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Volcanology, Geochemistry, and Petrology Perspectives on Integrated, Coordinated, Open, Networked (ICON) Science

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COMMENTARY
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Special Section:
The Power of Many: Opportunities and Challenges of Integrated, Coordinated, Open, and Networked (ICON) Science to Advance Geosciences

Key Points:

- To advance Integrated, Coordinated, Open, and Networked Science in volcanology, geochemistry and petrology, we call for the development of an open and inclusive international network-of-networks
- A visionary network should aim for equitable access to funding, analytical equipment, training and research resources, and mentors
- Opening dialogs and enhancing communication streams can result in mutually beneficial science

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Volcanology, Geochemistry, and Petrology Perspectives on Integrated, Coordinated, Open, Networked (ICON) Science

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Abstract This article is composed of a commentary about the state of Integrated, Coordinated, Open, and Networked (ICON) principles (Goldman et al., 2021, https://doi.org/10.1029/2021ea002099) in Volcanology, Geochemistry, and Petrology (VGP), and discussion on the opportunities and challenges of adopting them. VGP encompasses a broad field that addresses volcanic, magmatic, hydrothermal, geomicrobial systems; process investigations that span the physical, geochemical and biological realms, including planetary geology; and one that is extensively supported by state-of-the-art research facilities. We suggest that an open, inclusive, collaborative and evolving model of an international coordinated network is critical to answering the most pressing challenges in VGP. In this commentary piece, we begin to discuss the elements of, challenges to, and path forward in developing such a model. For this team, ICON means collaboration, equitable access to data for the entire scientific community, and forging of partnerships that potentially contribute to more innovative ways of coordinating and sharing research. It also means bringing more equity to science, by implementing effective measures which consider access to funding, analytical equipment, resources, and mentors. More importantly, ICON to us means having important conversations around what we value in the advancement of science, perhaps exploring outside the idea of meritocracy and evaluating what individual traits can contribute to science outside what has traditionally been considered the norm.

Plain Language Summary Of importance for the volcanology, geochemistry, petrology community to consider is how existing collaborations between scientists can be strengthened and adapted for maximum positive scientific impact. Our team suggests the development of an international network-of-networks that can create opportunities for meaningful connections, with all relevant groups represented and working together as equals. The power of such a network lies in its ability to mobilize people and serve as a foundation for a more international, collaborative, and open science model underpinned by strong communication channels. The broader consequences of such a network-of-networks model are not only its capacity for knowledge generation and scientific impact, but the potential for a radical transformation in how science is conducted.

1. Elements of ICON in VGP

Integrated, Coordinated, Open, and Networked (ICON) science aims to enhance synthesis, increase resource efficiency, and create transferable knowledge. This article belongs to a collection of commentaries (Goldman et al., 2021) spanning geoscience on the state and future of Integrated, Coordinated, Open, and Networked (ICON) science. ICON-VGP is described here in the context of the core fields of geochemistry, volcanology and petrology. An important aspect to acknowledge here is that Volcanology, Geochemistry, Petrology (VGP) is an extremely broad field and encompasses both application areas and fundamental research questions that span investigations of mid-ocean ridge volcanoes to the creation of mountains. Integration within (VGP), and working across interdisciplinary research boundaries, have therefore emerged in response to specific applications and research goals. As an example, volcanology is strongly integrated with traditional subdisciplines (geology/geochemistry/petrology) and allied fields (e.g., seismology, geodesy). However, traditional and structural definitions of volcanology and research modes hinder substantive integration, and integration is largely on the level of individual systems/specific challenges and not at a broader scale. The need for moving beyond traditional disciplinary boundaries is only now being recognized and these crossovers are being explicitly defined as volcanohydrology, archeological volcanology, etc. (e.g., Elson & Ort, 2018).

