Summary

SEISMIC RISK – Mitigation of induced seismic risk in urban environments – project expands the understanding of the effects of geothermal energy

SEISMIC RISK – Mitigation of induced seismic risk in urban environments, is a research project with consortium partners from the University of Helsinki, the VTT – Technical Research Center of Finland and the Geological Survey of Finland. The project studies, how to mitigate induced seismic risk associated with deep geothermal power stations in Finland (Fig. 1). Small-magnitude earthquakes could pose a risk to critical sensitive infrastructure such as hospitals, data centers and underground construction. The risk is mitigated with transparent permitting, seismic monitoring, and regional planning. Cross-border cooperation and clear communication between municipalities is essential to geothermal energy licensing process. Urban planning should facilitate and promote geothermal energy when supporting regional energy solutions. Green energy transition should be advanced via transparent and science-based planning.

The history of GTK's Apollo-era lunar samples

ALAN R. BUTCHER

GTK geological museum/exhibit

Any visitor to the Geological Survey of Finland's (GTK) Geological Exhibition/Museum (Geo/on) in Otaniemi (Espoo, Finland) cannot fail to be impressed and excited by the ability to examine samples of Moon rock up close. This was also a delight for the present author when he first visited the Museum, and it got him thinking about how Moon rocks happened to be at GTK, and who it was that organised for them to arrive in Finland, and what history lay behind these remarkable extra-terrestrial materials.

The main sample of the Moon that attracts most people's attention is a small piece of rock encapsulated in what appears to be an acrylic button, which is carefully mounted on a wooden plaque and exhibited along with a small Finnish flag, and two inscriptions (Fig. 1). It turns out that this particular Moon rock was one of many donated during 1970–1973 as a goodwill gift to the people of 135 countries, and the 50 states of America and overseas Territories, by the President of the United States, Richard Nixon. Finland was luckily one of them. The donated flag also travelled to the Moon and back again.

The sample, officially known as **70017**, is in fact only a fragment (1.1 g) from a much larger one (originally weighing 2,957 g, Fig. 1) and comprises an ilmenite-rich basalt, dated at

Figure 1. The peace and goodwill sample of the Moon, on display at the GTK's Geological Exhibition (Geo/on in Espoo, Finland). The original sample (bottom right) collected by Apollo 17 astronauts Gene Cernan and Harrison Schmitt, before it was cut up into small pieces and given away as a gift from President Nixon. Photos: Alan R. Butcher (left and upper right), NASA (bottom right).

Kuva 1. GTK:n Geo/on-näyttelyssä Espoossa esillä oleva rauhan ja hyväntahdon eleenä saatu kuunäyte. Alhaalla oikealla on Apollo 17 -kuulennon astronauttien Gene Cernanin ja Harrison Schmittin keräämä alkuperäinen näyte ennen kuin se pilkottiin pieniin paloihin ja jaettiin presidentti Nixonin lahjoina. Kuvat: Alan R. Butcher (vasen ja yläoikea), NASA (alaoikea).

3,700 million years old, that was collected by the last two astronauts to walk on the Moon – Apollo 17's Gene Cernan (Commander) and Harrison Schmitt (Lunar Module Pilot and Geologist) – just as they were about to lift off for return to Earth, which they affectionately named "The Children of the World Rock", in the hope that distribution of pieces of the rock would bring worldwide peace and goodwill. From what can be established, the exhibit was first given to Finnish President Urho Kekkonen by the US Ambassador at the time (V. John Krehbiel), who in turn gave the sample to Professor Birger Wiik to be taken to the GTK and put on display in our museum, where it still resides today. But who was **Professor Birger Wiik**?

GTK's historic connection to the Moon

Hugo **Birger Wiik** was a Finnish research chemist (1916–2003) who helped to pioneer the geochemical analysis of meteorites by **Instrumental Neutron Activation** (INAA)

Figure 2. Professor Birger Wiik attending the Moonstone Exhibition inside Restaurant Adlon, Helsinki Stock Exchange, during 29–30 September 1969, whilst holding 3-year-old Marja, who is wondering if the rocks are for a sandbox or something else! Photo: Pentti Koskinen / Helsingin Sanomat.

