Revision 1

Assuring the Future of Mineralogy

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Abstract

As the *American Mineralogist* and the Mineralogical Society of America (MSA) approach their centennials, troubling indicators cast a shadow on the future of the mineralogical sciences. These indicators include decreases in grant funding for research in mineralogical disciplines, a lack of attention to mineral resources, trends in Ph.D.'s awarded in the earth sciences, and the lack of emphasis on the earth sciences in state educational policies. Some of these problems can be traced to a lack of scientific literacy among the public and policy makers. Others can be attributed to actions or inactions by those whose research or teaching involves minerals. MSA and its members must do more to educate students, colleagues, and the public about the mineralogical sciences and their importance to the well being of society. If we are proactive and imaginative in promoting our science, the "future of mineralogy" can be assured.

Introduction

In 1921, Edward H. Kraus, the first President of MSA, predicted the future of mineralogy in America: "As the result of a more general recognition of the basic importance of mineralogy in pure and applied science and in various branches of industry, and with a national society boasting of a membership which includes the progressive investigators and devotees of the subject, and with a well-established and widely recognized official monthly publication, the future of mineralogy in America is assured (Kraus 1921)." As I think about the impending centennial years of *American Mineralogist* and the Mineralogical Society of America, I look with pride at the accomplishments of the Society and its premier journal that confirm Kraus's assurance. However, as I look to the next 100 years, I feel a mix of optimism and concern. In many ways, our science, our Society, and our journal are thriving, with a wide range of participants, research specialties, research tools, and advances in knowledge that could not have been imagined by our founders. At the same time, we face serious challenges as citizens, in education and understanding, in resources and the environment, and as scientists, in research funding, in jobs, and in recognition by colleagues and the public.

There are many positive signs regarding the health of the "mineralogical sciences," by which I mean the disciplines that bring members to MSA, including (but certainly not limited to) mineralogy, crystallography, mineral physics, geochemistry, economic geology, and petrology. One measure of this health is the MSA membership count. As shown in Figure 1, MSA membership has been on the rise since 2000, after a decline from its all-time high in 1983. Student membership was given a big boost by the introduction of the mineralogy textbook by Dyar et al. (2008), but non-student membership has also risen 12% since 2000. Institutional access to *American Mineralogist* has soared since the creation of *GeoscienceWorld*, reversing a long downward trend and returning to mid-1980's values with 1447 end-subscribers in 2014.

The number of pages published annually in *American Mineralogist* is also rising, with more pages published (2204) in 2013 than in any previous year (Figure 2), attesting to the pace of mineralogical research. Access to mineralogical sciences information has never been greater, from technical datasets of crystal structures (e.g., Downs and Hall-Wallace 2003) or rock chemistry (e.g., Lehnert et al. 2000) to information for all mineral enthusiasts (e.g., Ralph 2014). The range of approaches and tools being used for the study of minerals and rocks continues to expand, as exemplified by the diversity of papers in the recent issues of *American Mineralogist*. In addition, several specialties have grown into new research fields within the mineralogical sciences such as biomineralogy, Raman spectroscopy, health effects of minerals, clumped isotopes, nanomaterials, and mineral surfaces. Clearly, research in the mineralogical sciences is active and growing.

There are also some troubling indicators about the health of the mineralogical sciences. According to data compiled by the National Science Foundation (1998, 2013; Wilson 2014), US federal research and development dollars directed toward basic research in the geosciences have been declining since 1996, both in percentage of federal spending on basic research (10.6% in 1996, 5.6% in 2010) and as inflation-adjusted dollars ($1.53 billion in 1996, $1.27 billion in 2010 when CPI-corrected to 1996 dollars). Although geoscience enrollments and bachelor’s degrees have more than doubled in the last 25 years, graduate enrollments and number of Ph.D.’s awarded in the geosciences have changed little over the same period (Wilson 2014, Figs. 3.12, 3.13). In addition, the proportion of dissertation topics listed as mineralogy, petrology, or geochemistry has declined (Wilson 2014, Fig. 3.32), though some of this decrease may be due to rebranding. Based on a casual, web-based survey of geoscience degree requirements at US colleges, training of undergraduate students in mineralogy and petrology has declined, in some cases with only one or even no required course dedicated to minerals and rocks. Most readers will be familiar with these issues. Should they be of concern to MSA members? If so, what should be our response?

