEP) will be a one-stop platform for geoscience data preprocessing and analysis, which allows researchers to access and analyze existing data using a wide range of algorithms and models to tackle significant questions of earth sciences on evolution of life, geodynamics, materials and climate as elaborated under the Science Plan of the WP.

Scholar: DDE Scholar aims to construct a knowledge information system for geoscience scholars, which goes through knowledge arrangement, knowledge mining and step by step knowledge discovery. DDE Scholar will contain data, profile, report and service components. DDE Scholar provides multiple knowledge information visualization applications, including academic literature evaluation, analysis, and recommendations. Moreover, DDE Scholar develops some paper submission tools, including paper x-ray, paper similarity check system, and keywords trend analysis. Functions such as machine-reading of papers and knowledge graph Q&A system are being developed.

The DDE platform and other components of DDE cyberinfrastructure will enable DDE to build educational and science popularization modules in collaboration with internationally reputed geological educational institutions and scholars.

Some of the outcomes that could be derived from implementation objective 1 are:

- DDE advocacy of data-driven scientific discovery leads to DDE cooperation with international data organizations such as International Science Council-World Data System (WDS), the Committee on Data for Science and Technology (CODATA), Research Data Alliance (RDA) etc. Such cooperation will strengthen and enrich its data policies in line with international standards, improve DDE's ability to implement data standards, and promote the mutual access of its scientific databases with other international databases;
- DDE's Policy on Intellectual Property (IP) is widely shared with partner organizations engaged with DDE on data sharing and data-driven discovery and refined and improved to meet international standards and expectations;
- DDE big data system, as an open data storage system is able to support the data storage of scientific and technological journals, provide scientists with more convenient data storage services.
- Technologies and mechanisms of the DDE international data center are certified to build trust in its data storage capability and serve as one of the influential, international public storage platforms in the field of geosciences;
- DDE professional teaching and educational as well as science popularization (using themes of proven appeal such as dinosaurs) modules are developed and widely used;
- Conceptual basis and approaches to DDE's data sharing is made public including through at least 1 paper in a well-known data sciences journal

The deliverables under objective 1 are:

Year 1: (i) Overall design and key technology of DDE platform; (ii) DDE big data integration and sharing mechanism and standards and specifications for deep time earth big data; and (iii) Integrated communication strategy and communication standards

Years 2-3: (i) Reconstructed geoscience knowledge system ready for treatment by big data analyses, artificial intelligence and machine learning; (ii) Model for generation of knowledge graphics in the geosciences; (iii) DEEP central engine ready for serving as the DDE digital earth collaborative research platform; (iv) Communication activities and products for professionals, educators and deep-time geoscience popularizers; and (v) At least 3 organizations with vision and missions similar to DDE become new members of DDE.

Years 4-5: (i) 10-15 WGs generate knowledge graphics through the application of DDE group intelligent cooperation model; (ii) DDE data authentication center; (ii) DDE professional/ thematic databases, including regional, national, professional, industry and interest node networks; (iii) DDE digital earth integration, exchange and collaborative research platform; (iv) DEEP Platform provides professional applications such as Deep Earth, Deep Map, Deep Scholar, etc., and (v) At least another 3 organizations become new DDE members.

Objective 2:

DDE has a content-rich website and other on-line and print information dissemination and communication channels in cooperation with its members and partners for promoting the significance of big data analyses and applications and data driven discovery in geosciences.

Implementation: Big data science is reliant not only on availability of and access to data; but on computing power and skilled and competent personnel who are trained in direct and remotely sensed data collection, data analytics, machine learning, AI and other technologies. The latter skills and

competencies are distributed unevenly across and within different parts of the world and the members of the DDE network. Furthermore, data driven analyses is often used for novel means of displaying and presenting data; illustrating and demonstrating data driven "discovery", i.e., previously undetected trends, patterns and insights, or the generation of new knowledge will require careful choice of the questions/problems for study. Furthermore, clearly describing the "new" and "innovative" insights, trends and patterns and knowledge that data driven discovery had revealed would also require careful illustrations and writing. The conceptual basis, methods of data collation and analyses as well as interpretation of findings to draw conclusions and recommendations may well be new to even some geoscientists, particularly from less developed parts of the world, and others who are averse to or avoid intensely quantitative methodologies and approaches. Illustrating the potential of data driven discovery for policy and decision makers and to raise awareness of the general public of "deep-time" phenomena that underlies the geological sites they visit and appreciate would require refined science journalistic skills.

DDE communications, whether disseminated through web, scientific papers and reviews, policy briefs and non-specialized journalism outlets, members' websites etc., needs to be targeted at a diversity of audiences and needs to cater to their interests, curiosity and readiness to learn about data-driven discovery in sciences in general, and the geosciences, in particular.