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Currently there are several ways in which ICON is being implemented in the area of volcanology, geochemistry, and petrology. For instance, the existence of international conferences such as International Association of Geophysical Contractors (IAGC), International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI), and Goldschmidt, and groups such as the different divisions of the Mineralogical Society, Society for Geology Applied to Mineral Deposits (SGA), IEEE Geoscience and Remote Sensing Society, or International Ocean Discovery Program (IODP) already contribute greatly to networking opportunities within and beyond VGP. Another great example is the Marie Skłodowska-Curie Actions of the European Union that funds multidisciplinary and innovative research projects within different scientific fields, building networks between early career scientists and established researchers from different countries, with an emphasis on innovation, multidisciplinarity and outreach (citizen science). Such networks have a forward-thinking approach that significantly contributes to diversifying the outlook of early career researchers in their scientific field(s). In contrast to these, network opportunities are nonexistent or nascent in certain regions (e.g., Africa). The lack of networking opportunities and coordination among African VGP scientists have been linked to unequal access to resources and institutional support, resulting in "parachute science" carried out by high-income countries (North et al., 2020). Therefore, it is important to acknowledge that there is significant regional disparity when approaching ICON science in VGP. Additionally, gender disparity and inequality are issues of concern within the broader VGP community. For example, while there is increasing awareness of the potential dangers women face in isolated field camps (e.g., Wadman, 2017), there are other reasons that can result in women and diverse scientists quitting the VGP field altogether. We describe some of these challenges in more detail below.

Given the "parachute" science approach and regional disparities, it is safe to say that the sharing of standards, metadata, analytical protocols, and models has evolved along similar lines. That is, coordination for data generation across the VGP field has evolved much faster for certain application areas and regions, but is in its nascent stages in others. Because each application/problem is studied differently under an often loose rubric of tools/conceptual frameworks, there is a lack of standardization of observations as we move from one application area to the next, thereby keeping the field in "stamp-collecting" mode. Most success has been seen in geospatial and geophysical studies (e.g., OGC), model benchmarking activities (Mayer et al., 2015; Steefel et al., 2014), and the development of thermodynamic databases (Nordstrom & Archer, 2003). A common data stream for the VGP is remote sensing products, which are open and encompass Findable, Accessible, Interoperable and Reusable (FAIR) principles (Wilkinson et al., 2016) for most countries, but not all (e.g., Sentinel). These data streams are not free everywhere, and even so, require powerful processing systems and stable internet connectivity thereby creating unequal access opportunities (Alper & Miktus, 2019).

2. Challenges Hindering ICON in VGP

Some of the challenges that the VGP community faces regarding ICON science are related to the fact that VGP does not operate as a whole. As mentioned above, VGP is not a completely integrated field, with more collaborations occurring at a subgroup or an individual problem scale. In terms of data accessibility, the differences in data sharing protocols between research institutes/universities and industry pose a substantial challenge for VGP researchers, since data owned by oil and gas or mining companies is seldom made available to individuals or institutions outside these companies. Even if the data are shared, there are restrictions on how these data can be communicated or used thereby reducing the worth of such data.

If the standards and protocols throughout the VGP community are to be established, there needs to be a unified, global network so that data can enter such a framework in a standardized way. While defined protocols and standards exist in certain subdomains such as geochemistry and remote sensing, there is limited guidance on universal standards in other fields (Ewert et al., 2005). In response to these issues, a few research coordination networks are beginning to emerge, such as CONVERSE and SZ4D MDE, but they are mostly in their nascent stages and operating at country/regional scales. A critical issue here is that the lack of universal protocols hinders funding opportunities at a global scale (e.g., through World Bank) and this creates a vicious cycle with each undercutting the other.

Although elements of collaboration and coordination exist within the VGP community, the reach of current VGP networks and the extent of scientific exchange could be vastly improved, since networks in this field are often limited to the regional scale and/or early career networks with an acute focus on career path choices. Networks are therefore not being developed and/or implemented to their fullest potential, since there is also a lack of accessibility to instrumentation facilities for many researchers, especially in some parts of the world. In particular, access to analytical equipment and funding is not a guarantee in many developing countries (Globalize geoscience, 2015), which creates inequality in research opportunities.

