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Nationalist Science and International Academic Travel in the Early Nineteenth Century: Geological Surveys and Global Economics, 1800–1840

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This study examines the connection between international exchange and national service in the institutionalization of scientific research in the United States in the first half of the nineteenth century. In particular, it investigates the case of coal exploration as a motive for international academic travel among early-nineteenth-century geologists, placing both the coal industry and the flow of coal-oriented geological knowledge in global economic context. Drawing from the letters and travel diaries of such figures as Benjamin Silliman, William Maclure, and Henry Darwin Rogers, among others, it contends that shifts in the global demand for coal hastened the pursuit of international scientific exchange and, in turn, the progress of American geological research and scientific education. By the 1830s and 1840s, when many states were launching ambitious geological surveys that relied on well-trained geologists—many of whom had studied abroad—international academic exchange went hand in hand with distinctly nationalist economic and educational goals.

I. Introduction

Between 1830 and 1840, sixteen of the twenty-six U.S. states—North Carolina, South Carolina, Massachusetts, New York, Tennessee, Maryland, Connecticut, Virginia, New Jersey, Maine, Pennsylvania, Indiana, Michigan, New Hampshire, Delaware, and Ohio—con-

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ducted major geological surveys. These surveys often provided the nation's young scientists (not only geologists, but also botanists, zoologists, paleontologists, and others) with advanced training in their respective fields. As one historian has observed, the surveys offered the first opportunity for graduate-level education in the United States: "Decades before American colleges were capable of taking over the function," William Stanton explains in his bibliography of survey materials at the American Philosophical Society, "the surveys and explorations served as graduate schools and started many—often at a remarkably youthful age—on careers in science."[1] Indeed, a number of these young men (virtually all of them were men) went on to prominent academic careers.[2]

For the most part, historians of the state geological surveys have emphasized the dramatic tales of wilderness adventure, the original contributions to scientific knowledge, and the many political battles that accompanied the surveys' operations. Less thoroughly studied, however, has been the broader international—indeed, global—historical context in which these surveys emerged.[3] Typically cast as preeminently American endeavors for domestic scientific and economic development, the geological surveys in fact depended on a cross-national exchange of scholarly ideas. Indeed, these surveys, intended to advance the cause of domestic economic development, simultaneously reflected a global contest for commercial supremacy in a rapidly industrializing age. Put simply, the backdrop for state geological surveys in early-nineteenth-century America was a growing desire to outpace Europe, and especially Great Britain, in the discovery of natural resources. The race for mineralogical resources was a worldwide race, and the young scientists who led the first state geological surveys—many of whom received additional scientific training abroad—played a key role in bolstering the United States' competitive position.

The development of large-scale geological surveys in the United States coincided with similar developments elsewhere. Great Britain, for example, initiated far-reaching surveys in nearly every part of its global empire in the first half of the nineteenth century. In his biography *Scientist of Empire: Sir Roderick Murchison, Scientific Exploration, and Victorian Imperialism* (1989), for instance, historian Robert Stafford maps the detailed causes and consequences of British geological research under the administration of Sir Roderick I. Murchison (1792–1871), director-general of the British Geological Survey, president of the Royal Geographic Society, and indefatigable promoter of the scientific exploration and exploitation of natural resources across Britain's empire. "By promoting exploration, resource reconnaissance, commercial expansion, and imperial development and security" in the 1840s, 1850s, and 1860s, Stafford explains, Murchison "stimulated systematic exploitation of the empire and the entire periphery." Tracking his geologist-protagonist across five continents, Stafford notes that Murchison's "professed scientific internationalism" often gave way to his "competitive instincts" in a global contest for industrial profit and national prestige.[4]

It would be difficult to overstate the role that geologists played in this contest. As industrialization spread from Great Britain to the United States, demand for raw materials grew. Stafford observes: "As industrial technology evolved during the nineteenth century and metal production rose as a share of total manufacturing output, economic dependence on mineral resources and knowledge of the earth's structure intensified. Both the variety and quantity of minerals consumed by industry grew at an accelerating rate. . . . When the more easily accessible supplies of the scarcer ores were exhausted, production costs rose, [thus] stimulating exploration for new and cheaper supplies, and a number of peripheral production centres successively emerged to feed the voracious North Atlantic markets."[5] In such an environment, geologists found themselves in steadily increasing demand, and relations between scientists, industrialists, and government officials intensified. Indeed, the same combination of scientific and economic motives that drove geological activity in the British empire—that is, industrial profit and national prestige—also drove geological activity (as well as improved geological education) in the United States.[6]

As the demand for geologists expanded in the first half of the nineteenth century, so, too, did the demand for advanced training in the geological sciences. Such education was, however, difficult to obtain in the United States before mid-century. Consequently, most of the young scientists who later directed state geological surveys pursued advanced training abroad. Before institutions of higher education in the United States began to offer systematic courses in geology—or related fields such as mineralogy and paleontology—universities in Europe did so, and American scholars took advantage of these offerings. In doing so, they joined a growing network of "professional" geologists on both sides of the Atlantic devoted, in part, to original research and discovery and, in part, to promoting the commercial interests of their own respective nation-states. To understand this cross-national network of geologists—and the economic motives driving its development—one must first understand the global race for mineral resources in the early nineteenth century.

This study examines the overseas academic travel of three well-known geologists who studied in Europe, played leading roles in the first state geological surveys, and later held prominent scientific and scholarly posts. What each of these scholars shared while abroad was a heightened sense of national identity and a conviction that national service was a necessary component of every scholar's work.[7] Both directly and indirectly, these internationally educated American scientists, like their contemporaries in other fields and other countries, associated scholarship with nation-building.[8]

The three geologists are (1) Benjamin Silliman, who graduated from Yale in 1801 and received the university's first appointment to a chair in natural science in 1802, after which he traveled in England, Scotland, and Belgium—and was famously denied entry into France—in search of scientific apparatus and books for Yale; (2) William Maclure, an independently wealthy "gentleman scholar" who geologized his way through Sweden, Russia, Germany, Switzerland, Italy, France, and the eastern United States, played a key role in the leading scientific associations of Philadelphia, and published some of the first systematic works on North American geology; and (3) Henry Darwin Rogers, one of four Rogers brothers to achieve prominence in American science, who attended the College of William and Mary in the 1820s, studied for a year in England, led both the Pennsylvania and the New Jersey Geological Surveys while his brother, William Barton Rogers, led the Virginia survey, and taught at the University of Pennsylvania before ending his career on the faculty of the University of Glasgow.

Tracing the international academic travel of these geologists, this study examines their scientific experiences overseas and their drive to foster American economic growth upon their return. It looks in particular at the case of *coal exploration* as a primary motive for international academic travel among early-nineteenth-century geologists, placing both the coal industry and the flow of coal-oriented geological knowledge in global economic context. Ultimately, it argues that shifts in global demand for coal (owing to innovations in the technology

used to manufacture iron products) hastened the pursuit of international scientific exchange—and the progress of American scientific education—in the opening decades of the nineteenth century. In this period, international academic exchange went hand in hand with the pursuit of distinctly nationalist economic and educational goals.

This study draws on four interconnected historical literatures that often appear separately. First, it draws on a literature concerning the scientific and political history of the state geological surveys. Second, it draws on a literature concerning the international economic and geopolitical history of the iron and coal industries. Third, it contributes to a growing literature on the educational history of study abroad and the institutional history of graduate education in the United States in the early nineteenth century. Fourth, it adds to a comparative historical literature on early-nineteenth-century institution-building and professionalization in the natural sciences. As part of the "prehistory" of the American research university, the state geological surveys of the 1830s and 1840s gave American scientists a chance not only to advance their professional reputations—both at home and abroad—but also to serve the economic interests of the United States in an increasingly competitive global marketplace.

II. Benjamin Silliman: International Academic Travel in the Early Nineteenth Century

In 1801, the corporation of Yale College appointed Benjamin Silliman to a newly established professorship in chemistry, geology, and mineralogy.[9] Shortly thereafter, the corporation sent him to Europe to prepare for his lectures on the subject and to purchase equipment necessary for a modern chemical laboratory. It would be impossible to recount every detail of Silliman's journey in this brief study, but a few episodes merit attention. First, one must note the extent to which Silliman combined formal academic preparation with informal observations of practical geology in the field. He dedicated several months to lectures at the University of Edinburgh but spent much of his free time visiting active mines throughout England and Scotland.[10]

In the first volume of his diary, Silliman described at length his mining expedition to Derbyshire: "Ever since I have attended to chemistry and mineralogy," he commented, "it has been my wish to explore those dark recesses where nature has hidden the treasures of the mineral kingdom; I believed that no method of investigation could be so effectual as to leap at once into these dreary caverns and see with my own eyes the arrangement of strata, the position of [the] spars and crystals and the original state of the metallic veins. Accordingly, I started at 10 a.m. on a fine day, with an empty portmanteau to bring back anything which I might pick up in the mines." He went on:

> I was equipped as before with a candle and wore a short jacket and pantaloons with a handkerchief tied around my head. We descended down more than a hundred wood steps under a vault arched with stone. We then proceeded through passages generally narrow, low, and dirty from the constant oozing of water, but sometimes wide and lofty, presenting numerous caverns of various dimensions where rocks and cliffs projected and hung in every grotesque and threatening form. . . . At the bottom of this pit I saw several veins of the fluor and dug some of it up with the pick ax. I saw these veins also in many other parts of the mine. They are included in limestone, which formed the walls of this mine as well as the rest. I presented the same petrifications of skull fish and animals of various species. How came these animals here?[11]

Silliman's account filled page after page of his notebook, and he repeated this exercise in other mines throughout Derbyshire and Cornwall. Stowing mineral samples in his bag, he carefully recorded each specimen in his journal before moving on.

Silliman's description of the Dolcoath copper mine near Redruth was particularly elaborate and showed the degree to which his pursuit of geological knowledge was more than merely academic. He explicitly linked the educational value of his work to its future economic value. As he explained:

> Redruth is in the centre of a circle of about six miles diameter within which are contained the most important mines. I came into the country with the impression that tin was its principal production, but I find that copper is by far the greater concern, and that tin is only a secondary consideration. The tin is less abundant than formerly, but the copper is more so, and the high price which the latter article now commands makes it a very profitable business. The expenses of the Dolgoath [*sic*] mine are about 7,000 or 8,000 pounds sterling per month, and their clear profits for the last five months have been 18,000 pounds sterling. . . . The produce of the Cornish mines is now prodigious. That little district around Redruth is said to produce 500,000 pounds sterling per annum.[12]

Silliman's diary made it clear that he would apply the knowledge he gained in Europe not only to "pure" geological science but also to economic pursuits back in the United States. Whether the object of the miners' efforts was copper, tin, feldspar, silver, or some other resource, he intended to learn the geological stratum in which the mineral could be found (hence his interest in fossil "petrifications of skull fish and animals of various species" in the previous quotation), the methods employed to extract it, and its commercial uses.[13]

Silliman's travels brought him not only to England and Scotland but also to the continent. In his attempt to visit Paris, however, he confronted the political realities that surrounded geological research in the early nineteenth century. In the context of ongoing war between Great Britain and France, he could not persuade the French gendarmes that he was a neutral party traveling for benign scientific reasons. Instead, he was suspected of scientific espionage. When he reached the French border, the gendarmes demanded to know the purpose of his travel and whether he and his companions had recently been in England.[14] A heated discussion ensued:

> This demand was unexpected, for no American so far I had learned, had ever been questioned in the like manner, before. But it was obvious that the question was not proposed for the purpose of gaining [actual] information, for I had no doubt that . . . [the guard] . . . possessed from official sources the best evidence that we came from England. This evidence he had doubtless obtained from Rotterdam, and stood ready to throw it in our faces in case we had denied it. Such a denial would have fixed upon us the imputation of being spies and would without doubt have given us lodging in a prison that very night. . . . I enquired whether there was any doubt of our being *Americans*. He replied No! not the least. What then are we to do? "You may have your passports to return to Holland, or you may wait here, till we can lay your case before the department of foreign affairs." How long before we can have an answer? "It may be 10 or 15 days."[15]

Dismayed at the prospect of waiting two weeks for the French to resolve his case—and recalling that a fellow American seeking entry into France recently "fell under suspicion and was complimented with lodgings gratis in the national apartments," Silliman tried to persuade the guards that his work posed no political danger.[16] As he put it:

> I urged my official connection with a respectable literary institution, the interests of science, as connected with my mission, the diplomas and testi-

> monials of character which I bore from colleges and learned societies, my letters of recommendation from eminent men abroad to distinguished men in France and I particularly urged my letters to [Louis Bernard] Guyton de Morveau [a professor of chemistry at the École Polytechnique in Paris and a colleague of Antoine-Laurent Lavoisier] and Cassenove, men whom I stated to be equally high in the confidence of the French government as respected abroad, and on all these grounds solicited that I might still be suffered to go to Paris.

