Research Paper

GEOSPHERE

GEOSPHERE, v. 19, no. 6

https://doi.org/10.1130/GES02661.1

5 figures; 2 tables; 1 set of supplemental files

CORRESPONDENCE: dahlr4@wwu.edu

CITATION: Dahl, R.M., 2023, Geoscience academic hiring networks reinforce historic patterns of inequity: Geosphere, v. 19, no. 6, p. 1528–1538, https://doi.org/10.1130/GES02661.1.

Science Editor: Christopher J. Spencer

Received 8 March 2023
Revision received 31 May 2023
Accepted 25 July 2023

Published online 8 September 2023

GOLD OPEN ACCESS

THE GEOLOGICAL SOCIETY OF AMERICA®

Geoscience academic hiring networks reinforce historic patterns of inequity

Robyn Mieko Dahl

Department of Geology, Western Washington University, 516 High Street, Bellingham, Washington 98225, USA

ABSTRACT

An analysis of the academic hiring networks in geoscience reveals a severe imbalance that favors graduates from a small handful of institutions. In this study, social network analysis was conducted on a database consisting of every individual with a Ph.D. working in a geoscience degree-granting program in the United States (n = 6694) between 2015 and 2021. Individuals were mapped from the institution where they earned their Ph.D. to the institution where they currently work. Of the 895 geoscience degree-granting institutions included in the database, 10 alone produced nearly a quarter (24.6%) of the entire academic geoscience workforce. Network analysis also identified a small, closed network consisting of five of the top-10 institutions, which suggests that these networks hire more frequently from one another than from other institutions in the network. When academic rank was used to analyze the network for change over time, no significant shift in the hiring patterns was found. These imbalances in faculty production disadvantage scientists who are educated at programs other than the top-placing institutions and ultimately reinforces longstanding inequities in the field, such as the underrepresentation of people who are Black, Indigenous, People of Color (BIPOC), and first-generation college students in geoscience faculty. These patterns of inequity have also been shown to limit the spread of new scientific ideas throughout research communities.

INTRODUCTION

Academic hiring networks are shaped by perceptions of prestige (Merton, 1968; Weakliem et al., 2012; Morgan et al., 2018). Hiring committees are tasked with recruiting the best and brightest new minds in the field, and academic pedigree—where each candidate was educated and trained—often serves as shorthand for quality (Burris, 2004; Clauset et al., 2015). In this study, I use social network analysis to map and identify patterns in academic hiring practices in geoscience. This work builds on similar studies of academic hiring networks in other fields, then explores the implications for systemic inequities in academic hiring in geoscience, especially in light of the field's severe lack of diversity (Bernard and Cooperdock, 2018).

Robyn Dahl https://orcid.org/0000-0002-5969-2190

According to the American Geosciences Institute's *Directory of Geoscience Departments*, there are 199 universities in the United States that offer doctorates in geoscience (Keane, 2021). There are an additional 413 universities and colleges that have other geoscience degree-granting programs, from associates to masters. If the training provided to doctoral candidates at each of the Ph.D.-granting institutions were roughly equitable, we could expect that institutional representation in the workforce would be proportional to the number of graduates produced, but this is not the case. Most of the academic geoscience workforce has been trained at a small handful of universities.

This type of imbalance in academic training and hiring practices is not unique to the geosciences. An analysis of tenured and tenure-track faculty from all academic fields revealed a staggering degree of inequity: Eight universities alone produced 25% of all faculty at Ph.D.-granting universities in the United States (Wapman et al., 2022). This same study subdivided the data set by broad academic field and found similar patterns of inequity. Humanities scored highest (most unequal), and education, medicine, and health tied for lowest (Wapman et al., 2022). Other studies of specific fields examined anthropology (Kawa et al., 2018), political science (Fowler et al., 2007), communications (Barnett et al., 2010; Mai et al., 2015), computer science, business, and history (Clauset et al., 2015; De Bacco et al., 2018).

Imbalance in academic hiring practices, in which a small number of universities produce an outsized portion of faculty, is one of many factors equated with institutional prestige (Burris, 2004; Morgan et al., 2018; Wapman et al., 2022). Institutional prestige is often measured extrinsically; ranking schemes, such as the "Best University Rankings" published by *U.S. News and World Report*, are well known and often utilized in publicity campaigns and recruitment efforts (Fleming et al., 2023). In addition to outsized faculty production, faculty at prestigious institutions also earn more grant money, employ more research and support staff, publish more papers, and receive more citations and awards (Crane, 1965; Cole and Cole, 1974; Thomas and Zhang, 2005; Wieland et al., 2016). Close examination of higher productivity at prestigious institutions found that it was the result of substantial labor advantages and not due to inherent differences in talent (Zhang et al., 2022). Furthermore, when these commodities are concentrated in a small portion of all universities, the remaining universities (and the people who work and study at them) become under-resourced (McCambly and Colyvas, 2022).

Graduates of prestigious institutions reap many benefits as well. They are more likely to be hired into tenure-track positions, earn higher salaries, and win more grant money than others (Thomas and Zhang, 2005). They also often gain employment at less prestigious institutions, including other types of institutions (e.g., small liberal arts colleges and public masters- and bachelors-granting universities), and are therefore responsible for exporting the culture and practices of the institutions where they were educated (De Bacco et al., 2018; Wapman et al., 2022). Morgan et al. (2018) argue that this process exacerbates epistemic inequities by limiting the potential spread of new ideas because so many of the new faculty hires in academic programs were educated at the same institutions.

METHODS

Social network analysis is a powerful modeling tool that can illuminate patterns and relationships within complex networks (Barabási and Albert, 1999; Hanneman and Riddle, 2011; Yang et al., 2017). In this study, I use social network analysis to characterize the academic hiring network in geoscience. Institutions with geoscience degree-granting programs form the nodes of this network, and the movement of graduates into faculty and research staff positions form the edges or ties between nodes.

Study Population

The study population includes all individuals working at a geoscience degree-granting institution in the United States who have earned a Ph.D. in geoscience. For the purposes of this study, "geoscience" is broadly defined and includes departments of geology, geoscience, geological science, Earth science, and any multidisciplinary department that includes geoscience (e.g., "Department of Earth and Atmospheric Sciences"). The database created for this project to build the academic hiring network includes all types of positions that Ph.D.-holding individuals may have within an academic program, from tenured and tenure-track faculty (assistant, associate, and full professors) to contingent faculty (adjuncts, instructors, and lecturers) and other department staff (research scientists, lab managers, and museum curators). Emeritus professors were excluded from the database because they are fully or semi-retired. Research associates whose primary appointments were in other (non-geoscience) departments or at other non-academic institutions were also excluded.

Data Collection and Analysis

To conduct social network analysis of the academic hiring network in geoscience, I constructed a database consisting of every individual with a Ph.D. working in a geoscience degree-granting program in the United States. Data were initially sourced from the American Geosciences Institute's *Directory of Geoscience Departments* (Keane, 2021) and cross-checked against department web sites to ensure that the information was current and accurate. The data in the *Directory of Geoscience Departments* is self-reported. Each time a new edition of the directory is published, the American Geosciences Institute requests that participating departments update their entries. The edition used to build the database for this study was published in 2021, and the reporting years span 2015–2021. Therefore, it is possible that the database used for this study includes individuals who have retired or moved to different institutions.

