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"An Image of Science": Cameralism, Statistics, and the Visual Language of Natural History in the Nineteenth Century

ABSTRACT

This paper traces the emergence of a new visual language for statistical paleontology in the early nineteenth century as part of a broader project to uncover a deep genealogy of modern practices in data visualization. In the first decades of the nineteenth century, natural historians had amassed large quantities of taxonomic data, but lacked quantitative and visual methods to produce and communicate knowledge derived from their data collections. As our "main witness" (in Ian Hacking's sense), we call on the German paleontologist H. G. Bronn—one of the earliest proponents of a "data-driven" approach to statistical natural history—to highlight two unexpected sources of a transformative visual idiom introduced at the time: so-called spindle diagrams representing historical patterns in taxonomic diversity. The first source—which informed Bronn's general statistical approach to fossil data—was the bureaucratic science of cameralism, in which Bronn was steeped as a student and professor at the University of Heidelberg. The second was an earlier tradition of historical visualization popularized by Joseph Priestley and others, which represented time—or the "timeline"—as measured graphical space on the horizontal axis of a chart. In combining the tabular statistical approach of Heidelberg cameralism and the historical timeline, Bronn contributed to the emergence of a powerful new visual language for producing and communicating aggregative statistical generalizations.

KEY WORDS: natural history, paleontology, statistics, visual culture, cameralism, H. G. Bronn

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INTRODUCTION

In 1858, the eminent German paleontologist Heinrich Georg Bronn published his final major work, which he grandly titled *Untersuchungen über die Entwicklungs-Gesetze der Organischen Welt*, or "Investigations into the Laws of Development in the Organic World."[1] Bronn's *Untersuchungen* was a major theoretical examination of patterns of development and diversification of groups of organisms in the fossil record, and was based on a shorter treatise that had, in 1857, been awarded the Grand Prize of the Paris Academy of Sciences.[2] In it, Bronn argued that the history of life appears to follow a series of regular "laws" that have produced ever greater complexity, diversity, and "perfection" in living creatures, which he illustrated through a series of diagrams similar to those in Figure 1.

The *Untersuchungen* was the culmination of some three decades of empirical research and analysis, and at the time of its publication Bronn enjoyed a reputation as one of Europe's leading paleontologists, consulted by luminaries including Charles Lyell and Charles Darwin.[3] Today, he is almost entirely forgotten, his work having been eclipsed just a year later by Darwin's own theoretical opus, *On the Origin of Species* (1859). Our interest here in Bronn, however, is not with his major theoretical conclusions, nor with revising his place in the history of evolutionary biology or paleontology, but rather in his methodology—and in particular, his use of tables and images. Bronn's approach to the history of life was, put simply, to present a history of data, and his innovation—which is part of a broader general transformation in data practices in the nineteenth century—was to marry statistical natural history

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[1] Heinrich Georg Bronn, *Untersuchungen Über Die Entwickelungs-Gesetze der organischen Welt Während der Bildungs-Zeit unserer Erd-Oberfläche* (Stuttgart: Schweizerbart'sche Verlagsbuchhandlung, 1858). All translations in this article are ours unless otherwise specified.

[2] See Sander Gliboff, *H. G. Bronn, Ernst Haeckel, and the Origins of German Darwinism. A Study in Translation and Transformation* (Cambridge: The MIT Press, 2008); Lynn K. Nyhart, *Biology Takes Form: Animal Morphology and the German Universities 1800—1900* (Chicago: The University of Chicago Press, 1995).

[3] See Martin J. S. Rudwick, "Charles Lyell's Dream of a Statistical Palaeontology," *Palaeontology* 21 (1978): 225–44; Martin J. S. Rudwick, *Worlds before Adam: The Reconstruction of Geohistory in the Age of Reform* (Chicago: The University of Chicago Press, 2008); Martin J. S. Rudwick, *The Meaning of Fossils: Episodes in the History of Palaeontology* (London: Macdonald, 1972); Gliboff, *H. G. Bronn* (ref. 2).

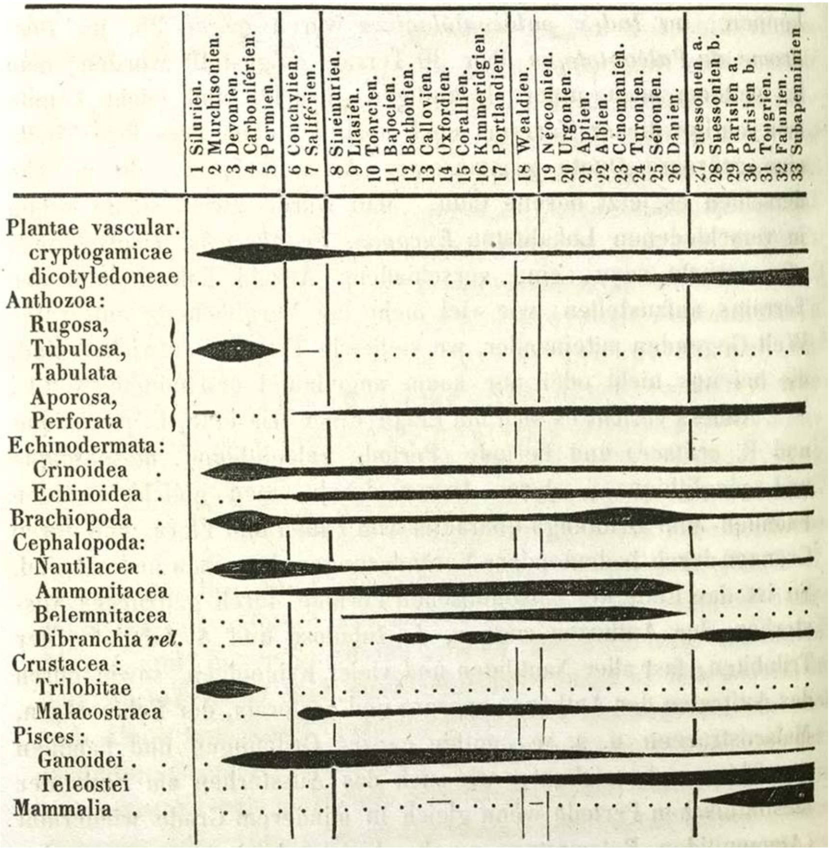

FIG. 1. One of the several spindle diagrams used by Heinrich Georg Bronn to visualize the history of nature and discover biological laws. In these diagrams, the horizontal axis represents time, and the vertical reflects the number of subtaxa (for instance, species within genera) present in the groups in the table on the left. The resulting line of fluctuating thickness "narrates" the changes in the diversity of groups over time. *Source*: Bronn, *Untersuchungen Über Die Entwickelungs-Gesetze* (ref. 1), 312.

with narrative visual techniques.[4] The humble diagram presented in Figure 1, then, is emblematic of this important shift.

Bronn spent much of his career amassing an enormous collection of data about fossils, which he culled both from his own fieldwork and from the avalanche of research published by paleontologists and geologists throughout

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[4] For additional background on Bronn's career, see David Sepkoski, "Towards 'a Natural History of Data': Evolving Practices and Epistemologies of Data in Paleontology, 1800–2000," *Journal of the History of Biology* 46, no. 3 (2013): 401–44.

the first half of the nineteenth century.[5] Bronn intended this collection—which may be analogized to a modern database—to be a resource for fellow practitioners as well as a source of his own theoretical contributions.[6] In 1849, he produced a massive two-volume work titled *Index palaeontologicus: Oder Übersicht der bis jetzt bekannten fossilen Organismen* (Index of paleontology: or an overview of the hitherto known fossil organisms), which both presented and synthesized his data on the history of life. The first volume, subtitled *Nomenclator Paleontologicus*, was essentially a catalog of all known fossil taxa, arranged in alphabetical and systematic order; the second, *Enumerator Paleontologicus*, was a repackaging of the catalog as many hundreds of pages of tables, followed by fairly simple statistical analysis and discussion. Included in the *Enumerator* section were a number of diagrams similar to the one reproduced above from the *Untersuchungen*—a type of visualization now known as a "spindle diagram." Bronn's *Index* was not the first or only attempt at a general catalog of fossils (indeed, French and British geologists had produced similar works since at least the 1820s), but it was regarded as the most complete and authoritative yet produced. Bronn was also the first naturalist to produce spindle diagrams, a genre of paleontological visualization that is now iconic in the field.

Why is this so important? In the first place, Bronn was one of the earliest innovators in an approach to studying the history of life through data—which we will call the "aggregative statistical" approach—that would achieve great prominence in paleontology, especially in the later twentieth century after the advent of digital electronic computers.[7] More generally, though, Bronn's career stands witness to an even more important transformation of practice

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[5] Rudwick, *The Meaning of Fossils* (ref. 3).

[6] David Sepkoski, "The Database before the Computer?," *Osiris* 32 (2017): 175–201; Marco Tamborini, "Die Wurzeln der ideographischen Paläontologie: Karl Alfred von Zittels Praxis und sein Begriff des Fossils," *NTM Zeitschrift für Geschichte der Wissenschaften, Technik und Medizin* 23 (2015): 117–42; Marco Tamborini, "Paleontology and Darwin's Theory of Evolution: The Subversive Role of Statistics at the End of the 19th Century," *Journal of the History of Biology* 48, no. 4 (2015): 575–612.