DDE Secretariat and GC, EC and SC must develop an overall, global vision of the diversity of target audiences the Program wishes to cater to. Members of the DDE Program may choose to cater to specialized epistemic communities of interest to them and specific sectors in policy and public domains with whom they interact closely. The same would apply to WTGs. Data scientists working with DDE may however, communicate with a rather different group, comprising for example, mainly of engineers, computer scientists and technologists, which may not include many geoscientists. Articulating the range and type of audiences DDE communications will be targeted at during the earliest stages of website design and development could help content richness and diversity and improve the relevance of information shared and transmitted via the website. Communications and networking to build and enhance DDE profile and reputation could also be pursued via the DDE Ambassador and other GC, EC, SC, StC, Secretariat and member representatives attending international conferences and seminars on themes linked to geo and data sciences as well as others sponsored by the UN and other global organizations of interest to DDE.

The implementation of objective 2 could aim for the following outcomes:

- DDE Website is a sophisticated platform catering to a diversity of audiences ranging from specialized scientific communities, policy professionals interested in sustainable development at local, national, regional and global scales, special interest groups in applications of geological knowledge (e.g., geological heritage management, geo-tourism), journalists and other day-to-day information providers on new trends in scientific and technological development etc.;
- DDE website hosts a series of webinars, dialogues and discussions bringing together geo and data scientists and other interest groups representing journalists, policy and development, business and entrepreneurial groups from energy, minerals, water, soils and other natural resources management sectors, managers and administrators of geoparks and geo-heritage sites, civil society organizations etc.;
- DDE websites and Member websites link to each other promoting and sharing information, data, insights and knowledge derived from data-driven discovery initiatives;
- DDE representatives attend and contribute to face-to-face as well as on-line conferences, seminars and workshops on themes and issues linked to data driven discovery in geosciences to highlight contributions of DDE and to advocate and promote DDE membership and partnerships.

Implementation of actions and activities under objective 2 will generate the following deliverables:

Year 1: (i) A thorough review of the DDE website and an updated design and plan catering to a clearly defined set of target audiences who can benefit from data driven discovery in the geosciences; (ii) initiation of dialogue and communications with current members, potential new members, partners who share interests in data driven discovery for addressing land, water, ocean, energy related problems and issues to create website linkages and data sharing arrangements; (iii) attendance and participation in international, regional and national events to promote DDE; and (iv) concept note, announcements and planning for convening a data-driven discovery in the geosciences expert dialogue, preferably linked to events to commemorate IUGS-60 and formally launch DDE launch.

Years 2-3: (i) An updated, content-rich DDE website linked to a minimum of 10 other websites of current and new members and partners; (ii) Evidence for growing interest and frequency of visits to the DDE website gathered and made available to EC, GC, SC and StC and members on a bi-monthly basis: (iii) With the help of IUGS and other potential partners DDE has established strong links with organizations like UNESCO, which coordinates the International Geosciences and Geoparks Program (IGGP) and similar ones on oceans, land, water, geological heritage etc., to establish mutually beneficial web-linkages and plan and implement joint initiatives; and (iv) Outcome of DDE sessions and special events organized as part of international, regional and national conferences and symposia disseminated through web, print and other media outlets.

Years 4-5: (i) Continued monitoring of web-site performance as described in item (ii) for years 2-3; (ii) DDE collaborates with Members and partners who have been linked to UN Decade on Sustainable Energy for All which will conclude in 2024 to issue special publications to demonstrate the importance of deep-time data in enabling energy transitions to combat climate change; (iii) DDE data driven discovery findings, data bases and approaches are used to design and launch 5 visitor and public education campaigns on “deep-time data and knowledge for society and development”, including in a selected number of well visited geoparks and geological heritage sites, both in China and elsewhere; (iv) At least 5 popular science articles in reputed Journals (e.g. National Geographic, GEO, National Geographic Traveler, Scientific American, New Scientist etc.) sponsored by DDE Members and partners.

Objective 3:

Creation and operation of a global network of Research Centers of Excellence (RCEs) that serve as a hub for scientific research and training of a new generation of geodata scientists and for promoting interactions with policy professionals and other interest groups that wish to use and benefit from data driven discovery in geosciences.

Implementation: Data sciences, in addition to having ready access to a wide range of data sources in geosciences also requires hardware and software as well as expertise in the use of machine learning, AI, big-data analyses and other high-tech applications. As observed earlier, the distribution of those technologies and expertise in the world are uneven and concentrated in selected countries and regions. Most geographical regions will have at least a few countries that have the necessary technological infrastructure and expertise. DDE foresees the establishment of Research Centers of Excellence (RCEs) and infrastructure development for the first RCE is well underway in Suzhou, China. The Suzhou RCE, in collaboration with some of the Founding Members of DDE, namely Korea Institute of Minerals and Geosciences (KIGAM) and the Coordinating Committee for Geosciences Program in East and Southeast Asia (CCOP) could serve the ASEAN group of 10 countries. China’s Belt and Road

Initiative (BRI) has several opportunities to link to many central, south and west Asian, as well as Gulf States, East African and east and central European countries and Russia for collaboration in data driven discovery in geosciences. Additional RCEs for development are underway in the UK and USA. Possibilities for creation of RCEs in Russia, the European Union, Latin America and the Caribbean, Africa and the Gulf States are worthy of exploration.