Every individual that met the requirements of the study population was included in the study database. Each entry in the database consisted of: (1) the individual's name, (2) the name of the current institution of employment, (3) the name of the current department or program, (4) the highest degree granted by that department or program, (5) the individual's academic rank or position title, (6) the institution at which the individual earned the Ph.D., and (7) the year in which the Ph.D. was earned. Because of the inconsistencies in the way Ph.D. institutions were reported in the *Directory of Geoscience Departments*, some programs were grouped together and treated as a single institution. Massachusetts Institution of Technology (MIT) and Woods Hole Oceanographic Institution (WHOI) were grouped together, as were University of California San Diego and Scripps Institution of Oceanography. Universities with multiple departments or programs under the broad Earth sciences umbrella were also treated as a single institution.

From this database, I created an edgelist and a nodelist[1]. The edgelist mapped each individual's Ph.D. institution (6) to the current institution of employment (2), resulting in a dataframe containing only institution names and the number of placements (hires) made from one institution to another. The nodelist describes each institution included in the database, including the highest degree offered (associates, bachelors, masters, or doctorate), whether the institution is public or private, the location (U.S. state or "international"), and the geographical region (based on the Geological Society of America's regional sections: Northeast, Southeast, North Central, South Central, Rocky Mountain, and Cordilleran).

The social network was built in the R programming environment using the network analysis package *igraph* (Csardi and Nepusz, 2006). Additional visualization was conducted using the program SocNetV (Kalamaras, 2015). Nodes in the network represent institutions and the edges that tie the nodes together and represent an individual's movement from the Ph.D. institution to the place of employment.

In most studies of academic hiring networks, analysis is limited to institutions that grant Ph.D.s (Clauset et al., 2015; Wapman et al., 2022). Other types of institutions (e.g., small liberal arts colleges, masters-granting universities, and community colleges) are not included because graduates of those institutions are not eligible to be hired as faculty, so potential reciprocity in hiring cannot be assumed for all nodes (Hanneman and Riddle, 2011). This

[1]Supplemental Material. Item S1: Network nodelist, a spreadsheet that includes all nodes included in the network. Item S2: Network edgelist, a spreadsheet that maps every connection between nodes in the network. Please visit **https://doi.org/10.1130/GEOS.S.23916066** to access the supplemental material, and contact editing@geosociety.org with any questions.

limitation impacts certain network metrics like density (node interconnectedness), reciprocity (how often a tie from one node to another is returned), and Gini coefficient (a measure of inequity). To compare the results of this study to those of previous work, I conducted a set of analyses on a subset of the database that was limited to Ph.D.-granting institutions only. This was done knowing that limiting the network to Ph.D.-granting institutions removes a vast portion of the academic workforce. Such a limitation would exclude faculty and staff at 411 of 612 geoscience degree-granting programs in the United States.

After analyzing the subset of Ph.D.-granting institutions, I conducted a set of analyses on the whole network that do not assume potential reciprocity. These analyses cannot be directly compared to other studies of different academic fields but do take into consideration all 612 geoscience degree-granting programs in the United States. To test if placement patterns have changed over time, the full database was sorted by academic rank (full professor, associate professor, and assistant professor). Academic rank can serve as a proxy for change over time because rank often correlates with the length of time an individual has been employed at an institution. In other words, full professors have typically been employed for the longest period of time at an institution and were hired years before assistant professors.

In both the whole network and the Ph.D.-institution network, standard node-level metrics were calculated, including out-degree (the number of outgoing ties from a node, or academic placements by that institution), eigenvector centrality (weighted centrality), and reciprocity. SpringRank (a weighted measure of prestige) was calculated for the Ph.D.-institution network using the methods developed by De Bacco et al. (2018). I also analyzed the networks for density, hybrid reciprocity (reciprocity of the whole network, not individual nodes), and Gini coefficient.

Node-Level Analysis

Out-degree or degree centrality is a measure of the number of connections a node has (Freeman, 1979). In this context, out-degree is equal to the number of academic placements an institution has made, or how many of its graduates have been hired into positions at other institutions. Eigenvector centrality is a weighted centrality measure and can function in this context as a proxy for prestige. Node reciprocity indicates how often the dyadic ties of each node are reciprocated, or how often an academic placement by one institution to another is reciprocated. In this context, low reciprocity (wherein Institution A places graduates at Institution B but does not hire graduates from Institution B) would indicate prestige and inequity.

Network-Level Analysis

In social network analysis, density is the most basic network-level analysis. It measures how interconnected the nodes are by dividing the total number of dyadic ties present in the network by the maximum number of potential dyadic ties (Yang et al., 2017). In the context of an academic hiring network, high density would indicate equality among institutions, whereas low density would indicate inequity or an imbalance, wherein some institutions are more likely to produce faculty than others.

Hybrid reciprocity also measures the interconnectedness of nodes, but unlike density, reciprocity only considers existent dyadic ties in the network. Reciprocity is calculated by dividing the number of reciprocated dyadic ties by the total number of dyadic ties in the network (Hanneman and Riddle, 2011). Networks with high hybrid reciprocity are considered more equal than those with low hybrid reciprocity.

Another method for quantifying the inequity in this network is to calculate the Gini coefficient (Gini, 1936). A Gini coefficient of $G = 0$ expresses perfect equality, whereas a Gini coefficient of $G = 1$ expresses the opposite: maximal inequality. For example, in a perfectly equal network, 10% of institutions would be responsible for 10% of academic geoscience placements. In previous studies of academic hiring networks, the Gini coefficient is only calculated for networks comprising solely Ph.D.-granting institutions. In this study, I calculated the Gini coefficient for the Ph.D.-granting institution network, so that the results could be compared to those of other studies, and I also calculated it for the whole network at different academic ranks (professor, associate professor, assistant professor, contingent faculty). The Gini coefficient for each rank cannot be compared to that of other studies, but it can be used to measure whether there has been a shift in the equity of the network over time.

The networks were also analyzed for community structure using the "cluster_walktrap" function in *igraph* (Csardi and Nepusz, 2006). This function identifies dense subgraphs (i.e., communities) within large, sparse networks by using random walks to measure similarities between nodes in the network. In this type of analysis, edge direction is ignored, so the analysis does not consider in which direction the ties between nodes are traveling. In other words, a tie between two institutions indicates that an individual was hired from one institution to the other, but the analysis does not consider in which direction the individual traveled. When edge direction is ignored, the resulting analysis measures how connected the nodes are, but not rank or prestige. Institutions that cluster together in this analysis are interconnected through hiring practices.

RESULTS

Full Database: All Geoscience Placements in the United States

The full database included 6994 individuals and 895 nodes (Fig. 1). Of the 895 nodes, 612 were institutions located in the United States, and 283 were located in other countries (737 individuals in the network were educated internationally).