In addition to the aforementioned points, we believe that the following social and inequality issues are obstacles to achieving open and networked science:

1. Many non-native English-speaking researchers are at a disadvantage in sharing their work and advancing their career, which ultimately leads to less data or fewer ideas being shared ("O" in ICON).
2. Apart from women scientists being at a historical disadvantage within the VGP ("N" in ICON), there is also a lack of support for researchers with young children (i.e., childcare). Such constraints often put parents at a disadvantage, with women in particular quitting their careers (Powell, 2021). Caregiving challenges can also affect mid- to late-career faculty impacting career and retirement planning.
3. There is a lack of diversity in the role models that are currently available to students and early career researchers of diverse genders, races, and ethnicities. This does not provide equal opportunities in terms of motivation and career projection, and is a direct impediment to "N" in ICON.
4. Mental health struggles such as depression and anxiety in early career researchers in VGP are currently not being addressed with adequate support measures (Hill et al., 2021; C. M. John & Khan, 2018).

Removing stereotypes and building upon personal connections can result in improved networked science (e.g., Barnes et al., 2018). Networking with diverse stakeholders (e.g., women in science, underrepresented communities) is not only intended to create awareness regarding diverse needs, but equally important for the enterprise of science itself.

3. Looking Forward

We close with a few suggestions on how we might tackle these challenges hindering ICON science.

First, we need an international network-of-networks to develop an open, shared and evolving model as a learning framework for the VGP community to help overcome some of the issues that limit our progress. Such a prototypical network should address the ongoing prevalence of low gender and ethnic diversity at all levels throughout academia, government and industry. If we encourage such culture to include society's diversity at an international scale and across employment sectors, this may positively impact research output in an indirect way (Powell, 2018; Ramirez et al., 2017). While international conferences provide an opportunity to network, creating and participating in an international collaborative network ("N" in ICON) such as the one described here increases the feeling of community and gives all participants more opportunities for direct access to potential mentors, collaborators, and colleagues (Arora et al., 2021; Glessmer et al., 2012; Luna et al., 2019; Rauser et al., 2015). These networks could also facilitate the establishment of collaborative relationships with local, indigenous communities and establish open dialogs through which mutual interests, needs, and concerns can be discussed.

Second, ideal networks should include opportunities and training for early career researchers (where early career is defined by career stage and not by age) to network, train and receive mentorship. Given the international setup of such a network, the establishment of a diverse set of role models and mentors could be facilitated and support mechanisms put in place. This could also be setup across employment sectors depending on the interests of the mentee (and mentor) for example, government – academia, industry – academia. Training opportunities, such as the ones offered by NAGT-NSF have often been credited by early geoscience faculty as beneficial to navigating academic waters (Beane et al., 2020). In a similar vein, we recommend such training be developed to encourage development at all career stages and across sectors: undergraduates considering graduate school, junior faculty considering administrative positions (chair, dean, etc.,), and for navigating government and industrial jobs. We further recommend that such a prototypical network incorporate training on unlearning biases and inclusive leadership to reduce implicit bias and enhance collaborations across diverse teams. In addition, we recommend clear reporting procedures for graduate students (and faculty) to report issues pertaining to their advisors, mentors, colleagues, and research environments to the institution at large without fear of retaliation (Clancy et al., 2014; Mahmoudi, 2019).