But he was not permitted to pass. "I was heard with some degree of patience," he wrote, "but the subprefect replied . . . that even a member of the French National Institute had been the other day arrested with his daughter for having been in England and that French men under our circumstances would be immediately arrested."[17] The guard's demeanor then changed:

> He now demanded of me in a menacing tone whether I did not know that I had no right to come from England to France. I replied that as a neutral I supposed I had a right! Next, did not I know that people going from France to England were arrested in that country and imprisoned? I replied that I had a personal knowledge that the fact was not so, for I knew that such people went at large in England and were not molested. I expected every moment that he would break out into a passion from my urging the discussion so far. But he was pleased to compliment us by saying that although nothing appeared against us, *we might still have political views* and added with insulting politeness that *the most honest and open countenance might still cover a spy.*[18]

Silliman was incensed. "The character of a spy was quite a new one to me. I smiled at his remark, but I believe my countenance expressed a mixed emotion of mirth and contempt and anger, for I felt all three."[19] Nothing he could say would change the guard's position. So, accused of being a spy, he grudgingly took his passport and headed back to England.

Silliman's experience at the French border was not unusual in this period, when the trials of war cast doubt even on those whose scientific motives may in fact have been "pure" (though, given the overlap between scientific and economic aspirations in this era, claiming to have perfectly pure motives was difficult). Silliman's contemporary, William Maclure, faced similar accusations of espionage on a geological tour of Europe between 1805 and 1808. An independently wealthy amateur scientist who had gone to Europe to settle a financial claim of the U.S. government in France, Maclure quickly finished this business and set off with his friend Joseph Cabell (who later assisted Thomas Jefferson in the creation of the University of Virginia) on a geological tour of France, Germany, Italy, Switzerland, and Spain. Despite—or perhaps because of—his role as a representative of the U.S. government, Maclure faced constant resistance in his attempts to collect mineral specimens from European mines.[20]

Even with their scientific and diplomatic credentials and their claim to be working for purely academic purposes, Maclure and Cabell were barred from several of the mines they hoped to visit. As Cabell explained during their stop in Clermont in southern France:

> [W]e found at Clermont what Mr. Maclure had experienced in Germany: that the learned men of the country were unwilling to make known to us the places where minerals were to be found. The motives: to prevent a knowledge of the places to all but themselves in order for some to profit by the commerce of the minerals; others, to have the sole credit of presenting the specimens to strangers; and others, to keep all the facts to themselves in order no to have rival writers at a distance.[21]

Maclure added that, "Although we had several letters during this short excursion through Auvergne, they were of no use. We could get no information, not even a guide who knew anything of the country. Men who have crawled over a country for thirty years to know whether the stones are round or square don't easily give up [to foreigners] what they have acquired. They rather look with jealousy on strangers."[22] Far from experiencing a global fellowship of mutually cooperative scientists, Maclure encountered what he considered to be a national conspiracy to prevent outsiders from learning the contents of French mines.

Such obstacles to mineralogical inquiry were not limited to France or Germany. Maclure and Cabell encountered similar barriers in Spain. "Even the fine officers of the government [in Spain] . . . believe the rocks we have taken on their mountains contain gold and silver, and that we have the means of extracting it. They can't even keep their ignorance to themselves, but talk of it before us and seem to say, 'you come here to take away our riches and diamonds.' They have not the smallest idea of any science. To tell them we collect specimens of all the rocks in order to know what substances the different mountains are formed of, is out of their conception."[23] Even when Maclure insisted that his scientific motives were untainted, he could not escape mistrust; indeed, his traveling companion in Spain, an Italian geologist named Matthieu Tondi, was twice arrested and detained on suspicion of being a spy.

Eighteen months later, in 1809, Maclure faced similar barriers in Sweden, where, he discovered, members of the Council of Mines at Stockholm were "mineral merchants" hording specimens for profit.[24] "The chief at Fahlun sold the rocks that came out of the mine at twelve shillings for each specimen," he noted, adding:

> It will cost rather dear to buy from them the duplicates I want for the schools. Also, it will be difficult to have them from the place where they are found, as they no doubt have an interest in preventing any stranger from visiting such places or from being able to procure any when there. It is one of my stumbling blocks to find men who pretend to science, warping and distorting the truth to serve the purpose of their trade.[25]

According to Maclure, such mineral-hording posed serious obstacles to the advancement of geological education. Unable to obtain specimens of gadolinite or pyrophysalite, he noted, both "substances are held out as rare and . . . are kept at [artificially] high prices, which makes a kind of monopoly of the science of mineralogy and makes it accessible only to the rich. . . . In this country, where minerals of all kinds are thrown out in heaps, there are mineral cabinets for instruction only at Stockholm and Upsala."[26]

Maclure did not, however, present the whole story behind his own mineralogical investigations. Despite his frequent protestations to be working solely for the purposes of "pure" science and geological education, he fully expected to use the data he collected to advance the cause of commercial and industrial development in the United States. In the fifteen months *before* his tour of Sweden, he had conducted an unprecedented geological survey of the entire eastern seaboard of the United States. He visited sites in Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Delaware, Pennsylvania, Maryland, the Carolinas, and Georgia, and, upon the completion of his survey, gave a landmark paper, "Observations on the Geology of the United States, Explanatory of a Geological Map," to listeners at the American Philosophical Society in Philadelphia. The timing of Maclure's paper—and its novel map of East Coast

geology—was significant. A few months earlier, explorers Meriwether Lewis and William Clark had returned from their historic western journey, and popular enthusiasm for geological research was growing. Special interest attached, for example, to rumors of commercially valuable coal and iron deposits west of the Appalachians.

Thus, when Maclure visited Sweden in 1809, it was not unreasonable to assume that he linked his focus on "pure" geological research to a parallel focus on commercial development in the United States. As John Doskey, editor of Maclure's extensive travel journals, notes of the wary reception he received from Swedish mine officials, "Although Maclure was a naturalized American citizen [he was born in England but had come to the United States with his father at the age of thirteen], he may have aroused the suspicions of some of the more important officials (and a number of scientists) who were concerned with protecting the Swedish iron industry and also monopolizing the mineral trade." In particular, Doskey points to Erik Thomas Svendenstjhema, a professor of geology at the Swedish College of Mines and a supervisor of iron manufacturing in northern Sweden, as one who seemed nervous about Maclure's visit. Svendenstjhema had visited England in 1802 and 1803, Doskey explains, "and was baffled and terrified by the advances [the new puddling technique] made by the English and Scottish iron works, which apparently were as yet unknown in Sweden."[27] Svendenstjherna may have feared that Maclure's visits to Swedish mines and factories threatened his country's economic interests.

Until the late eighteenth century, Sweden had been Europe's dominant supplier of high-quality wrought iron products. Maclure's visit, however, coincided with Sweden's rapid loss of market share to England. What made the difference was the new "puddling" process in England, which removed impurities from iron ore and made it easier to shape into finished products. Earlier, these impurities—precipitated by sulfur fumes introduced during the blasting process when the ore was heated to extreme temperatures—had to be removed by pounding the pig iron with giant hammers. The puddling process invented in England used chemicals to accomplish the same goal much less expensively. By the early nineteenth century, low-priced British "puddled" iron threatened to undermine Sweden's hammered iron production. As economic historian Ernst Söderlund has noted:

> [T]he new market situation emerging from the expansion of the puddling process in Britain also carried serious consequences for the Swedish iron industry. Its [Sweden's] exports to Britain, even in the late eighteenth century, had comprised 40 percent or more of [its] total exports; after the Napoleonic wars they fell to 15–20 percent.[28]

Swedish producers found themselves in a difficult spot, because the puddling techniques required the extreme heat generated by coal-powered furnaces, and Sweden, while rich in forest materials needed for charcoal-powered furnaces, had no coal.

The Swedes had good reason to be suspicious of William Maclure as he snooped around in their mines and factories. After all, they had responded to British competition in the first decades of the nineteenth century by sending most of their surplus charcoal-fired iron to the United States—a market where domestic iron production was practically non-existent and where tariffs on hammered (Swedish) iron were far lower than tariffs on puddled (British) iron. As Söderlund writes:

> Even before the end of the Napoleonic wars, direct exports [of Swedish hammered iron to the United States] went up to about 10,000 tons annually and reached over 20,000 tons in the 1820s. In the 1830s, annual exports to the United States were normally between 20,000 and 30,000 tons per annum, thus exceeding even the highest eighteenth-century level of exports to England. An important cause contributing to this expansion of American iron imports from Sweden was the fact that import duties on hammered iron—and all Swedish bar iron at this time was hammered—were considerably lower than those on rolled iron, i.e. primarily British puddled iron.[29]

Sweden made the most of this competitive advantage over Britain in the U.S. market for the first two decades of the nineteenth century, but this advantage did not last forever. By the 1830s, when state geological surveys began to locate more sources of iron and coal, domestic American manufacturers entered the fray. Like the Swedes, the American iron manufacturers initially did not adopt the puddling technique, preferring to heat their ore in charcoal-powered furnaces. But after the discovery of coal in Pennsylvania, Americans saw an opportunity to outmatch both Swedish *and* British producers by delivering high-quality, low-cost puddled iron to their own domestic market.[30]

Domestic production of iron for the American market depended fundamentally on the availability of large quantities of coal, and the

availability of coal depended, in turn, on new geological discoveries. Awareness of iron and coal deposits in the United States expanded dramatically in the early nineteenth century. As early as 1807, the first load of anthracite coal made its way out of the Wyoming Valley in eastern Pennsylvania, and the following year, the use of anthracite as a fuel agent got a boost from the invention of the anthracite fire-grate.[31] The first extensive use of anthracite *outside* Pennsylvania began during the War of 1812, when manufacturers in New England lost access to both British and Swedish wrought iron goods and had to produce their own—a situation that sharply increased demand for anthracite to power blast furnaces.[32] After the war, land speculators bought property rich in coal in Pennsylvania and began to lobby aggressively for canals to ship this resource to eastern markets.[33] As demand for coal grew and profits began to rise, appeals for state-funded geological surveys—together with appeals for improved geological education in American colleges—followed. In this context, economic motives joined whatever "purely scientific" motives geological research may once have claimed. Indeed, both Silliman and Maclure embraced this new, economically motivated quest for coal.[34]

III. Institutionalizing the Geological Sciences in the United States

After his return from Europe in 1806, Benjamin Silliman began offering a course in chemistry to seniors at Yale. Four years later, in 1810, Yale acquired the mineralogical cabinet of Colonel George Gibbs, which included samples from several famous European collections, including those of Gigot d'Orcy, Count Gregoire Razamovski, and Count de Bournon.[35] With this cabinet at hand, Silliman began to offer mineralogical instruction at Yale. He also wrote a "Sketch of the Mineralogy of the Town of New Haven," which he delivered in an address to the Connecticut Academy of Arts and Sciences.[36] Noting both the scientific and the economic benefits of his survey, he claimed it would "lead to such discoveries as will certainly be subservient to science, and may not improbably open new sources of domestic wealth, and materials for architectural and manufacturing industry." Slowly but surely, young Silliman began to demonstrate the practical utility of advanced geological education in the United States. By 1816, he reported more than fifty "unusually attentive" pupils (a quarter of the student body) enrolled in his chemistry and mineralogy courses at

Yale.[37] As one alumnus wrote from Georgia, "the science of Chymistry [*sic*] is deservedly gaining ground in the estimation of all well informed circles in America, and the introduction of a Professor of this useful branch of Education into Yale College has greatly increased the former['s] good fame."[38]

Over the next decade or so, the geological and mineralogical sciences grew more organized—and more professionalized—in the United States. John Gorham and William Dandridge Peck, whose company Silliman had enjoyed in Edinburgh, initiated a course in chemistry, mineralogy, and geology at Harvard; Frederick Hall started a similar course at Middlebury; and Parker Cleaveland soon followed suit at Bowdoin.[39] Then, in 1819, the leading scholars in the field convened at Yale to create the American Geological Society. Presiding over the new society was William Maclure and serving as vice president (one of three vice presidents) was Silliman, who, in 1818, had founded his *American Journal of Science* as a clearinghouse for scientific discoveries.[40] Also joining the Society's early activities was Amos Eaton, who had attended Silliman's geology courses at Yale in 1815 and in 1817 had returned to his alma mater, Williams College, as professor of chemistry and mineralogy. In 1818, Eaton had published *An Index to the Geology of the Northern States: With a Transverse Section from the Catskill Mountains to the Atlantic*, a textbook recognized as the period's best introduction to geological science.[41]

Like Silliman, Eaton blended scientific, economic, and educational motives in his geological work, and his activities over the next decade reveal many connections between these aspects of the new science. In 1819, the year the American Geological Society first met at Yale, Eaton gave a series of geological lectures to state legislators in New York who had recently authorized a canal linking the Atlantic Ocean—via the Hudson River—to Lake Erie. Among those who heard Eaton was Stephen Van Rensselaer, a key sponsor of the Erie Canal, who used his post as head of New York's Central Board of Agriculture to hire Eaton to study the fertility of land along the canal route (land that Van Rensselaer himself owned). Eaton finished this task in 1821, and two years later, in 1823—the year Van Rensselaer was first elected to Congress, where he joined the House Committee on Agriculture—Eaton extended his survey to cover the entire length of the canal (and more of Van Rensselaer's vast holdings).[42] With political as well as financial patronage from Van Rensselaer, young Eaton put his geological expertise to use, advancing scientific as well as economic interests.