Node-level metrics reveal significant inequities (Table 1). Out-degree shows that 10 institutions are responsible for 24.6% of all placements in the network.

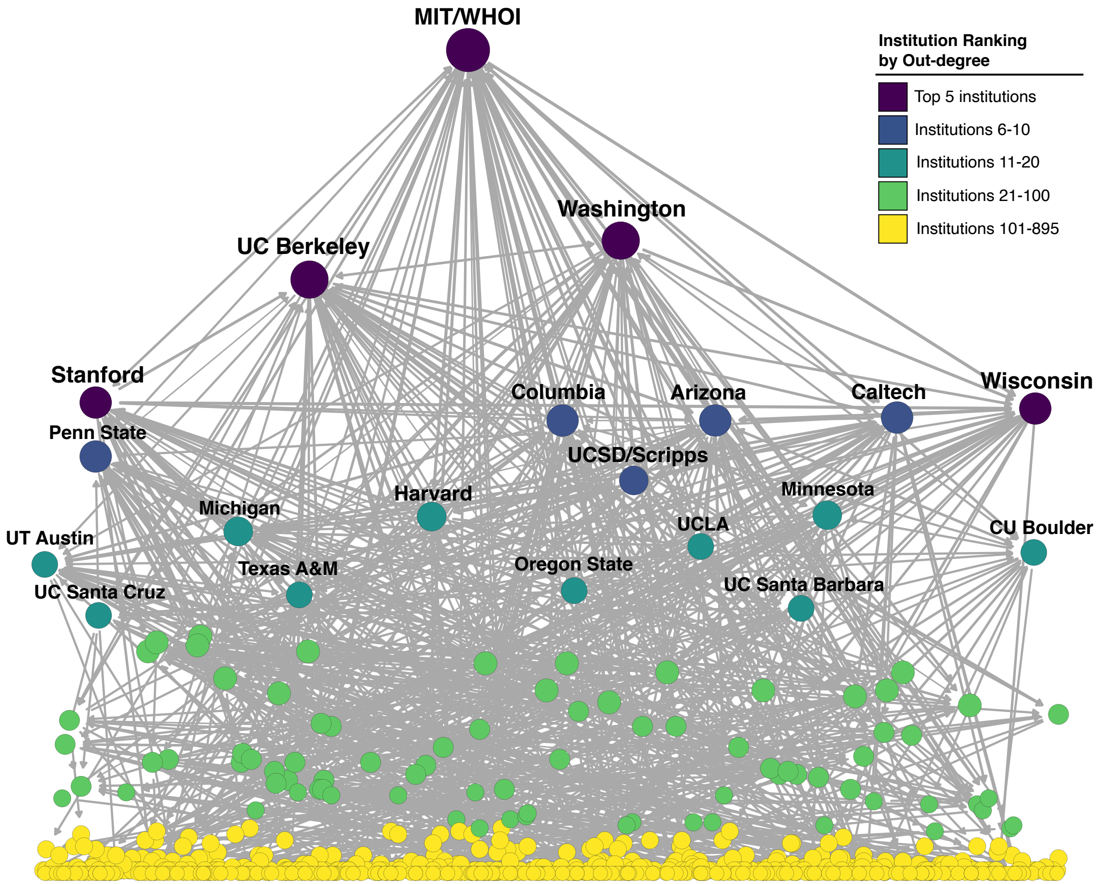

Figure 1. Full network (n = 895). Node size, color, and placement were determined by degree centrality. Top-20 institutions by out degree (placement) are labeled. CU—Colorado University; MIT/WHOI—Massachusetts Institute of Technology/ Woods Hole Oceanographic Institution; UC—University of California; UCLA—University of California, Los Angeles; UCSD—University of California San Diego; UT—University of Texas.

Those "top-10" institutions are: (1) MIT/WHOI; (2) University of Washington; (3) University of California, Berkeley; (4) Stanford University; (5) University of Wisconsin; (6) Caltech; (7) University of Arizona; (8) Columbia University; (9) Pennsylvania State University; and (10) University of California San Diego/ Scripps Institution of Oceanography. Roughly one in every four geoscientists working at an institution of higher education in the United States earned a doctorate at one of these 10 institutions. These top-10 institutions all have high SpringRank scores and relatively low reciprocity compared to other institutions in the network.

Additional institutional demographics were tabulated for the top-20 institutions by out-degree, including the current size of each geoscience department's faculty and staff and whether the university was federally designated as a minority-serving institution (MSI). The top-20 institutions account for 39.1% of all placements within the network. There was no significant correlation between the size of an institution's faculty and the out-degree value ($P = 0.053$). Of the top-20 institutions, six were federally designated as either a Hispanic-serving institution (HSI; University of Arizona and Texas A&M), an Asian American Native American Pacific Islander–serving institution (AANAPISI; University of California San Diego and University of California, Santa Barbara), or as both (University of Texas at Austin and University of California, Santa Cruz). None of the top-20 institutions were designated as a predominantly Black institution (PBI), historically Black college or university (HBCU), or tribal college or university (TCU). This result was expected, as no doctoral programs in geoscience currently exist at PBIs, HBCUs, or TCUs (U.S. Department of Education, 2022).

Network-level metrics suggest that there has been little change over time in the degree of inequity in this network. When the network was divided into subsets by academic rank (a proxy for change over time), the Gini coefficient

TABLE 1. TOP-20 INSTITUTIONS BY OUT-DEGREE

Rank	Institution	Out-degree	Current geoscience faculty and research staff	SpringRank	University endowment (in billions USD)*	MSI status[†]
1	MIT/WHOI	**276**	**137**	2.341	24.6	–
2	University of Washington	211	102	2.327	4.88	–
3	UC, Berkeley	198	42	2.506	6.8	–
4	Stanford University	157	31	2.574	36.3	–
5	University of Wisconsin	155	81	2.095	4.0	–
6	Caltech	151	38	2.603	4.6	–
7	University of Arizona	151	143	2.052	1.2	HSI
8	Columbia University	139	108	2.285	13.3	–
9	Pennsylvania State University	131	70	2.185	6.2	–
10	UC San Diego/Scripps	118	71	2.395	2.6	AANAPISI
11	Harvard University	117	29	**2.634**	**53.2**	–
12	University of Minnesota	114	76	2.160	5.4	–
13	University of Michigan	109	66	2.193	17.0	–
14	UCLA	107	53	2.435	5.1	–
15	University of Colorado Boulder	103	35	2.361	2.13	–
16	University of Texas at Austin	88	56	2.125	42.9	AANAPISI, HSI
17	Texas A&M	87	108	1.842	18.0	HSI
18	Oregon State University	86	84	2.081	0.82	–
19	UC, Santa Cruz	83	47	2.308	0.29	AANAPISI, HSI
20	UC, Santa Barbara	79	20	2.395	0.59	AANAPISI

Notes: Node-level metrics for top-20 institutions by placement, including out-degree (number of placements of graduates into academic positions); size of current geoscience faculty and academic staff; SpringRank, a weighted measure of network prestige; university endowment as of fiscal year 2021; and minority-serving institution (MSI) status. The highest value for out-degree, faculty size, SpringRank, and endowment are bolded. MIT/WHOI—Massachusetts Institute of Technology/Woods Hole Oceanographic Institution; UC—University of California; UCLA—University of California, Los Angeles. USD—U.S. dollars. Dashes indicate that institution has no MSI status.