[7] David Sepkoski, *Rereading the Fossil Record: The Growth of Paleobiology as an Evolutionary Discipline* (Chicago: The University of Chicago Press, 2012). Our use of the term "aggregative" here is indebted to Dan Bouk's analysis of the practice of statistically summarizing personal data in state and corporate bureaucracies. We follow Bouk in asserting that aggregation not only presents a new mode of visually representing data (as summarizing illustrations), but a new way of thinking as well: the aggregative mode treats the statistical average, rather than the individual case, as the relevant level of resolution for understanding regularities or trends involving complex phenomena. Dan Bouk, "The History and Political Economy of Personal Data over the Last Two

and epistemology that was taking place across many disciplines—spanning the human and natural sciences—during the middle of the nineteenth century. Broadly, this transformation has been described by Theodore Porter and other historians as "the rise of statistical thinking," or, in other words, the establishment of the belief "that order is to be found in large numbers."[8] At its basis is the recognition that certain phenomena—broad trends or regularities in demographics or financial fortunes—can be identified through the collection and analysis of large quantities of numerical data. This was a historical development that, in Porter's words, required a scientific community familiarized "with the use of aggregate numbers and mean values for studying an inherently variable object," who were gradually convinced by statistical authors that large statistical samples "could be presumed to generate large-scale order and regularity which would be virtually unaffected by the caprice that seemed to prevail in the actions of individuals."[9]

One important feature of the gradual establishment of what Porter calls "trust in numbers" was a strong initial influence from the social sciences. Statistics was, in its inception, a practice of bureaucratic administrators—"statists"—tasked with tracking the finances and resources of European states, and was associated with large-scale collection of data in the form of censuses and surveys during the second half of the eighteenth century.[10] At the same time, large statistical projects were underway in the natural sciences as well. In botany and zoology, followers of Alexander von Humboldt were avidly collecting numerical data about plants and animals in order to establish patterns of biogeography in Europe and elsewhere. Janet Browne has described this approach as "botanical arithmetic," which she characterizes as "an elementary numerical technique that reduced absolute figures into statements of a proportional kind, which could then be arranged with others in a table."[11] Like contemporary bureaucratic statistics, though, she sees this practice as ultimately self-limiting: in most cases, "the purpose of the exercise rested in the figures, not

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Centuries in Three Acts," *Osiris* 32 (2017): 85–106. On aggregative statistics, see also Stephen M. Stigler, *Seven Pillars of Statistical Wisdom* (Cambridge, MA: Harvard University Press, 2016).

[8] Theodore M. Porter, *The Rise of Statistical Thinking, 1820–1900* (Princeton, NJ: Princeton University Press, 1986), 6. See also Alain Desrosières, *The Politics of Large Numbers: A History of Statistical Reasoning* (Cambridge, MA: Harvard University Press, 1998); Ian Hacking, *The Taming of Chance* (Cambridge: Cambridge University Press, 1990).

[9] Porter, *The Rise of Statistical Thinking* (ref. 8), 5.

[10] Ibid., 38.

[11] Janet Browne, *The Secular Ark: Studies in the History of Biogeography* (New Haven, CT: Yale University Press, 1983), 59.

in the conclusions which might be drawn from them," and Browne argues that "to modern eyes many of these numerical surveys seem somewhat pointless," since they "were rarely used to substantiate specific hypotheses, nor did they generate any important new questions about geographical phenomena."[12]

This paper will build on some of the insights of these earlier histories of statistics, but will posit a somewhat alternative genealogy of the emergence of modern approaches to statistical aggregation. H. G. Bronn was, as a paleontologist, intimately familiar with the Humboldtian vision of data accumulation in natural history. However, unlike the Humboldtian botanists and zoologists Browne describes,[13] Bronn approached his data collection with more ambitious goals in mind: he sought nothing less than the discovery of timeless regularities or statistical "laws" hidden in the messy accumulation of numerical data on fossils he amassed—what one of us has described as "a natural history of data."[14] Furthermore, Bronn came to his statistical paleontology directly from bureaucratic statistics; his primary appointment at the University of Heidelberg, where he would eventually hold the first Chair in Zoology, was as a professor of *Kameralwissenschaft*, or "cameralism," which was a dominant approach to bureaucratic statistics in the late eighteenth and early nineteenth centuries.[15] As a school of economic rationalization, cameralism has been strongly associated with the purely descriptive, "numbers for numbers' sake" tradition of early statistics. Links between cameralism and natural science in

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[12] Ibid., 73 and 80.

[13] Our paper contributes to recent literature taking what Nils Güttler has described as a "skeptical view on the actual role of Humboldt and 'his' science on the development of last eighteenth and early nineteenth-centuries quantitative practice." Nils Güttler, "Drawing the Line: Mapping Cultivated Plants and Seeing Nature in Nineteenth-Century Plant Geography," in *New Perspectives on the History of Life Sciences and Agriculture*, ed. Denise Phillips and Sharon Kingsland (London: Springer, 2015), 30.

[14] Sepkoski, "Towards 'a Natural History of Data'" (ref. 4).

[15] On the general structures of cameralism, see Andre Wakefield, *The Disordered Police State: German Cameralism as Science and Practice* (Chicago: The University of Chicago Press, 2009); Keith Tribe, *Governing Economy: The Reformation of German Economic Discourse 1750–1840* (Cambridge: Cambridge University Press, 1988); Oskar Poller, *Schicksal der ersten Kaiserlauterer Hochschule und ihrer Studierenden* (Ludwigshafen Rhein: Arbeitsgemeinschaft Pfälzisch-Rheinische Familienkunde, 1979); Alexandra Plettenberg, *Die Hohe-Kameral-Schule zu Lautern 1774–1784* (München: Typo-Druck, 1983); David F. Lindenfeld, *The Practical Imagination: The German Sciences of State in the Nineteeth Century* (Chicago: The University of Chicago Press, 1997); Andre Wakefield, "Books, Bureaus, and the Historiography of Cameralism," *European Journal of Law and Economics* 19 (2005): 311–20; Keith Tribe, "Cameralism and the Science of Government," *Journal of Modern History* 56 (1984): 263–84; Wilhelm Bleek, *Von der Kameralausbildung zum Juristenprivileg* (Berlin: Colloquium, 1972).

the eighteenth century are well known, but cameralism is rarely credited with making much impact on later statistical or mathematical practice.[16] However, Bronn was a member of a distinctive cameralist school at Heidelberg that sought a more ambitious goal for statistics—or "statics," as they called it—in which numerical data were accumulated for the expressed purpose of revealing patterns, regularities, and laws.[17] Bronn effectively translated his cameralistic statistical practice to paleontology, and his work far surpassed in ambition the tradition of Humboldtian arithmetic described by Browne.

Indeed, although a general desire to identify patterns and underlying order, as well as to formulate prescriptions for action, was already widespread among eighteenth-century cameralists, the main differences between these cameralists and Bronn's nineteenth-century approach are threefold.[18] First, unlike his eighteenth-century colleagues, Bronn did not restrict his quantitative methods to practical or "auxiliary" sciences like forestry, mineralogy, hydraulics, etc.[19] His approach was distinctive in that he adapted cameralistic statistical practice to the study of natural history (a field of proper *Wissenschaft*), extrapolating his scale of analysis from the local and temporally limited domain of state administration to the global and vast temporal canvas of geology and paleontology.

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[16] On Linnaeus' interest in cameralism, see Lisbet Koerner, *Linnaeus: Nature and Nation* (Cambridge, MA: Harvard University Press, 1999). On the relationships between state science and chemistry, see Ursula Klein and Wolfgang Lefèvre, eds., *Materials in Eighteenth-Century Science: A Historical Ontology* (Cambridge, MA: MIT Press, 2007); Jean-Pierre Poirier, *Lavoisier: Chemist, Biologist, Economist* (Philadelphia: The University of Pennsylvania Press, 1993).

[17] Statics was a distinctive tradition among early nineteenth-century German cameralists. The agronomist Albrecht Daniel Thaer (1752–1828) was one of first cameralists to develop this method at the beginning of the nineteenth century, although Thaer's student Carl von Wulffen (1785–1853) in fact coined the term "statics." In his 1810 *Principles of Agriculture*, Thaer defined agricultural statics as "the doctrine of the relationship, in which are compared the capacity of the soil, the profit of the crops, and soil exhaustion." Albrecht Daniel Thaer, *Grundsätze der rationellen Landwirthschaft*, vol. 2 (Berlin, 1810), xiv. Agricultural statics investigated the relationships between forces that act on and regulate crop fertility, much in the same way as physical statics analyzed and balanced the forces of a physical system. Although Thaer's statics had a profound impact on the development of quantitative cameralism, in this paper we focus particularly on the Heidelberg influences on Bronn's practices. We are preparing a broader account of early nineteenth-century quantitative practices in a book-length treatment, where the differences between 1727 Hale's *Vegetable Staticks* and nineteenth-century statics are investigated in-depth. On Thaer's statics, see Peter M. Jones, "Making chemistry the 'science' of agriculture, c. 1760–1840," *History of Science* 54, no. 2 (2016): 169–94.

[18] See, for instance, John L. Heilbron, Tore Erangsmyr, and Robin E. Rider, eds., *The Quantifying Spirit in the Eighteenth Century* (Berkeley: The University of California Press, 1990).

[19] For a recent study on the notion of useful knowledge and practice, see Ursula Klein, *Nützliches Wissen: Die Erfindung der Technikwissenschaften* (Göttingen: Wallstein, 2016).

Second, Bronn's theoretical ambition was significantly different from eighteenth-century cameralists', such as the hydraulic engineer and mathematician Johann Albert Eytelwein, who tended to shy away from overt theorizing or identification of laws.[20] In contrast, Bronn aimed to uncover fundamental laws of physical and organic development, which he outlined in his major theoretical treatise, the 1858 *Untersuchungen*. These laws of development were derived from decades of data collection and statistical analysis, and were an attempt at an explanation of natural history that was every bit as ambitious as Leonhard Euler's was for physics or Bernard de Bélidor's for hydraulics.