The broader historical context of Eaton's surveys was important, because, in 1819 and 1820, the American economy had plunged into a financial crisis with global origins. Specifically, a disruption in the world supply of precious metals—caused in part by the struggle for independence in Mexico and in part by the fact that European governments, still burdened with debt after the Napoleonic Wars, were hording their specie—had led to a massive panic in global financial markets. When lenders were asked to redeem loans in specie, they could not find the required metal currencies; then, in an effort to buy specie at inflated rates, they called in other debts, which, in turn, led to a general collapse of the American credit system. Blaming this crisis on the financial mismanagement of President Monroe and his Democratic-Republican administration, Van Rensselaer ran for Congress in 1823 as a Federalist committed to restoring the stability of the National Bank. He also promised to aid industries hurt in the panic by offering government support for domestic manufactures (along the lines his friend Alexander Hamilton had described in his *Report on the Subject of Manufactures* [1791]).[43] Van Rensselaer's concern for both national and personal recovery in the wake of a global monetary crisis influenced his activities in this period, including his patronage of Eaton's geological surveys in New York.[44]

Upon the completion of Eaton's surveys in 1823, Van Rensselaer hired the young scientist to give a series of popular lectures on natural resources across the state—lectures ostensibly academic in purpose but also designed to publicize the increasing value of Van Rensselaer's own holdings. Always keen to associate his own interests with the interests of the nation, Van Rensselaer also donated a large sum, in 1824, for the establishment of a new school in Troy, New York, to promote advanced scientific and technical education. Initially chartered as the Rensselaer School, then the Rensselaer Institute, and finally the Rensselaer Polytechnic Institute, the school was unusual for its time.[45] With no courses in classical languages or theology, its curriculum stressed "the application of experimental chemistry, philosophy and natural history to agriculture, domestic economy, the arts and manufactures."[46] While not entirely unique (the Franklin Institute in Philadelphia opened the same year with a similar mission), the

Rensselaer School set a striking new standard for scientific education in the United States.[47]

Van Rensselaer recruited Eaton to direct his new school, and Eaton saw to it that "applied" science pervaded every aspect of the school's program. After the Erie Canal opened in 1825, for example, Eaton took advantage of its potential as a teaching aid. In the summer of 1829, he launched his first "Rensselaer School Flotilla," marketed as an eight-week summer "Term of Traveling Instruction."[48] With twenty students assigned to a fleet of tow-boats, the flotilla worked its way up the Erie Canal from New York City to Lake Erie in June and back in July. Offering an elaborate scheme of field-based courses from geology and mineralogy to botany, zoology, and applied mathematics (the latter to include lectures in land surveying, harbor surveying, and civil engineering), the flotilla gave students opportunities for "direct inspection of rocks and minerals in place, plants and minute animals in their native localities, the work of the engineer in actual operation, the labor of the agriculturalist where he labors in good earnest on a large scale, and the principles of mechanical philosophy efficiently applied to various engines and hydraulic works, as at Rochester, Lockport, etc."[49]

Unburdened by the constraints of traditional (so-called classical) education, the Rensselaer School Flotilla stressed the practical analysis and commercial uses of mineral resources. Flotilla participants studied, for example, "the boiling and evaporating works, growing marine plants, saliferous rocks, and pseudo-morphous crystals" at Syracuse and Salina, "manlius beds of gypsum, lias, vermicular limestone, pseudo-morphous crystals of salt," the "geodiferous limestone and its disseminated minerals" on the banks of the Genesee River, the "stratified tufa and shell-marl, with shell and vegetable impressions" at Nine Mile Creek, and the "pyritiferous rocks, petrifactions and bituminous shale" at Eighteen Mile Creek on Lake Erie.[50] This last site was particularly interesting for its link to coal deposits (as well as petroleum), while the varied forms of marls were important to students' education in agricultural fertilizers.[51] At each stop, the students learned skills needed to conduct basic geological surveys—the ability to assess soil quality, to identify useful minerals, to recognize geological strata, to see fossil remains, and so on. Along the way, they acquired the knowledge they needed not only to pursue scientific research but also to serve as consultants to farmers and miners.[52]

As it happened, the launching of Eaton's flotilla coincided with a series of breakthroughs in the mining industry—both in New York and in Pennsylvania, where mining had continued to develop with help from geological experts. In 1827, Benjamin Silliman announced in his *American Journal of Science* the initiation of a "Geological Survey of Pennsylvania," commenting that "the cause of natural science will be greatly advanced; the value of lands, at present apparently useless, will be fully developed and incalculably increased; important aid will be afforded to the grand system of internal improvement; the manufacturing and agricultural interest of the country will be essentially promoted; and the whole commonwealth enriched, and most materially and beneficially affected, in her various and most interesting relations."[53] Silliman was acutely aware of the role that geological science could play as a handmaiden of mineral extraction—a connection that became tighter and tighter over time. In 1829, as Eaton's inaugural flotilla made its way down the Erie Canal, the Lehigh Coal and Navigation Company opened its own Lehigh Canal, which provided the first water access to anthracite mines in western Pennsylvania and set the stage for unprecedented growth in American iron manufacturing.

In 1829, Silliman himself had visited Pennsylvania to assess the depth and quality of coal seams, and, the next year, he published a "Notice of the Anthracite Region in the Valley of the Lackawanna and Wyoming on the Susquehanna."[54] Then, in 1831, another young geologist, Henry Darwin Rogers, issued a similar article on "The Anthracite Coal Region of Pennsylvania" in the *Messenger of Useful Knowledge*.[55] These reports carried the authority of scientific expertise and—in an age of increasing financial speculation—boosted demand for anthracite. As economic historian Alfred D. Chandler, Jr., has noted:

> The long burning, clean [anthracite] coal was proving cheaper to use, particularly in the larger cities like Philadelphia and New York, than wood, charcoal, or Virginia and foreign bituminous. The head of the Pennsylvania Hospital in Philadelphia reported in November 1825 that his average cost of heating and cooking with wood over a four year period had been almost $3,200. In the previous year, with the use of anthracite, costs had dropped to about $2,100. Metal manufacturers found the cheaper anthracite also required less attention than charcoal or bituminous coal. A ton of anthracite could do the work of 200 bushels of charcoal. Anthracite had a

cost advantage in cities like Philadelphia (and after 1830 New York), when charcoal was at $6 to $8 a bushel and anthracite at $7.50 to $8.00 a ton.[56]

With help from geologists like Silliman and Rogers, mine owners steadily increased their extraction of Pennsylvania anthracite and, in due course, drove prices down. After 1830, Chandler has shown, "the price of anthracite at Philadelphia fell from between $7.00 to $7.50 a ton (it had been from $8.50 to $10.00 a ton from 1822 to 1824) to below $6.00 a ton, and then from 1833 to 1835 to under $5.00 a ton."[57] This drop in anthracite prices—made possible by geologists' discovery of new deposits—had a direct effect on industrial development in the United States.

New geological discoveries also had an effect on the United States' position in the global coal trade. The more anthracite geologists discovered, the more anthracite flooded the market; the more anthracite flooded the market, the lower the price fell; and the lower the price fell, the more American manufacturers gained the upper hand over their British competitors. "From 1830 until 1850," Chandler asserts, "the price of the best Newcastle coal on the London Coal Exchange consistently listed higher than the price of anthracite in Philadelphia."[58] By the 1830s, transportation improvements in the form of new canals pushed domestic coal production in the United States beyond the level of foreign imports for the first time. Chandler explains:

> In 1825, with the finishing of the initial work on the Lehigh Valley canal connecting Mauch Chunk to Easton and the first section of the Schuylkill connecting Reading to Philadelphia, shipments to tidewater [that is, to the eastern coast] from the anthracite fields jumped from about 9,500 to almost 35,000 tons, a total that exceeded for the first time the imports of coal to the east coast from abroad.[59]

Later, with the development of railroads, American demand for coal grew exponentially. Between 1830 and 1832, Pennsylvania's saw annual demand for coal jump from 175,000 to 364,000 tons: an increase of 108 percent in just three years.[60] Over time, coal—and the well-trained geologists who could find it—became more and more important to American economic growth.[61]

Yet, geological training and coal discoveries were not the only factors driving the rapid growth of American coal output in this period. Also aiding this development were high tariffs intended to protect domestic industries from foreign competition. In France, a tariff in 1822 had set the duty on British puddled iron as high as 160 percent.[62] Six years later, in 1828, the U.S. Congress passed what critics dubbed the Tariff of Abominations, which significantly raised prices on imports of all kinds. This tariff stimulated American industrialization and, in turn, boosted demand for coal (once again increasing the demand for well-trained geologists able to locate new deposits of this resource). Under the Tariff of Abominations, domestic iron production in the United States began to outpace British imports. In 1832, British pig-iron exports totaled 17,591 metric tons, 47 percent of which flowed into the American market (despite the additional costs associated with the Tariff of Abominations); after 1832, however, the percentage of British iron exports flowing to the United States gradually declined. By 1836, only 39 percent of British exports came to American shores, and, by 1840, only 10 percent reached the American market.[63] By mid-century, thanks to high tariffs and a steadily improving infrastructure for the delivery of Pennsylvania coal to East Coast iron manufactories, the United States had become a self-sufficient iron producer and a world power in this industry.[64]

IV. Geology and Economic Development: Henry Darwin Rogers in England and America

It was in this context of rapid industrial expansion and increasing demand for coal that state-sponsored geological surveys commenced in New York and Pennsylvania and, later, in other states. As early as 1820—the year Van Rensselaer hired Eaton to conduct his agricultural surveys in New York—amateur naturalist and Philadelphia attorney Peter Browne had proposed a survey of his state, asserting that "Owners of Pennsylvania lands, which are now scarcely worth the annual taxes, may be agreeably surprised, by finding them an exhaustless source of wealth, to themselves and to the nation." The notion of a state-sponsored geological survey in Pennsylvania did not make any significant headway, however, until the next decade.[65] In 1832, Browne and his associates, including Professor Robert Maskell Patterson of the University of Pennsylvania—who had spent three years from 1809 to 1812 studying geology, mineralogy, and chemistry in England, France, and the Netherlands and had played an important role in the establishment of the Academy of Natural Sciences of Philadelphia—

founded the Geological Society of Pennsylvania, the sole purpose of which was to secure public funds to pay for a state geological survey.[66]

Housed along with the growing Franklin Institute inside Philadelphia's landmark Independence Hall, the Geological Society of Pennsylvania pushed aggressively for state aid to internal improvements.[67] In fact, its rhetoric on behalf of a state-funded geological survey drew heavily on the arguments of Friedrich List, a German exile whose theory of "economic nationalism" garnered widespread support in this era. List asserted that each nation had an obligation to protect its own industrial development and material prosperity in any way it could.[68] Public funding to secure the natural resources needed for industrial expansion fit List's idea of economic nationalism, but the fact that List was not a citizen of the United States raised suspicions that he might not have the nation's best interests in mind. Pointing to his view that modern economics involved "war between the powers of industry of different nations," some accused List of surreptitiously "advocating the cause of England" in this war.[69] Indeed, List's ties with the Geological Society of Pennsylvania may have hampered its lobbying efforts: The Society found itself under close scrutiny for its roster of foreign members—a roster that included Sir Roderick Murchison of Britain, Alexander von Humboldt of Prussia, and Andres del Rio of Mexico (del Rio, a professor at the Mexican School of Mines, lived briefly in Philadelphia and served temporarily as the Geological Society's president).

Despite concerns about its members' economic loyalties, the Geological Society of Pennsylvania eventually persuaded lawmakers to fund a state geological survey. Funds came through in 1836, and the man recruited to direct the survey was twenty-eight-year-old Henry Darwin Rogers.[70] Educated at William and Mary under his father Patrick Kerr Rogers, young Rogers had taught chemistry at Dickinson College (where he wrote his aforementioned article on the anthracite regions of Pennsylvania). He also came from a renowned family of scientists and science educators. His eldest brother, James Rogers, taught chemistry at the Franklin Institute, Cincinnati College, and later the University of Pennsylvania; his youngest brother, Robert Rogers, taught chemistry at the University of Virginia and succeeded James at the University of Pennsylvania; and his middle brother, William Rogers, the most famous of all, taught chemistry at the University of Virginia and led the Virginia Geological Survey before becoming the founding president of the Massachusetts Institute of Technology. As a group, the Rogers brothers held a place of great prominence in American science and science education.[71]

Of the four Rogers brothers, Henry was the first to pursue advanced study abroad, and his experiences in England in 1832–33 (that is, the three years *prior* to his geological survey of Pennsylvania) shed light on his view of the relationship between international academic travel and national economic development—and, in particular, his view of the role institutions of higher education could play in preparing future American scientists for commercially valuable research. In an era of rapid industrialization, Rogers became more and more convinced of the need to cultivate the natural sciences (and mainly geological science) in American colleges. To this end, he took time in England to acquaint himself with the leading scientists and scientific institutions of his day. He made a special effort, for example, to meet Michael Faraday, whose research into electromagnetism was fast leading to breakthroughs in the development of electromagnetic generators (which ran on coal). "Faraday is at present [lecturing] on electricity at the Royal Institution," Rogers wrote excitedly to his brother William. "Yesterday he was melting the metals, etc., by the most powerful battery I ever beheld, with two enormous machines in full action. Three days ago it was electrical light, and a more successful and splendid series of experiments could not be performed by any one."[72]