*Endowment size as of fiscal year 2021.

[†]Federally designated MSI types here include Hispanic-serving institutions (HSI) and Asian American and Alaska Native Pacific Islander-serving institutions (AANAPISI).

did decrease by rank (professor $G = 0.86$, associate professor $G = 0.82$, assistant professor $G = 0.81$, contingent faculty $G = 0.81$), but the change was not significant (Fig. 2 and Table 2). There was variation in the top-10 placing institutions for each rank, and the percentage of placements that the top 10 were responsible for did decrease by rank (professor 28.94%, associate professor 28.88%, assistant professor 24.41%, and contingent faculty 22.11%), but none of the values were significantly different. Network density and hybrid reciprocity were not calculated for the whole network because of the limitations described in the methods.

Network of Ph.D.-Granting Institutions Only

An additional set of analyses was conducted on a network that included only Ph.D.-granting institutions. While this reduced network does not accurately reflect the whole academic geoscience community, it does allow for some additional types of analyses to be conducted that are not possible when all institution types are included. In this reduced network, every institution is theoretically capable of placing graduates at any other institution in the network. Therefore, measures like the Gini coefficient, network density, and hybrid reciprocity can be evaluated for the network and compared meaningfully to the results of other studies.

The top-10 placing institutions in this reduced network are shown in Figure 3. These 10 institutions are: (1) MIT; (2) University of Washington; (3) University of California, Berkeley; (4) Stanford University; (5) University of Wisconsin; (6) Caltech; (7) University of Arizona; (8) Columbia University; (9) Pennsylvania State University; and (10) University of California San Diego. These institutions were responsible for 1323 graduates in academic geoscience positions, which accounted for 35.04% of all academic geoscience positions at institutions that grant geoscience Ph.D.s. This indicates that the Ph.D.-granting institution network is more unequal than the whole network; more placement power is concentrated in the top-10 institutions.

For this network, the Gini coefficient is $G = 0.64$, which indicates a high level of inequity in the network (Fig. 4). This score falls just below the range of Gini coefficients found in a larger study of all academic fields (from $G = 0.67$ for medicine and health to $G = 0.77$ for humanities) (Clauset et al., 2015) and

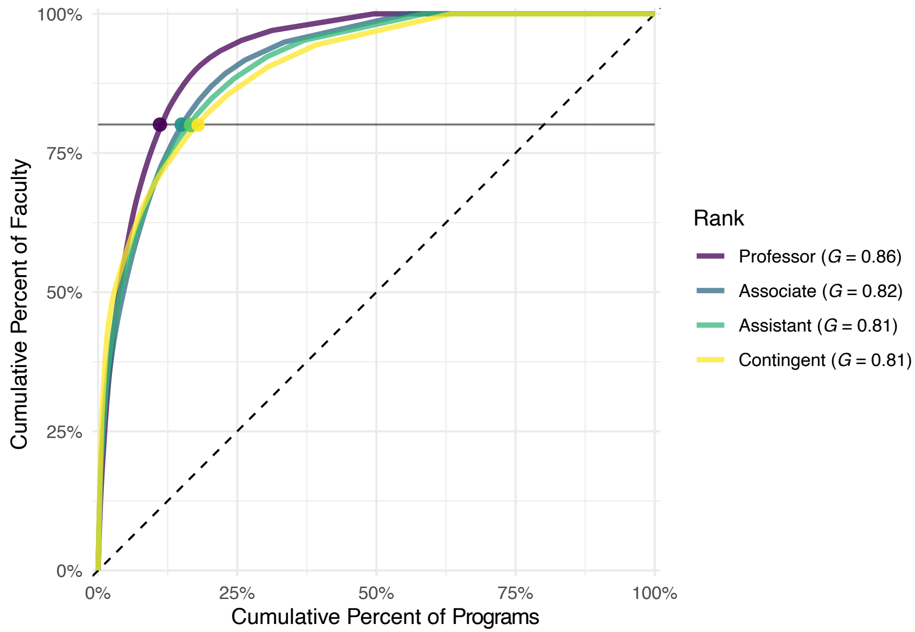

Figure 2. Lorenz curves indicating inequity in the whole network separated by academic rank (professor, associate professor, assistant professor, and contingent faculty). The Gini coefficient for each rank is indicated in the key, and the dashed line indicates hypothetical perfect equity, in which academic hires are spread evenly across all institutions. A point is placed along each rank curve at which 80% of individuals are accounted for.

TABLE 2. TOP-10 INSTITUTIONS FOR EACH RANK

	Professor		Associate professor		Assistant professor		Contingent faculty	
Rank	University	Out	University	Out	University	Out	University	Out
1	MIT/WHOI	167	MIT/WHOI	52	Arizona	44	Arizona	15
2	Washington	118	UC Berkeley	45	MIT/WHOI	35	Minnesota	15
3	UC Berkeley	110	Washington	45	Penn State	35	Washington	14
4	Stanford	97	Wisconsin	35	UC Berkeley	29	UT Austin	13
5	Caltech	95	Stanford	34	Washington	29	Texas A&M	13
6	Columbia	95	Arizona	33	Caltech	27	Columbia	12
7	Wisconsin	92	Penn State	32	UT Austin	23	UCSD/Scripps	12
8	UCSD/Scripps	78	Colorado	28	Stanford	20	Michigan	11
9	Harvard	74	Minnesota	24	Minnesota	18	Oregon State	11
10	Michigan	66	UCLA	24	UCSD/Scripps	18	MIT/WHOI	10
Percentage:		29.84%		23.88%		24.41%		22.11%
Gini Coefficient		0.86		0.82		0.81		0.81

Notes: Whole network top-10 institutions by out-degree (placements) subset by academic rank. The percentage of total placements by the top-10 institutions for each academic rank and the Gini coefficient for each academic rank are included. Differences in top-10 percentage and Gini coefficient are not significantly different. MIT/WHOI—Massachusetts Institute of Technology/Woods Hole Oceanographic Institution; UC—University of California; UCLA—University of California, Los Angeles; UCSD—University of California San Diego; UT—University of Texas.