And third, visualizations played a quite different role in both cultures. Although both Eytelwein and Bronn visualized their quantitative data by means of lines and graphs, Bronn's spindle diagrams were, first and foremost, essential epistemic instruments. They enabled, he believed, the discovery of biological phenomena that were otherwise invisible, and they took the form of narrative historical arguments. Whereas the practice of using tables and graphs to convey information "at a glance" was widespread and well-established, Bronn's visualization of quantitative data to reveal broad historical patterns represents an emerging tradition in natural history that would come to have great explanatory power over the next century and beyond.[21]

Indeed, in his paleontological work Bronn was one of the earliest innovators in a problem that would occupy economic statisticians only several decades later: the marriage of statistics to history. In the first decades of the nineteenth century, European naturalists amassed a huge amount of data about fossils, much of which was directed toward solving the problem of universal stratigraphy (the correlation of layers of the earth with a relative

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[20] For instance, in her study of Eytelwein's (1764–1848) quantitative practice and the systematization of hydraulic engineering in the *Oberbaudepartement*, Kathryn M. Olesko has remarked, "'Theory' for [hydraulic engineers] came to mean the derivation of empirical laws under controlled local conditions, not the laws of hydrodynamics as developed by Euler, the French, and others. 'Practice' meant the experience-based techniques and methods that had proven effective in dealing with the Prussian landscape from the Oderbruch project to the partitioning of Poland, not the blanket acceptance of [Bernard de] Bélidor's highly regarded hydraulic engineering." Kathryn M. Olesko, "Geopolitics and Prussina Technical Education in the Late-Eighteenth Century," *Actes d'història de la Ciènca i de la Tècnica, Nuova Ѐpoca* 2, no. 2 (2009): 11–44, on 28.

[21] See, for instance, Sybilla Nikolow, *Statistiker und Statistik: Zur Genese der statistischen Disziplin in Deutschiand zwischen dem 18. und 20. Jahrhundert* (PhD dissertation, Technische Universitat Dresden, 1994). The physicist Hermann von Helmholtz also used graphs and lines to present complex phenomena "at a glance." See, for instance, von Helmholtz, *The Values of Precision*, ed. Norton M. Wise (Princeton, NJ: Princeton University Press, 1995), 211.

temporal scale via characteristic fossils). However, some geologists (including, in addition to Bronn, Georges Cuvier, Alexandre Brongniart, Charles Lyell, Alcide d'Orbigny, John Phillips, and others) recognized that fossils could also be used to reconstruct a history of life on earth, which scientists were only just beginning to realize was far more ancient and dynamic than previously suspected. Bronn was among the first to have the insight that fossils could be obtained in sufficient quantities to sketch out a general narrative of life's history. But to do so, Bronn reasoned that the narrative would have to be reconstructed from a great many data points, and its outlines would only come into view via statistics.

Bronn's solution to this problem ultimately involved developing a new visual mode for expressing temporal patterns in data. The dominant approach to representing historical patterns in data was, in the first part of the nineteenth century, the table. Cameralists and bureaucratic statisticians of all stripes had a positive fetish for tables, and were so enamored of the device that a (mildly pejorative) German word was coined to describe the approach—*Tabellenstatistik*. Tables are, of course, a kind of visualization, but they are not the most effective genre for both revealing and communicating patterns or narratives, especially if one has thousands of pages of them. Naturalists of the period were also drawn to the tabular format, and it is common to find tables accounting numbers of plants, animals, or fossils in contemporary works of natural history. Indeed, Bronn himself made great use of numerical tables, which we have argued were a kind of proto-database for his statistical analyses. But, beginning in his works of the 1840s, Bronn also realized that there are other kinds of visualizations that can abstract patterns *from* the numerical data without necessarily *reproducing* those data: his spindle diagrams are a classic example of this. In composing his diagrams, Bronn merged the insights of statistical cameralism with an entirely distinct tradition of visual culture: the pictorial historical timeline, a genre made famous by the charts of history produced by Joseph Priestley and imitators in the later eighteenth century. Instead of having to pore through hundreds of pages of tables of data, a naturalist could simply view a diagram that shows, in outline, the patterns those data take as a visual narrative of the past. This is commonplace today, but at the time Bronn first published it was a radically new idea, one which would not have been obvious at all to his contemporaries.

The spindle diagram we began this paper with, then, highlights both the general transformation in statistical practice and visualization that was occurring during the middle of the nineteenth century, as well as the local contexts and knowledge transfers that contributed to this broader change.[22] Bronn's approach anticipated by some two decades or more similar innovations in graphical statistics in the social sciences, reinforcing the conclusion that the transfer of knowledge between bureaucratic and natural sciences was very much a two-way street. Bronn's adoption of this new visual convention—the image of data as graphical narrative—was his most striking singular contribution, but it was developed in a fluid context where a variety of distinctive practices and visual cultures—some of which have not been linked in previous scholarship in the history of statistics and visualization—contacted and overlapped one another. Bronn was not the only nineteenth-century natural historian to adopt an aggregative statistical method, but he was among the first, and he contributed to changing the way historical science was practiced. Although virtually nobody visualized natural historical data in this way before Bronn's lifetime, it is now the standard convention, not just in paleontology but in all natural sciences that describe temporal change historically. Our goal here, however, is not to celebrate Bronn as the "inventor" of a modern visual-statistical genre. Rather, we use Bronn's somewhat idiosyncratic background and career as witness to the highly contingent interactions between statistical and visual conventions from several independent knowledge traditions that contributed to the nineteenth-century emergence of "trust in numbers."

KAMERALWISSENSCHAFTEN, STATISTICS, AND STATICS: THE ROOTS OF THE QUANTITATIVE FRAMEWORK

Before turning to Bronn's implementation of statistical visualizations to natural history, a general picture of statistical and visual practices among contemporary cameralists should be sketched out. The broad administrative practice known as "cameralism" was a heterogeneous discipline composed of a core of administrative, economic, and bureaucratic disciplines integrated with several essential "auxiliary sciences," ranging from forestry to geology to mathematics. It was an approach that was widely pursued during the eighteenth century in northern Europe (and especially Scandinavia), reflecting a general Enlightenment sensibility of order and rationality.[23] In the German states, cameralism was institutionalized in the early eighteenth century (1727), during the reign of

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[22] See also Wolfgang Schäffner, "Nicht-Wissen um 1800: Buchführung und Statistik," in *Poetologie des Wissens um 1800*, ed. Joseph Vogl (München: Fink, 1999), pp. 123–45.

[23] Koerner, *Linnaeus* (ref. 16).

Friedrich Wilhelm I, where it evolved from a mostly qualitative approach in its initial inception to, by the early nineteenth century, a fairly rigorously quantitative means of assessing and managing the natural resources and human capital of the state. The first Institute for Cameral Studies in southern Germany was established in Lautern in 1774 with the aim of training bureaucratic staff for the administration of Western Palatinate.[24] This institute would particularly influence the development of German natural sciences during the first decades of the nineteenth century after it was incorporated into the university of Heidelberg in 1784, where it initiated and spread a distinctively quantitative approach to summarizing numerical data.[25]

The *Hohe Kameral-Schule zu Lautern* was established on the basis of an existing agricultural association in 1774 and was the first school in Germany to offer *Kameralwissenschaft* as a major course of study. The head of the school was the botanist and physician Friedrich Casimir Medicus (1736–1808). Six weeks after its foundation, Georg Adam Succow (1751–1813) was hired to teach pure and applied mathematics, natural history, and natural philosophy. For the education of future *Kammerbediensteten*, Succow proposed courses in various disciplines not strictly related to public finance. The training was intended to provide all the possible tools required not only to collect and classify data, but also to manage them, and thus included intensive training in a number of auxiliary disciplines. For instance, the first semester of the curriculum introduced students to philosophy, pure mathematics, natural philosophy, and natural history. In Succow's plan, it was not until the third semester that students were taught general principles of state administration and finance.

Ten years after its foundation, the cameral school was moved to Heidelberg and eventually incorporated into the philosophical faculty of that university on the 13th of May, 1803. This transition signaled the growth and establishment of cameralism as a university discipline. However, the study of *Kameralwissenschaft* in Heidelberg maintained its commitment to practical and theoretical goals even after the subsequent reorganization of the University of Heidelberg

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[24] On the relationship between the Kameral Hohe Schule in Lautern and the other cameralistic schools, see Heinrich Webler, "Die Kameral-Hohe-Schule zu Lautern," *Mitteilungen der Historischen Vereins der Pfalz* 43 (1927): 1–168; Poller, *Schicksal der ersten Kaiserlauterer Hochschule* (ref. 15); Plettenberg, *Die Hohe-Kameral-Schule Zu Lautern* (ref. 15); Lindenfeld, *The Practical Imagination* (ref. 15).

[25] According to the historian Keith Tribe, the Lautern-Heidelberg school became "the most successful and lasting example of Cameralistic training in the German university, and was recognized as such at the time." Tribe, *Governing Economy* (ref. 15), 41.

and its annexation to the Grand Duchy of Baden.[26] After the incorporation of the school into the university, Succow became the director of the state economy section of the philosophical faculty, thus strengthening his institutional authority. Here he continued to promote the agenda he had developed at Lautern: through his teaching (he taught mainly chemistry, physics, biology, and mathematics) he promoted the strong unity among and exchange of knowledge between auxiliary sciences, technology, and state sciences. Particularly after Succow's death in 1813, many professors both in Heidelberg and elsewhere argued for new approaches to state science that eventually transformed cameralism into what later became the independent discipline of "economics" (*Oekonomie*).[27] However, far from abandoning the pluralistic spirit of the cameralistic method, this evolving disciplinary tradition continued to foster a rich and mutual exchange of practices and knowledge between the classical cameralistic subjects and the natural sciences.