I think it is fair to say that mineralogy and mineralogists do not have the same status in the scientific community today as they did when MSA was founded. Indeed, there are geoscientists who do not see the relevance of the mineralogical sciences to current, pressing problems. Some of us would say we have an image problem. One successful colleague told me, “Mineralogy is a powerful science, as it is one of the few that is truly interdisciplinary. However, scientists still need to be labeled, and many of my colleagues do not consider me a mineralogist. I'm often called a chemist, physicist, or materials scientist (I've never once been called a geologist).” Others will say that our actions are responsible for this attitude. As one reviewer wrote: “Mineralogy is in trouble because it is relatively limited in its scope as generally practiced, while at the same time other sciences have exploded in their scope. In general (although there are clear exceptions to this), mineralogists have not been good at connecting to other sciences to stay relevant. Mineralogy is too isolated as a field, in effect trying to survive on its own. The problem is not the rest of the world, or the rest of society; the problem is us.” Another colleague observed, "Mineralogy is sort of like math or arithmetic, widely used but not considered as being used when folks get caught up in its application. Mineralogy is in trouble because it widened its scope to the point it has become subsumed and nearly invisible in the wider science(s) in which it is used." Whatever the cause, I believe that we should proactively address these issues of image, relevance, and status both as individuals and as a Society by (1) ensuring that research we do (borrowing NSF wording) not only has “intellectual merit”, but that it also has “broader impacts” to society beyond mineralogy, and by (2) working to explain, justify, and promote our research and its impacts to the scientific community and to the wider world. *We* know that mineralogy is not just about another pretty crystal. *We* know that minerals are a critical part of a broad range of scientific problems. *We* know that mineralogical understanding is an essential part of any solution to those problems. It is up to us to convince others of the value of mineralogy through our actions and words.

Scientific Literacy

Some of the problems facing the mineralogical sciences are intertwined with broader societal shortcomings in the area of scientific literacy. When the progress of scientific research depends on government grants and policies, it is essential that those who make the decisions and those who elect the decision makers have a reasonable understanding and appreciation of the nature and importance of science. There are many reasons to think work is needed on the scientific literacy of US citizens. Beginning in 2000, the Organization for Economic Cooperation and Development (OECD) has administered mathematics, science, and reading literacy tests to 15-year-olds from several countries every three years. OECD-PISA (Program for International Student Assessment) science literacy results, including the most recent in 2012, consistently show the US as "…not measurably different from the OECD average" of all participating countries and well-below the best-performing countries (Kelly et al. 2013; Layton 2013). Similarly, the OECD Survey of Adult Skills (PIAAC) taken by over 150,000 adults aged 16 to 65 in 24 countries and sub-national regions gave the US low marks, although scientific literacy was not directly tested (OECD 2013a,b; Carey 2014).

When a demonstrated lack of factual knowledge is in the area of earth or mineralogical sciences, I find it especially troubling. In a recent report by the National Science Board (2014) on science and engineering indicators, Table 7-8 lists results from the 2012 General Social Survey for physical and biological science questions asked in about 2000 interviews of US citizens. 26% of those interviewed incorrectly answered the question: “Does the Earth go around the Sun, or does the Sun go around the Earth?” 47% of those interviewed did not know that electrons are smaller than atoms. And 61% described as false the statement “The universe began with a huge explosion.” The same National Science Board (2014) report notes similar misconceptions in other countries. At least some of the lack of earth science literacy in the US can be attributed to educational policies. Although 47 states assess Earth and space science concepts at the secondary level, only one state requires a year-long geoscience course to graduate from high school (AGI 2013).

Not understanding the relative size of an electron might not have an adverse effect on the lives of many citizens. But not understanding the importance of mineral commodities as critical to our daily lives could lead to actions (e.g., voting, policy choices) that do not protect the supply of those resources. According to the US Geological Survey (2014) more than half of the supply of 40 important mineral commodities is imported, and all of the supply of 19 of them is imported. Recently, the supply of rare earth elements got a lot of attention when it became clear that China controlled the world’s supply of these elements, which are essential to the manufacture of mobile phones and other electronics (Humphries 2013). But there are many other elements crucial to our society that are at risk, such as indium, manganese, niobium, and platinum group metals (National Research Council 2008). In an increasingly complex global economy, the voting public needs an appreciation of the value of mineral resources and of the challenges to corporations, governments, and the environment associated with their mining and supply.