Relishing his opportunities for scientific discovery, young Rogers looked forward to developing his scientific career back home—a career he expected to devote to the field of geology. "I find that I am acquiring an intimacy in geological fossils especially, much beyond what I could ever have gained at home," he wrote, emphasizing his "fine chances for making myself a geologist by the free access I may have to the [Geological Society of London's] superb museum."[73] He marveled, too, at the mineral collections of the British Museum—its specimens reflecting a vast empire—and told his brothers, "should there be any subject connected with science concerning which you may wish to be satisfied, pray mention it, as I have access to the libraries both of the Mechanics Institution and of the British Museum. This last place [has] by far the most completely furnished reading and research [library] which Europe perhaps possesses . . . . I am at present pursuing geology there, and the facilities [are] very great."[74] Absorbing as much as he could, Rogers came gradually to see himself as a junior member of a *professional* scientific community. "My intercourse with the men of science is every day becoming more easy and valuable," he wrote. "I go, free of ceremony, to almost any of the societies . . . and, now that Faraday and I are familiar, without even a member's ticket, to the Royal Institution."[75]

Besides Faraday, young Rogers also spent time with Edward Turner, secretary of the Geological Society of London (1825). When he arrived, he found Turner engrossed in experiments to develop a new thermometer to measure both temperature and humidity far below the earth's surface and, thus, to determine the conditions needed for the formation of coal.[76] "Turner is in every sense a gentleman," Rogers wrote in one letter home. "I am present at his lectures almost daily. He experiments very much and in a beautiful style, most of his instruments being on a large scale. Today, treating of hygrometers [a device used to measure atmospheric humidity], after showing us all the varieties, he presented one of his own, the most simple and perfect of all. It is merely a cup of silver [mercury] two inches by half an inch, gilt and burnished outside. A few grains of freezing mixture, half nitre and half sal-ammoniac, are dissolved and stirred with a small thermometer on which you mark the dew points."[77] With every lecture-demonstration he attended, Rogers gained a better sense of the institutions promoting modern experimental sciences—and scientific education—in Britain. Like his predecessor Silliman, whose detailed notes on laboratories in Edinburgh had provided a blueprint for innovations at Yale, Rogers hoped to use the lessons he learned overseas to improve scientific education back home.

Rogers learned much from Turner and Faraday—and from the esteemed geologist Charles Lyell, who gave a series of lectures in 1832 and 1833 at the newly established University College, London—but his most important and influential teacher by far was Sir Henry Thomas De la Beche. De la Beche, who had published a *Geological Manual* in 1831, recruited young Rogers to edit this work for distribution in the United States—an honor Rogers gladly accepted. "De la Beche is bringing out an entirely new edition of his work in very perfect form," he wrote home. "He very kindly offers to put the new edition proofs in my hands when I go, sending the remainder after me as they appear, that I may *republish* it with *notes* of my own,—a mark of regard that I value."[78] In later years, De la Beche founded a Museum of Practical

Geology in London and wrote several other books, including *Researches in Theoretical Geology* (1834).[79] What secured his fame, however, was his discovery of the so-called Devonian System. This discovery constituted a major contribution to geological science—not least because the Devonian stratum sits directly beneath the Carboniferous stratum, the chief source of coal.[80]

In 1832, when De la Beche began his study of geological strata in Devonshire, he invited Rogers to join him on his daily excursions, and Rogers seized this opportunity to improve his field research skills. As he wrote to his brothers:

> De la Beche is occupied with a geological survey of Devonshire, Cornwall, and most of the South of England just now, for the great ordnance maps, under the direction of [the] Government, and he desires that I shall visit him in Devonshire to study the subject practically from nature and from his lessons. This I esteem a great privilege, as it will fit me, as you perceive at once, to do the like at home, whenever the pursuit may prove desirable. And I shall take notes, collect specimens, and I doubt not, in the exquisite air of Devonshire, get fat and rosy cheeks.[81]

Rogers gained immeasurably from his daily participation in De la Beche's research. He learned not only the art of geological surveying but also new techniques for identifying mineral deposits and discerning their commercial uses. To locate the Devonian stratum was, after all, to pinpoint the layer nearest the sources of coal—a valuable lesson that De la Beche was kind to share given the competitive search for coal in this period. Indeed, De la Beche's willingness to share this research with Rogers showed that, unlike William Maclure's experience with "mineral merchants" two decades earlier, Rogers's experience introduced him to an international community of professionals who at least occasionally were able to overcome a proprietary approach to geological knowledge to embrace a pure exchange of scientific ideas.

In 1833, in recognition of Rogers's acceptance into this professional community, De la Beche, along with Edward Turner and Sir Roderick Murchison, nominated him for membership in the Geological Society of London. He thus became the first American so honored—and he used this recognition to advantage upon his return to the United States. A year later, when seeking the position of state geologist in Pennsylvania, Rogers told Joseph Henry, a professor at Princeton and a friend of Pennsylvania's Geological Society who later became the first director of the Smithsonian Institution (and who, incidentally, had joined Amos Eaton's first Rensselaer School Flotilla in 1829), that the person leading Pennsylvania's state survey needed "to be familiar from practice with field research of a scientific kind such as I have witnessed with De la Beche in England."[82] Noting that few Americans in the 1830s could make reliable geological maps, Rogers commented on the "extreme scarcity at present felt everywhere throughout our country of scientific persons of accurate knowledge and practical skill in the geological profession."[83] His unparalleled training abroad, Rogers hinted, made him uniquely qualified to lead Pennsylvania's state survey.

Joseph Henry—who soon departed for his own scientific tour of Europe—agreed, as did Alexander Dallas Bache, a leading Pennsylvania scientist and a great-grandson of Benjamin Franklin who subsequently directed the U.S. Coastal and Geodetic Survey. In 1834, as Rogers pitched his skills to Pennsylvania's legislators, he and Bache published an "Analysis of Some Coals in Pennsylvania" in the *Journal of the Academy of Natural Sciences of Philadelphia*.[84] This exhaustive analysis drew on the latest European methods to demonstrate the commercial applications of modern geological theory and the benefits of modern scientific education. While the Rensselaer Institute, the Franklin Institute, and the U.S. Military Academy at West Point (where Bache had been valedictorian in 1825), offered courses in basic surveying and engineering, none of these schools taught modern geological theory. Other institutions such as the Maryland Institute, the Albany Institute, Union College, and Norwich University offered limited coursework in practical geology, but more than a decade would pass before the Lawrence Scientific School at Harvard or the Sheffield Scientific School at Yale would pursue more theoretical instruction.[85] Thus, in 1834, Rogers could perhaps legitimately claim to have the most up-to-date geological education of any scientist in the United States.[86]

This was not to say, however, that geological training had not progressed in recent years. On the contrary, geological instruction had grown steadily in American colleges in the previous decade. In 1825, for example, Edward Hitchcock, who had studied under Silliman at Yale, began teaching geology at the newly founded Amherst College (where he later became president). Similarly, Lardner Vanuxem, a Philadelphia native who had studied at the École des Mines in Paris, offered courses in geology at Columbia College in South Carolina (before heading to post-revolutionary Mexico as a mining consultant). Vanuxem later participated in the New York Geological Survey, and Hitchcock went on to play a leading role in the New York, Vermont, and Massachusetts Geological Surveys, publishing a *Report of a Geological Survey of Massachusetts* in 1832 and a *Report on a Re-Examination of the Economical Geology of Massachusetts* in 1838.[87] Neither of these men, however, could match Rogers's expertise. As Bache told Governor Peter Vroom of New Jersey (who was planning a geological survey of his own) in 1835: "Rogers has had the advantage, enjoyed by no other American, of making his studies in geology under the auspices of some of the leading men of the English school. Fully imbued with the science and familiar with all its practical parts, he has labored constantly since his return to this country to illustrate its geology."[88]

Indeed, what Rogers had learned above all in England was an appreciation for the relationship between geological education and economic growth. He firmly believed that geological research could (and should) foster industrial development, and others agreed. In 1836, Rogers landed the directorship of *both* the Pennsylvania Geological Survey *and* the New Jersey Geological Survey. Meanwhile, in the same year, his brother William landed the directorship of the Virginia Geological Survey.[89] With Henry in Pennsylvania and New Jersey and William in Virginia, the brothers were well positioned to study the geology of coal-rich areas in three states, particularly in the Appalachian Mountains. As biographer Patsy Gerstner has observed, the Rogers' fascination with the Appalachians stemmed from their awareness that "economically valuable iron ores, anthracite coal, and bituminous coal were located there."[90] Historian Anne Marie Millbrooke adds that, when Henry published his Pennsylvania survey, "he prudently devoted six hundred pages of his final report to coal."[91] This emphasis on coal was unsurprising. After all, the chief motive behind the Pennsylvania, New Jersey, and Virginia surveys was resource reconnaissance to fuel industrial growth and foster national economic development.

V. Geologists and Global Economics in the Early Nineteenth Century

State-funded geological surveys in the United States coincided with increasingly global competition for natural resources. Indeed, both the geological surveys and the push for better geological education in the 1820s and 1830s fit into a complex global historical context. Henry Darwin Rogers's survey work in Pennsylvania, Virginia, and New Jersey, for instance, overlapped with his mentor De la Beche's work elsewhere around the world. In 1835, a year before Rogers commenced his Pennsylvania survey, De la Beche became director-general of the Geological Survey of the United Kingdom, a job that placed him in charge of worldwide geological investigations for the British empire. Coordinating its efforts with the needs of the powerful East India Company, the British Geological Survey gathered detailed information on mineral deposits around the globe—especially deposits of gold, silver, copper, and coal.[92] In his capacity as director-general of the Survey, De la Beche supervised mining explorations in India, Australia, New Zealand, the Caribbean, Central America, South America, the Middle East, China, the Philippines, and southern Africa.[93] In 1836, for example, as Rogers began his work in Pennsylvania, De la Beche asked British colonial administrators in Bengal "to ascertain the location and quality of the presidency's coal reserves"—reserves that were critical for the introduction of steam-powered military and transport ships throughout the British empire.

Britain's demand for coal to run steam-powered vessels mounted steadily in the 1830s and became a strategic preoccupation of its geological surveys around the world. In this context, the British and the Americans frequently clashed over mineral deposits in far-flung places. For example, in 1837, an American merchant vessel sailing in the South China Sea noted extensive coal deposits along the northern coast of Borneo. Hearing this news, De la Beche had dispatched Sir James Brooke, a fellow of the Royal Geographical Society, to go to Borneo to gain control over these deposits, along with precious metals in the region. As historian Robert Stafford has recounted, Brooke sailed for Sarawak (on the north coast of Borneo) in 1838, "armed with a list of exploring desiderata which included the collecting of '*all particulars*' concerning precious metals, and he corresponded with the Society about his progress." Stafford continues:

> In 1840, three years after an American trader had first reported the existence of coal in Brunei, the Society published a memoir on Borneo [written by East India Company naturalist George Tradescant Lay] which mentioned a deposit of coal on the nearby island of Labuan and anticipated a large supply being obtained there. . . . The following year [the renowned geologist] William Buckland predicted to the Society that if Lay's report proved true, Labuan might "become a station of inestimable value for effecting intercourse by steam between China, India, and Australia, and the great islands of the Malay Archipeligo." The island was in fact soon to be acquired as a colony by Britain precisely because of its mineral resources.[94]

To make a rather long story short, Brooke gained the confidence of the sultan of Brunei by helping to defeat local rebels on the island, and his assistance had been rewarded with a grant of total control over the Sarawak province. From his post as the "White Raja" of Sarawak, the ambitious Brooke went on to seize the coal deposits on Labuan, which the British hoped to develop as a refueling station for navy ships.

At the same time, however, Americans made their own bid for influence over the natural resources—including coal—in this area.[95] In 1840, the renowned U.S. Exploring Expedition under the direction of Lieutenant Charles Wilkes made its way around Cape Horn and then across the South Pacific to Australia, collecting geological, mineralogical, botanical, zoological, and ethnological data along the way. The presence of the six-vessel U.S. Exploring Expedition, coupled with Britain's (well-justified) suspicion of American commercial motives in the region, seems to have increased Britain's anxiety over control of Labuan's coal. Evidently, the British feared that Brooke, their own scientific emissary, would desert his country and ally himself with the Americans, seeking naval protection from the United States in exchange for access to Labuan coal. The risk of losing control of these deposits was simply too great, however, so the British arranged to purchase the island of Labuan from the sultan of Brunei. As Stafford explains:

> Brooke advertised Labuan's potential as a coal source and sought naval protection for Sarawak in exchange for exclusive mining rights to these deposits. . . . De la Beche's laboratory analysed the specimens of what was identified as bituminous lignite. Their favorable performance as steam fuel, coupled with Labuan's potential as a commercial entrepot and the threat that Brooke might grant his mining rights to the United States in

> return for a guarantee of Sarawak's independence, led to Britain's purchase of the island from the Sultan of Brunei in 1847 and the appointment of Brooke as the new colony's governor.[96]

By 1840, as the United States and Great Britain jockeyed for economic dominance—and, indeed, as Britain fought its first Opium War for commercial supremacy in this region—competition for control of foreign coal (so closely associated with military and industrial power) grew. Moreover, the relative advantage of each country in this struggle relied on the expertise of well-trained geologists. Among the young scientists traveling with the U.S. Exploring Expedition, for example, was James Dwight Dana, later a distinguished professor of geology at Yale (who, incidentally, had begun his geological studies under Amos Eaton at Rensselaer and had continued under Benjamin Silliman at Yale).[97]

Competition between the United States and Britain over mineral resources in Asia was not, however, limited to coal. As Brooke's instructions from the Royal Geographical Society indicated, this competition also extended to precious metals.[98] Political economist John Ramsay McCulloch's *Dictionary of Commerce*, published in London in 1833, noted that Asian mines—a number of them under British colonial administration—had recently supplanted American and European mines in the production of gold and silver. This shift affected the international balance of trade, giving the edge to British colonies and causing a great deal of consternation in the United States. "It appears," McCulloch noted,

> that the total imports of gold and silver from Europe and North and South America into Bengal, Madras, and Bombay, during the 3 years [ending] with 1830–31, amounted to 479,388*l*. [that is, $2,430,018, using the exchange rate suggested below]; whereas the total exports of the precious metals from these 3 presidencies to Europe and America during the same 3 years were 1,119,973*l*. [$5,677,143], being an excess of 640,585*l*. [$3,247,125]; so that India, instead of importing, as formerly, large quantities of bullion from the Western World, supplied, during the period in question, about 213,000*l*. [$1,079,697] a year to its markets![99]

McCulloch went on to show that India, besides exporting gold to Europe and the United States, also *imported* gold from China, which, in turn, imported "considerable supplies of that metal from Borneo,

Celebes, and the Malay peninsula."[100] Given this situation in the global market for gold—a situation in which Borneo held the competitive advantage—it was no wonder that the United States and Great Britain scuffled over control of resources in Asia.