The close relationship between cameralism and the auxiliary sciences contributed to their growth as autonomous disciplines, as well as to the establishment of a broader quantitative framework able to manage and visually represent the increasing flood of data and information about state resources. This was, after all, the beginning of the period when, as Hacking has put it, Europeans were drowning in an "avalanche of printed numbers."[28] The cameralistic framework at Heidelberg aimed to transcend a mere accumulation of data, and to move toward a methodology that emphasized a theoretical approach to data management, analysis, and visual representation. This emphasis resulted from the influence of simple mathematical practices on the auxiliary disciplines that made up the cameralist curriculum. Cameralists applied mathematical practices to connect and aggregate their data in order to reveal patterns that were not immediately apparent in the avalanche of numbers. They transformed a mere statistical accumulation of data into quantitative method, which compared tabulated numerical data to uncover possible economic patterns. In short, following what Thaer had initiated in Berlin during the 1810s, they converted statistics into statics. In

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[26] Peter Wolgast and Eike Classen, *Kleine Geschichte der Universitat Heidelberg* (Berlin, Heidelberg: Springer, 1983).

[27] As, for instance, noted by Bleek, "both national economy and economy grew out of the old cameralism. These came from it and were separated into independent sciences." Bleek, "Von der Kameralausbildung zum Juristenprivileg" (ref. 15), 96.

[28] Ian Hacking, "Biopower and the Avalanche of Printed Numbers," *Humanities in Society* 5 (1982): 279–95.

doing so, the Heidelberg version of cameralism formulated one of the essential characteristics of the aggregative approach that Bronn would establish in natural history.

As has been widely discussed by historians of quantification and statistics, the German economist and statistician Gottfried Achenwall (1719–1772), who occupied a professorship in natural law and politics at the University of Göttingen between 1761 and 1772, understood statistics or description of the state (*Staatbeschreibung*) to quantitatively describe the objects in a particular area.[29] Statistics strived to give an exhaustive account of the existing resources of the state. As such, Achenwall considered it a purely descriptive branch of knowledge that did not deal with explanatory patterns or rules. Likewise, in his *Theorie der Statistik* (1804), August Ludwig von Schlözer (1725–1809), Achenwall's successor in Göttingen, emphasized that "Statistics is stationary history, history is moving statistics."[30] Statistics is a synchronic treatment of historical facts; history narrates those facts in time. This statement set the agenda for the further statistical treatment of data by cameralists.

In the early cameralistic curriculum, statistics was considered to be the mere description of data, which did not attempt to determine causal relationships. Its distinctive visual idiom was the numerical table, which emphasized the tabular arrangement of data to better facilitate their comparison (Fig. 2).

The best example of this approach is the Prussian Statistical Bureau, which was established in 1805 and eventually came under the direction of Leopold Krug (1770–1843). Krug held firmly to the belief that tables were the appropriate form for presenting statistical data about the state. Above all, he believed that statistics was a merely descriptive enterprise that should make no causal or prescriptive assumptions. As he wrote in his 1807 *Ideen zu einer staatswirthschaftlichen Statistik* (Ideas on a statistics of state economy),

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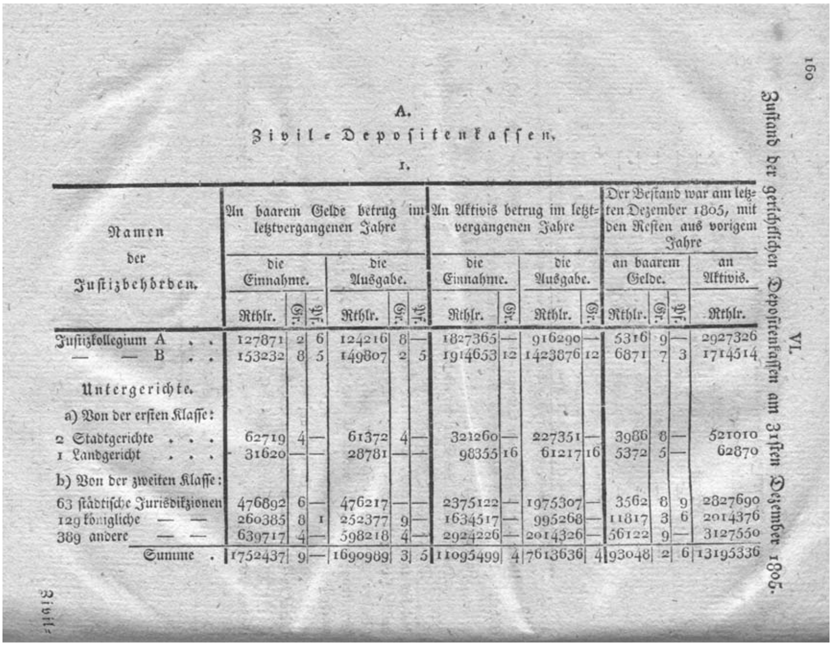
[29] See Theodore M. Porter, *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life* (Princeton, NJ: Princeton University Press, 1995); Porter, *The Rise of Statistical Thinking* (ref. 8); Hacking, *The Taming of Chance* (ref. 8); Desrosières, *The Politics of Large Numbers* (ref. 8); Wolfram Fischer and Andreas Kunz, eds., *Grundlagen der historischen Statistik von Deutschland: Quelle, Methoden, Forschungsziele* (Darmstadt: Westdeutscher Verlag, 1991); Wieland Sachse, *Bibliographie zur Preußischen Gewerbestatistik 1750–1850* (Göttingen: Schwartz, 1981); Hans-Georg Herrlitz, *Anfänge Göttinger Sozialwissenschaft: Methoden, Inhalte und Soziale Prozesse im 18. Und 19. Jahrhundert* (Göttingen: Vandenhoeck & Ruprecht, 1987); Wolfgang Schäffner, "Topographie der Zeichen: Alexander von Humboldts Datenverarbeitung," in *Das Laokoon-Paradigma. Zeichenregime im 18. Jahrhundert*, ed. Michael Franz and Inge Baxmann (Berlin: Akademie Verlag 2000), 359–82.

[30] August Ludwig von Schlözer, *Theorie der Statistik* (Göttingen, 1804), 86.



160 Zuſtand der gerichtlichen Depoſitenkaſſen am 31ſten Dezember 1805. VI.

A.

Zivil-Depoſitenkaſſen.

1.

Namen der Juſtizbehörden.	An baarem Gelde betrug im letztvergangenen Jahre						An Aktivis betrug im letztvergangenen Jahre				Der Beſtand war am letzten Dezember 1805, mit den Reſten aus vorigem Jahre			
	die Einnahme.			die Ausgabe.			die Einnahme.		die Ausgabe.		an baarem Gelde.			an Aktivis.
	Rthlr.	Gr.	Pf.	Rthlr.	Gr.	Pf.	Rthlr.	Gr.	Rthlr.	Gr.	Rthlr.	Gr.	Pf.	Rthlr.
Juſtizkollegium A . .	127871	2	6	124216	8	—	1827365	—	916290	—	5316	9	—	2927326
— — B . .	153232	8	5	149807	2	5	1914653	12	1423876	12	6871	7	3	1714514
Untergerichte.														
a) Von der erſten Klaſſe:														
2 Stadtgerichte . . .	62719	4	—	61372	4	—	321260	—	227351	—	3986	8	—	521010
1 Landgericht . . .	31620	—	—	28781	—	—	98355	16	61217	16	5372	5	—	62870
b) Von der zweiten Klaſſe:														
63 ſtädtiſche Jurisdikzionen	476892	6	—	476217	—	—	2375122	—	1975307	—	3562	8	9	2827690
129 königliche — —	260385	8	1	252377	9	—	1634517	—	995268	—	11817	3	6	2014376
389 andere — —	639717	4	—	598218	4	—	2924226	—	2014326	—	56122	9	—	3127550
Summe .	1752437	9	—	1690989	3	5	11095499	4	7613636	4	93048	2	6	13195336

Zivil=

FIG. 2. A classical example of statistical data in tabular form. *Source*: Leopold Krug, *Ideen zu seiner* (ref. 21), 160.

> As a historical science, statistics shall only represent objects as they are and must abstain from all judgments or suggestions about how they should be.... Since these sources are poor in many countries and states, it must seek to arrive at results by combining all the individual notes according to their probability sets, which due to the lack of historical information are initially only hypotheses ... or find more historical data, whose viewing gives the statesman a hint at to what items he has to direct his attention.[31]

Despite the widespread popularity of this approach to statistics, the Heidelberg school of *Kameralwissenschaften* went well beyond this more limited view. That is to say, although Heidelberg cameralists embraced the tabular form of representation, they rejected the notion that statistics involved the mere accumulation of data, instead developing fairly complex practices to deal with tabular data. Although they understood the importance of tables, they reinforced the tabular mode of visual presentation with a broader theoretical and mathematical framework. One of the most important Heidelberg practitioners of this broader quantitative treatment of tabular data was the cameralist

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[31] Leopold Krug, *Ideen zu seiner staatswirthschaftlichen Statistik* (Berlin: 1807), ix.