Third, it would be helpful to have a searchable, centralized network of instrumentation facilities to allow people within VGP to access analytical equipment regardless of their affiliation, personal networks, or geographic location. Using the FAIR guiding principles (Chamberlain et al., 2021; Wilkinson et al., 2016), we suggest creating such a resource/database that summarizes the analytical capability of institutions, contact information for the lab Principal Investigator(s), and associated costs for using (and visiting) the facility either in person or remotely. As researchers travel to different countries and new research investigations require more international coordination ("C" in ICON), such a database would be extremely beneficial. In a similar manner, teaching resources in VGP can be shared and made accessible to educators. SERC Carleton (especially INTEGRATE) and FCAEM are wonderful examples of how such resources can be shared and widely distributed to the community. In addition, the Earth Educator's Rendezvous provides an annual opportunity to review items for SERC and to build a community of practice (St. John et al., 2020). For the VGP field, it would make sense to broaden the availability and distribution of such resources across diverse teams, application sectors, and regional boundaries.

Fourth, to increase data accessibility ("O" in ICON), it would be beneficial to promote exchange and communication between industry and research institutes. However, instead of promoting a "street bazaar" of open repositories, we recommend that data sharing follows the FAIR principles so as to enable productive use of such datasets. Establishing a data use code of conduct will further promote this cause (Molnár-Gábor & Korbel, 2020). An increasing emphasis on standardization and developments in cyberinfrastructure tools would enhance data discovery and decision making in VGP (Brantley et al., 2020; Feblowitz, 2013; Hubbard et al., 2020; Varadharajan et al., 2019). An international network-of-networks approach is expected to enhance data sharing, standardization and open exchange among participating researchers; however, it is important to recognize that this shift in practice and culture will need time and incentives.

Fifth, such a network cannot work without the inclusion and investments from funding agencies, program managers and other relevant stakeholders ("I" in ICON). This can be achieved through the joint organizations of workshops and/or town halls wherein nonscientific experts and industries, policymakers, and communities come together to understand and address challenges.

Last, but not the least, it is important to recognize that ICON in VGP can be strengthened through communication. While we can enhance communication streams through developing such a network, we also recommend the following:

1. Communications in native/plain language: While there are a few existing networks that enhance collaboration among scientists (e.g., SEG-Africa: mineral exploration), opening or creating more of these – especially around specific sites - would be relevant. A successful example is the Latin American network (ALVO) where scientists speaking native languages are forming friendships and developing networks. Thus, encouraging communication in multiple languages and in plain language (as AGU journals currently do) would help facilitate the dissemination of information more globally and to communities who may be directly impacted by the research, but are not scientists themselves. In this regard, plain language training for students and faculty will further improve communication.
2. Promoting the use of social media networks for research growth, community building, and global connections: One such example of a network is in the field of volcanology where communication of accurate information is provided across the globe in real time during events – for example, the IVHHN and the use of social media during volcanic eruptions - https://www.facebook.com/ivhhn/. Such networks could also be beneficial for dissemination of information under other climate change/disturbance events. Other social media avenues provide additional opportunities – for example, blogs to highlight early career researchers (e.g., https://www.aguecohydrology.org/blog-adding-our-leaves), video sharing of research (e.g., CUAHSI on YouTube), and websites that support specific communities (e.g., https://eswnonline.org/). Social media takeovers can also be helpful to early career researchers in disseminating their research, while also practicing science communication skills (again, could be done in multiple languages). In addition, video-conferencing platforms (e.g., Zoom, Microsoft Teams) are providing important opportunities for remote and distance learning especially during the COVID-19 pandemic. As would be expected, these varied social tools have subtle differences (e.g., Facebook vs. Discord; Zoom vs. Gather Town), but for researchers they offer a platform to connect with each other, share and disseminate research, tools and ideas. The convenient thing about these platforms is that if one is not a good fit, there is almost always a new one in the pipeline (Ovadia, 2014).