Action Required

I believe that mineralogical scientists have an important role to play in addressing deficiencies in scientific literacy because of the cornerstone of our disciplines: minerals. Many people love minerals and rocks. Beautiful minerals attract people to the natural world. Children are fascinated by rocks and minerals and make collections of them. How many geologists have been lured to study the earth because of their love of minerals? Collectors populate mineral clubs and support mineral shows around the world. Students learn more when they have a personal interest in and connection to the material. Because so many people like minerals, mineralogy can be an effective portal to science education. If we take advantage of the lure of minerals and devote more of our time to outreach, we can have a broader effect on society through increased scientific literacy as well as a positive effect on our own disciplines. However, as we do this, we must find ways to make connections between the crystals people love and their potential to help understand and solve larger questions of importance to society today.

Mineralogical outreach can take many forms. I suggest that those of us in academia start with our own teaching. Our classes should be especially interesting, relevant, and accessible to the students we have. As cultures, technology, and the critical needs of society evolve, so do college students. To be effective, our teaching must evolve, too. If students are interested in social media and video games, we should look for ways to use those interests to improve student learning in our courses. If students prefer to use online data, rather than printed reference material, we should ask them questions that build upon online datasets, exposing both their strengths and weaknesses. If new instruments are providing important data for the mineralogical sciences, we should incorporate their use in our classes. If hydraulic fracturing or climate change are receiving a lot of press, we should replace older instructional activities with new ones that are relevant to these issues. Few of our students will become “mineralogists” in the sense of those who founded MSA. But nearly all of them will need a good mineralogical foundation to be geoscientists. So perhaps most importantly, we must make sure that our courses demonstrate and emphasize aspects of mineralogy that will be helpful to them whether they are interested in volcanic hazards, clean water, surface chemistry, energy resources, evolution, etc. No matter how good our courses were last year, there must be changes if they are to be as good this year and remain current. When our students report that their courses in the mineralogical sciences are their favorite courses, then we have succeeded. If not, we can do better. I have argued this point previously (Brady 1995), but I think it is more important today than ever.

Children are better learners than adults. Children turn into college students, citizens, and decision makers. Effort put into educating K-12 students can have long-lasting returns. As a society, MSA has recognized the value of outreach to children through the creation and support of the Mineralogy-4-Kids website (http://www.mineralogy4kids.org/). This popular resource currently has over 300,000 visitors and over 1.5 million page views annually. Another way that we can reach children would be to encourage students in our classes to consider careers in K-12 education. Elementary school teachers teach all subjects, and few have a strong background in science. As individuals, our outreach to children can include cooperative activities with local schools. Visiting classrooms, arranging tours of your lab, or leading field trips are examples of things you might do. If there are “out-of-school-time” activities in your community (Bell et al. 2009), consider sharing your science expertise with these program. When talking with children, remember both to emphasize the significance of minerals and to be a Pied Piper for science.

An even more important opportunity exists right now to have a major educational policy impact through your support for The Next Generation Science Standards (NGSS) (National Research Council 2013; see also www.nextgenscience.org). This is a unique opportunity, which grew out of a 2011 National Research Council report (National Research Council 2012; Wysession 2014). The NGSS are practice-based, performance expectations that emphasize processes and ask for assessment of what students can do, rather than giving tests on terminology and memorization. The NGSS place Earth and space sciences on a par with life sciences and physical sciences in the K-12 curriculum, which should lead to considerably more exposure to Earth and space science in high school. If you can get your state to accept the NGGS, Earth and space (and mineralogical!) sciences understanding by high school graduates should dramatically increase. So might college enrollments and other indicators of an appreciation of the importance of Earth and space sciences. Look into the processes and politics of NGGS adoption in your state and find out how you can promote it.

The general public, voters, and government policymakers make decisions that should be informed by the mineralogical sciences. Even if the Next Generation Science Standards are adopted by all states, it will take many years to have the desired effect on science literacy. Policymakers and the public should know that the research of mineralogical scientists can help locate deposits of rare earth elements, can help document the Earth’s past climate, can help solve environmental problems, and much more. We need to tell them what we do in words that they can understand, as a Society and as individuals. According Falk and Dierking (2010), because people spend only about 5% of their life in a classroom "…the best way to increase the public understanding of science is to reach people during the other 95 percent of their life."