Eduard Baumstark (1807–1889). An important politician and professor of cameral studies at Heidelberg between 1825 and 1838, he argued in his monumental *Kameralistische Encyclopädie* (1835) that cameralism was neither a mere statistical treatment of data nor only the compilation of dry and cold statistics. It was, rather, a historical reflection based upon general principles:

> I do not mean that the doctrine of public finance gives only a poor historical introduction based on dates and cold statistical data [*kalten-statistischen Daten*], but I mean that the whole public economy should be grounded on historical principles, instead of on simple dogmatics, and it should be developed as a result of research in the history of transport, of culture, of the state and of humankind generally.”[32]

Baumstark's assertion that “cold statistical data” are meaningless if not connected with, and based upon, historical principles is particularly interesting in the context of Bronn's adaptation of cameralist statistics to paleontology. Bronn and Baumstark were colleagues in the cameralist faculty at Heidelberg during the same period, which was also—as we will discuss below—the time when Bronn first began to seriously explore an aggregative approach to paleontology.

The model most favored by Heidelberg *Kammerbediensteten* for this more theoretically sophisticated approach was “statics” (*Statik*), a practice implemented in agriculture by Thaer and Carl von Wulffen in the mid-1810s, and associated with the branch of physics that analyzes mechanical forces in equilibrium. The main difference is that statics, unlike statistics, is based on a set of mathematical principles for describing the relationships among forces in a system; it implicitly assumes that the regular, lawful behavior in the phenomena it treats can be described by simplifying equations. Physical statics was a regular part of the Heidelberg *Kammerbediensteten* curriculum, where it became a model for a kind of cameralist statics that could be applied to specific disciplines.

For example, the forestry scientist Johann Christian Hundeshagen (1783–1834) applied statics to the study of forestry. In his important *Encyclopädie der Forstwissenschaft, systematisch abgefasst* (Encyclopedia of forest science, systematically prepared) he explained that “we use here the word ‘forestry statics’ as the sum of all the finite causes, which determine the success (yield, income, etc.), as well as all proportionate ratios.”[33] In other words, forestry statics

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[32] Edward Baumstark, *Kameralistische Encyclopädie* (Heidelberg, Leipzig: Karl Gross, 1835), viii.

[33] Johann Christian Hundeshagen, *Encyclopädie der Forstwissenschaft, systematisch Abgefasst* (Tübingen: Laupp, 1828), 29.

(*forstliche Statik*) sought to uncover the causes responsible for increasing the state's potential earnings from its forests. It aimed to investigate possible patterns in the collected statistical data: it pursued "only the general lawful or the determinable in all relationships," whereas statistics dealt with the accumulation of particular data alone.[34]

The use of statistics and statics thus formed a two-step process: first, the cameralist had to gather and tabulate his data, which was a statistical task; second, he calculated the possible mathematical relationships within the data tables, which was statics. This aims at reaching general conclusions about how to balance what there is with what there is supposed to be, and one cannot estimate what is supposed to be without some general rules or principles.[35] Hence, the main difference between statistics and statics is that, whereas the former merely allows the state administrator to collect data in tabular form, the latter seeks "the general legality in every relationship,"[36] that it "should go hand in hand with theory,"[37] and so that it "draws the balance between 'to have' and 'to be expected to.'"[38]

KAMERALWISSENSCHAFT AND PALEONTOLOGY: H. G. BRONN AND DATA AGGREGATION

Heinrich Georg Bronn may have been trained as a cameralist, but his reputation was made as a paleontologist.[39] He was the first Professor of Zoology at

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[34] Ibid.

[35] On the key meaning of "balance" in the eighteenth and nineteenth centuries, see Wise, *The Values of Precision* (ref. 21); and Norton M. Wise, "Mediations: Enlightenment Balancing Acts; or, The Technology of Rationalism," in *World Changes: Thomas Kuhn and the Nature of Science*, ed. P. Horwich. (Cambridge, MA: MIT Press, 1993).

[36] Johann Christian Hundeshagen, *Encyclopädie Der Forstwissenschaft* (ref. 33), 29.

[37] G. W. Wedekind, "Inhaltsübersicht der forstlichen Verhältnißkunde," *Neue Jahrbucher der Forstkunde*, 18 (1840): 146–53.

[38] Julius Adolph Stöckhardt, *Chemische Feldpredigten für deutsche Landwirthe* (Leipzig: Georg Wigand's Verlag, 1857), 23.

[39] On Bronn's place in the history of biology and paleontology see Gliboff, *H. G. Bronn* (ref. 2); Nyhart, *Biology Takes Form* (ref. 2); Sepkoski, "Towards 'a Natural History of Data'" (ref. 4); Tamborini, "Paleontology and Darwin's Theory of Evolution" (ref. 6); Tamborini, "Die Wurzeln der ideographischen Paläontologie" (ref. 6); Walter Baron, "Zur Stellung von Heirich Georg Bronn (1800–1862) in der Geschichte des Evolutionsgedankens," *Sudhoffs Archiv für Geschichte der Medizin und der Naturwissenschaften* 45 (1961): 97–100; Nicolaas A. Rupke, "Neither Creation nor Evolution: The Third Way in Mid-Nineteenth-Century Thinking about the Origin of Species," *Annals of the History and Philosophy of Biology* 10 (2005): 143–72; Hans Querner,

the University of Heidelberg and actively contributed in the organization, administration, and prestige of that university, eventually becoming prorector in 1859.[40] Today, if Bronn is remembered at all, it is for being the first German translator of the first two editions of Charles Darwin's *Origin of Species*.[41] However, Bronn was one of the leading paleontologists in Europe during the nineteenth century, and his reputation was firmly based in his statistical approach to the history of life. Although he was not the only paleontologist or naturalist of his era to use statistics, he was an acknowledged pioneer among his peers; for example, in July of 1832 and again in 1833, Charles Lyell sought out Bronn in Heidelberg to discuss his quantitative approach, which Lyell hoped to adapt to his own work on *Principles of Geology* (1830–33).[42] After his death in 1862, the *Allgemeine Deutsche Biographie* commemorated Bronn as "one of the brightest stars in the sky of the German science," and the chronicle of the University of Heidelberg reported that his "extraordinary scholarship and erudition made him famous throughout Europe."[43]

Although his seminal works in paleontology established his scientific reputation, Bronn's initial training and first appointment at the University of Heidelberg was in *Kameralwissenschaft*. In fact, his initial commitment was to cameralism, but a year after enrolling in the cameralist curriculum at Heidelberg in 1817, he decided to expand his studies to include natural history. During his

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"Heinrich Georg Bronn und Seine Entwicklungslehre," in *Semper Apertus: 600 Jahre Ruprecht-Karls-Universität Heidelberg 1386–1986: Festschrift in sechs Bänden. Das Zwanzigste Jahrhundert: 1918–1985*, ed. Wilhelm Doerr (Berlin, Heidelberg: Springer, 1985).

[40] The Heidelberg Institut für Zoologie was the fifth in Germany. See Nyhart, *Biology Takes Form* (ref. 2).

[41] This is the context in which Bronn has been most frequently discussed in historical scholarship. Gliboff, for example, has written extensively on Bronn's theoretical work as a kind of bridge between Humbodtian ideals of *Wissenschaft* and Darwinian evolutionary biology. Although we agree that Bronn's theoretical work is interesting, we feel that Gliboff, in virtually ignoring Bronn's statistical methodology, largely passes over what is more significant about Bronn's impact on natural history. It would be hard to find a German naturalist of the period who was not impressed by von Humboldt's philosophy of science; what was distinctive about Bronn was his grounding in the methodology and practice of cameralistic statics. See Gliboff, *H. G. Bronn* (ref. 2). On the broader notion of *Wissenschaft* in eighteenth end nineteenth centuries, see Denise Phillips, "Bacon among the Germans: Stories from when 'Science' meant 'Wissenschaft'," in "Languages of Science," ed. Michael Gordin and Konstantinos Tampakis, *History of Science* 53, no. 4 (2015): 378–94.

[42] On Lyell's statistical approach, see Rudwick, "Charles Lyell's Dream" (ref. 3).

[43] Wilhelm von Gümbel, "Bronn, Heinrich Georg.," in *Allgemeine Deutsche Biographie* (Leipzig: Duncker & Humblot, 1876), 355; Anonymous, "Nachruf," in *Chronik Der Universität Heidelberg* (Heidelberg: 1862), 961.

cameralist education Bronn attended the lectures given by Einrich Eschenmayer (1763–1845), a professor of state science and the author of various important works on state finance and cameralism. In the preface of his influential 1806 book *Über Staats-Aufwand und die Bedeckung desselben* (On state expenditures and their coverage), Eschenmayer described state science as a discipline that depicts "how it is possible to both bring and manage systematic order and punctual accuracy into the financial system and accountancy."[44] The key words in this quotation are "bring and manage systematic order"; in Eschenmayer's view, what made state science "scientific" was that it aimed at systematically bringing order to chaotic phenomena. Moreover, although he regarded order to be a necessary condition for the fruitful handling of state financial problems, mere organization was not the principal aim of the science; rather, the central question that state science sought to answer was quantitative and not qualitative. It is about "how much, from what and when does the nation have to pay?"[45]

Eschenmayer thus conceived cameralism as a science that provides order by means of quantitative tools. This order was best represented in tables to facilitate comprehension of the acquired results.[46] The importance of the tabular approach was not lost on Bronn, who was in a position as a student at Heidelberg to reflect on the importance of quantitative order in both the application of Heidelberg cameralism and the study of natural history. Eschenmayer's tabular format became an important template onto which Bronn would eventually project his system of natural history and his aggregative approach to data visualization: in his later work, paleontological data were organized into tables just like items in a census report. Furthermore, Bronn absorbed the Heidelberg attitude that tables were not a matter of data accumulation for its own sake, but rather a means to reveal broader economic patterns. Bronn would apply these lessons to his study of natural history, but he also continued his cameralist teaching duties throughout his entire academic career.