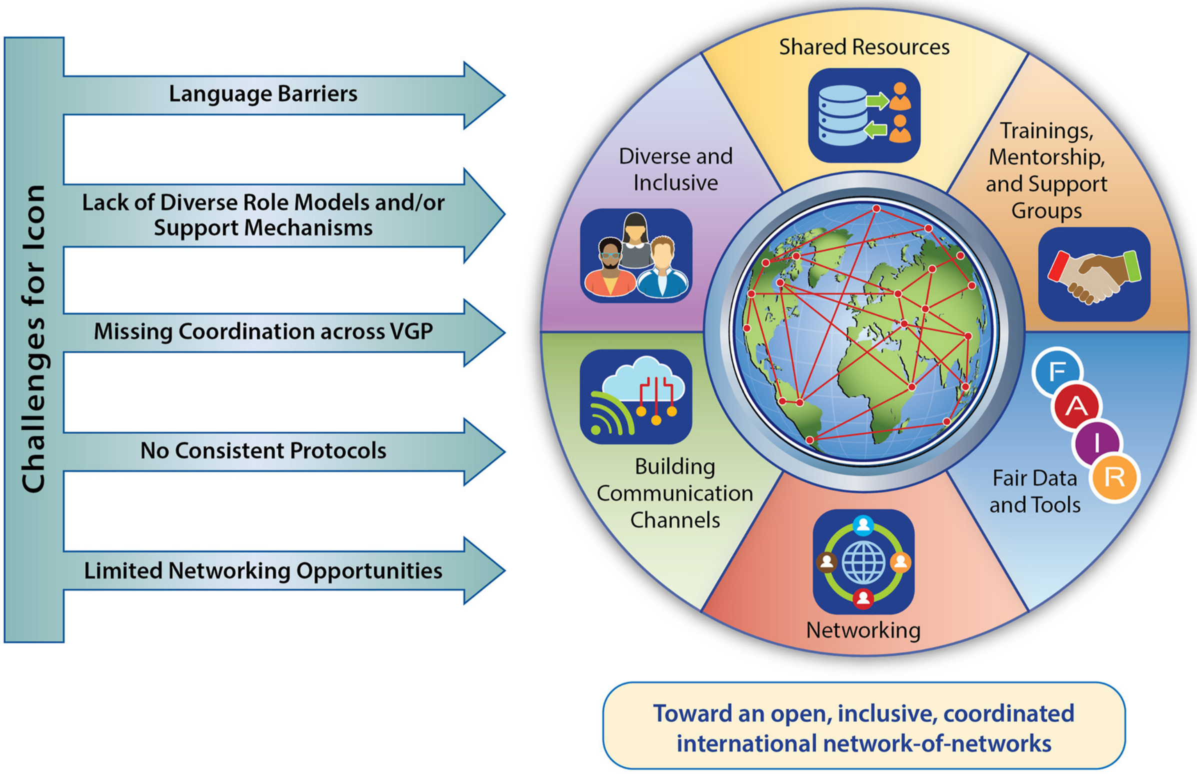

Figure 1. Toward an open, inclusive, coordinated, international network-of-networks to enable next generation innovation in Volcanology, Geochemistry, Petrology (VGP).

3. Online/hybrid tools for communication: As mentioned above, women are often excluded from the pipeline, both intentionally and unintentionally. It became clear from the COVID-19 pandemic-era that remote participation and hybrid learning encourages more international and diverse participation (Sarabipour et al., 2021; Wu et al., 2021). Additionally, hybrid meetings offer increased flexibility, reduced cost, and the ability to include participants who may have otherwise been unable to join the meeting. This is yet another reason to support communication infrastructure (stable internet, reliable computer networks).

In this manner, we believe that creating an international network-of-networks, improving networking opportunities for researchers worldwide, sharing resources, coordinating research activities, as well as considering the individualities and needs of different groups/stakeholders has the potential to significantly contribute to improving the status of ICON within VGP (Figure 1). In order to ensure the success of such a borderless network-of-networks construct, we recommend incorporating the values, goals, and principles of ICON in the Earth Science/VGP curriculum and training the next generation of VGP scientists.

Data Availability Statement

No datasets were generated or analyzed during the current study.

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