Our education as scientists has not prepared us well for effective communication with non-scientists, so outreach to the general public may be our most difficult task. This is an area where working together through MSA makes sense. *Elements* magazine has proved to be a successful platform for mineralogical sciences outreach, but it is written for scientifically literate readers. Similarly, thanks to Editor Keith Putirka, there are now regular summaries of especially interesting results reported in *American Mineralogist*, but these are also for scientists. We need strategies and personnel to translate this material into press releases, website pages for public consumption, popular science blogs, letters to members of congress, YouTube® videos, and more. A new initiative proposed by current MSA President Steve Shirey to create Minerals Matter Geoscience Sheets (MMGS), written for the high school level in a "News and Views" style and published in *American Mineralogist*, is exactly the kind of activity needed. Please consider writing an MMGS that focuses on the role of minerals in your research. We must be proactive and imaginative in promoting our science and MSA is a good organization to coordinate this effort.

Implications

According to the original MSA bylaws, "The object of the Society shall be the advancement of mineralogy, crystallography, geochemistry, and petrology, and the promotion of their use in other sciences, industry, education, and the arts." If you are reading this, you either are or should be a member of MSA. It is we, MSA members, who must advance and promote our science. I argue here that education and outreach require our ongoing and increased attention. Our students, our scientific colleagues, the public, and our politicians must see minerals as a critical part of their lives, and see studies involving minerals as a growth area for the advancement of science and for solving important problems. The potential benefits are not only for the mineralogical sciences, but also for science in general and for the public good. Even though these activities will take time from our research, it will be time well spent and should help assure a second centennial of *American Mineralogist* and MSA.

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References Cited

AGI (2013) Earth and Space Sciences Education in U.S. Secondary Schools: Key Indicators and Trends. Earth and Space Sciences Report Number 10, American Geosciences Institute, Alexandria, VA, 10p.

Bell, P., Lewenstein, B., Shouse, A.W., and Feder, M.A., eds. (2009) Learning Science in Informal Environments: People, Places, and Pursuits. The National Academies Press, Washington, D.C.

Brady, J.B. (2010) MSA Presidential Address: Will mineralogy save the world? Geological Society of America Abstracts with Programs, 42, 5, 480.

Brady, J.B. (1995) Confessions of a mineralogy professor: Geotimes, 40, 4.

Carey, K. (2014) Americans think we have the world's best colleges. We don't. New York Times, June 28, 2014.

Downs, R.T., and Hall-Wallace, M. (2003) The American Mineralogist Crystal Structure Database. American Mineralogist 88, 247-250.

Dyar, M.D., Gunter, M. ., and Tasa, D. (2008) Mineralogy and Optical Mineralogy. Mineralogical Society of America, Chantilly, Virginia, 708 pp.

Falk, J.H, and Dierking, L.D. (2010) The 95 percent solution. School is not where most Americans learn most of their science. American Scientist, 98, 486-493.

Humphries, M. (2013) Rare Earth Elements: The Global Supply Chain. Congressional Research Service Report for Congress R41347, 27 p.

Kelly, D., Xie, H., Nord, C.W., Jenkins, F., Chan, J.Y., and Kastberg, D. (2013). Performance of U.S. 15-Year-Old Students in Mathematics, Science, and Reading Literacy in an International Context: First Look at PISA 2012 (NCES 2014-024). U.S. Department of Education, Washington, DC: National Center for Education Statistics, 39p.

Kraus, E.H. (1921) The future of mineralogy in America. American Mineralogist, 6, 23-34.

Lehnert, K., Su, Y., Langmuir, C., Sarbas, B., and Nohl, U. (2000) A global geochemical database structure for rocks. Geochemistry Geophysics Geosystems, 1, doi:10.1029/1999GC000026.

Layton, L. (2013) U.S. students lag around average on international science, math and reading test. Washington Post, December 3, 2013.

National Research Council (2008) Minerals, Critical Minerals, and the U.S. Economy. The National Academies Press, Washington, D.C., 264 p.

National Research Council (2012) A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. The National Academies Press, Washington, D.C., 400 p.

National Research Council (2013) Next Generation Science Standards: For States, By States. The National Academies Press, Washington, D.C., 532 p.

National Science Board (2014) Science and Engineering Indicators 2014. Arlington VA: National Science Foundation (NSB 14-01), 601 p.

National Science Foundation (1998) Federal Funds for Research and Development: Fiscal Years 1996, 1997, and 1998, Detailed Statistical Tables, NSF 98-332. National Science Foundation, Arlington, VA., 320 p.