Indeed, in 1821, Bronn obtained his *Habilitation* in applied natural history and systematic state science, and immediately began teaching cameralism at Heidelberg. From 1821 until his retirement he regularly taught forestry and agriculture as well as natural history. In fact, it was only after 1833 that Bronn began lecturing in general natural history and zoology. The records at the University of

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[44] Heinrich Eschenmayer, *Über Staats-Aufwand und die Bedeckung desselben* (Heidelberg: Mohr und Zimmer, 1806), iv.

[45] Ibid., 4.

[46] See, for example, Eschenmayer, *Anleitung zu einer systematischen Einrichtung des Staats-Rechnungswesens* (Heidelberg, 1807).

Heidelberg preserve the course catalogs from the years that Bronn taught there, which reveal important information about Bronn's teaching. For example, Bronn almost always assigned Hundeshagen's *Encyclopädie der Forstwissenschaft* as the textbook in his cameral studies lectures on forestry and agriculture. Bronn was deeply acquainted with all of Hundeschagen's publications (and even reviewed several of Hundeshagen's books in contemporary journals), and he and Hundeschagen exchanged correspondence. We can be fairly confident, then, that Bronn absorbed Hundschagen's quantitative approach to cameralism.

Bronn's first publications were modest contributions to the study of agriculture and forestry. In addition to several articles, he published a short book in 1830, titled *Ueber Zweck und Einrichtung Landwirthschaftlicher Vereine überhaupt, und mit besonderer Beziehung auf Baden* (On the aims and establishment of agriculture associations in general and with special reference to Baden), where he practiced and spread the quantitative cameralistic framework he had learned and taught. In this book, Bronn explicitly endorsed Hundeshagen's definition of statics, defining "agricultural statics" as "the determination of how much food can be subtracted from a field, how much remains, and what types of fruit and in what quantity can still be produced; or how many parts we must enforce it again, to give a desired yield."[47] For Bronn, agricultural statics was a quantitative and arithmetic discipline. It quantified how much there was, there is, and there will be, and sought regular patterns in these relationships. There is thus a strong similarity between Bronn's agricultural statics, Thaer's agricultural statics, Hundeshagen's forestry statics, and what Bronn would eventually call "paleontological statics."

At the same time—during the 1820s—Bronn began actively researching geology and paleontology, and made two trips to Switzerland, southern France, and Italy (in 1824 and 1827) to gather important advice, fossil specimens, and especially to meet key naturalists of the day. As it emerges from his published travel reports, Bronn took notes, commented on, and sought to quantify everything he encountered connected to the fields of agriculture, forestry, and natural history. For instance, he made detailed notes on several farms in Pavia, and described local practices of forestry in Italy.[48] Meanwhile, he was engaged in a project that was very different from his cameralistic pursuits: he had become

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[47] Heinrich Georg Bronn, *Ueber Zweck und Einrichtung Landwirthschaftlicher Vereine überhaupt, und mit besonderer Beziehung auf Baden* (Heidelberg: Winter, 1830), 17. Here Bronn explicitly linked his practice also with Thaer's works on statics.

[48] See Heinrich Georg Bronn, *Ergebnisse meiner Naturhistorisch-Öconomischen Reisen* (Heidelberg: 1826); Heinrich Georg Bronn, *Ergebnisse meiner Naturhistorisch-Öconomischen*

interested in the problem of the temporal and geographical distribution of fossils in the Italian Tertiary formations (i.e., in rocks dating from roughly 66 to 2.5 million years old according to modern radiometric dating). This was a topic that had engaged a number of other geologists of his day—including Lyell—since during the 1820s naturalists were just beginning to become aware of the vast expanses of time that were represented by geological strata.[49]

Bronn believed, like Lyell, that a statistical method could be devised to date the layers that make up the Tertiary formations based on careful study of the fossils that correspond to certain strata. So, given his training and background, he approached this problem like a good cameralist: first, he made a census of the families, genera, and species of marine invertebrate fossils found in the Italian formations. Although he did collect his own specimens, he also relied on the sound administrative practice of drawing from reliable firsthand accounts—the published and unpublished reports and catalogs composed by contemporary geologists—to compile his census. Next, he faced the same problem that had daunted state administrators for decades: how to make sense of a collection of scattered and heterogeneous information? Bronn's solution to this was also cameralistic: he converted the taxonomic information to numerical data, essentially by counting the number of distinct taxonomic entries for different periods, and arranged them in tables. This allowed the Tertiary formation to be represented—visually and numerically—as a series of summarizing tables of data that could be absorbed at a glance (Fig. 3).

Bronn published these in his first major paleontological work, *Italiens Tertiär-Gebilde und deren organische Einschlüsse* (The Italian Tertiary formations and their organic components), alongside a taxonomic catalog of the raw data that comprised his catalog of Tertiary fossils. The advantage of the tabular, aggregative (and cameralistic) approach was clear: whereas the catalog of fossil taxa ran to some 140 pages, in a single table he could present a numerical summary that also revealed important quantitative relationships, such as the representative proportion of a particular genus of mollusk at different times in the Tertiary, or the approximate rate of extinction of groups over time.[50] Since

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Reisen 2.—Skizzen und Ausarbeitungen über Italien: Nach einem zweyten Besuche (Heidelberg; Leipzig: Groos, 1827).

[49] Martin J. S. Rudwick, *Bursting the Limits of Time: The Reconstruction of Geohistory in the Age of Revolution* (Chicago: The University of Chicago Press, 2005), 90–91; Rudwick, "Charles Lyell's Dream" (ref. 3).

[50] For a more detailed discussion of Bronn's Italian Tertiary work, see Sepkoski, "Towards 'a Natural History of Data'" (ref. 4).

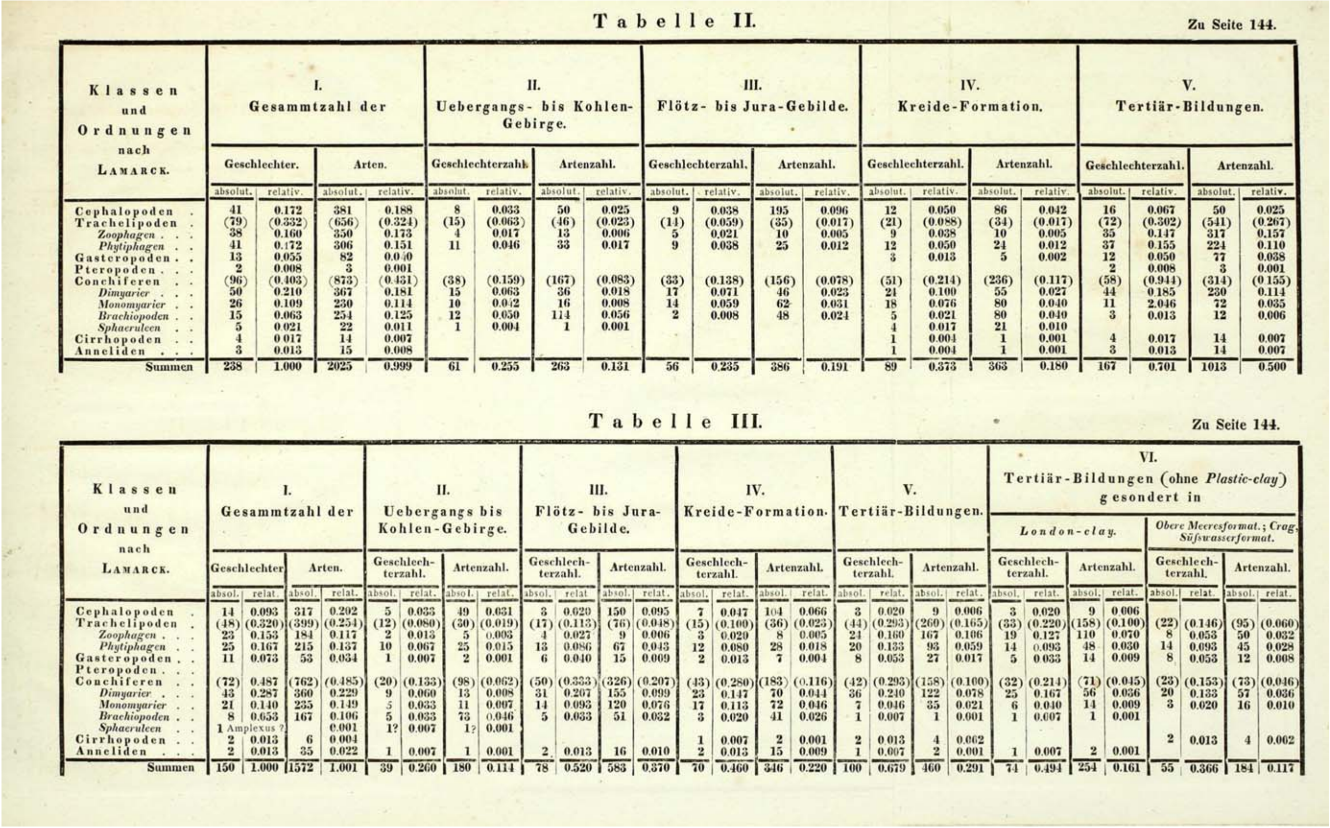

Tabelle II.

Zu Seite 144.