The broad contours of international geological exploration in the early nineteenth century become clear only when multiple narratives flow together. One must consider not only the economic but also the educational history of geological research, along with the geopolitical history of global resource exploitation. The rise of geological surveys in the United States in the first half of the century makes sense only when one places domestic circumstances in the context of worldwide competition for economic preeminence. When examining the Rogers brothers' surveys in Pennsylvania, New Jersey, and Virginia in the 1830s, for example, one cannot overlook the economic tensions that surfaced between the United States and Great Britain, tensions that peaked in 1839 when the Bank of England, increasingly worried about unbridled financial speculation in the American West (largely among coal brokers in western Pennsylvania) cut off credit to firms doing business in the United States, thus exacerbating what became a prolonged economic depression.[101] The banking crisis of 1839 (like the earlier Panic of 1819) revealed the international economic context in which the first state geological surveys took shape.[102]

State geological surveys in the first half of the nineteenth century were not simply domestic affairs; they fit into a truly global context. This period witnessed a constantly expanding network of international scientific exchange as well as a rush to establish new educational institutions to promote American competitiveness in a rapidly industrializing age. Historians of American higher education often emphasize the proliferation of new institutions offering practical instruction or applied science in this period. Some point to institutions like Rensselaer or Franklin; others highlight institutions such as the Lawrence Scientific School at Harvard or the Sheffield Scientific School at Yale; still others note the various "mechanics institutes" that came and went in this era. While historians stress the rising demand for technical instruction in the United States, they often fail to note the simultaneously growing demand for *theoretical* expertise in this period. By the 1840s, more and more American scientists had come to realize that merely technical or applied skills could not assure the United States' competitive advantage in a rapidly globalizing marketplace: Only experimental research leading to theoretical innovations could keep the nation ahead of its competitors.

Of course, theoretical innovation in fields like geology required a new approach to scientific education in the nation's colleges—an approach shaped by the international "state of the art" but also directed toward specifically national demands. By the 1830s, internationally educated geologists like Henry Darwin Rogers had begun to re-imagine the future of American scientific education. With every library and every laboratory he visited, with every museum and every mine he investigated abroad, Rogers gained a new understanding of what cutting-edge science in the nineteenth century would require. And herein lay the significance of "study abroad." What motivated study abroad in this period was not only a desire to participate in the international exchange of ideas but also a desire to promote the interests of one's own nation-state. International exchange and nationalist science went hand in hand. As study abroad became more and more common—and more and more institutionalized—in these years, so, too, did scholars' dedication to distinctly *national* service. Put simply, internationally trained scientists associated scholarship with nation-building, and this association grew tighter and tighter over time.[103] One need only consider a few of Rogers's scientific successors to see the strength of this connection.

Rogers's assistant on the Pennsylvania survey, James Curtis Booth, had studied in Germany at the same time that Rogers had studied in England. After completing his work for Rogers on the Pennsylvania survey, Booth led the Delaware Geological Survey, then accepted a professorship in chemistry and mineralogy at the University of Pennsylvania. His introductory course, "On the Elements of Technical Philosophy," linked science to political economy, stressing above all the link between "Wealth and [the] independence of nations."[104] Similarly, Rogers's successor as state geologist in Pennsylvania, J. Peter Lesley, who, like Booth, also served as Rogers's assistant, graduated from the University of Pennsylvania in 1838, studied in Germany in 1844 and 1845, and, specializing in the geology of iron and coal, eventually became secretary of the United States Iron and Steel Association. In 1856, Lesley published an influential *Manual of Coal and Its Topography* and, in 1859, an *Iron Manufacturer's Guide* to the use of this resource.

This latter volume complemented the publication of Roger's final report on the geology of Pennsylvania, a huge work of 1,631 pages (as well as twenty-three full-page plates, eighteen folded interior maps, and 778 figures and diagrams in the text), which appeared in 1858. Along with a comprehensive review of Pennsylvania's rock formations, Rogers included comparisons of coal reserves in the United States and Great Britain as well as statistics on the relative strength of coal and iron deposits in several other countries. He also included a long section on "the method of searching for, opening, and mining coal, as pursued in Pennsylvania."[105] Close attention to economically valuable information characterized the work of later generations of American geologists, who consistently blended science with a sense of service to national economic development. Virtually all the leading geologists of the mid-nineteenth century—Josiah Whitney, James Dana, Joseph Leidy, James Hall, and others—studied abroad (following the path laid down by Silliman), and virtually all saw geological research as a contribution to national economic development.[106] By mid-century, study abroad had become an informal requirement among American geologists, but the driving motive behind international academic travel was *national* service.

Notes

1. William Stanton, "American Scientific Exploration: 1803–1860," American Philosophical Society, Publication 15 (1995), available online at http://www.amphilsoc.org/library/guides/stanton/ (accessed on October 25, 2004). See also Robert V. Bruce, *The Launching of Modern American Science, 1846–1876* (New York, 1987); Nathan Reingold, "Graduate School and Doctoral Degrees: European Models and American Realities," in Nathan Reingold, *Science, American Style* (New Brunswick, N.J., 1991); Anne Marie Millbrooke, "State Geological Surveys of the Nineteenth Century" (Unpublished Ph.D. dissertation, University of Pennsylvania, 1981); Walter Hendrickson, "Nineteenth-Century State Geological Surveys: Government Support of Science," *Isis* 52 (1961), 357–371; and George P. Merrill, *The First One Hundred Years of American Geology* (New Haven, 1924).
2. See Sally Gregory Kohlstedt, "The Geologists' Model for National Science, 1840–1847," *Proceedings of the American Philosophical Society* 118:2 (1974), 179–195. For information on women in geology in this period, see Sally Gregory Kohstedt, "In the Periphery: American Women in Science, 1830–1880," *Signs* 4:1 (Autumn 1978), 81–96; Deborah Jean Warner, "Science Education for Women in Antebellum America," *Isis* (March 1978), 58–67.
3. For more on the historiography of science linked to national identities, institutions, and traditions, see Nathan Reingold, "Between American History and

History of Science," *Studies in History and Philosophy of Science* 27:1 (1996), 115–129; "The Peculiarities of the Americans, Or, Are there National Styles in the Sciences?" *Science in Context* 4 (1991) 347–366; *The Sciences in the American Context: New Perspectives* (Washington, D.C., 1979); and *Science in America since 1820* (New York, 1976). See also Stephen Shapin, "Discipline and Bounding: The History and Sociology of Science as Seen Through the Externalism-Internalism Debate," *History of Science* 30 (1992), 333–369; and Arnold Thackray, "History of Science in the 1980s," *Journal of Interdisciplinary History* 12 (1981), 299–314. For transnational histories of science in the nineteenth century, see Patsy A. Gerstner, "Vertebrate Paleontology, an Early Nineteenth-Century Transatlantic Science," *Journal of the History of Biology* 3 (1970), 137–148.

4. Robert A. Stafford, *Scientist of Empire: Sir Roderick Murchison, Scientific Exploration, and Victorian Imperialism* (Cambridge, England, 1989), 1–3.
5. Ibid., 197.
6. Ibid., 189.
7. For treatment of similar issues in a later period, see Elizabeth Crawford, *Nationalism and Internationalism in Science, 1880–1939: Four Studies of the Nobel Population* (Cambridge, England, 1992). For more on the role of evolutionary thought in shaping cross-national exchange, see Adam R. Nelson "Nationalism, Transnationalism, and the American Scholar in the Nineteenth Century: Thoughts on the Career of William Dwight Whitney," *New England Quarterly* 78:3 (September 2005), 341–376.
8. The historical literature on the rise of nationalism in the nineteenth century is vast. See, for example, Eric J. Hobsbawm, *Nations and Nationalism since 1780: Programme, Myth, Reality* (New York, 1990). For more on this subject as it applies to the United States, see Wilbur Zelinsky, *Nation into State: The Shifting Symbolic Foundations of American Nationalism* (Chapel Hill, 1988); Lloyd Kramer, *Nationalism: Political Cultures in Europe and America, 1775–1865* (New York, 1998); and David Waldstreicher, *In the Midst of Perpetual Fetes: The Making of American Nationalism, 1776–1820* (Chapel Hill, 1997). See also Thomas J. Bender, ed., *Rethinking American History in a Global Age* (Berkeley, 2002).
9. For more on Benjamin Silliman, see Chandos Michael Brown, *Benjamin Silliman: A Life in the Young Republic* (Princeton, 1989); Leonard G. Wilson, ed., *Benjamin Silliman and His Circle: Studies on the Influence of Benjamin Silliman on Science in America* (New York, 1979); John F. Fulton and Elizabeth H. Thomson, *Benjamin Silliman, 1779–1864: Pathfinder in American Science* (New York, 1947); Francis Parsons, *Six Men of Yale* (New Haven, 1936); and George P. Fisher, *Life of Benjamin Silliman: Late Professor of Chemistry, Mineralogy and Geology in Yale College; Chiefly from His Manuscript Reminiscences, Diaries, and Correspondence* (New York, 1866).
10. Benjamin Silliman, Journal #1, Microfilm Reel #5 (n.d., 1805). Yale University Library, New Haven, CT. Selections from this journal were later published as Benjamin Silliman, *Journal of Travels in England, Holland, and Scotland, and of Two Passages Over the Atlantic, in the Years 1805 and 1806* (New York, 1810; republished 1812).

11. Ibid. For more on British mining techniques and their connection to geological science in this period, see Hugh Torrens, *The Practice of British Geology, 1750–1850* (Burlington, Vt., 2002).
12. Ibid. For more on copper and the global market for precious metals, see Jonathan Leitner, "Red Metal in the Age of Capital: The Political Ecology of Copper in the Nineteenth-Century World Economy," *Review* 24:3 (Fernand Braudel Center, 2001), 373–437.
13. For more on Silliman's international scientific correspondence after his return to the United States, see Kennard B. Bork, "Correspondence as a Window on the Development of a Discipline: Brongniart, Cleaveland, Silliman, and the Maturation of Mineralogy in the First Decades of the Nineteenth Century," *Earth Sciences History* 18:2 (1999), 198–245.
14. Benjamin Silliman, Journal #1, Microfilm Reel #5 (n.d., 1805).
15. Ibid.
16. Ibid. As Silliman explained, one of his traveling companions, a "Mr. Amory of Boston," had recently been accused of espionage and had "enjoyed the honor of a six week's residence in the Temple at Paris."
17. Ibid.
18. Ibid.
19. Ibid.
20. For more on Maclure's travels, see John S. Doskey, ed., *The European Journals of William Maclure* (Philadelphia, 1988).
21. Ibid., 23.
22. Ibid., 27. Back in the United States, Maclure received an invitation to dine with President Jefferson at the White House, and the subject of French surveillance arose. "'You need not speak so low,' said Mr. Jefferson smiling, 'you see we are alone and our walls have no ears.' 'I have so long been living in Paris, where the walls have ears,' replied Mr. McClure [*sic*], 'that I have contracted the habit of speaking in an undertone.'" Quoted in Margaret Bayard Smith, *Forty Years of Washington Society*, ed., Gaillard Hunt (London, 1906), 388. See also John C. Greene and John G. Burke, "The Science of Minerals in the Age of Jefferson," *Transactions of the American Philosophical Society* 68:4 (1978), 39. For a history of espionage in the textile industry, see David J. Jeremy, "Transatlantic Industrial Espionage in the Early Nineteenth Century: Barriers and Penetrations," *Textile History* 26:1 (1995), 95–122; and *Transatlantic Industrial Revolution: The Diffusion of Textile Technologies between Britain and America, 1790–1830's* (Cambridge, Mass., 1981).
23. Doskey, *The European Journals of William Maclure*, 146–147.
24. See ibid., 219.
25. Ibid., 164.
26. Ibid., 174.
27. Ibid., 170n4.
28. E. F. Söderlund, "The Impact of the British Industrial Revolution on the Swedish Iron Industry," in L. S. Pressnell, ed., *Studies in the Industrial Revolution* (1960), 52–65, reprinted in R.A. Church, ed., *The Coal and Iron Industries*

(Oxford, England, 1994), 58.