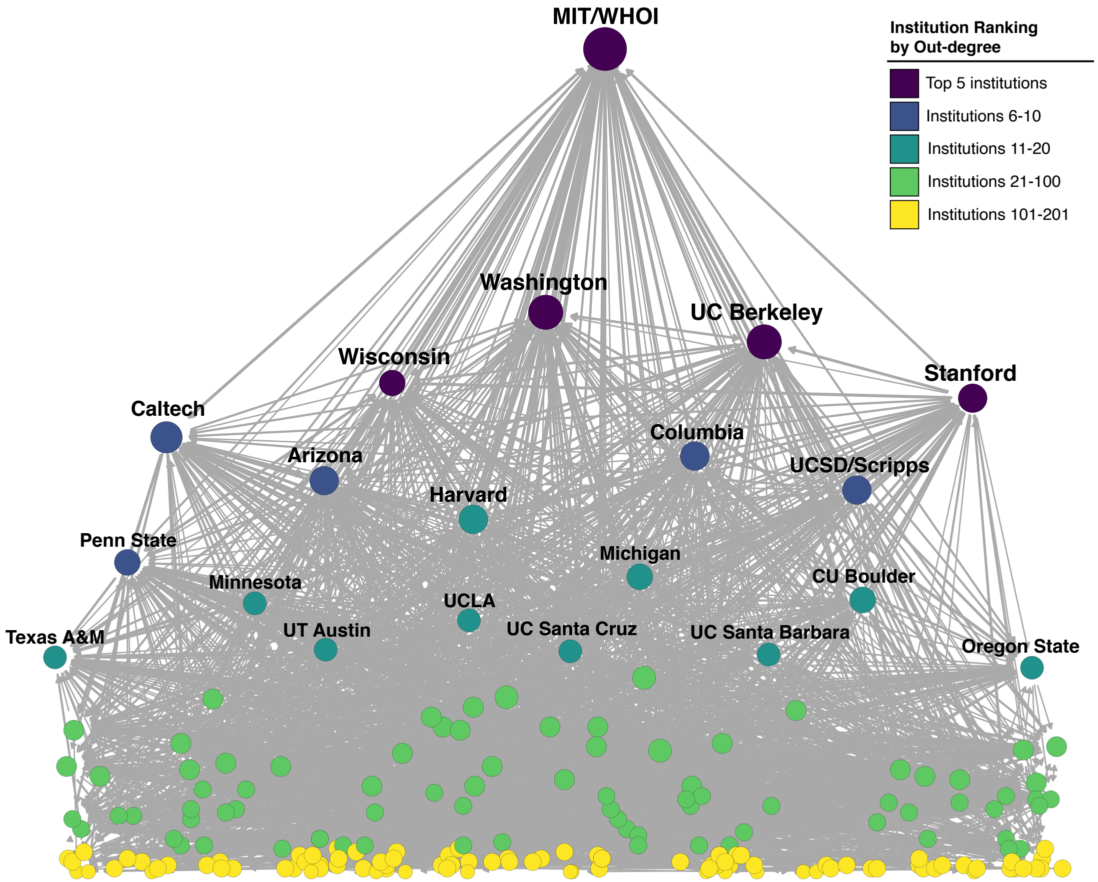

Figure 3. Network comprising Ph.D.-granting universities only (n = 201). Node size, color, and placement are determined by degree centrality. Top-20 institutions by out degree (placement) are labeled. CU—Colorado University; MIT/WHOI—Massachusetts Institute of Technology/Woods Hole Oceanographic Institution; UC—University of California; UCLA—University of California, Los Angeles; UCSD—University of California San Diego; UT—University of Texas.

suggests a slightly lower degree of inequity in geoscience than in other fields. The Lorenz curve is a method of visually representing the inequity reflected by Gini coefficients (Lorenz, 1905). This network's Lorenz curve shows that 25% of institutions are responsible for 75% of academic geoscience placements.

The network density for this network was 0.0662, which indicates that 6.62% of the possible edges, or connections, in the network were filled. The network's hybrid reciprocity was 0.1866, which indicates that 18.66% of edges were mutual. Like the Gini coefficient, the low-density and low-reciprocity scores both suggest a high degree of inequality in the network.

Community analysis of the whole network indicates a smaller, closed network of prestigious institutions consisting of MIT; University of Washington; University of California, Berkeley; Columbia University; and Stanford University, which comprise five of the top-10 institutions by out-degree (Fig. 5). This suggests that these institutions share the most connections in the network. In other words, these institutions hire graduates from one another more frequently than from other institutions. This cluster is nested within a larger community of institutions that includes all but two of the top-20 institutions (Fig. 5).

DISCUSSION

Scientific careers do not succeed on individual merit alone. Systems of power and privilege pave educational pathways for some while simultaneously blockading progress for others. This study illustrates that the institution at which a geoscientist earns a Ph.D. plays a significant role in determining the type of institution at which he or she ultimately ends up working. Other factors, like parents' education level, race/ethnicity, and mentorship, also impact the

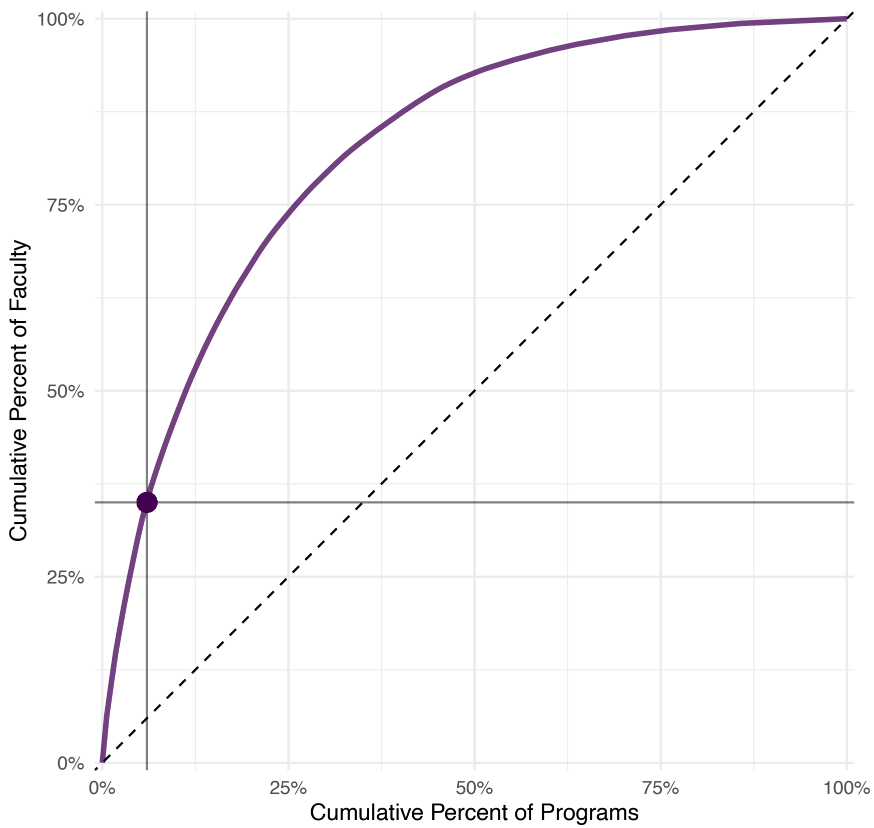

Figure 4. Lorenz curve for Ph.D.-only network, with Gini coefficient included (*G* = 0.63). Roughly 12.5% of all Ph.D.-granting institutions have produced 50% of geoscience faculty and staff at other Ph.D.-granting institutions. Dashed line indicates hypothetical perfect equity, in which academic hires are spread evenly across all institutions. A point is placed along the curve representing the percentage of faculty produced by the top-10 programs.

educational pathways that geoscientists travel (Levine et al., 2007; Baber et al., 2010; Stokes et al., 2014; Hernandez et al., 2020).