Klassen und Ordnungen nach LAMARCK.	I. Gesammtzahl der				II. Uebergangs- bis Kohlen-Gebirge.				III. Flötz- bis Jura-Gebilde.				IV. Kreide-Formation.				V. Tertiär-Bildungen.			
	Geschlechter.		Arten.		Geschlechterzahl.		Artenzahl.		Geschlechterzahl.		Artenzahl.		Geschlechterzahl.		Artenzahl.		Geschlechterzahl.		Artenzahl.	
	absolut.	relativ.	absolut.	relativ.	absolut.	relativ.	absolut.	relativ.	absolut.	relativ.	absolut.	relativ.	absolut.	relativ.	absolut.	relativ.	absolut.	relativ.	absolut.	relativ.
Cephalopoden	41	0.172	381	0.188	8	0.033	50	0.025	9	0.038	195	0.096	12	0.050	86	0.042	16	0.067	50	0.025
Trachelipoden	(79)	(0.332)	(656)	(0.324)	(15)	(0.063)	(46)	(0.023)	(14)	(0.059)	(35)	(0.017)	(21)	(0.088)	(34)	(0.017)	(72)	(0.302)	(541)	(0.267)
Zoophagen	38	0.160	350	0.173	4	0.017	13	0.006	5	0.021	10	0.005	9	0.038	10	0.005	35	0.147	317	0.157
Phytiphagen	41	0.172	306	0.151	11	0.046	33	0.017	9	0.038	25	0.012	12	0.050	24	0.012	37	0.155	224	0.110
Gasteropoden	13	0.055	82	0.040									3	0.013	5	0.002	12	0.050	77	0.038
Pteropoden	2	0.008	3	0.001													2	0.008	3	0.001
Conchiferen	(96)	(0.403)	(873)	(0.431)	(38)	(0.159)	(167)	(0.083)	(33)	(0.138)	(156)	(0.078)	(51)	(0.214)	(236)	(0.117)	(58)	(0.944)	(314)	(0.155)
Dimyarier	50	0.210	367	0.181	15	0.063	36	0.018	17	0.071	46	0.023	21	0.100	55	0.027	44	0.185	230	0.114
Monomyarier	26	0.109	230	0.114	10	0.042	16	0.008	14	0.059	62	0.031	18	0.076	80	0.040	11	2.046	72	0.035
Brachiopoden	15	0.063	254	0.125	12	0.050	114	0.056	2	0.008	48	0.024	5	0.021	80	0.040	3	0.013	12	0.006
Sphaeruleen	5	0.021	22	0.011	1	0.004	1	0.001					4	0.017	21	0.010				
Cirrhopoden	4	0.017	14	0.007									1	0.004	1	0.001	4	0.017	14	0.007
Anneliden	3	0.013	15	0.008									1	0.004	1	0.001	3	0.013	14	0.007
Summen	238	1.000	2025	0.999	61	0.255	263	0.131	56	0.235	386	0.191	89	0.373	363	0.180	167	0.701	1013	0.500

Tabelle III.

Zu Seite 144.

Klassen und Ordnungen nach LAMARCK.	I. Gesammtzahl der				II. Uebergangs bis Kohlen-Gebirge.				III. Flötz- bis Jura-Gebilde.				IV. Kreide-Formation.				V. Tertiär-Bildungen.				VI. Tertiär-Bildungen (ohne *Plastic-clay*) gesondert in							
																					London-clay.				*Obere Meeresformat.; Crag, Süſswasserformat.*			
	Geschlechter		Arten.		Geschlechterzahl.		Artenzahl.		Geschlechterzahl.		Artenzahl.		Geschlechterzahl.		Artenzahl.		Geschlechterzahl.		Artenzahl.		Geschlechterzahl.		Artenzahl.		Geschlechterzahl.		Artenzahl.	
	absol.	relat.	absol.	relat.	absol.	relat.	absol.	relat.	absol.	relat	absol.	relat.	absol.	relat.	absol.	relat.	absol.	relat.	absol.	relat.	absol.	relat.	absol.	relat.	absol.	relat.	absol.	relat.
Cephalopoden	14	0.093	317	0.202	5	0.033	49	0.031	3	0.020	150	0.095	7	0.047	104	0.066	3	0.020	9	0.006	3	0.020	9	0.006				
Trachelipoden	(48)	(0.320)	(399)	(0.254)	(12)	(0.080)	(30)	(0.019)	(17)	(0.113)	(76)	(0.048)	(15)	(0.100)	(36)	(0.023)	(44)	(0.293)	(260)	(0.165)	(33)	(0.220)	(158)	(0.100)	(22)	(0.146)	(95)	(0.060)
Zoophagen	23	0.153	184	0.117	2	0.013	5	0.003	4	0.027	9	0.006	3	0.020	8	0.005	24	0.160	167	0.106	19	0.127	110	0.070	8	0.053	50	0.032
Phytiphagen	25	0.167	215	0.137	10	0.067	25	0.015	13	0.086	67	0.043	12	0.080	28	0.018	20	0.133	93	0.059	14	0.093	48	0.030	14	0.093	45	0.028
Gasteropoden	11	0.073	53	0.034	1	0.007	2	0.001	6	0.040	15	0.009	2	0.013	7	0.004	8	0.053	27	0.017	5	0.033	14	0.009	8	0.053	12	0.008
Pteropoden																												
Conchiferen	(72)	0.487	(762)	(0.485)	(20)	(0.133)	(98)	(0.062)	(50)	(0.333)	(326)	(0.207)	(43)	(0.280)	(183)	(0.116)	(42)	(0.293)	(158)	(0.100)	(32)	(0.214)	(71)	(0.045)	(23)	(0.153)	(73)	(0.046)
Dimyarier	43	0.287	360	0.229	9	0.060	13	0.008	31	0.207	155	0.099	23	0.147	70	0.044	36	0.240	122	0.078	25	0.167	56	0.036	20	0.133	57	0.036
Monomyarier	21	0.140	235	0.149	5	0.033	11	0.007	14	0.093	120	0.076	17	0.113	72	0.046	7	0.046	35	0.021	6	0.040	14	0.009	3	0.020	16	0.010
Brachiopoden	8	0.653	167	0.106	5	0.033	73	0.046	5	0.033	51	0.032	3	0.020	41	0.026	1	0.007	1	0.001	1	0.007	1	0.001				
Sphaeruleen	1 Amplexus ?			0.001	1?	0.007	1?	0.001																				
Cirrhopoden	2	0.013	6	0.004									1	0.007	2	0.001	2	0.013	4	0.062					2	0.013	4	0.002
Anneliden	2	0.013	35	0.022	1	0.007	1	0.001	2	0.013	16	0.010	2	0.013	15	0.009	1	0.007	2	0.001	1	0.007	2	0.001				
Summen	150	1.000	1572	1.001	39	0.260	180	0.114	78	0.520	583	0.370	70	0.460	346	0.220	100	0.679	460	0.291	74	0.494	254	0.161	55	0.366	184	0.117

FIG. 3. Bronn's statistical treatment of the data gathered in Italy. *Source*: Bronn, *Italiens Tertiär-Gebilde* (ref. 53).

he explicitly believed that there was a historical succession to geological strata and organic life, these tables were also a kind of narrative. This conception reflects Schlözer's assertion that history is "statistics in motion."

In other words, Bronn literally applied cameralism to the study of natural history. But as a paleontologist, he faced an additional problem: although the number of inhabitants of a state, or the approximate number of trees in a forest, or some other economic or natural resource could be fairly reliably estimated (provided one had enough census takers), a "true" picture of the diversity of extinct life is virtually impossible to achieve. This is because, unlike data on state resources, the fossil record is inherently unreliable, due to both the imperfect nature of geological preservation and the inaccessibility of most layers of the earth to human observation. This problem was acknowledged by both Lyell and Darwin as well, the latter of whom famously wrote in the *Origin* that "I look at the natural geological record, as a history of the world imperfectly kept, and written in a changing dialect; of this history we possess the last volume alone, relating only to two or three countries. Of this volume, only here and there a short chapter has been preserved, and of each page, only here and there a few lines."[51] Indeed, Bronn himself anticipated Darwin by a year in his own major theoretical work, the *Untersuchungen*, writing that "the earth crust is a great book which pages are incomplete, broken, jumbled up and faded before us; we need to organize them and to search to supplement what is missing."[52]

However, unlike Darwin, who regarded the problem as essentially insoluble and attempted almost no quantitative study of any kind, Bronn used his cameralist training to resolve this dilemma. As Bronn forthrightly acknowledged in the introduction to *Italiens Tertirär*, "these studies are based on very poor foundations"; however, he also predicted that in theory "the relationship of one Tertiary basin with another can be expressed mathematically, if one could assume to know every fossil species in the area well." He concluded that "these studies are sufficient not only to settle a dispute concerning the Italian Tertiary structure, but also to demonstrate the application of a numerical approach to characteristics of the fossil deposits in rock strata, that has so far not been considered."[53]

As a consequence, Bronn spent the rest of his career attempting to achieve his vision of treating the fossil record as a record of data that could be subjected

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[51] Charles Darwin, *On the Origin of Species* (London: John Murray, 1859), 310–11.

[52] Bronn, *Untersuchungen* (ref. 1), 75.