National Science Foundation (2013) Federal Funds for Research and Development: Fiscal Years 2010–12, Detailed Statistical Tables, NSF 13-326. National Science Foundation, Arlington, VA., 351 p.

OECD (2013a) OECD Skills Outlook 2013: First Results from the Survey of Adult Skills. OECD Publishing, Paris 462 p.

OECD (2013b) Time for the U.S. to Reskill?: What the Survey of Adult Skills Says. OECD Skills Studies, OECD Publishing, Paris 106 p.

Ralph, J. (2014) mindat.org - the mineral and locality database. http://www.mindat.org/, accessed Aug.14, 2014.

U.S. Geological Survey (2014) Mineral commodity summaries 2014: U.S. Geological Survey, 196 p.

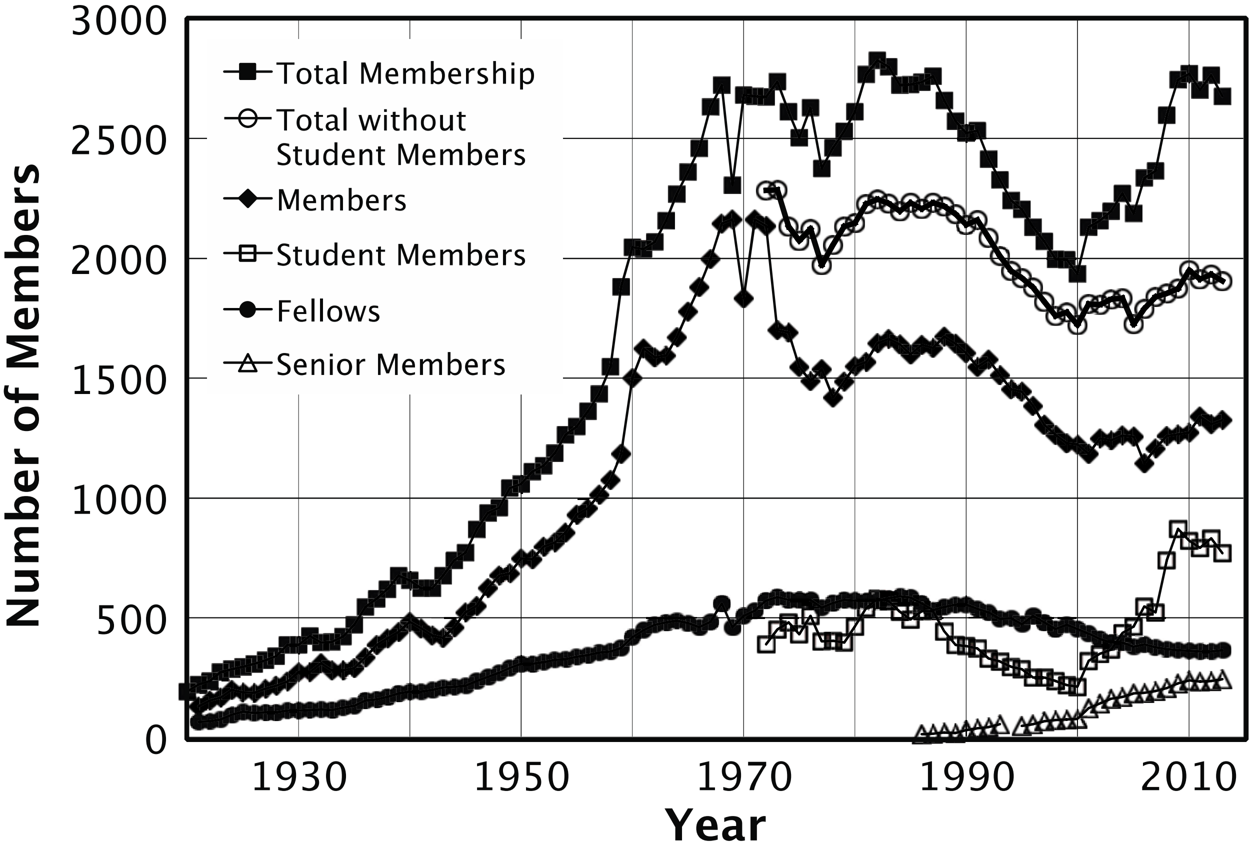
Wilson, C. (2014) Status of the Geoscience Workforce 2014. American Geosciences Institute, Alexandria, VA, 125p.