The imbalance in academic hiring illustrated in this study is likely one of the mechanisms responsible for the marked lack of diversity in geoscience. As Bernard and Cooperdock (2018) illustrated, there has been no progress toward racial diversity in recipients of geoscience doctorates over the past four decades. While the results of this study do not encompass the same timeframe as that of the Bernard and Cooperdock study, it does find that there has been no significant change in academic hiring practices over time. Academic hiring is one of many mechanisms that shape the diversity of the field, and the findings of this study provide a potential explanation for why there has been no progress toward racial diversity. White people continue to be overrepresented in the field, leaving Black, Indigenous, and People of Color (BIPOC) severely underrepresented. Fleming et al. (2023) showed that academic hiring practices that favor graduates from a limited pool of prestigious institutions exclude most BIPOC candidates because their educational pathways often travel through minority-serving institutions, international institutions, or institutions that are not ranked in the "top 25" by *U.S. News and World Report*. Rebalancing academic hiring practices to ensure that all competent candidates, regardless of academic pedigree, are considered more equally would aid in diversifying the academic geoscience workforce. This is doubly important because diversity amongst faculty and other department staff has been tied to the engagement and persistence of BIPOC geoscience students (Levine et al., 2007; Baber et al., 2010; Stokes et al., 2014). Failure to rebalance hiring practices will ensure ongoing stagnation in progress toward diversifying the field.

As the discussion around diversity in the geosciences has grown more widespread, BIPOC geoscientists have produced frameworks for understanding and addressing these challenges. For example, Ali et al. (2021) developed an anti-racism plan for geoscience organization that includes a framework for dismantling the institutionalized racist structures that have kept BIPOC scholars out of the geosciences and led to a severe overrepresentation of White geoscientists. This framework built on work by Dutt (2019), who outlined how

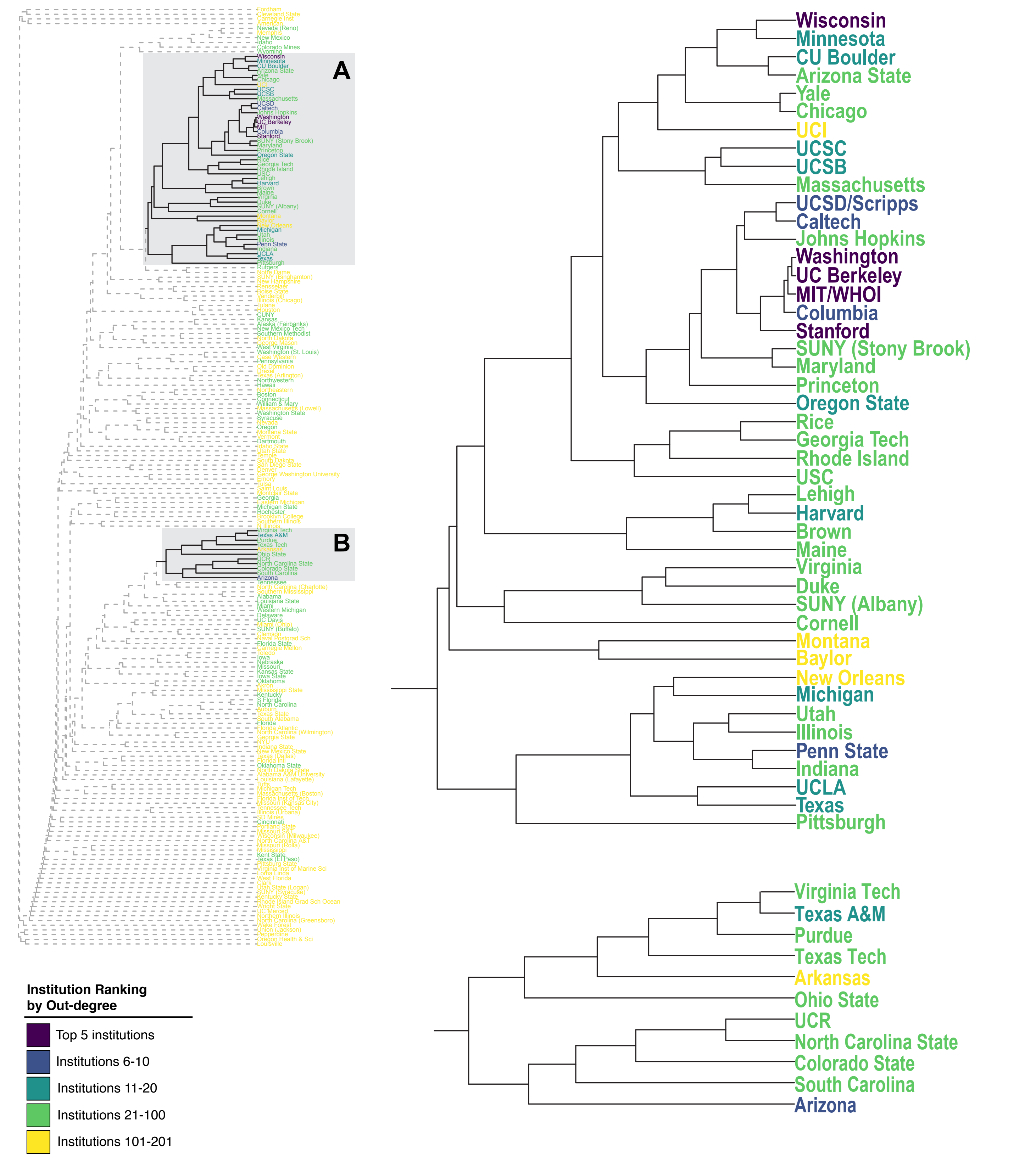

Figure 5. Dendrogram illustrating communities within the Ph.D.-only network. Ranking by out-degree is indicated by color; all of the top-20 institutions are included within clusters A and B, highlighted in gray, and shown in detail to the right. Four of the top-5 institutions by out-degree (Massachusetts Institute of Technology [MIT]; University of Washington; University of California [UC], Berkeley; and Stanford) cluster together, indicating that they hire from one another more frequently than from any other institutions in the network. UCI—University of California, Irvine; UCSC—University of California, Santa Cruz; UCSB—University of California, Santa Barbara; UCSD—University of California San Diego; MIT/WHOI—Massachusetts Institute of Technology/Woods Hole Oceanographic Institution; SUNY—State University of New York; USC—University of Southern California; UCR—University of California, Riverside.

structural racism manifests within geoscience, and Marín-Spiotta et al. (2020), who identified *historical legacies of exclusion* and *hierarchical power dynamics* as two significant barriers to increasing diversity in the geosciences. The Ali et al. (2021) framework specifically names *investing and recruiting from minority-serving institutions* as one of 20 action steps that organizations can take to address racism. This type of action has been recommended by several other studies (e.g., McDaris et al., 2017; Morris, 2021; Duncan et al., 2022). In this study, only six of the top-20 institutions by out-degree were MSIs, and none were PBIs, HBCUs, or TCUs. Academic hiring committees should take this into consideration when crafting the desired qualifications and characteristics included in job ads. Since no doctoral programs in geoscience currently exist at PBIs, HBCUs, or TCUs, recruiting candidates from MSIs requires attention to a candidate's earlier education, not just the Ph.D.-granting institution.