29. Söderlund, "The Impact of the British Industrial Revolution on the Swedish Iron Industry," 58–59. Swedish iron exports to the United States had a long history. As Söderlund explains, "This export had already begun during the period of the 'Continental System,' when American ships were seeking return cargoes from Europe and thus, in part, make up for an earlier re-export of Swedish bar iron from England."
30. To remain competitive in the world market, the Swedish iron producers eventually developed their own modified puddling technique. See Söderlund, "The Impact of the British Industrial Revolution on the Swedish Iron Industry," 62.
31. In the early nineteenth century, the U.S. federal government tried to regulate the use of newly discovered western mineral lands, but oversight proved difficult. As George P. Merrill notes, "beginning with 1807, all government lands containing ores were reserved from sale and a system of leasing adopted. No leases were, however, issued until 1822, and little mining was done previous to 1826. For a few years . . . rents for the mining lands were paid by the operators with comparative regularity, but, after 1834, in consequence of the innumerable fraudulent entries of lands as agricultural which should, in reality, have been reserved as mineral, the smelters and miners refused to make any further payments, and the government officials were unable to enforce the claims." Consequently, in 1839, the House of Representatives called for a survey of federal lands in Iowa, Wisconsin, Indiana, and Illinois preliminary to setting their price for sale. David Dale Owen, the son of Scottish immigrant and utopian socialist Robert Owen as well as the European traveling companion of Henry Darwin Rogers in 1832–33, directed this survey of Iowa, Wisconsin, Indiana, and Illinois and claimed that "the district surveyed is one of the richest mineral regions, compared to extent, yet known in the world." Merrill, *The First One Hundred Years of American Geology*, 196, 198. See Clark Kimberling, "David Dale Owen and Joseph Granville Norwood: Pioneer Geologists in Indiana and Illinois," *Indiana Magazine of History* 92:1 (1996), 2–25; and Herman R. Friis, "The David Dale Owen Map of Southwestern Wisconsin," *Prologue: Journal of the National Archives* 1:1 (1969), 8–28.
32. See Alfred D. Chandler, Jr., "Anthracite Coal and the Beginnings of the Industrial Revolution in the United States," *Business History Review*, 46:2 (Summer 1972), 141–181, reprinted in R. A. Church, ed., *The Coal and Iron Industries* (Oxford, England, 1994), 395–435. As Chandler explains, anthracite coal, or "'Stone Coal' had almost pure carbon content, ranging from 85 percent to 100 percent. It burned with a tiny blue flame, producing intense heat and virtually no smoke." Once the uses of anthracite became known, demand swelled. Previously, most American factories had been powered by water (i.e., water wheels cranked by fast-moving rivers or streams). Only in sparsely populated areas of western Pennsylvania did small-scale factories make use of steam power generated by coal-burning furnaces. As late as 1832, U.S. Treasury Secretary Louis McLane noted that, when businesses in Pittsburgh were excluded, only *four* of the nation's 249 businesses capitalized at $50,000 or more used coal for power; the other 245 used water.

33. In this period, domestic iron production was practically nonexistent. As Chandler notes, "Of the 166 blacksmiths in Maine who provided information in the McLane Report, 97 percent (161) depended entirely on iron from abroad, and the 3 percent who did use American iron used only small amounts." Even after iron works began to emerge in Pennsylvania, it still took awhile for eastern factories to purchase their iron domestically. "While many of the bigger general iron producers had begun to rely quite heavily on Pennsylvania iron, many of even the very largest of the New England iron users, including the nail and hoops works at Wareham, the nail, tack, and iron works at Bridgewater, and the Warner, Hunt axe company at Douglas (all in Massachusetts) and a large rolling mill in Norwich, Connecticut, still purchased up to 70 percent of their requirements in Europe." Chandler, "Anthracite Coal and the Beginnings of the Industrial Revolution in the United States," 146.
34. See Paul Lucier, "Commercial Interests and Scientific Disinterestedness: Consulting Geologists in Antebellum America," *Isis* 86:2 (1995), 245–267.
35. Brown, *Benjamin Silliman: A Life in the Young Republic*, 211. Gibbs's cabinet included more than 10,000 specimens from all over the world. As Brown notes, "There was nothing else like the Gibbs Cabinet in the United States. Of its three parts, the collection of Gigot d'Orcy alone contained over four thousand specimens, which had taken the Frenchman nearly forty years to assemble. He was executed on the guillotine during the Revolution in France, and Gibbs purchased the entire cabinet, 'well arranged, and scientifically and minutely described,' from his surviving brother. The 'Russian Cabinet' originally belonged to Count Gregoire Razamovski, a Russian who had lived for many years in Lausanne. The count worked in association with Heinrich Struve to acquire representative samples from Russian and Siberian localities and amassed about six thousand specimens, including an excellent array of 'gold and copper ores, chromates of lead, the native iron of Pallas, Beryls, Jaspers, etc.' Gibbs also studied with Struve and met Razamovski at the home of the Swiss mineralogist. When the Russian decided to return to his homeland, Gibbs used a part of his patrimony to buy the main part of the collection. The third general division of the cabinet descended from Jacques-Louis, Comte de Bournon. This cabinet, representing principally the British Isles and West Indies, was made up in part of duplicates of the famous Greville Cabinet, familiar to Silliman, which later formed the nucleus of the collection at the British Museum."
36. For more on Silliman's "Sketch of the Mineralogy of the Town of New Haven," see Brown, *Benjamin Silliman: A Life in the Young Republic*, 200. "The 'Sketch' represents the first of Silliman's professional endeavors, and in many ways it captures the essence of his scientific style, which remained remarkably consistent throughout the remainder of his long career. The work was of utility to the college and of service to Connecticut and to the town of New Haven." Brown adds that Silliman "soon discovered that he could command a considerable fee for his professional judgment. The Embargo prompted some Boston merchants to consider the development of native resources . . . in May 1810, at the request of Colonel Thomas H. Perkins and Isaac Davis, Silliman rode to Northampton, where they wanted him to survey the site of a prospective lead mine. He went

over the ground carefully and made a report of his findings, which he later published in Bruce's *Mineralogical Journal*. Perkins and Davis appeared satisfied and, to Silliman's surprise, presented him with fifty dollars in gold—he had expected at most ten dollars." Brown, 258.

37. Brown, *Benjamin Silliman: A Life in the Young Republic*, 204, 304.
38. Quoted in Brown, *Benjamin Silliman: A Life in the Young Republic*, 232.
39. See, for example, Parker Cleaveland, *Elementary Treatise on Mineralogy and* Geology (Boston, 1816); Frederick Hall, *Catalogue of Minerals Found in the State of Vermont and in the Adjacent States, Together with Their Localities: Including a Number of the Most Interesting Minerals which have been Discovered in Other Parts of the United States* (Hartford, 1824).
40. Initially, the full title of the journal was *American Journal of Science, More Especially of Mineralogy, Geology, and Other Branches of Natural History; Including also Agriculture and the Ornamental as Well as Useful Arts*. Brown, 305. For more on the origins of the *American Journal of Science*, see S. W. Jackman, "The Tribulations of an Editor: Benjamin Silliman and the Early Days of the *American Journal of Science and the Arts*," *New England Quarterly* 52:1 (1979), 99–106. In 1810, the Edinburgh-educated physician Archibald Bruce, who studied chemistry and mineralogy with Abbe Haüy in Paris, launched his *American Mineralogical Journal* to introduce Americans to recent European discoveries in this field.
41. For more on Amos Eaton, see Ethel M. McAllister, *Amos Eaton: Scientist and Educator, 1776–1842* (Philadelphia, 1941).
42. Ray Palmer Baker, *A Chapter in American Education: Rensselaer Polytechnic Institute, 1824–1924* (New York: Charles Scribner's Sons, 1924), 9. For more on Eaton's work, see by Cecil J. Schneer, "Ebenezer Emmons and the Foundations of American Geology," *Isis* 60:4 (Winter 1969), 439–450.
43. See, for example, Murray Newton Rothbard, *The Panic of 1819: Reactions and Policies* (New York, 1962); and Edwin J. Perkins, "Langdon Cheves and the Panic of 1819: A Reassessment," *Journal of Economic History* 44:2 (June 1984), 455–461.
44. See Michael Lind, ed., *Hamilton's Republic: Readings in the American Democratic Nationalist Tradition* (New York, 1997). When the presidential election of 1824 went to the House of Representatives for a vote, newly elected Van Rensselaer cast the deciding vote against Andrew Jackson and in favor of John Quincy Adams. See Richard McMillan, "Election of 1824: Corrupt Bargain or the Birth of Modern Politics?" *New England Journal of History* 57:2 (2001), 27–40.
45. See Henry B. Nason, *Biographical Record of the Officers and Graduates of the Rensselaer Polytechnic Institute, 1824–1886* (Troy, N.Y., 1887), 123.
46. See "An Act to Incorporate the Rensselaer School" (March 21, 1826), available online at http://www.lib.rpi.edu/dept/library/html/Archives/early_documents/index.html (accessed on November 23, 2004).
47. For more on the origins of the Rensselaer School, see Samuel Rezneck, *Education for a Technological Society: A Sesquicentennial History of Rensselaer Polytechnic Institute* (Troy, N.Y., 1968); and Palmer C. Ricketts, *History of Rensselaer Polytechnic Institute, 1824–1934* (New York, 1934). See also Markes E. Johnson, "The Parallel Impacts of William Maclure and Amos Eaton on American Geology, Education, and Public Service," *Indiana Magazine of History* 94:2 (1998), 151–166; Donald E. Pitzer, "William Maclure's Boatload of Knowledge: Science and Education into the Midwest," *Indiana Magazine of History* 94:2 (1998), 110–137; and Sally Gregory Kohlstedt, "Reassessing Science in Antebellum America," *American Quarterly* 29:4 (1977), 444–453. See also Stanley M. Guralnick, *Science and the Antebellum American College* (Philadelphia, 1975); and James X. Corgan, ed., *The Geological Sciences in the Antebellum South* (Tuscaloosa, Ala., 1982).

48. See Samuel Rezneck, "A Traveling School of Science on the Erie Canal in 1826," *New York History* 1959 40(3), 255–269.
49. Rensselaer School Flotilla Circular (1830) available online at http://www.lib.rpi.edu/dept/library/html/Archives/early_documents/index.html (accessed on November 7, 2004). Assuring students they would have on-board access to "sufficient chemical and philosophical apparatus, mathematical instruments, . . . mineralogical, geological, and conchological cabinets . . . [and] a scientific library, adapted to the course of studies," as well as scientific lectures on each day's observations, Eaton noted that each student would be required to "collect and preserve for himself a complete suit of geological specimens (as this route presents every formation); also a suit of all minerals and plants, to be obtained in all the places visited."
50. Ibid.
51. The presence of various limestones along the canal route indicated a resource used in mortars (chiefly the cement used in canal walls) and in soil nutrients. See Michele L. Aldrich, "American State Geological Surveys, 1820–1845," in Cecil J. Schneer, ed., *Two Hundred Years of Geology in America: Proceedings of the New Hampshire Bicentennial Conference on the History of Geology* (Hanover, N.H., 1979), 133–144. Advances in the mining industry only added to the appeal of the Rensselaer School Flotilla. The chief purpose of the "term of traveling instruction," was to cultivate its students' awareness of the natural bounty contained within the new territory made accessible by canals—a bounty ripe for exploration and exploitation. Eaton promised that the flotilla would lead to new discoveries in soil composition, forestry, medicinal botany, and other subjects. Given both the scientific and economic benefits of this research, he anticipated that other institutions would soon initiate canal-based learning programs. As he observed while preparing his students for the flotilla's second voyage, "it is to be hoped that other Schools may adopt similar summer courses, and that numerous steam-boats and tow-boats may become traveling seminaries of learning, which shall literally carry useful knowledge to every part of our extended empire." Amos Eaton, "Rensselaer School Flotilla for the Summer of 1830" (Troy, N.Y., January 28, 1830).
52. Among the students on the first flotilla were Eben Horsford, later professor of chemistry at Harvard, and Douglass Houghton, later professor of geology at the University of Michigan. See Baker, *A Chapter in American Education*, 53, and Rezneck, "The European Education of an American Chemist and Its Influence

in Nineteenth-Century America: Eben Norton Horsford," *Technology and Culture* 11:3 (1970), 366–388. Also among Eaton's students at Rensselaer were "James Dwight Dana, professor natural history at Yale; Chester Dewey, professor of chemistry at Rochester; Asa Gray, professor of natural history at Harvard; Joseph Henry, professor of natural history at Princeton; Albert Hopkins, professor of astronomy at Williams, and John Torrey, professor of chemistry at Columbia. . . ." Baker, *A Chapter in American Education*, 11.