Wysession, M. . (2014) Next Generation Science Standards present unprecedented opportunities (and challenges) for K-12 education. In the Trenches, 4:2, 1-3.

Figure Captions

Figure 1. Membership of the Mineralogical Society of America by membership category and year. Membership has been on the rise in nearly all categories since 2000. Data compiled by the MSA Business Office.

Figure 2. *American Mineralogist* pages published and institutional subscription data. The large drop in number of pages published in 1973 was due to a change in format to a larger page size. Starting in 2000, institutions subscribing to *Geoscience World* (GSW) were given electronic access to *American Mineralogist*. Data compiled by the MSA Business Office.



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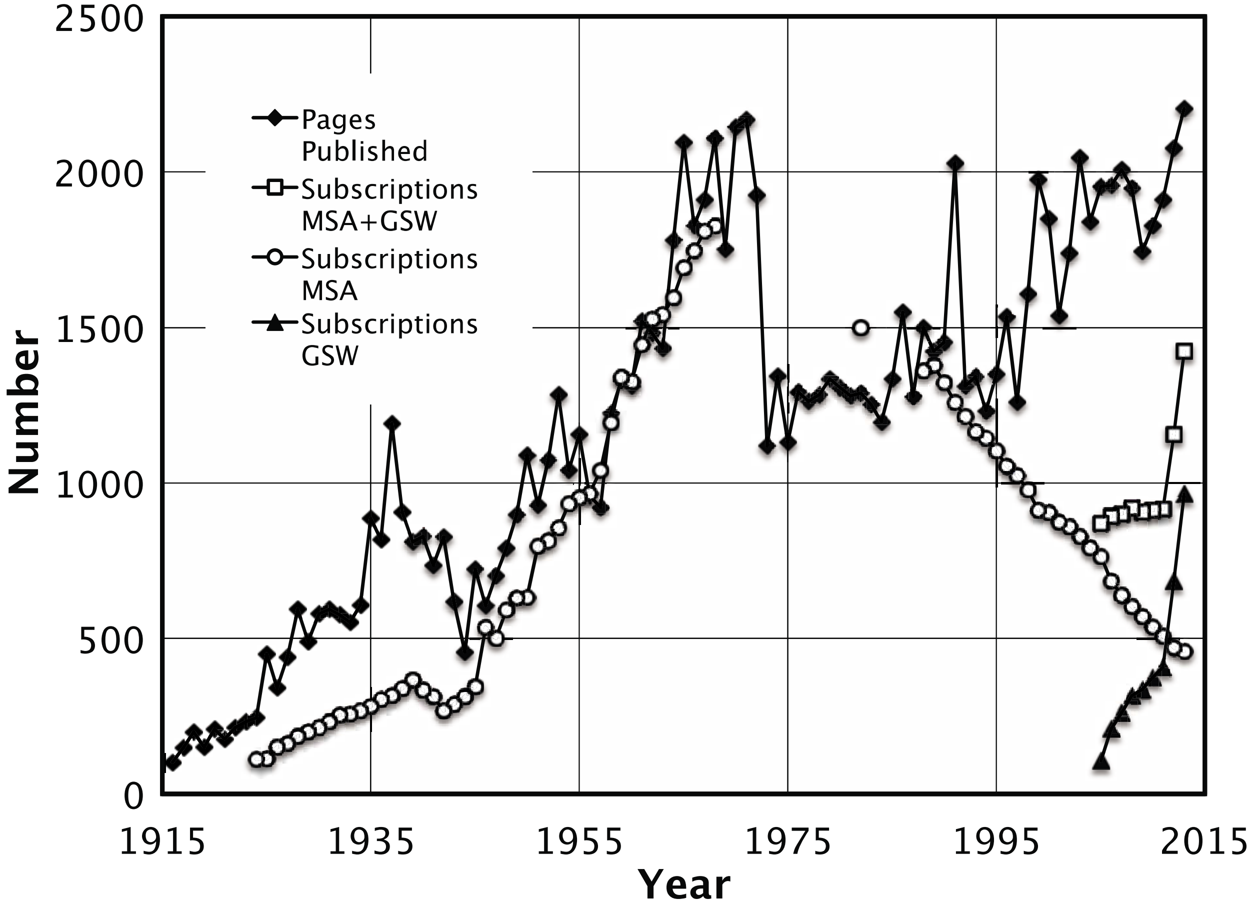

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