The results of this study support these recommendations; if we wish to address the lack of the diversity in geoscience, academic hiring must draw from a broader pool of applicants. The status quo approach to academic hiring in geoscience heavily favors graduates from the top schools, so academic hiring committees must take conscious action to seriously consider qualities of candidates beyond those most strongly associated with graduates of top programs. The needs of a diverse student population cannot be met by faculty that were all trained at the same 10 institutions.

This study also has implications for geoscience graduate programs. Programs with high rates of faculty production (i.e., those that ranked high in out-degree) should take into consideration the likelihood that many of their graduates will gain employment at institutions that are very different in scope and purpose. Along with research training, graduate students should receive training in student-centered teaching pedagogy and mentoring a diverse student population. Teaching and mentoring are important factors in the recruitment and retention of students from underrepresented groups (Baber et al., 2010; Freeman et al., 2014; Stokes et al., 2014; Pugh et al., 2019). For example, multiple studies have shown the importance of Indigenous faculty and the incorporation of traditional ecological knowledge in the recruitment and retention of Indigenous students and other students of color (McKinley et al., 2022; Todd et al., 2023).

LIMITATIONS

This study relied on the data curated and published in the American Geosciences Institute's *Directory of Geoscience Departments*, and though efforts were taken to confirm accuracy, it is likely that some departmental data were outdated. Furthermore, by focusing on the movement of individuals from the Ph.D.-granting institution to the institution of current employment, this study does not take into consideration other stops along an individual's career progression, including postdoctoral fellowship positions and previous workplaces. Mapping these different pathways would likely provide valuable insight into patterns of success and persistence in the geosciences and would help define the role of other types of institutions (e.g., two-year colleges and masters-granting institutions) within geoscientist education and training. Mapping complete educational pathways would likely require the examination of every individual's curriculum vitae, so there is no feasible mechanism for collecting those data at the scale of this study, but other methods of inquiry could explore the nuances of varying educational pathways.

CONCLUSIONS

This study reveals longstanding patterns in the geoscience academic hiring network that have reinforced historical inequities that privilege graduates of prestigious programs over all others. Changing the patterns in academic hiring revealed in this study will not happen without dedicated work, likely over years or possibly decades. In their study of perceptions of departmental prestige over time, Weakliem et al. (2012) found that prestige rankings rarely change. But departments and programs that are committed to changing patterns could adopt frameworks such as the Ali et al. (2021) framework to help guide institutional transformation and remove barriers.

ACKNOWLEDGMENTS

I acknowledge the work of Katie Stelling, who helped with data entry in the early stages of this project. This paper also benefitted immensely from the insightful reviews of Elena A. Miranda and two anonymous reviewers.

REFERENCES CITED

Ali, H.N., Sheffield, S.L., Bauer, J.E., Caballero-Gill, R., Gasparini, N.M., Libarkin, J., Gonzalez, K., Willenbring, J., Amir-Lin, E., Cisneros, J., Desai, D., Erwin, M., Gallant, E., Gomez, K.J., Keisling, B.A., Mahon, R., Marín-Spiotta, E., Welcome, L., and Schneider, B., 2021, An actionable anti-racism plan for geoscience organizations: Nature Communications, v. 12, https://doi.org/10.1038/s41467-021-23936-w.

Baber, L., Pifer, M.J., Colbeck, C., and Furman, T., 2010, Increasing diversity in the geosciences: Recruitment programs and student self-efficacy: Journal of Geoscience Education, v. 58, p. 32–42, https://doi.org/10.5408/1.3544292.

Barabási, A.-L., and Albert, R., 1999, Emergence of scaling in random networks: Science, v. 286, p. 509–512, https://doi.org/10.1126/science.286.5439.509.

Barnett, G.A., Danowski, J.A., Feeley, T.H., and Stalker, J., 2010, Measuring quality in communication doctoral education using network analysis of faculty-hiring patterns: Journal of Communication, v. 60, p. 388–411, https://doi.org/10.1111/j.1460-2466.2010.01487.x.

Bernard, R.E., and Cooperdock, E.H.G., 2018, No progress on diversity in 40 years: Nature Geoscience, v. 11, p. 292–295, https://doi.org/10.1038/s41561-018-0116-6.

Burris, V., 2004, The academic caste system: Prestige hierarchies in PhD exchange networks: American Sociological Review, v. 69, p. 239–264, https://doi.org/10.1177/000312240406900205.

Clauset, A., Arbesman, S., and Larremore, D.B., 2015, Systematic inequality and hierarchy in faculty hiring networks: Science Advances, v. 1, https://doi.org/10.1126/sciadv.1400005.

Cole, J.R., and Cole, S., 1974, Social stratification in science: American Journal of Physics, v. 42, p. 923–924, https://doi.org/10.1119/1.1987897.

Crane, D., 1965, Scientists at major and minor universities: A study of productivity and recognition: American Sociological Review, v. 30, p. 699–714, https://doi.org/10.2307/2091138.

Csardi, G., and Nepusz, T., 2006, The igraph software package for complex network research: InterJournal: Complex Systems, v. 1965, https://igraph.org.

De Bacco, C., Larremore, D.B., and Moore, C., 2018, A physical model for efficient ranking in networks: Science Advances, v. 4, https://doi.org/10.1126/sciadv.aar8260.

Duncan, C., Terrell Shockley, E., and Asa-Awuku, A., 2022, Accounts and recommendations for recruitment of under-represented groups in the geoscience STEM discipline: Journal of Geoscience Education, v. 71, p. 320–331, https://doi.org/10.1080/10899995.2022.2106813.

Dutt, K., 2019, Race and racism in the geosciences: Nature Geoscience, v. 13, p. 2–3, https://doi.org/10.1038/s41561-019-0519-z.

Fleming, G.C., Patrick, A.D., Grote, D., Denton, M., Knight, D., Lee, W., Borrego, M., and Murzi, H., 2023, The fallacy of "there are no candidates": Institutional pathways of Black/African American and Hispanic/Latino doctorate earners: Journal of Engineering Education, v. 112, p. 170–194, https://doi.org/10.1002/jee.20491.

Fowler, J.H., Grofman, B., and Masuoka, N., 2007, Social networks in political science: Hiring and placement of Ph.D.s, 1960–2002: Political Science & Politics, v. 40, p. 729–739, https://doi.org/10.1017/S104909650707117X.