RCEs, in collaboration with DDE Members and partners could provide human resources development in the interface between and data and geosciences in all parts of the world through training and exchange of expertise and knowledge. In particular training of young scientists from less developed countries in Africa, Central and South America and Southeast, South and West Asia in the RCEs through short-courses as well as Masters/Doctorate Programs could result in a new generation of scientific collaborators for data driven discovery in geosciences. The 10-year (2019-2029) DDE Science Plan will significantly benefit from having a distributed network of a new generation of academics, researchers and policy and management practitioners who are familiar with models, algorithms and other tools of data-driven discovery and have acquired skills and competencies for interpreting outcomes of big-data analyses and allied approaches to resolve specific natural resources management and development issues and problems. A networked system of DDE RCEs could provide residencies for post-doctoral fellows, visiting scientists, policy professionals interested in learning about the use of data-driven geosciences applications in natural resources development and as venues for the organization of workshops, seminars and similar gatherings on selected DDE research themes and questions.

The implementation of objective 3 could aim for the following outcomes:

- Completion of the construction of the RCE in Suzhou, Beijing and its regular use by visiting scientists, DDE member and partner representatives and for the organization of scientific research, training and technical workshops and public relations dialogues with journalists, policy professionals etc., to promote data driven discovery in the geosciences;
- Planning, negotiations, funding and other aspects for the establishment of RCEs in at least two other countries completed. Opportunities for establishing other RCEs in at least two additional regions/countries of the world, (Russia, EU and preferably Africa), explored and pursued;
- At least one initiative for demonstrating the feasibility and value of converting published and unpublished paper data (the "long-tail" of data characterizing many geo and other earth sciences disciplines) derived from an on-going international cooperation program in the geosciences to digital mode. The International Geological Correlation Program (IGCP) implemented by IUGS and UNESCO, will commemorate its 50th anniversary in the year 2022 and could be an ideal candidate for such a demonstration initiative. Products and services that data-driven discovery can deliver could be illustrated using the IGCP as a test-case and benefiting from the visibility that could be generated through its 50th year commemoration activities scheduled for 2022 under the auspices of UNESCO, IUGS and others who have fostered the program;
- A special DDE initiative for post-doctoral fellowships (for geo and data scientists) designed and operated with funding resources for their residency in RCEs to carry out DDE sponsored data-driven discovery initiatives.

Implementation of actions and activities under objective 3 will generate the following deliverables:

Year 1: (i) RCE, Suzhou infrastructure development completed; (ii) RCE Suzhou designs, organizes and completes (a) one training workshop for geo and data scientists from less developed countries and (b) a scientific workshop that includes participants bringing data from their own countries for treatment with AI, machine learning and similar technologies used by DDE geo and data scientists;

(iii) At least 5 scientific publications or reports produced by WTGs and Members to demonstrate the benefits of data-driven discovery in geosciences; (iv) DDE, IUGS and UNESCO collaborate to explore outcomes and results of 50-years of IGCP Projects for designing products and services such as "IGCP Google" (including perhaps an "IGCP Google Scholar") with open access in particular to less developed countries.

Year 2-3: (i)"IGCP Google" that includes an "IGCP Google Scholar" or a similar product/service that centralizes 50 years of IGCP outputs launched in partnership with IUGS and UNESCO to commemorate IGCP-50, raising visibility and profile of DDE; (ii) two new RCEs are established and operational; (iii) interest and opportunities to launch RCEs in other regions/countries, e.g. Russia, EU, Africa, Latin America and the Caribbean, Arab States etc., explored and country(ies)/region(s) with the greatest likelihood in succeeding the creation of new RCEs identified; (iv) RCE, Suzhou hosts at least 3 visiting scholars from member and/or partner organizations to design and launch cooperative initiatives on data-driven discovery in geosciences in countries and/or regions participating in China's BRI initiative; (v) concept and proposal development and fund-raising campaigns for supporting post-doctoral fellows in RCEs.

Years 4-5: (i) At least one new RCE launched and networked with existing RCEs in China and in countries that established RCEs in years 2-3; (ii) the reception and level/extent of use of the "IGCP Google" tracked and achievements highlighted and constraints and problems for its better use, particularly by less developed nations, addressed; (iii) RCEs already established in China and at least in 3 other countries, together host 10 visiting scholars from member and/or partner organizations to design and launch co-operative initiatives on data-driven discovery in geosciences; (iv) a program to host geo and data science, post-doctoral fellows contributing to DDE/RCE Network Research and Training Program financed and operational.

Objective 4:

Priority setting and financing of WTG and member initiatives on questions on evolution of life, evolution of geodynamics, evolution of earth materials and evolution of climate to demonstrate the creation of new, meta-databases by integrating existing ones and incorporating unpublished, "long-tail" data.

