3D printing – an introduction to its uses in geoscientific research

ANA HAIVIO REALES AND IAN CORFE

3D printing has shown great potential in geosciences through research in petroleum geology, geomechanics, geomorphology and paleontology. In recent years, Geological Survey of Finland (GTK) has expanded on the potential of 3D printing with diverse projects including a variety of geomaterials and geoscientific methods. With further research and development, 3D printing could have broad utility in the geosciences, including new areas like fluid mechanics and critical raw material research.

3D printing, also known as additive manufacturing, has become increasingly popular throughout the past few decades, yet it is still relatively new to geosciences. The method was first used for rapid prototyping, but its use has expanded to high-value, low quantity products (aerospace, medical) and starts now to be applied in mass-production of custom objects and small-scale general manufacturing. Alongside its uses in education, early applications in geosciences, for example in petroleum transport and storage in geological reservoirs (e.g., Ishutov et al. 2015), geomechanics (e.g., Kong et al. 2017), and paleontology (e.g., Johnson & Carter 2019) have already shown its potential in geoscientific research.

With 3D printing, complex digital designs can be rather quickly and cost-efficiently turned into repeatable physical replicas with a variety of materials, polymers and metals being the most popular. There are multiple 3D printing methods, but one of the most popular and accessible is fused filament fabrication (FFF), where a plastic-based filament is melted and deposited layer-by-layer (Fig. 1). Plastics – often bioplastics made from food waste such as PLA (polylactic acid), rather than

Figure 1. Fused filament fabrication 3D printer constructing a synthetic rock sample layer by layer at the research laboratory in GTK, Espoo. Photo: Ana Haivio Reales.

Kuva 1. Sulatettua filamenttipursotustekniikkaa käyttävä 3D-tulostin muodostamassa synteettistä kivinäytettä kerros kerrallaan GTK:n tutkimuslaboratoriossa Espoossa. Kuva: Ana Haivio Reales.

Figure 2. GTK logos 3D printed using different processing stages of copper ore from Outokumpu with PLA bioplastic binder as material: ground, unseparated ore (front), beneficiated copper (middle), and tailings waste material (back). Outokumpu copper ore sample on the left. Photo: Heli Lallukka, GTK.

Kuva 2. GTK:n logot 3D-tulostettuina käyttäen materiaalina Outokummun kuparimalmin eri prosessituotteita ja PLA-biomuovia sidosaineena: murskattu, erottamaton malmi (edessä), kuparirikaste (keskellä) ja rikastushiekka (takana). Outokummun kuparimalminäyte vasemmalla. Kuva: Heli Lallukka, GTK.

oil-based plastics – are the most commonly used materials, but other materials, such as clays, ceramics and concrete, can be 3D printed using similar techniques. Furthermore, plastic can as a binder be compounded with other materials, such as minerals and other geomaterials (Fig. 2). The complexity of the models is demonstrated in, for example, a study on petroleum reservoirs and flow mechanics (Ishutov et al. 2015). The study explored lab analysis of pore connectivity and fluid flow in a porous medium using 3D printed sandstone models which were based on X-ray computed microtomography (XCT).

3D printing in GTK

The Geological Survey of Finland (GTK) has a 3D printing facility at its research laboratory in Espoo. Run by Dr. Ian Corfe, it's used for both general engineering purposes and research projects. The former includes part replacement, modification and custom design of e.g. analytical machines, surveying equipment, with the most-commonly printed engineering parts including adapters and sample holders to optimise analytical machine efficiency. Ongoing research projects incorporating 3D printing into the geosciences include the EU Horizon funded MaDiTraCe project on critical raw material supply chain traceability (www.maditrace.eu) and the EU ERDF funded SETELIT project exploring the use of mine tailings in new geomaterials (https://projektit.gtk.fi/setelit). Past projects have explored the potential of 3D printing to realise the concept of geo-inspiration by using the composition, texture and physical properties of natural geomaterials as inspiration for the design and production of new materials (Butcher & Corfe 2021). For example, volcanic ash from the 2021 La Palma eruption was used as an analogue of

Figure 3. Left: Plant pots printed with PLA bioplastic and volcanic ash from the 2021 La Palma eruption, used as an analogue for lunar regolith (Moon 'soil') in In Situ Resource Utilisation (ISRU) project. Right: Growth experiment in ISRU project using varying soil and volcanic ash ratios (ISRU analogue experiment). Photos: Kati Kiviniemi, GTK.