53. Quoted in Millbrooke, "State Geological Surveys of the Nineteenth Century," 79–80. Governor George Wolf of Pennsylvania outlined the economic benefits of a geological survey, saying "it would unfold the localities in which are contained mineral substances, pregnant with those manuring and fertilizing qualities which would enable him to reclaim and enrich his soil: to the manufacturer there would be developed, and applied to their proper uses, that endless variety of ores, sands, clays, and other materials so essential to the profitable prosecution of his business: and to our citizens generally, there would be discovered many new sources of wealth, in their mines and their quarries, which lie concealed from them now, but which, the measure proposed would enable them to realize, and convert to profitable and valuable uses." Millbrooke, "State Geological Surveys of the Nineteenth Century," 88.

54. Benjamin Silliman, "Notice of the Anthracite Region in the Valley of the Lackawanna and Wyoming on the Susquehanna," *American Journal of Science* 18 (1830), 1–21. For more on the commercial advantages of anthracite over bituminous coal, see Chandler, "Anthracite Coal and the Beginnings of the Industrial Revolution in the United States," 159. "Not only was [anthracite] more economical than the faster burning bituminous but it did not have sulfuric and other fumes to contaminate the iron being processed." See also Peter Temin, "A New Look at Hunter's Hypothesis about the Antebellum Iron Industry," *American Economic Review* 54 (1964), 344–351, reprinted in R. A. Church, ed. *The Coal and Iron Industries* (Oxford, England, 1994), 478–486.

55. Henry Darwin Rogers, "Anthracite Coal Region of Pennsylvania," *Messenger of Useful Knowledge* 1:8 (March 1831), 113–115. See also Mark Wardell and Robert L. Johnston, "Class Struggle and Industrial Transformation: The U.S. Anthracite Industry, 1820–1902," *Theory and Society* 16:6 (November 1987), 781–808. "Until 1822, 100 percent of the recorded annual anthracite coal shipments came from the middle, or Lehigh, field. The southern, or Schuylkill, field produced approximately 40 percent of the recorded annual shipments in 1822, the other 60 percent being produced in the Lehigh filed. Shipments from the northern, or Wyoming, field were not recorded until 1829 and at that time constituted slightly more than 6 percent of the annual shipments. These early variations in production were not strictly related to the amount of coal reserves in each field or to their accessibility to markets. Coal was not developed seriously in the Schuylkill field until the late 1820s, even though it contained the largest deposits (approximately 275 square miles) in two main seams with many outcroppings. Of the three fields, coal was the most accessible in the Schuylkill, and the Schuylkill Canal, built between 1816 and 1825, provided reasonably efficient transportation of the coal to Philadelphia. The Wyoming field consisted of one major seam (approximately 176 square miles) but coal could not be efficiently mined unless shafts were sunk below water level or cheaply transported on water to New York, the principal market for the coal. The Lehigh field contained the fewest deposits (approximately 33 square miles) consisting of nine small seams, some being flat and others being steeply pitched slopes. Although the coal in this field initially was more accessible than in the Wyoming field, transportation costs were about 90 percent of the market price in the early years, and by 1830 the Lehigh field had lost its prominence as the chief producer of anthracite coal." Wardell and Johnston, "Class Struggle and Industrial Transformation," 784.

56. Chandler, "Anthracite Coal and the Beginnings of the Industrial Revolution in the United States," 152–153.
57. Ibid., 156.
58. Ibid. For the continuation of this competitive trend, see Robert C. Allen, "International Competition in Iron and Steel, 1850–1913," *Journal of Economic History* 39:4 (1979), 911–937.
59. Chandler, "Anthracite Coal and the Beginnings of the Industrial Revolution in the United States," 153.
60. Ibid., 154.
61. Access to anthracite became all the more significant after 1837, when the issue of igniting the hard-to-light substance was resolved. Again, technology originating in Great Britain found its way into a scientific journal in the United States (in this case, the journal of the Franklin Institute in Philadelphia). As historian of science Patsy Gestner notes: "By the early 1830s, experiments to use the hot blast for smelting ore with raw anthracite, rather than coke, were under way, and in 1837, a process using hard coal and the heated blast was introduced in Wales and was reported that year to the British Association for the Advancement of Science. The Franklin Institute reported the new process in its journal almost immediately." Patsy Gerstner, *Henry Darwin Rogers, 1808–1866: American Geologist* (Tuscaloosa, Ala., 1994), 81.
62. Rainer Fremdling, "Foreign Trade Patterns, Technical Chance, Cost, and Productivity in the West European Iron Industries, 1820–1870," in R. Fremdling and P. K. O'Brien, eds., *Productivity in the Economies of Europe* (1983), 154, reprinted in R. A. Church, ed. *The Coal and Iron Industries* (Oxford, England, 1994), 322–344. See also Rainer Fremdling, *Anglo-German Rivalry over Coal Markets in France, the Netherlands, and Germany, 1850–1913* (Groningen, The Netherlands, 1995); and Jon Ulrich Nef, *The Rise of the British Coal Industry* (Freeport, N.Y., 1972).
63. See Donald J. Daley, *Tariff and Science Policies: Applications of a Model of Nationalism* (Toronto, 1976). See also Stanley Engerman, "The American Tariff, British Exports, and American Iron Production, 1840–1860," in D. N. McCloskey, ed., *Essays on a Mature Economy: Britain After 1840* (1971), 27, reprinted in R. A. Church, ed. *The Coal and Iron Industries* (Oxford, England, 1994), 487–511.
64. Fremdling, "Foreign Competition and Technological Change: British Exports and the Modernisation of the German Iron Industry from the 1820s to the 1860s,"

reprinted in R. A. Church, ed., *The Coal and Iron Industries* (Oxford, England, 1994), 345–374; cited material on 65 and 49. See also Robert W. Fogel and Stanley L. Engerman, "A Model for the Explanation of Industrial Expansion during the Nineteenth Century: With an Application to the American Iron Industry," *Journal of Political Economy* 77:3 (May 1969), 306–328.

65. The delay in launching the Pennsylvania Geological Survey came primarily from an economic downturn in Pennsylvania that lasted from 1832 to 1834. See Gerstner, *Henry Darwin Rogers*, 49.

66. See Anne Millbrooke, "The Geological Society of Pennsylvania, 1832–1836," *Pennsylvania History* 7:6 (1976), 7–11 and 8:2 (1977), 12–16. The Geological Society of Pennsylvania kept close ties with the *Monthly American Journal of Geology and Natural Science*, founded in 1832 and published by George Featherstonaugh, a British immigrant who had lobbied for a national geological survey and who, in 1834, received a congressional appointment to survey the area between the Missouri and Red rivers. See Edmund Berkeley and Dorothy Smith Berkeley, *George William Featherstonaugh: The First U.S. Government Geologist* (Tuscaloosa, 1988). See also Merrill, *The First One Hundred Years of American Geology*, 137–138. For more on competition between Featherstonaugh's *Monthly American Journal of Geology and Natural Science* and Silliman's *American Journal of Science*, see Simon Baatz, "'Squinting at Silliman': Scientific Periodicals in the Early American Republic, 1810–1833," *Isis* 82:312 (1991), 223–244.

67. For more on the Franklin Institute, see Bruce Sinclair, *Philadelphia's Philosopher Mechanics: A History of the Franklin Institute, 1824–1865* (Baltimore, 1974). See also Simon Baatz, "Philadelphia Patronage: The Institutional Structure of Natural History in the New Republic, 1800–1833," *Journal of the Early Republic* 8:2 (1988), 111–138; and John Sinkankas, "William Maclure and the Library of the Academy of Natural Sciences of Philadelphia," *Earth Sciences History* 19:1 (2000), 33–35. See also Julius A. Stratton and Loretta H. Mannix, *Mind and Hand: The Birth of MIT* (Cambridge, Mass., 2005), 32–34.

68. Frierich List had accompanied the Marquis de Lafayette on his much-lauded tour of the United States in 1826 to commemorate the fiftieth anniversary of American independence. His "Outlines of American Political Economy," issued under the title "The American System" in 1827, outlined his idea of economic nationalism and contributed to the passage of the new tariff (the Tariff of Abominations) in 1828. For more on List, see Eugen Wendler, *Friedrich List, 1789–1989: An Historical Figure and Pioneer in German-American Relations*, trans. Lynne Bils-Baumann and Louis Bloom (Gräfelfing, 1989); W. O. Henderson, *Friedrich List, Economist and Visionary 1789–1846* (London, 1983); and Roman Szporluk, *Communism and Nationalism: Karl Marx versus Friedrich List* (New York, 1991).

69. Quoted in Andreas Etges, *Wirtschaftsnationalismus: USA und Deutschland im Vergleich, 1815–1914* (Frankfurt, 1999), 67. Some accused List of pushing an "Anti-American System."

70. Millbrooke, "State Geological Surveys of the Nineteenth Century," 87. See also Bradford Willard, "Pioneer Geologic Exploration in Pennsylvania," *Pennsylvania History* 32:3 (1965), 236–253.

71. See *Life and Letters of William Barton Rogers, Edited by His Wife*, 2 vols. (Boston, 1896). See also Alex J. Angulo, "William Barton Rogers and the Idea of M.I.T." (Unpublished Ph.D. dissertation, Harvard University, 2003); and Joseph Carson, "Memoir of the Life and Character of James B. Rogers" (Philadelphia, 1852).

72. *Life and Letters of William Barton Rogers*, 96–97, 107.

73. Henry Rogers to his uncle (December 21, 1832), Box 1, Folder 9, MC1, Institute Archives, Massachusetts Institute of Technology, Cambridge, Massachusetts (hereafter designated MIT Archives). See also *Life and Letters of William Barton Rogers*, 107–108.

74. See Henry Darwin Rogers to his uncle (December 14, 1832), *Life and Letters of William Barton Rogers*, 97–98. "Dr. Turner, last night, introduced me to the Geological Society, of which he is secretary . . . . I was introduced personally to several of the members, De la Beche, Lyell, Babbage, and others." See also John C. Thackray, *To See the Fellows Fight: Eyewitness Accounts of Meetings of the Geological Society of London and Its Club, 1822–1868* (Stanford in the Vale, Faringdon, Oxfordshire, 2003), and Horace B. Woodward, *The History of the Geological Society of London* (New York, 1978).

75. *Life and Letters of William Barton Rogers*, 107.

76. Rogers later prepared the seventh edition of Edward Turner's *Elements of Chemistry*, along with William Gregory's *Outlines of Organic Chemistry*, in one volume, for distribution in the United States (Philadelphia, 1846).

77. Henry Darwin Rogers's study of the hygrometer in England may have informed his theoretical work in geology in the United States, specifically as it pertained to atmospheric conditions that led to the formation of coal. See Merrill, *The First One Hundred Years of American Geology*, 245. "H.D. Rogers was one of the first to show by direct calculation that the earth had been in the past, as at present, robbing the atmosphere of some of its constituent parts and gradually storing them up in its solid crust, although [Lardner] Vanuxeum in 1827, while connected with South Carolina College, had pointed out the probable change in the atmosphere during geologic time through the absorption by the earth of the nitrogen and oxygen, and also the probability of a warm, moist climate during the period of coal formation." For more on Lardner Vanuxem, see Schneer, "Ebenezer Emmons and the Foundations of American Geology," 444–445.

78. *Life and Letters of William Barton Rogers*, 106. See also Tom Sharpe, *The Papers of H. T. De la Beche (1796–1855) in the National Museum of Wales* (Cardiff, 1998).

79. See William Smith, "A New Geological Atlas of England and Wales [Showing] the Situation of the Best Materials for Building, [the] Making of Roads, [and] the Construction of Canals, and Pointing out Those Places Where Coal and Other Valuable Materials Are to Be Found," *William Smith's Geological Maps* (London: British Museum [Natural History], 1975), 4 pp., mentioned in William M. Jordan, "Geology and the Industrial-Transportation Revolution in Early to

Mid Nineteenth-Century Pennsylvania," in Schneer, *Two Hundred Years of Geology in America*, 91–103.