Implementation: DDE is not seen as a global program for carrying out new geo and/or data sciences research. But, as the vision and mission of the DDE White Paper (and this MTP) for 2019-2029 states[4], DDE aims to transform earth science by harmonizing global geoscience data and sharing global geoscience knowledge that could nurture a deep-time data driven research paradigm. The following quote from the Science article entitled "Earth scientists plan a geological google"[3] on the building of the Chinese Geodiversity Database (GBDB), initiated in 2006 by the Chinese scientist Fan Junxuan, who is the Secretary General of DDE, is informative and could guide efforts to deliver specific outputs under this objective:

"Norman MacLeod, a paleobiologist at the Natural History Museum in London who is advising DDE, says GBDB has succeeded where similar efforts have stumbled. In the past, he says, volunteer earth scientists tried to do nearly everything themselves, including informatics and data management. GBDB instead pays nonspecialists to input reams of data gleaned from earth science journals covering Chinese findings. Then, paleontologists and stratigraphers review the data for accuracy and consistency, and information technology specialists curate the database and create software to search

and analyze the data. Consistent funding also contributed to GBDB's success MacLeod says. Although it started small, Fan says GBDB now runs on "several million" yuan per year."

GBDB resulted from collaboration between paleontologists and stratigraphers, 2 of the 19 WGs recognized under DDE at present. The challenge during the next 5 years would be to emulate the approach taken by GBDB while being conscious of the need highlighted by the current Chair of DDE GC, Michael Stephenson to ensure that databases resulting from DDE efforts "use the same standards and references"[3].

Of the 19 WGs and 8TGs (note: one of the TGs is on "Standards") some may be better suited to collaborate with one another than others in the sense paleontology and stratigraphy chose to collaborate in the development of GBDB. Data, information, results, outputs generated by some of the WTGs perhaps overlap and similarities in the geological aspects investigated by them render data integration easier. The 4E themes and the large number of research questions described under each one of them by the WP could serve as a guide to identify the combinations of WGs and TGs which, with necessary support from the DDE cyberinfrastructure group, could generate innovative, new meta databases. The SC of DDE could determine scientific questions detailed in the WP (or other new ones) and the best WTG combinations that could generate "easy, yet interesting wins" within the next 5 years in order to raise the recognition and profile of DDE as a leading IUGS initiative in data-driven discovery. Currently several initiatives between different WGs, some of them financed by enabling funds mobilized by the DDE RCE, Suzhou are about to be initiated. It will be useful if the deliverables of these initiatives in terms of creating new meta-databases via integrating existing databases, referred to in the Table 2 of the paper by Chengshan et al[3], are defined explicitly and the outputs and results when ready widely shared and publicized. Information on comparability of standards of the databases expected to arise from on-going initiatives to that of GBDB and/or others would also be helpful in guiding work under this objective towards specific deliverables.

The implementation of objective 4 could aim for the following outcomes:

- DDE SC undertakes a review of ongoing efforts of WTGs to provide GC, EC, the Secretariat and members and partners of DDE an understanding of the range of databases that could be expected to emerge from them and issues and problems related to comparability of standards and other aspects that are likely to impact user-friendliness of the databases;
- DDE SC in consultation with WTGs leaders, members and partners identifies and prioritizes those collaborations between WTGs that have the best chances of delivering successful outcomes similar to that delivered by GBDB within the next 5-year period;
- SC, in collaboration with the Secretariat identifies and describes the resource needs, including funding, for creating at least 5 databases similar to GBDB that has the best chances of success during the 5-year schedule of this plan;
- Secretariat, in collaboration with the relevant Members and partners mobilizes the necessary resources for creation, testing and validation of at least 5 databases similar to that of GBDB; they could be the result of combining existing databases or establishing new ones where the potential for establishment had been recognized but not been realized due to unavailability of resources and data sciences expertise; and
- The TG on "Standards" organizes workshops or other forums for the SC prioritized collaborations among WTGs to help them "use the same standards and references"[3].

The implementation of actions and activities under objective 4 could deliver the following:

Year 1: (i) SC requests all WTGs and Member organizations to provide a brief description (1-2 pages) of work they would undertake as part of their contributions to DDE. They would be requested to define their expectations on how the outcomes of their work could lead to (a) integration of data they generate into existing databases, and (b) bring together data from two or more WTGs to generate new meta databases. (ii) SC reviews all descriptions received from WTGs to establish the 10 best cases of database creation that have the likelihood of success during the 2019-2029, time frame of the WP. (ii) SC Committee prioritizes the top 5, out of the 10, and invites the concerned WTGs, Members and partners to prepare requests for mobilizing support for financing the top 5 ventures.

Years 2-3: (i) Secretariat, in collaboration with concerned WTGs, members and partners launches campaigns to support the top 5 ventures for database establishment; (ii) Support needed for the execution of at least 2 of the 5 generated and activities for database establishment mobilized; (iii) outcome of campaigns to raise support for the remaining three reviewed and changes, including replacing one or more of them whose chances for attracting support deemed minimal being replaced by others from the next 5-best options, made as appropriate; and (iv) Mobilizing support needed for the execution of an additional 2 database creation initiated.

Years 4-5: (i) Review of the performance of the 2 earliest database creation ventures from the previous biennium and lessons learned shared with members and partners for use in designing and developing future initiatives; (ii) 2 databases launched and operational with measures for receiving regular feedback from users of the data bases outlined; (iii) Support for creating at least 2 additional databases mobilized and necessary work completed; (iv) identification of additional 5 ventures with high potential for success from the original top 10 identified by SC in year 1 and/or from new opportunities that may have risen during years 2-3 for support campaigns for implementation as part of the next 5 years of DDE work.