Kuva 3. Vasemmalla: PLA-biomuovista ja La Palman vuoden 2021 tulivuorenpurkauksen tuhkasta tulostettuja kukkaruukkuja. Tuhkaa käytettiin analogiana kuun regoliitille (Kuun 'maaperälle') tutkittaessa sen hyödyntämistä raaka-aineena (In Situ Resource Utilisation -projekti, ISRU). Oikealla: ISRU-projektin kasvinkasvatuskoe, jossa käytetään vaihtelevia suhteita multaa ja vulkaanista tuhkaa. Kuvat: Kati Kiviniemi, GTK.

moon regolith to produce containers (Fig. 3) for plant growth experiments for future application in sustainable lunar habitation (Butcher et al. 2023).

3D printing in petrophysics and critical mineral research

The ability to design and 3D print models with selected properties and components (porosity, minerals, etc.) makes 3D printing an excellent candidate for assisting in petrophysical research. For her master's thesis, in collaboration with GTK, Haivio Reales (2025) explored the potential of 3D printing technology in petrophysics focusing on the study of flake graphite and electrical conductivity. Relatively coarse (100–125 µm) flake graphite powder was compounded with a bioplastic binder to produce a graphite-rich filament for 3D printing. Synthetic samples with various graphite distributions surrounded by a porous plastic matrix were 3D modelled and printed to simulate graphitic formations in nature (Fig. 4). The electrical conductivities of the 3D printed synthetic samples were then measured at GTK's geophysical laboratory (Fig. 5) and compared to natural graphite-bearing rock samples. The results show that the electrical conductivities of the synthetic rocks were comparable to natural rocks and increased with graphite concentration. Despite the graphite concentration controlling the electrical conductivity, the mineral's distribution was observed to have a positive effect in samples with continuous or semicontinuous graphite formations, i.e. samples with better flake-to-flake connectivity.

The MSc thesis showed great potential for 3D printing in petrophysical research.

Figure 4. 3D printed synthetic “rocks” with varying graphite content and distributions. Photo: Ana Haivio Reales.

Kuva 4. 3D-tulostettuja synteettisiä ”kiviä” eri grafiittipitoisuuksilla ja -jakaumilla. Kuva: Ana Haivio Reales.

Figure 5. Measuring the electrical properties of graphite-rich 3D printed sample using the MAFRIP instrument at the geophysical laboratory at GTK, Espoo. Photo: Ana Haivio Reales.

Kuva 5. Grafiittipitoisen 3D-tulostetun näytteen sähköisten ominaisuuksien mittausta MAFRIP-laitteella GTK:n geofysiikan laboratoriossa Espoossa. Kuva: Ana Haivio Reales.

With further development of the method, 3D printing could be used to select and model specific minerals and structures in order to study their contribution to the overall properties of a rock type, enhancing the scientific understanding of individual minerals. This may aid in linking the petrophysical properties of minerals to larger scale geophysical anomalies such as those in the deep crust. This MSc thesis can be considered as a pilot for a larger developing project, which will both expand the petrophysics to cover other physical properties and integrate other contributing minerals, such as sulphides, to explore their contribution to the rock's overall geophysical signature.

Acknowledgments – Kiitokset

The authors would like to thank Juha Laakkonen as well as the editorial team for their help in reviewing the manuscript and especially the Finnish summary.

Kirjoittajat haluavat kiittää Juha Laakkosta sekä lehden toimituskuntaa tekstin ja erityisesti tiivistelmän oikoluvusta.

MSC. ANA HAIVIO REALES
(ana-belen.haivioreales@helsinki.fi)

DR. IAN CORFE
(ian.corfe@gtk.fi)

Ana Haivio Reales is a recent MSc graduate from the University of Helsinki aspiring to pursue a PhD. Her research incorporates 3D printing technology into geosciences through petrophysical analyses of 3D printed mineral distributions analogous to their natural appearance, with a focus on graphite-bearing rocks. Ian Corfe is a researcher at GTK's research laboratory in Espoo. His research focuses on the incorporation of diverse geomaterials, including critical raw materials and secondary/waste-stream materials, into 3D printing.