Kuva 2. Professori Birger Wiik Kuukivinäyttelyssä 29.–30.9.1969 ravintola Adlonissa, Helsingin Pörssitalon tiloissa. Hiekkalaatikkokiviäkö vai mitä, pohtii kolmivuotias Marja-tyttö professori Wiikin sylissä. Kuva: Pentti Koskinen / Helsingin Sanomat.

whilst he was at the Chicago University during 1954–1955 (working with Harold Clayton Urey), the Geological Survey of Finland (1956–1963), the University of Arizona during 1964–1966 (working with Herbert G. Fales, H. H. Nininger and Barringer Jnr), and in the late 1960's at the Swedish University, the University of Helsinki (with Professors Sahama and Mason). At the Geological Survey of Finland he became Chemistry Laboratory Director. INAA is a very sensitive quantitative multi-elemental analysis method, which requires access to a research reactor, (where the samples are irradiated, and then analysed for the gamma rays that are emitted), which at the time was operational in Otaniemi.

With such a stellar background, and good timing, Birger was in the right place and at the right time to be selected by NASA as a candidate for receiving the first human-collected Apollo return samples, and so in 1969 he became eligible as a Principal Investigator for Apollo 11 samples, which he brought back to Finland in the September of that year (Wiik 1970).

The Apollo 11 samples were initially put on display in downtown Helsinki for a short time (29th September 1969), at the Stock Exchange, where the public queued up outside in the rain for hours to view three small Moon samples displayed inside under a glass dome (Fig. 2). There were also models of spaceships and photos