Objective 5:

Demonstration of the value of existing and/or new DDE created databases and combinations thereof to perform studies, analyses and/or syntheses that generate findings of significance to meeting UN SDG targets linked to land, water, ocean and energy.

Implementation: DDE Science Plan that forms the major part of the WP foresees addressing "many applied geological problems associated with prospecting for energy, mineral and water resources thus, helping security of supply and contributing to the UN's Sustainable Development Goals (SDGs)[4]". Several of the questions that the DDE Science Plan raises under 4E themes are likely to attract interests of Governments, business and civil society organizations as well as the general public. Examples include: how did ecosystems respond to extreme climatic conditions? How did terrestrial ecosystems originate and evolve? Can we predict as yet undiscovered minerals and where they may be found? How do major fluctuations in ocean chemistry affect marine ecosystem evolution? What are the controlling factors of regional versus global sea-level change? What will the earth be like in 2100? etc.

Linking work under this objective to other UN initiatives whose timing coincide with 2019-2029 and UN Agenda 2030 on SDGs will provide DDE the opportunity to develop new partnerships and open access to new databases. Another IUGS initiative, Resources for Future Generations (RFG) could be a strong candidate for a DDE partnership for implementing actions

under this objective. Questions on mineral and metal needs for green energy and economy infrastructures that underpin hopes for sustainable and low carbon futures are not receiving the level of attention they deserve. A DDE-RFG partnership could launch initiatives that contribute data-driven insights and knowledge to this much neglected area of thinking and discussion in sustainable development and climate change forums.

2020-2030 is also the International Decade on Ocean Sciences for Sustainable Development. The International Ocean Discovery Project (IODP) is a TG of DDE; this could help in DDE/IODP linking up with UNESCO International Oceanographic Commission (IOC), an intergovernmental program that has been operational since 1960 and has accumulated vast volumes of data. Such a partnership may attract other partners, e.g., the Ocean Foundation, committed to the sustainability of ocean resources. 2020-2030 is also the UN Decade on Ecosystem Restoration (2020-2030); the 2019-2029, time frame of the WP also overlaps with UN Decade on Water for Sustainable Development (2018-2028) and the Decade on Sustainable Energy for All (2014-2024).

The DDE Science Plan's vision to develop a DDE Empowering and Enabling Platform (DEEP) will depend on DDE's abilities to establish complimentary relations with other existing initiatives. Some such initiatives referred to in the DDE Science Plan, e.g., EarthCube, had expressed reservations about the feasibility of collaborating with DDE. The US National Science Foundation financed EarthCube project focuses on current issues of climate change and biodiversity and biosphere-geosphere interactions and the Director of that Program felt that EarthCube and DDE had "very different objectives with very little overlap"[3]. Such reticence must be overcome by demonstrating that the work of DDE, through its use of "deep-time" data and knowledge has demonstrable relevance to the understanding and search for solutions to contemporary natural resources, ecosystem and climate change problems and challenges. The contributions DDE could make to the various UN Decades referred to above would also of be of interest to IUGS as the organization is intending to focus it attention on geosciences contribution to climate change and related problems.

Actions and activities to implement Objective 5 could lead to the following outcomes:

- DDE SC takes the lead to convene discussions and invites WTGs to submit brief proposals to develop applied studies and data analyses to address specific questions that relate to water, energy, minerals, land, ecosystems, oceans and other themes that can lead to the design and development of new, meta databases relevant to the work UN SDGs and UN decades referred to above;
- DDE SC, with the approval of GC and EC identifies 5 proposals that relate to energy, minerals, water, ecosystems, ocean and/or land that can attract new partners and give DDE access to complimentary databases and expertise for launching specific initiatives during the 5-year duration of this Plan;
- DDE SC and the Secretariat determine resource requirements and needs to launch at least 5 initiatives during 5-year time-horizon of this Plan, with due consideration to potential support from UN and other interested partners, and establish a priority ranking for the initiatives based on feasibility, strengths and databases and other tangible results deliverable during the 5-year time period;

- Support campaigns for at least 5 initiatives whose expected outcomes having direct benefits to UN initiatives that are linked to delivering on SDGs are launched and their results and outputs widely shared with relevant UN bodies and other users from academic, policy and business communities and the general public.

The implementation of actions and activities under objective 5 could deliver the following

Year 1: (i) WTGs invited to submit proposals for undertaking application of geosciences knowledge and databases to addressing contemporary natural resources issues and problems that could yield results of significance to SDGs and other UN Decades' work on ecosystems, energy, water and oceans; (ii) SC reviews the proposals to identify the 5 that has the best chances of yielding tangible results within the 5-year period, based on study-concept, partners and their contributions and financial feasibility; and (iii) Secretariat and the prioritized WTGs and their partners initiate support campaigns to mobilize financing for the 5 priority projects in cooperation with relevant UN agencies, IUGS and other partners;