Freeman, L., 1979, Centrality in social networks: I. Conceptual clarification: Social Networks, v. 1, p. 215–239, https://doi.org/10.1016/0378-8733(78)90021-7.

Freeman, S., Eddy, S.L., McDonough, M., Smith, M.K., Okoroafor, N., Jordt, H., and Wenderoth, M.P., 2014, Active learning increases student performance in science, engineering, and mathematics: Proceedings of the National Academy of Sciences of the United States of America, v. 111, p. 8410–8415, https://doi.org/10.1073/pnas.1319030111.

Gini, C., 1936, On the measure of concentration with special reference to income and statistics: Colorado College Publication: General Series, v. 208, p. 73–79.

Hanneman, R.A., and Riddle, M., 2011, Concepts and measures for basic network analysis, *in* Carrington, P.J. and Scott, J., eds., The SAGE Handbook of Social Network Analysis: Los Angeles, SAGE Publications, Inc., p. 340–369.

Hernandez, P.R., Adams, A.S., Barnes, R.T., Bloodhart, B., Burt, M., Clinton, S.M., Henderson, H., Pollack, I., and Fischer, E.V., 2020, Inspiration, inoculation, and introductions are all critical to successful mentorship for undergraduate women pursuing geoscience careers: Communications Earth & Environment, v. 1, 7, https://doi.org/10.1038/s43247-020-0005-y.

Kalamaras, D., 2015, Social Network Visualizer (SocNetV): http://socnetv.org (last accessed May 2023).

Kawa, N.C., Clavijo Michelangeli, J.A., Clark, J.L., Ginsberg, D., and McCarty, C., 2018, The social network of US academic anthropology and its inequities: American Anthropologist, v. 121, p. 14–29, https://doi.org/10.1111/aman.13158.

Keane, C.M., 2021, Directory of Geoscience Departments: American Geosciences Institute.

Levine, R., González, R., Cole, S., Fuhrman, M., and Carlson Le Floch, K., 2007, The geoscience pipeline: A conceptual framework: Journal of Geoscience Education, v. 55, p. 458–468, https://doi.org/10.5408/1089-9995-55.6.458.

Lorenz, M.O., 1905, Methods of measuring concentrations of wealth: Publications of the American Statistical Association, v. 9, p. 209–219, https://doi.org/10.2307/2276207.

Mai, B., Liu, J., and González-Bailón, S., 2015, Network effects in the academic market: Mechanisms for hiring and placing PhDs in communication (2007–2014): Journal of Communication, v. 65, p. 558–583, https://doi.org/10.1111/jcom.12158.

Marín-Spiotta, E., Barnes, R., Berhe, A.A., Hastings, M., Mattheis, A., Schneider, B., and Williams, B.M., 2020, Hostile climates are barriers to diversifying the geosciences: Advances in Geosciences, v. 53, p. 117–127, https://doi.org/10.5194/adgeo-53-117-2020.

McCambly, H., and Colyvas, J.A., 2022, Institutionalizing inequity anew: Grantmaking and racialized postsecondary organizations: Review of Higher Education, v. 46, p. 67–107, https://doi.org/10.1353/rhe.2022.0013.

McDaris, J.R., Manduca, C.A., Iverson, E.R., and Huyck Orr, C., 2017, Looking in the right places: Minority-serving institutions as sources of diverse Earth science learners: Journal of Geoscience Education, v. 65, p. 407–415, https://doi.org/10.5408/16-224.1.

McKinley, C., Showalter, G.M., Crofoot, T., and Stone, K., 2022, Systematic evaluation of geoscience education programs that are designed for Indigenous students, or use traditional knowledge: Journal of Geoscience Education, v. 71, p. 428–441, https://doi.org/10.1080/10899995.2022.2112491.

Merton, R.K., 1968, The Matthew Effect in science: Science, v. 159, p. 56–63, https://doi.org/10.1126/science.159.3810.56.

Morgan, A.C., Economou, D.J., Way, S.F., and Clauset, A., 2018, Prestige drives epistemic inequality in the diffusion of scientific ideas: EPJ Data Science, v. 7, p. 40, https://doi.org/10.1140/epjds/s13688-018-0166-4.

Morris, V.R., 2021, Combating racism in the geosciences: Reflections from a Black professor: AGU Advances, v. 2, p. 1–6, https://doi.org/10.1029/2020AV000358.

Pugh, K.J., Phillips, M.M., Sexton, J.M., Bergstrom, C.M., and Riggs, E.M., 2019, A quantitative investigation of geoscience departmental factors associated with the recruitment and retention of female students: Journal of Geoscience Education, v. 67, p. 266–284, https://doi.org/10.1080/10899995.2019.1582924.

Stokes, P.J., Levine, R., and Flessa, K.W., 2014, Choosing the geoscience major: Important factors, race/ethnicity, and gender: Journal of Geoscience Education, v. 63, p. 250–263, https://doi.org/10.5408/14-038.1.

Thomas, S.L., and Zhang, L., 2005, Post-baccalaureate wage growth within four years of graduation: The effects of college quality and college major: Research in Higher Education, v. 46, p. 437–459, https://doi.org/10.1007/s11162-005-2969-y.

Todd, W.F., Towne, C.E., and Brown Clark, J., 2023, Importance of centering traditional knowledge and Indigenous culture in geoscience education: Journal of Geoscience Education, v. 3, p. 403–414, https://doi.org/10.1080/10899995.2023.2172976.

U.S. Department of Education, 2022, 2023 Eligibility Matrix, https://www2.ed.gov/about/offices/list/ope/idues/2023eligibilitymatrix.xlsx (last accessed 25 July 2023).

Wapman, K.H., Zhang, S., Clauset, A., and Larremore, D.B., 2022, Quantifying hierarchy and dynamics in US faculty hiring and retention: Nature, v. 610, p. 120–127, https://doi.org/10.1038/s41586-022-05222-x.

Weakliem, D.L., Gauchat, G., and Wright, B.R.E., 2012, Sociological stratification: Change and continuity in the distribution of departmental prestige, 1965–2007: The American Sociologist, v. 43, p. 310–327, https://doi.org/10.1007/s12108-011-9133-2.

Wieland, M.M., Dawkins, M.C., and Dugan, M.T., 2016, Assessing the elite publication benefits of academic pedigree: A joint examination of PhD institution and employment institution: Accounting Perspectives, v. 15, p. 229–340, https://doi.org/10.1111/1911-3838.12131.

Yang, S., Keller, F., and Zheng, L., 2017, Social Network Analysis: Methods and Examples: Los Angeles, SAGE Publications Inc., https://doi.org/10.4135/9781071802847.

Zhang, S., Wapman, K.H., Larremore, D.B., and Clauset, A., 2022, Labor advantages drive the greater productivity of faculty at elite universities: Science Advances, v. 8, p. 1–9, https://doi.org/10.1126/sciadv.abq7056.