Tiivistelmä

3D-tulostuksen käyttö geotieteellisissä tutkimuksissa

3D-tulostuksen suosio on kasvanut nopeasti viimeisten vuosikymmenten aikana. Alkujaan prototyyppien nopeaan tuotantoon tarkoitetun menetelmän käyttö on laajentunut ensin esimerkiksi lääketieteessä ja ilmailuteollisuudessa tarvittavien erikoiskomponenttien tulostuksesta edelleen nykyisenlaiseksi massatuotannoksi ja räätälöityihin tuotteisiin. Geotieteissä 3D-tulostusteknologia on yhä melko uusi menetelmä, mutta varhaiset sovellukset esim. öljyteollisuudessa, geomekaniikassa ja paleontologiassa ovat osoittaneet sen potentiaalin alan tutkimuksissa.

Geologian tutkimuskeskus (GTK) hyödyntää 3D-tulostusta sekä tieteellisissä tutkimuksissa että teknisissä tarkoituksissa, kuten tulostettaessa erilaisten laitteiden osia niiden toiminnan optimoimiseksi. GTK on viime vuosina perehtynyt geo-inspiraatiokonseptin tutkimiseen ja kasvattanut 3D-tulostuksen potentiaalia hyödyntämällä luonnollisten geomateriaalien koostumusta, rakennetta ja fysikaalisia ominaisuuksia (Butcher & Corfe 2021). Butcher ym. (2023) sovelsivat konseptia tutkiessaan La Palman 2021 tulivuorenpurkauksen tuhkan käyttöä ruukkujen tuottamiseen kasvinkasvatuskokeita varten, tähtäimessä parantaa mahdollisuuksia Kuun pitkäaikaiseen ja kestävään asuttamiseen. Esimerkkinä käynnissä olevista tutkimuksista voidaan mainita Euroopan unionin rahoittamat MaDiTraCe- ja SETELIT-hankkeet, joissa tutkitaan kriittisten raaka-aineiden toimitusketjujen jäljitettävyyttä (www.maditrace.eu) sekä kaivosteollisuuden rikastushiekan uudelleenkäyttöä uusissa 3D-tulostettavissa geomateriaaleissa (https://projektit.gtk.fi/setelit/). Edellä mainittujen hankkeiden lisäksi 3D-tulostuksen potentiaalia petrofysiikan tutkimuksissa tutkittiin Haivio Realesin

pro gradu -tutkielmassa yhteistyössä GTK:n kanssa. Opinnäytetyö osoitti räätälöityjen synteettisten näytteiden olevan käyttökelpoisia, kun tutkitaan suomugrafiitin vaikutusta kivien petrofysikaalisiin ominaisuuksiin ja toimii pohjana tulevalle laajemmalle projektille.

3D-tulostus on osoittautunut hyödylliseksi geotieteiden eri aloilla, kuten virtaus- ja geomekaniikassa sekä paleontologiassa. Vastaavasti GTK:n 3D-tulostusta kehittävissä hankkeissa on hyödynnetty monipuolisesti erilaisia geotieteellisiä menetelmiä ja geomateriaaleja, edistäen jatkuvaa uusien innovaatioiden kehitystä.

Bibliography

Butcher, A. R. & Corfe, I. J., 2021. Geo-inspired science, engineering, construction, art and design. Geology Today 37, 184–193. https://doi.org/10.1111/gto.12368

Butcher, A. R., Windmill, R., Corfe, I. J., Lim, S., Jolis, E. M., et al., 2023. Volcanic ash as a resource for future research on Earth and the Moon. Geology Today 39, 144–148. https://doi.org/10.1111/gto.12442

Haivio Reales, A. B., 2025. Electrical conductivity of 3D printed synthetic rocks with variable graphite concentration and distribution. MSc thesis. Department of Geology and Geography, HELDA University of Helsinki, 61 pp. http://hdl.handle.net/10138/598247

Ishutov, S., Hasiuk, F. J., Harding, C. & Gray, J. N., 2015. 3D printing sandstone porosity models. Interpretation 3, SX49–SX61. https://doi.org/10.1190/INT-2014-0266.1

Johnson, E. H. & Carter, A. M., 2019. Defossilization: a review of 3D printing in experimental paleontology. Frontiers in Ecology and Evolution 430, 7 pp. https://doi.org/10.3389/fevo.2019.00430

Kong, L., Ostadhassan, M., Li, C. & Tamimi, N., 2017. Rock Physics and Geomechanics of 3-D Printed Rocks. In American Rock Mechanics Association US Rock Mechanics/Geomechanics Symposium. ARMA US Rock Mechanics/Geomechanics Symposium. American Rock Mechanics Association, California, 8 pp.