Years 2-3: (i) Funding for at least 2 of the 5 initiatives mobilized and they begin operations; one of the 2 could focus on energy linked databases so as to generate outputs for the Decade on Sustainable Energy for All which ends in 2024; (ii) Continuing efforts to mobilize financing for the other 3 priority ranked projects; (iii) review of efforts to raise funds for the latter 3 projects and replacing any of the three projects which do not show promise for attracting partners or financing with others from the original set of proposal received;

Years 4-5: (i) Funding for at least 2 additional initiatives mobilized and they are operational; (ii) Review of outputs and results of the original 2 initiatives and presentation of key outputs relevant to UN SDGs at appropriate UN and other forums to raise profile and recognition of DDE and partner achievements; (iii) Based on the experience of the MTP implementation, drawing up a plan for strengthening on-going initiatives and launching new ones for the subsequent 5-year period with priority for feeding results and outputs into the remaining years of the UN 2030 Agenda on UN SDGs and UN Decades on Ocean Sciences for Sustainable Development, Ecosystem Restoration and Water for Sustainable Development.

Objective 6:

DDE's financially sustainability secured through agreements and partnerships for implementing this MTP and the Science Plan until 2029.

Implementation: Direct funding available to the DDE Program during 2019-2020 was US$ 660,000 (US$ 320,000/year from the Kunshan Mayoralty in Suzhou hosting the Secretariat and US$ 20,000 by IUGS). DDE Secretariat has raised an additional US$ 200,000 to support 4 enabling projects and proposals from Founding Members and WTGs. A 5th project is implemented under the banner of DDE, financed entirely by resources of the China Geological Survey. Each of the 4 projects is expected to receive a maximum of US$ 50,000/year for years 2021-2023. Furthermore, each WTG is also due to receive US$5,000/year for their efforts to support DDE development. Given the above the current financing of DDE is in the range of about US$ 650,000 per year; almost 99% of those financing originate from sources within China.

Expanding the funding sources beyond China however, requires that DDE meets certain requirements. One is performance, including ensuring the timely production of deliverables of this MTP. The other is

more structural; funds, foundations and donors, particularly those from North America, Western Europe, Australia and New Zealand, would need to view DDE as a Program that is committed to gender and geographical diversity in its Governance, Advisory and Operational Organs and the leadership of its WTGs. DDE needs to project EDI (equality, diversity and inclusivity) in all its planning and operations if it is to succeed to mobilizing resources outside of China for implementing this MTP as well as other projects and initiatives in the remaining years until 2029.

The distribution of the types of financing mobilized so far, mainly in China, gives an indication of the potential modalities for raising the necessary funding and financial support for the implementation of this 5-year Plan: i.e. (i) direct, "unearmarked" funds provided to the DDE Secretariat for use by the DDE Program for any components of plan implementation as recommended by SC and decided by EC/GC; (ii) "earmarked" funds for defined uses, for example data-driven projects under a particular theme or linked to one or more of the objectives of this MTP and not for any other DDE costs such as running costs of the Secretariat; and (iii) direct sponsorship of human, technological, data and financial needs of one or more projects by an external partner with regular reports from the partner for review by and feedback from SC, EC and GC.

There may well be other forms of support that could be mobilized. For example, negotiations with suppliers of hardware/software, patent holders of algorithms, models and other analytical tools could lead to DDE WTGs, members and partners receiving equipment and/or rights to use models and tools at no or subsidized cost. When RCEs are operational, a variety of existing fellowship schemes and other arrangements for visiting scientists, both in China and elsewhere, could be used to finance residencies of scientists in the RCEs who could lead/support the implementation of specific initiatives. There may be opportunities for young post-doctorates to obtain fellowships from their own national academies to spend time with RCEs to gain international working experience; such a scheme is operated by the Chinese Academy of Sciences for young post-doctoral fellows.

As the plan implementation proceeds, and activities in relation to the 5 previous objectives begin to deliver tangible products and services DDE may have opportunities to generate revenues through sale of products and services. Reviewing and regularly updating of DDE Website information could also attract potential partners who may wish to invest in the DDE program.

Activities to implement objective 6 could lead to the following outcomes

- A preliminary budget for the implementation of this plan is prepared once the drafting of the plan is completed and the contents of the plan had been approved by the EC/GC;
- WTGs, members and partners are invited to assume, if they able to do so, responsibilities for raising funds and support for either full or part implementation of specific objectives of this plan and respond to the DDE Secretariat with their offers and suggestions;
- DDE Secretariat, based on offers for help for financing the implementation of the plan received from WTGs, members and partners estimates the amount of additional funds that need to be raised for the full implementation of the plan and prepares a "road-map" for securing those funds through direct, indirect, in-kind and sponsorship modalities;
- DDE, after the mid-term evaluation of the results and outcomes of this plan by the end of the 30th month (i.e., 2.5 years), revises and updates its "road-map" to ensure continuing financial sustainability for the latter half of this plan and for the remaining years until 2029 to ensure satisfactory completion of the implementation of the Science Plan as described in the WP for 2019-2029[4].