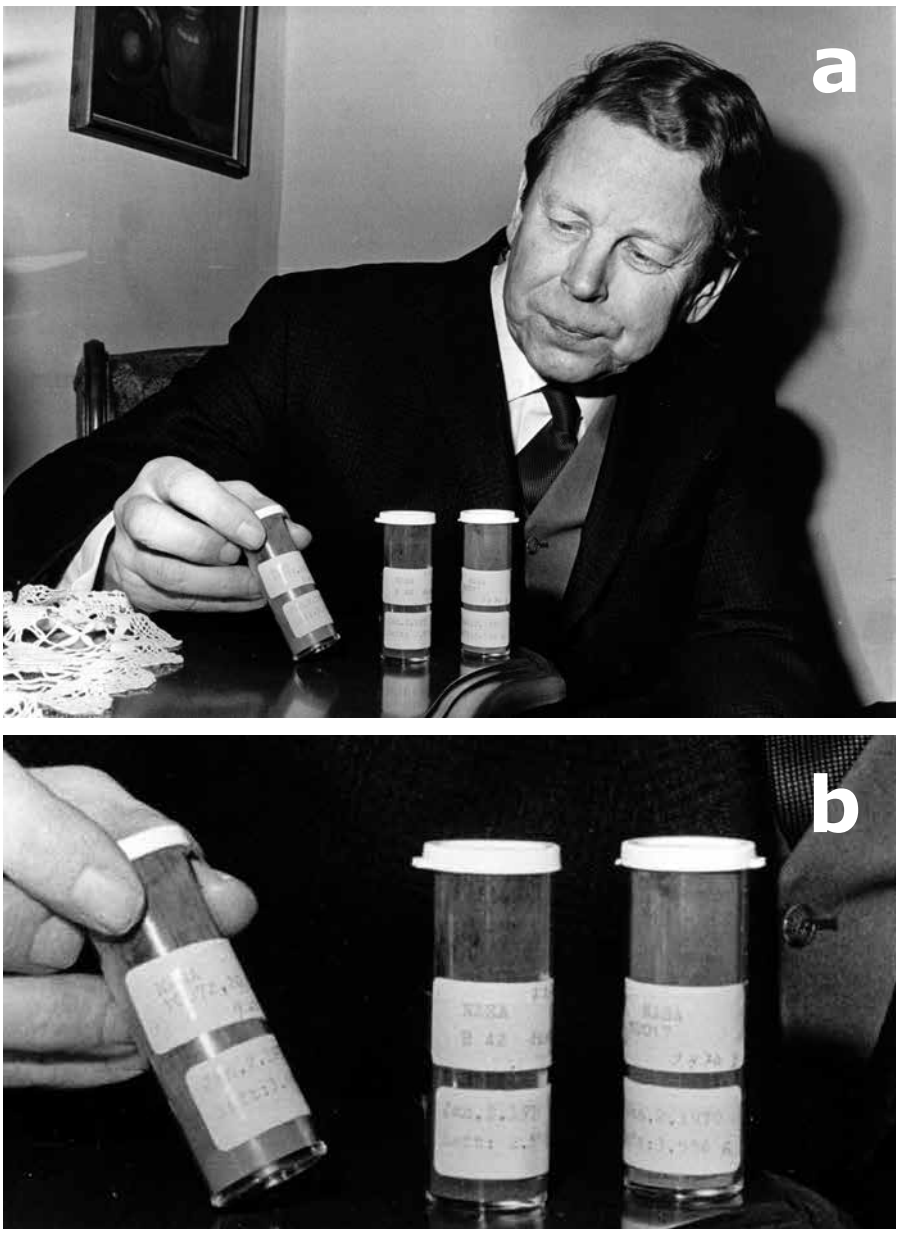

Figure 3. Professor Wiik examining the three original Apollo 11 samples that he hand-carried back to Finland from Houston, (USA) in 1969 (a). Samples labelled from left to right as: NASA 10072,20 – a vesicular rock; NASA 10084,102 – Moon dust; and NASA 10017,10 – a crystalline rock (b: close-up). Photo: Pentti Koskinen / Helsingin Sanomat.

Kuva 3. Professori Wiik tutkimassa kolmea alkuperäistä Apollo 11 -kuulennon näytettä, jotka hän kuljetti Suomeen Houstonista, Yhdysvalloista vuonna 1969 (a). Näytteet merkittyinä vasemmalta oikealle: NASA 10072,20 – vesikulaarinen kivi; NASA 10084,102 – kuupöly; ja NASA 10017,10 – kiteinen kivi (b: lähikuva). Kuva: Pentti Koskinen / Helsingin Sanomat.

as part of the exhibition. In fact, Professor Birger had only managed to bring back a total of 26.6 g of Moon rock to Finland, but still this was enough to entice over 2,300 visitors to come and see them! Professor Birger Wiik and the story in pictures of his remarkable involvement in the first analysis of human-collected Moon rocks from the Apollo 11 mission is seen in Figures 2–5.

After the exhibition, Birger, and his team at GTK and the Finnish Government Commission of Natural Sciences, set about analyzing the three special lunar samples (known as **10017,10 –** a crystalline rock, **10072,20** – a vesicular rock and **10084,102** – Moon dust, Fig. 3), and reported their results at the first **Lunar Science Conference** in Houston, Texas, held during 5–8 January

Figure 4. US Ambassador to Finland, Val Peterson, at the Moonstone Exhibition 29–30 September 1969, Restaurant Adlon, shaking hands with Professor Birger Wiik, and hoping that he has fun with the rocks, after handing over an Apollo 11 photo album. Photo: Pentti Koskinen / Helsingin Sanomat

Kuva 4. Yhdysvaltain suurlähettiläs Val Peterson kättelee professori Birger Wiikiä kuukivinäyttelyssä 29.–30.9.1969 ravintola Adlonissa. Val Peterson toivoo, että professori Wiikillä olisi hauskaa kivien kanssa ja luovuttaa samalla Apollo 11 -kuumatkasta kertovan valokuvakansion. Kuva: Pentti Koskinen / Helsingin Sanomat.

