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3D Printing in Geology and Geophysics: A New World of Opportunities in Research, Outreach, and Education

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Editorial on the Research Topic

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3D printing is progressively becoming a mainstream technology and an important asset for researchers and educators in the geosciences. Market demand and the expiration of key patents have driven improvements in reliability, speed, resolution, and printing materials, while costs are simultaneously dropping. 3D printers are now commonplace in universities, public libraries, and schools around the world.

This Special Research Topic was inspired by the ever-growing community of geoscientists using 3D printing in educational and research applications. Our editorial initiative to assemble 3D printing studies in Geology and Geophysics started in the Fall of 2019, continuing into the COVID-19 global pandemic. The COVID-19 pandemic has raised many health and safety concerns regarding educational hands-on activities including the use of 3D printed surfaces, and at the same time generated the necessity to implement innovative and effective ways of remote teaching. Based on the current circumstances, this Special Research Topic is a particularly timely contribution that highlights the advantages of 3D printing both as a research and education tool.

The collection of papers presented in this special volume are a testament to the broad extent of 3D printing applications in the geosciences. The discussed topics span from the structural interpretation of seismic data, to astrophysical models to fault physics experiments. These studies not only highlight the significance of 3D printing as a specialized tool for academics, but also as a technology that makes unique and rare datasets (e.g., museum specimens) accessible to the public.

One of the great benefits of 3D printing is that it facilitates the explanation of complex geologic topics, especially where 2D visualization does not allow a complete exploration and inspection of 3D models. Chenrai, "*Case Study on Geoscience Teaching Innovation: Using 3D Printing to Develop Structural Interpretation Skill in Higher Education Levels*" presents a detailed guide on how to set up a classroom and use 3D printing to support the structural interpretation of digital seismic data. The author discusses the benefits and advantages of using 3D printing, but also points to current limitations of this technology, providing a roadmap of possible obstacles for future users.

Global geophysical datasets are nowadays widely available in many different formats and on different visualization platforms (e.g., topography in Google Earth). However, they still pose a challenge for educators when it comes to teaching complex topics such as geoid undulations, density anomalies, dynamic topography, seismic tomography, and structures in Earth's interior. Koelemeijer and Winterbourne, "*3D Printing the World: Developing Geophysical Teaching Materials and Outreach Packages*", provide a complete guide on how to "fuse" global geophysical datasets into 3D printed globes. They also provide instructions on how to successfully implement these globes in outreach and education events.

Arcand et al., *Holding the Cosmos in Your Hand: Developing 3D Modeling and Printing Pipelines for Communications and Research*, review how 3D printing can be used outside traditional solid earth geophysics, transforming astrophysical data into physical objects. While 3D printing astronomical concepts is perhaps less intuitive, the authors emphasize that the tactile nature of 3D models is an important factor in enhancing inclusivity of blind and visually impaired audiences, with the Tactile Universe project (Bonne et al., 2018) as successful example.

Paleontological studies have been at the forefront of using 3D printing technologies on a range of scales, from 3D printing microfossils to an entire dinosaur skeleton. Ziegler et al., *Applications of 3D Paleontological Data at the Florida Museum of Natural History*, discusses how CT scanning can be used in combination with 3D printing to make facsimiles of rare museum specimens accessible in public homes and schools.

3D printing is not only useful for visualizing geology and geophysics concepts, but increasingly utilized in research projects as well. Vincent-Dospital et al., *Frictional Anisotropy of 3D-Printed Fault Surfaces*, show how 3D printing has important applications in laboratory earthquake physics experiments, making use of its ability to represent complex surfaces. The authors specifically discuss how 3D printing technologies can be used to study the effects variable frictional properties (frictional anisotropy) have on fault slip and fault stability in general.

Many of the topics presented in this Special Research Topic relate to the fact that 3D printing is being progressively implemented in geology and geophysics, both inside and outside the classroom. For that reason, it is important to find efficient ways to train scientists in both the use of 3D printing software and 3D printers. Ishutov et al., *A 3D Printing Short Course: A Case Study for Applications in the Geoscience Teaching and Communication for Specialists and Non-experts*, presents an extended discussion regarding the organization and offered course materials in a one-day 3D printing course for geoscientists and engineers. The authors also discuss the efficiency of their teaching approach using a post-course questionnaire.

Advances in 3D scanning software and the implementation of LIDAR scanners in mobile phones suggests that 3D models, and their physically 3D-printed manifestations, will increasingly be a part of our everyday lives. Multiple websites, such as Thingiverse, already serve as free-to-use repositories for 3D models placed in the public domain. It would be beneficial to the geoscience community to establish a digital library for geological and geophysical objects useful for teaching, outreach and supplementary files to peer-reviewed journal articles. Such a library of models would not be limited in scope to 3D printing, but also to Augmented Reality (AR) and Virtual Reality (VR) datasets, increasingly accessible and complementary technologies with many use cases in outreach and education. These modern technologies also provide a natural contact point for the interactions between scientists and artists, that can help to spread specialized knowledge.

The geosciences have a long history of requiring a deep understanding of complex spatial structures and problems; it is only logical that geosciences should continue to be at the forefront of spatial visualization. We hope that the assemblage of contributions in this Special Research Topic inspires new creative adaptations of 3D printing applications.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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