The implementation of actions and activities under objective 6 could deliver the following

Year 1: (i) A preliminary budget for the full implementation of this plan ready within a month after the adoption of this plan by the GC; (ii) WTGs, members and partners indicate their willingness to take responsibility for full or part implementation of specific objectives of this plan; and (iii) DDE Secretariat estimates the amount of additional funding and in-kind support it must mobilize and prepares a "road map" for generating them.

Years 2-3: (i) At least 75% of funding and support estimated by the Secretariat for implementation of activities under specific objectives of this plan mobilized; at least 30% of the new financing originates from sources outside of China; (ii) a review of fund-raising, financing and in-kind support mobilization efforts undertaken to improve performance during the next biennium; and (iii) evidence for growth in the interest of potential donors and partners ready to work with DDE and fund specific, remaining components of this MTP.

Years 4-5: (i) Based on the review carried out during the previous biennium an up-dated "road map" for fund raising and financing the remaining years of this plan and the additional period up to 2029 is ready to be put into effect; (ii) the total amount of the funds estimated in year 1 for the implementation of this MTP secured; the contribution from sources outside of China is at least 50% of the total raised; and (iii) At least 40% of the funding needed for the implementation DDE Science Plan contained in the WP till 2029 identified and administrative and contractual arrangements for funds-flow concluded.

When this Plan is nearing 2.5 years of implementation, a mid-term evaluation of the performance will be carried out. The findings of the evaluation may lead to the revision of some of the objectives, outputs and deliverables described for years 4-5.

KEY PERFORMANCE INDICATORS FOR MEASURING SUCCESS IN THE IMPLEMENTATION OF THIS 5-YEAR MTP

The total number of deliverables defined under the six objectives of this plan is above 30. While many of them may be individually delivered, DDE's success will however, be determined by the collective impact they would have on the perception of key stakeholders, including IUGS, on the performance of DDE. The key performance indicators (KPI) defined below for the mid-term and end-of-term evaluation of this Plan have been defined in order to assess the overall performance of DDE and its ability to meet its vision and mission as defined by the WP for 2019-2029.

Key Performance Indicators (KPIs) for mid-term (around month 30) and end-of-plan (around month 60) evaluations

For mid-term evaluation:

- Fully operational cyberinfrastructure support for promoting DDE data-driven discovery research paradigm;
- At least 3 new Members join DDE; significant improvements of gender and geographical diversity of representation in GC, EC and SC and the leadership of WTGs
- Assurance of support and funding for implementing at least 75% of this Plan;

- At least 3 RCEs established and functional; financing for post-doctoral fellowships of young scientists secured;
- Content-rich website linked to at least 10 other WTG, member or partner websites; evidence for high use by academic and scientific communities and moderate-to-high use by policy and development professionals, industry and business sectors and specific public interest groups of the DDE website;
- Outcome and results of collaboration between data and geoscientists demonstrated via the launch of 3-5 new/integrated databases and at least 10 scholarly, popular and journalistic outputs based on DDE achievements;
- Specific contributions demonstrating the value of "deep-time data discovery" to the future of UN Decade on Sustainable Energy for all that ends in 2024;
- 5 working partnerships with UN, business and industry sector and/or specific public sector interests that support and help DDE to generate results and outcomes that have a global impact.

For end-of-Plan evaluation:

- The Plan fully funded and security for financing at least 40% of funding needed for the remaining years until 2029 assured through conclusion of appropriate partnership agreements and/or administrative arrangements; e.g., MOUs, letters of commitment etc.
- At least 3 more new Members join DDE; the GC, EC and SC and WTG leadership show improvements in gender and geographical diversity compared to years 2-3;
- 20 scientific/scholarly publications, reports, policy-briefs, popular and journalistic outputs demonstrating importance of "deep-time data discovery" to UN SDGs on land, water, oceans, energy and mineral and materials;
- 5-10 new/integrated meta databases with evidence for their widespread use by geo and data scientists in big-data research;
- DEEP Platform offering products (models, algorithms, big data) and services (data platforms, data scholar, data knowledge etc.) to 5-10 clients representing UN, scientific/research, academic and/or business and industry sectors;
- Media reports, science news and other documentary and visual evidence for the recognition of DDE as a global hub for using "deep-time data" for science and socio-economic wellbeing of communities;
- Fully financed global network of DDE/RCEs with frequent exchanges and residencies of scholars and scientists regularly launching new data-driven discovery initiatives;
- 5 or more products (documentaries, films) or activities (regular webinars, educational and/or science popularization series) that inform and raise public awareness of the relevance of deep-time data for planetary sustainability and human wellbeing.

RISKS AND THEIR MITIGATION

The COVID-19 pandemic and consequences have caused changes in international and national contexts, including those related to priorities for research, funding and program financing opportunities, now (in early 2021) in comparison to the pre-COVID 19, context in February 2019 when DDE was launched. Public health, epidemiology and related research and development themes and

issues have risen higher in national and international priorities. Hence, there are risks associated with mobilizing the necessary funding and financial resources for implementation of this Plan and for the remaining years until 2029 for a program like DDE which focuses on the promotion of a new paradigm on data driven discovery in the geosciences. The pandemic however, has raised awareness of the significance of data in public policy; hence, there is also an opportunity for DDE to capitalize on growing data-friendliness within the policy community to demonstrate the importance of geosciences data to addressing contemporary global challenges.