Figure 5. Professor Birger Wiik arriving back in Finland from Houston after delivering his paper at the Lunar Science Conference in Houston, Texas, held during 5–8 January 1970 on the results of the first analysis on human-collected Moon rocks from Apollo 11 spaceflight. Photo: Pentti Koskinen / Helsingin Sanomat.

Kuva 5. Professori Birger Wiik saapumassa Suomeen Houstonista toimitettuaan artikkelinsa 5.–8.1.1970 pidetyssä Lunar Science Conference -konferenssissa Houstonissa, Texasissa. Artikkelissa esitettiin ensimmäisiä tuloksia Apollo 11 -avaruuslennolla kerättyjen kuukivinäytteiden tutkimuksista. Kuva: Pentti Koskinen / Helsingin Sanomat.

Figure 6. Moon dust samples currently on display at the GTK Geo/on Geological Exhibition from the Apollo 16 and 17 Missions, along with sealed glass vials used by Professor Birger Wiik to perform INAA analysis. Photo: Alan R. Butcher.

Kuva 6. Apollo 16- ja 17-kuulennoilta kerätyt kuupölynäytteet ovat esillä GTK:n Geo/on-näyttelyssä yhdessä sinetöityjen lasiampullien kanssa, joista professori Birger Wiik on tehnyt INAA-analyysit. Kuva: Alan R. Butcher.

1970. By all accounts, the initial results were well-received by the NASA community, and it resulted in papers published in Science (Wiik & Ojanpera 1970) and Geochimica et Cosmochimica Acta Supplement in 1970 (Maxwell et al. 1970), thus securing Birger's place in history. Not only that, but it was also around this time he most likely met up with John A. Maxwell (Geological Survey of Canada), whom he would go on and collaborate with on further Apollo sample return missions.

Solving the mystery of glass tubes filled with Moon dust

Apart from the single acrylic-encased Apollo 17 sample, visitors to the current Geological Exhibition at GTK are also able to view further Moon rocks. These occur in the form of 2 glass tubes, filled with powdered rock, which are labelled as having been part of the Apollo 16 and 17 lunar missions, and are exhibited along with thinner, doubly end-sealed glass tubes (Fig. 6). After some sleuthing by the author, it is now apparent that these are likely to be some of the original samples prepared for, and analysed by, Professor Wiik using the technique of INAA (which requires the sample to be ground and sealed before irradiation). In fact, it seems that Birger was involved in every one of the Moon landing missions from Apollo 11 through to Apollo 17, which was a fantastic testament to his technical capabilities at the time, and the importance of GTK as an internationally recognised research centre for geochemical analysis. The results are presented in several journal publications, for example with samples from: Apollo 11 (Wiik 1970); Apollo 12 (Maxwell & Wiik 1971; Rosenberg & Wiik 1971; Wiik 1971; Raitala 1980); Apollo 14 (Rosenberg 1972; Wiik et al. 1973); and Apollo 15 (Maxwell et al. 1972) spaceflights.