80. The basic geological strata are: precambrian, cambrian, ordovician, silurian, devonian, carboniferous, permian, triassic, jurassic, cretaceous, eocene, and miocene. See Martin J. S. Rudwick, *The Great Devonian Controversy: The Shaping of Scientific Knowledge among Gentlemanly Specialists* (Chicago, 1985). While De la Beche was developing the Devoninan system based on observations in Devon, Roderick Murchison was developing his Silurian system and Adam Sedgwick his Cambrian system based on observations in Wales. See D. R. Oldroyd, *The Highlands Controversy: Constructing Geological Knowledge through Fieldwork in Nineteenth-Century Britain* (Chicago, 1990).
81. *Life and Letters of William Barton Rogers*, 106.
82. Quoted in Millbrooke, "State Geological Surveys of the Nineteenth Century," 93. For more on Joseph Henry's participation in the Rensselaer School Flotilla, see Samuel Rezneck, "Joseph Henry Learns Geology on the Erie Canal in 1826," *New York History* 50:1 (1969), 29–42. As a youth, Joseph Henry served as private tutor in the Van Rensselaer family and, owing to this connection, was appointed chief engineer on a survey to build a road along the Erie Canal. In 1837, he went to Europe to purchase equipment for physics laboratories at Princeton. See Allen G. Shenston, "Joseph Henry's Bills, 1832–1837–1844–1865," *Princeton University Library Chronicle* 28:3 (1967), 150–155. For more on Henry, see Albert E. Moyer, *Joseph Henry: The Rise of an American Scientist* (Washington, D.C., 1997); Arthur P. Molella, ed., *A Scientist in American Life: Essays and Lectures of Joseph Henry* (Washington, D.C., 1980); Thomas Coulson, *Joseph Henry: His Life and Work* (Princeton, 1950); Nathan Reingold, "The New York State Roots of Joseph Henry's National Career," *New York History* 54:2 (1973), 133–144; and Michael Francis Conlin, "Science Under Siege: Joseph Henry's Smithsonian, 1846–1865" (Unpublished Ph.D. dissertation, University of Illinois, 1999); and Sally Kohlstedt, "A Step toward Scientific Self-Identity in the United States: The Failure of the National Institute, 1844," *Isis* 62:3 (Autumn 1971), 339–362.
83. Quoted in Millbrooke, "State Geological Surveys of the Nineteenth Century," 97. The need to "resurvey" existing geological maps in Pennsylvania stemmed from the fact that no geographically accurate map of Pennsylvania existed in the 1830s. The only complete map, done in 1818, did not represent the vertical aspects of the land (e.g., cross-sections or profiles). See Gerstner, *Henry Darwin Rogers*, 63.
84. Alexander Dallas Bache and Henry Darwin Rogers, "Analysis of Some Coals in Pennsylvania," *Journal of the Academy of Natural Sciences of Philadelphia* 7, pt. 1 (1834), 158–177. In 1836 and 1837, Bache traveled in England, Scotland, France, Switzerland, Belgium, Holland, Germany, and Italy to collect data on European education for help in developing Girard College in Philadelphia. See Alexander Dallas Bache, *Report on Education in Europe, to the Trustees of the Girard College for Orphans* (Philadelphia, 1839). Joseph Henry joined Bache in Europe in 1837, and Bache later served as a trustee of the Smithsonian when Henry was director. For more on Bache, see Hugh Richard Slotten, *Patronage, Practice, and the Culture of American Science: Alexander Dallas Bache and the U.S. Coast Survey* (New York, 1994); Merle Odgers, *Alexander Dallas Bache: Scientist and Educator, 1806–1867* (Philadelphia, 1947); Robert Post, "Science, Public Policy, and Popular Precepts; Alexander Dallas Bathe and Alfred Beach as Symbolic Adversaries," in Nathan Reingold, ed., *The Sciences in the American Context: New Perspectives* (Washington, D.C., 1979), 77–98; and A. Hunter Dupree, "The Founding of the National Academy of Sciences: A Reinterpretation," *Proceedings of the American Philosophical Society* 1957 101(5), 434–440.

85. For more on the history of Sheffield and Lawrence, see Russell H. Chittenden, *History of the Sheffield Scientific School of Yale University, 1846–1922*, 2 vols. (New Haven, 1928); George A. Baitsell, ed., *The Centennial of the Sheffield Scientific School* (New Haven, 1950); Gerald T. White, "Benjamin Silliman, Jr., and the Origins of the Sheffield Scientific School," *Ventures* 8:1 (1968), 19–25; Clark A. Elliott and Margaret W. Rossiter, *Science at Harvard University: Historical Perspectives* (Bethlehem, Penn., 1992); Clark A. Elliott, "Founding of the Lawrence Scientific School at Harvard University, 1846–1847: A Study in Writing and History," *Archivaria* 38 (1994), 119–130; James Lee Love, *The Lawrence Scientific School in Harvard University, 1847–1906* (Burlington, N.C., 1944); and Louis I. Kuslan, "The Founding of the Yale School of Applied Chemistry," *Journal of the History of Medicine and Allied Sciences* 1969 24(4), 430–451.
86. See George H. Daniels, *American Science in the Age of Jackson* (New York, 1968).
87. See Edward Hitchcock, *Report of a Geological Survey of Massachusetts: Made under an Appointment by the Governor* (1832); and *Report on a Re-Examination of the Economical Geology of Massachusetts* (1838).
88. Quoted in Gerstner, *Henry Darwin Rogers*, 46.
89. See Patsy Gerstner, "Partners in Geology, Brothers in Frustration: The Antebellum Geological Surveys of Virginia and Pennsylvania," *Virginia Magazine of History and Biography* 106:1 (1998), 5–34; Peter Lessing, "The Rogers-Hotchkiss Geological Maps of Virginia and West Virginia," *Earth Sciences History* 14:1 (1995), 84–97; and Robert C. Milici and C. R. Bruce Hobbs, Jr., "William Barton Rogers and the First Geological Survey of Virginia, 1835–1841," *Earth Sciences History* 6:1 (1987), 3–13. The economic motive of the Rogers brothers' surveys was clear. As William commented, "All are willing to admit the great extent and value and diversity of our mineral wealth, and at the same time to confess that its distribution through our territory, its precise boundaries in any one locality, its exact nature as ascertained by science, and its susceptibility of economical and profitable application to the purposes of commerce, manufactures and the arts of life, are matters of which scarcely anything as yet has been accurately determined." Quoted in Stratton, 80. See also William B. Rogers, *Report of the Progress of the Geological Survey of the State of Virginia for the Year 1838* (Richmond, 1839).
90. Gerstner, *Henry Darwin Rogers*, 77. Later credited with pioneering a new theory of mountain formation, many of the Rogers brothers' ideas on the subject origi-

nated with French geologist Leoncé Elie de Beaumont, whose paper on mountain formation De la Beche had published shortly before Rogers arrived in London in 1832. De Beaumont held that a molten core at the center of the earth was slowly cooling and shrinking in size, thereby causing the earth's crust to "crumple" and causing the elevation of mountain ranges (formed when geological strata broke apart and climbed atop one another). Henry and William Rogers adapted this "catastrophic" theory of mountain formation to explain the origins of the Appalachians. See Mott T. Greene, *Geology in the Nineteenth Century: Changing Views of a Changing World* (Ithaca, 1982), 69–92. De Beaumont's catastrophic theory differed from the so-called uniformitarian theory, which held that mountains resulted from gradual continental up-lift combined with corrosive forces such as wind and water. The chief spokesman for the uniformitarians was Charles Lyell, who, in 1830, published his landmark work, *Principles of Geology*. A decade later, Lyell visited the United States to deliver the second annual series of lectures at the Lowell Institute in Boston (the first series having been delivered by Benjamin Silliman). See Margaret W. Rossiter, "Benjamin Silliman and the Lowell Institute: The Popularization of Science in Nineteenth-Century America," *New England Quarterly* 44:4 (1971), 602–626. See also Robert H. Dott, Jr., "Lyell in America: His Lectures, Field Work, and Mutual Influences, 1841–1853," *Earth Sciences History* 15:2 (1996), 101–140; and Leonard Wilson, *Lyell in America: Transatlantic Geology, 1841–1853* (Baltimore, 1998). When the Rogers brothers issued their theory of "tangential movement" to explain the formation of mountains (basically, the idea that mountain chains result from the folding of strata caused, in turn, by undulations of lava beneath a flexible crust—an idea that led others to hypothesize the existence of tectonic plates), their work gained support from De la Beche. See Greene, *Geology in the Nineteenth Century*, 124. "The Appalachians, when seen in true vertical scale, gave considerable cogency to the idea that a tangential movement was responsible for the folding. Indeed, Henry De la Beche, who was the strongest contemporary proponent in England of tangential compression as the motive force in the creation of mountain structure, had argued strenuously for more attention to true vertical scaling in geological mapping when he inaugurated the Geological Survey of Great Britain."

91. Millbrooke, "State Geological Surveys of the Nineteenth Century," 104. Some argue that Rogers's geological survey of Pennsylvania emphasized academic more than economic issues—perhaps to his own professional detriment. See Francis Boscoe, "'The Insanities of an Exalted Imagination': The Troubled First Geological Survey of Pennsylvania," *Pennsylvania Magazine of History and Biography* 127:3 (2003), 291–308.
92. See James A. Secord, "The Geological Survey of Great Britain as a Research School, 1839–1855," *History of Science* 24 (1986), 223–275; and "'King of Siluria: Roderick Murchison and the Imperial Theme in Nineteenth Century British Geology," *Victorian Studies* 25 (1982), 413–442. See also Suzanne Zeller, "The Colonial World as a Geological Metaphor: Strata(gems) of Empire in Victorian Canada," *Osiris* 15 (2000), 85–107.
93. In addition to collecting mineralogical data, the Geological Survey of the United Kingdom also collected information on soil quality needed for the efficient cultivation of plantation crops throughout the empire. In this way, its work was quite similar to the work of state geological surveys in the United States. See Stafford, *Scientist of Empire*, 110–131.

94. Ibid., 147–148. See also M. C. Cleary, "Indigenous Trade and European Economic Intervention in North-West Borneo c.1860–1930," *Modern Asian Studies* 30:2 (May 1996), 301–324; John S. Galbraith, "The Chartering of the British North Borneo Company," *Journal of British Studies* 4:2 (May 1965), 102–126; and Amarjit Kaur, "The Babbling Brookes: Economic Change in Sarawak 1841–1941," *Modern Asian Studies* 29:1 (February 1995), 65–109.
95. See K. G. Tregonning, "American Activity in North Borneo, 1865–1881," *Pacific Historical Review* 23 (1954), 357–372.
96. Ibid.
97. For more on the U.S. Exploring Expedition, see Charles Wilkes, *Narrative of the United States Exploring Expedition during the Years 1838, 1839, 1840, 1841, 1842*, 5 vols. (Philadelphia, 1845); David B. Tylor, *The Wilkes Expedition: The First United States Exploring Expedition, 1838–1842* (American Philosophical Society, 1968); William Stanton, *The Great United States Exploring Expedition of 1838–1842* (Berkeley, 1975); Herman J. Viola and Carolyn Margolis, eds., *Magnificent Voyagers: The U.S. Exploring Expedition, 1838–1842* (Washington, D.C., 1985); Roberta A. Sprague, *The Wilkes Expedition: Framework for American Expansionism: The United States Exploring Expedition, 1838–1842* (Unpublished M.A. thesis, University of Hawaii, 1988); and Barry Alan Joyce, *The Shaping of American Ethnography: The Wilkes Exploring Expedition, 1838–1842* (Lincoln, Neb., 2001).
98. See Charles Harvey and Jon Press "Overseas Investment and the Professional Advance of British Metal Mining Engineers, 1851–1914," *Economic History Review* 42:1 (February 1989), 64–86.
99. Quoted in Francis Wayland, *The Elements of Political Economy* (New York, 1837), 465–472. See also John R. McCulloch, *The Principles of Political Economy, with a Sketch of the Rise and Progress of the Science* (Edinburgh, 1825); *Observations on the Duty on Sea-borne Coal, and on the Peculiar Duties and Charges on Coal in the Port of London* (London, 1830); *Observations on the Influence of the East India Company's Monopoly on the Price and Supply of Tea, and on the Commerce with India, China, etc.* (London, 1831); and *Historical Sketch of the Bank of England, with an Examination of the Question as to the Prolongation of the Exclusive Privileges of that Establishment* (London, 1831).
100. Ibid.
101. See Millbrooke, "State Geological Surveys of the Nineteenth Century," 108. Pennsylvania was not immune to the effects of the Panic of 1837. As Millbrooke writes, "Like many other states, Pennsylvania had borrowed heavily to finance programs of internal improvement. Although expected to pay for themselves, the public works—canals, turnpikes, and railroads—generated little revenue. That income was not nearly enough to pay the interest on loans made to finance the projects. Pennsylvania paid the interest on its growing debt with premiums

for new loans. The nationwide Panic of 1837 did not halt the borrowing, but the banking collapse of 1839 did, and in January of 1840 Governor [David Rittenhouse] Porter declared Pennsylvania's internal improvements a financial failure. The state sought to pay its debt by enacting tax bills, issuing relief notes, and selling bank stock. These measures carried Pennsylvania until August of 1842, when the state defaulted. It was the eighth of nine states that defaulted during the depression."

102. The international scope of the financial crisis of 1837 shaped Francis Wayland's analysis in his famous *Elements of Political Economy* (1837), which appended material on precious metals from McCulloch's *Dictionary of Commerce*. "The subject of the Currency occupies, at present, so prominent a place in the public attention," Wayland wrote, that McCulloch's report on precious metals in India, China, and Borneo had become deeply relevant to his topic.
103. George W. White, "The History of Geology and Mineralogy as Seen by American Writers, 1803–1835: A Bibliographic Essay," *Isis* 64:2 (June 1973), 197–214.
104. James Curtis Booth, "Lectures on the Elements of Technical Philosophy" (n.d.), Box 2, Folder 50, Ms. 160, James Curtis Booth Papers, Annenberg Rare Book and Manuscript Library, University of Pennsylvania, Philadelphia, Pennsylvania.
105. Merrill, *The First One Hundred Years of American Geology*, 374.
106. For more on Josiah Whitney, see Edwin Tenney Brewster, *Life and Letters of Josiah Dwight Whitney* (Boston, 1909). For more on Joseph Leidy, see Leonard Warren, *Joseph Leidy: The Last Many Who Knew Everything* (New Haven, 1998). For more on James Hall, see John Mason Clarke, *James Hall of Albany: Geologist and Palaeontologist, 1811–1898* (Albany, 1923). For more on James Dwight Dana, see Daniel C. Gilman, *The Life of James Dwight Dana: Scientific Explorer, Mineralogist, Geologist, Zoologist, Professor in Yale University* (New York, 1899).