Success will depend on identifying key partners with a shared interest in "deep-time data sciences" from both theoretical and practical perspectives. A systematic approach to fund raising and financing around the 6 objectives of this Plan, if supported by DDE Members and partners will have a high probability of success. Monitoring the outcome of fund raising and generating other kinds of support (objective 6) must be frequent to make necessary adaptations that could capture previously unforeseen opportunities generated through individuals and organizations connected to DDE and based on its achievements in the first 1-2 years of the implementation of this Plan.

27 WTGs currently working under the umbrella of DDE rightly have their own preferred themes and issues concerning data driven discovery in geosciences. Setting priorities for receiving support to be mobilized as part of this Plan based on combinations of WTGs' skills, data and expertise to attract additional partners and financing and generating results, products and services of interest to international initiatives such as UN SDGs and UN Decades is critical for success. Tendencies of WTGs to limit their interest to their own disciplinary boundaries is a risk and should mitigated through incentives for interdisciplinary collaboration. DDE cannot, during the implementation of this Plan satisfy the wishes and needs of all the growing number of WTGs, members and partners. Efforts to focus on initiatives that can deliver some "easy-and interesting-wins" as well as attract global recognition and international attention need to be given priority over individual disciplinary attachments.

Another risk is insufficient collaboration between the WTGs and DDE cyberinfrastructure participants. Geo and data sciences are peopled by different epistemic communities and networks and they may find collaborating with one another constrained by techniques, vocabulary and other characteristics of their respective disciplinary backgrounds. The example of collaboration that led to the creation of GBDB could hopefully be repeated. All initiatives implemented under this Plan must engage geo and data sciences communities and benefit from expertise and resources of both networks.

For DDE to be seen as a global, data-driven geosciences initiative fresh efforts must be made to engage countries and organizations from the global south. For fund-raising efforts to succeed, DDE should also be seen as a strong adherent of equality, diversity and inclusivity (EDI) principles in Governance, Advisory services, management and operations. If DDE work, results and outputs are usable only by developed and a few technologically advanced emerging economies then opportunities for fund-raising and financing as well as partnership building for data-access – the most critical element that will determine the success of DDE – may be negatively impacted.

MONITORING AND EVALUATION

Annual reports on the implementation of this plan will be presented to EC and GC sessions to ensure the timely identification of problems, constraints and weaknesses and their rectification. SC

will play a critical role in determining, reviewing and recommending prioritized lists of initiatives for approval by GC, particularly in relation to objectives 4 and 5. EC and GC may call for special sessions to address some unforeseen issues and problems that may arise during the implementation of the Plan. A mid-term (between 25-30 months of plan implementation) and an end-of-plan (between 55-60 months of plan implementation) are foreseen.

During the preparation of the Plan there were considerations to match the time frame of this Plan with that of IGCP/IGC cycles and the tenure of GC, EC and SC Members, i.e., 4 years. However, the cancellation of IGC-36 scheduled for 2020 and it's possible replacement by an IGC of a different format and character in 2022 has interrupted the IUGS/IGC cycle of 4 years. The next IUGS/IGC will be in 2024, in South Korea, 2 years after the March 2022, IGC-36 being planned in New Delhi, India. The release of the results of the mid-term evaluation, i.e., at the end of 2023, will coincide with times when the IUGS community will be preparing its next IGC to be convened in South Korea in 2024. It may provide opportunities for IUGS communities to recommend measures for the future development of DDE including the revision of the time frame of the following 2 years and the years after that leading up to 2029. In 2024, IUGS and others organizations collaborating with DDE may consider it useful to adjust the implementation of this Plan to match the IUGS/IGC cycle of 4 years after the conclusion of IUGS/IGC 37 in 2024 in South Korea.

EC and GC will jointly determine the nature of mid-term and end-of-term evaluations (internal/external or engaging a hybrid group comprising a mix of internal/external representatives) and will ensure funding needed for conducting the evaluations are included in fund-raising and financing "road-maps" foreseen for development under objective 6 soon after this Plan is adopted before the end of the first half of 2021.

FOOTNOTES AND REFERENCES

1. Normile, D. (2019). Earth scientists plan a 'geological Google'. Science 363 (6430) 917. 1 March 2019. DOI: 10.1126/science.363.6430.917 Science 363 (6430)
2. International Union of Geological Sciences Recognized Big Science Program (undated): Deep-time Digital Earth (DDE). IUGS
3. Chengshan, W. and 16 other authors (undated). Deep-time Digital Earth Program: Data Driven Discovery in the Geosciences. DDE perspective_v30_SA_noEndNote. DDE Centre, Suzhou.
4. Deep-time Digital Earth (DDE) 2019-2029. International Union of Geological Sciences Recognized Big Science Program. October 2020. DDE Secretariat, Suzhou, China.
5. Minutes of the 1st EC session of the DDE Program for brief descriptions as well as ppt presentations on the current state of development of DDE Data, DDE Platform, DDE Scholar and DDE Knowledge. The Minutes could be obtained from the DDE Secretariat.