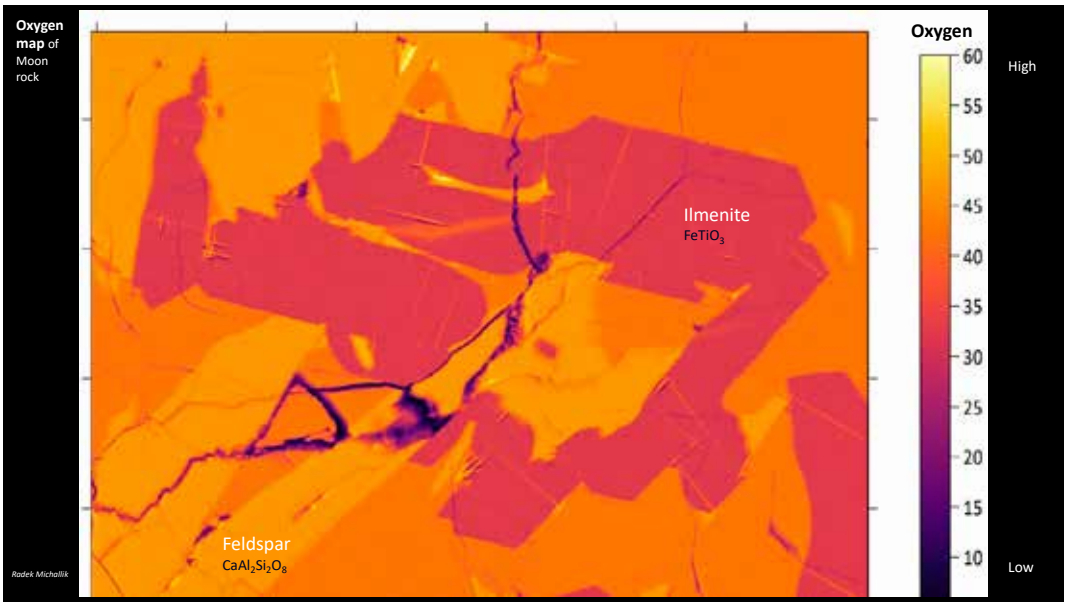

Figure 7. Oxygen distribution map of a selected area of sample 10044, an ilmenite-rich basalt (low potassium) from the Apollo 11 NASA collection, brought back to Earth by Neil Armstrong and Buzz Aldrin in 1969, showing that feldspar is the mineral with the most contained oxygen, and ilmenite the least. Image: Radoslaw Michallik.

Kuva 7. Hapen jakaumakartta näytteestä 10044 osoittaa, että maasälpämineraalissa on eniten happea ja ilmeniitissä vähiten. Näyte on Apollo 11 -kuulennon NASA-kokoelmasta peräisin oleva ilmeniittipitoinen basaltti (alhainen kalium), jonka Neil Armstrong ja Buzz Aldrin toivat Maahan vuonna 1969. Kuva: Radoslaw Michallik.

GTK's on-going involvement with the Moon

In the tradition of working on the Moon, GTK researchers continue to work on various Moon-related projects, largely in collaboration with the Open University (OU) in the United Kingdom. One such current project is the reinvestigation of Neil Armstrong's original (first human-collected) Apollo 11 samples, where we were able to showcase our new FEG-EPMA imaging and analysis capabilities (Fig. 7). We could demonstrate the texture and micro-chemistry of the minerals that contain the most oxygen, as a prelude to returning one day through NASA's Artemis Program, and designing volatile extraction methods for use in lunar habitats. Another project is the use of microwave space technology for the extraction of metals, along with volatiles, and subsequent 3D printing of residues (Butcher & Corfe 2021), which we hope one day will be used in terrestrial mining and involves a new zero-waste concept applied to Earth (Anand et al. 2023). A third project is the characterization of lunar-like materials, such as recently erupted volcanic ash on the Canarian Island of La Palma, where we have been experimenting with growing plants in 3D printed plant pots, in collaboration with colleagues from INVOLCAN, ITER and the OU (Butcher et al. 2023a) as part of future lunar habitation planning.

Other Moon rocks in Finland

The only other known samples of the Moon from the Apollo-era in Finland can be found in the collections at Tamminiemi, now known as the Urho Kekkonen Museum, in the Meilahti district of Helsinki. Four exceedingly small fragments of rock from the Apollo 11 mission were hand-delivered by the astronauts of the Apollo 12 mission (Conrad, Gordon and Bean) as part of a world public relations tour that included Helsinki. The crew first met the Minister of Education Johannes Virolainen and the Lord Mayor Teuvo Aura at the airport, and then President Urho Kekkonen in Tamminiemi, during which time they handed over the gift with greetings from President Nixon. The samples are not on permanent display, but appear in the Urho Kekkonen Museum occasionally for special events, such as anniversaries of the Moon landings.

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Rolph Rosenberg is especially thanked for his invaluable insights into the activities of Professor Birger Wiik, having worked with him in the 1970's on INAA analysis of various lunar materials. Kari Kinnunen also supplied useful background information on Birger. The author would also like to thank the following GTK colleagues for their contributions with the ongoing studies of Apollo samples and lunar meteorites: Krisztian Szentpeteri, optical imaging; Sari Lukkari, SEM-EDS and translation; Pasi Heikkilä, XRD; Radoslaw Michallik, EPMA; Satu Vuoriainen, sample preparation; Ian Corfe, X-CT and 3D printing; Jukka Kuva, X-CT, Ester M. Jolis, scanning micro-XRF; Merja Mehtälä, historic publications; Jaro Kuikka and Tuure Nyholm, access to samples; Marja Lehtonen for general support and encouragement. Mahesh Anand (Open University, UK) is particularly thanked for his enthusiasm for all things to do with the Moon, access to lunar samples, and who spurred me on to undertake the present study, along with Richard Windmill and Sungwoo Lim. Matthew Pankhurst enabled access to La Palma and contributed to the lunar regolith concepts arising from the 2021 eruptions. The Academy of Finland is acknowledged for having funded the acquisition of GTK's FEG-EPMA (2022), along with other key infrastructure including our scanning micro-XRF (2021) and X-CT (2017). Other information has been sourced from Jarkko Kettunen's web site on Finnish meteorites. Helsingin Sanomat / Markku Niskanen are thanked for permission to publish photos in Figures 2–5. Special thanks also go to the photographer, Pentti Koskinen, who captured the moments of Birger Wiik's Apollo sample studies in Figures 2–5 and who also gave permission to use these in this article.

PROF. ALAN R. BUTCHER
alan.butcher@open.ac.uk
School of Physical Sciences
Faculty of Science, Technology, Engineering & Mathematics
The Open University, Walton Hall, Milton Keynes, MK7 6AA UK

Alan R. Butcher was Professor of Geomaterials & Applied Mineralogy at the Geological Survey of Finland from 2017 to 2023. In 2024, he became a Visiting Professor at The Open University (UK) in the field of Geoinspired Utilisation of Planetary Materials. Alan is also Chief Scientist and Technical Director at Hafren Scientific (UK).

Tiivistelmä

GTK:n Apollo-aikaisten kuunäytteiden historia

Vuosien varrella kuukivinäytteet Geologian tutkimuskeskuksen (GTK) geologisessa näyttelyssä (Geo/on) ovat houkutelleet ja tehneet

vaikutuksen moniin vierailijoihin. Tämä artikkeli tiivistää näiden näytteiden historian. Yksi näytteistä on upotettu hartsiin ja oli Yhdysvaltojen presidentti Richard Nixonin lahja Suomen kansalle (kuva 1). Näyte on osa Apollo 17 -kuulennon *Children of the World Rock* -kivinäytettä, joka on ilmeniittipitoista basalttia. Muut näytteet ovat professori Birger Wiikin (kuvat 2–5) analysoimia materiaaleja (kuva 6) ja osa GTK:n Apollo-kuulentoaikakautisten näytteiden historiallisia tutkimuksia. Näiden tutkimustuloksia on raportoitu tässä viitatuissa artikkeleissa (Wiik 1970; Maxwell & Wiik 1971; Rosenberg & Wiik 1971; Wiik 1971; Maxwell ym. 1972; Rosenberg 1972; Wiik ym. 1973; Raitala 1980). GTK:lla tehdään edelleen kuututkimusta: uusinta teknologiaa edustavat analyyttiset menetelmät selvittävät yhä uusia ja mielenkiintoisia faktoja Kuusta (kuva 7, Butcher ym. 2023a, b).

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