[53] Heinrich Georg Bronn, *Italiens Tertiär-Gebilde und deren Organische Einschlüsse: Vier Abhandlungen* (Heidelberg: Groos, 1831), 175 and 74.

to numerical analysis to reveal patterns of life's history that could be reduced to principles or even laws. For Bronn this approach had three significant advantages over more descriptive paleontological practices. In the first place, converting fossils to numerical data opened up the possibility of quantitative analysis that could reveal temporal and geographical patterns (such as diversification over time) or even phenomena (such as major extinctions) that were otherwise invisible. Second, treating the fossil record as a record of data allowed him to partially mitigate the problem of the incomplete fossil record; the quantitative approach allowed Bronn to treat fossil populations as statistical aggregates, and the relationships and patterns he uncovered could be considered probabilistically. In a sense, this involved setting a new epistemic standard in paleontology: as Bronn made clear in his later writings, data summaries are mere abstractions based upon an incomplete induction. They have no mathematical necessity; that is, they are not deterministic but rather probabilistic, and "new observations can modify or invalidate them."[54]

And third, Bronn saw in data a new strategy for visually narrating the complex history of life. In the first instance, he accomplished this through tables that were exact analogues of the tabular method of the cameralists. Summarizing tables allow for an at-a-glance snapshot of relationships between data, and it is likely that to a trained cameralist eye many of the patterns of diversification and extinction that Bronn identified would have been apparent. But Bronn's ambition surpassed merely presenting data in the most concise format possible. Here he went beyond his cameralist training to develop an important new tool: summarizing diagrams that presented historical patterns in his data as pictorial images that depicted formerly hidden phenomena. The nineteenth century saw the growth of such pictorial representations of data, but Bronn appears to have invented a special kind—the spindle diagram—that has remained, to this day, one of the iconic data visualizations in paleontology.

However, to achieve these broader objectives, Bronn needed a massive data collection—or a proto-database—of all known taxonomic groups that have ever lived. Since in the early 1830s such a collection did not yet exist, Bronn set out to create one. This required assembling data not just about fossil taxonomy, but also from geology, biogeography, zoology, and botany, and other sources. Furthermore, this information would have to be synthesized and then analyzed statistically, which required up-to-date knowledge of mathematics.

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[54] Heinrich Georg Bronn, *Index Palaeontologicus oder Übersicht der bis Jetzt bekannten Fossilen Organismen* (Stuttgart: Schweizerbart'sche Verlagsbuchhandlung, 1849), 89.

This was a task, in other words, that was perfectly suited to a cameralist, since Bronn had been teaching and thinking for years about the importance of unifying disparate disciplines to produce broader, aggregative understanding. As Bronn put it in his 1854 *Allgemeine Einleitung in die Naturgeschichte* (General introduction to natural history), "the development of natural science is possible only if every discipline that composes it proceeds together; every discipline receives and gives to the others new light."[55]

Bronn's crowning achievement in data collecting was his 1849 *Index palaeontologicus*.[56] The *Index* was compiled from hundreds of published and unpublished sources of paleontological data (such as regional fossil atlases, descriptive monographs, taxonomic treatises, collection catalogs, etc.), and in its day it was the most complete source of paleontological data ever assembled. As previously mentioned, the *Index* was composed of two parts: the first, the *Nomenclator paleontologicus*, is a thousand-plus-page taxonomic list of every known plant and animal fossil, arranged in alphabetical order. This, on its own, was a herculean task, given the amount of anatomical knowledge (from botany and zoology) Bronn was required to assimilate just to organize the fossils into their correct classifications. But this was only a first step. Heidelberg cameralists did not merely collect information for the sake of collection; they wanted that information to tell them something about some broader phenomena or relationships. As Bronn put it in the *Index*, "what can this enterprise enable us to do?" The answer was direct: "It is impossible for the paleontological field to move forward without such work!"[57] So his next step was to painstakingly convert the alphabetized taxonomic lists of the *Nomenclator* to tabular form. This was the second part of the *Index*, the *Enumerator paleontologicus*, which rearranges the taxonomic lists of the *Nomenclator* into some 745 tables showing where each taxonomic group appears in the temporal geological record.

This tabular re-formatting has a strongly visual component. As can be seen from the example in Figure 4, at the top of the page are the fields for the

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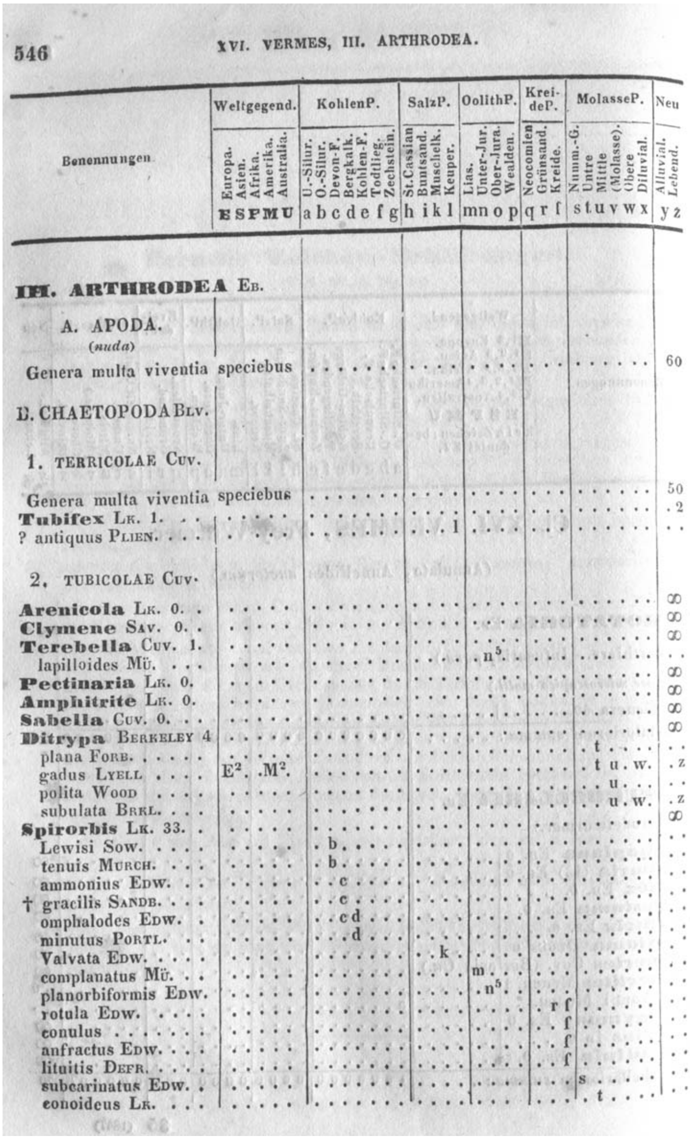
[55] Heinrich Georg Bronn, *Allgemeine Einleitung in die Naturgeschichte* (Stuttgart: Mueller's Berlafshandlung, 1854), 188.

[56] Somewhat confusingly, Bronn's *Index* was published multiple times with different titles. Although both the "Nomenclator" and "Enumerator" sections were published together as *Index Paleontolgicus, oder Übersicht der bist jetzt bekannten Fossilen Organismen* (ref. 54), they were also included in an expanded, three-volume work published the same year titled *Handbuch einer Geschichte der Natur* (Stuttgart: Schweizerbart'sche Verlagsbuchhandlung, 1849). To avoid confusion, our quotations are taken from the *Handbuch*, but we retain Bronn's title *Index Paleontologicus* (which was the subtitle of one section of the *Handbuch*).

[57] Bronn, *Handbuch einer Geschichte Der Natur* (ref. 56), v.



546 XVI. VERMES, III. ARTHRODEA.

Benennungen	Weltgegend.	KohlenP.	SalzP.	OolithP.	Krei-deP.	MolasseP.	Neu
	Europa. Asien. Afrika. Amerika. Australia. E S P M U	U.-Silur. O.-Silur. Devon-F. Bergkalk. Kohlen-F. Todtlieg. Zechstein. a b c d e f g	St.Cassian Buntsand. Muschelk. Keuper. h i k l	Lias. Unter-Jur. Ober-Jura. Wealden. m n o p	Neocomien Grünsand. Kreide. q r ſ	Numm.-G. Untre Mittle (Molasse). Obere Diluvial. s t u v w x	Alluvial. Lebend. y z
III. ARTHRODEA Eb.							
A. APODA. (*nuda*)							
Genera multa viventia speciebus		. . . .	. . . .	. . . .	. . .	. . . . . .	60
B. CHAETOPODA Blv.							
1. TERRICOLAE Cuv.							
Genera multa viventia speciebus		. . . .	. . . .	. . . .	. . .	. . . . . .	50
Tubifex Lk. 1.	. . . . .	. . . .	. . . .	. . . .	. . .	. . . . . .	. 2
? antiquus Plien.	. . . . .	. . . .	. . . l	. . . .	. . .	. . . . . .	. .
2. TUBICOLAE Cuv.							
Arenicola Lk. 0.	. . . . .	. . . .	. . . .	. . . .	. . .	. . . . . .	∞
Clymene Sav. 0.	. . . . .	. . . .	. . . .	. . . .	. . .	. . . . . .	∞
Terebella Cuv. 1.	. . . . .	. . . .	. . . .	. . . .	. . .	. . . . . .	∞
lapilloides Mü.	. . . . .	. . . .	. . . .	. n^5 . .	. . .	. . . . . .	. .
Pectinaria Lk. 0.	. . . . .	. . . .	. . . .	. . . .	. . .	. . . . . .	∞
Amphitrite Lk. 0.	. . . . .	. . . .	. . . .	. . . .	. . .	. . . . . .	∞
Sabella Cuv. 0.	. . . . .	. . . .	. . . .	. . . .	. . .	. . . . . .	∞
Ditrypa Berkeley 4	. . . . .	. . . .	. . . .	. . . .	. . .	. . . . . .	∞
plana Forb.	. . . . .	. . . .	. . . .	. . . .	. . .	. t	. .
gadus Lyell	E^2 . . M^2 .	. . . .	. . . .	. . . .	. . .	. t u . w .	. z
polita Wood	. . . . .	. . . .	. . . .	. . . .	. . .	. . u . . .	. .
subulata Brkl.	. . . . .	. . . .	. . . .	. . . .	. . .	. . u . w .	. z
Spirorbis Lk. 33.	. . . . .	. . . .	. . . .	. . . .	. . .	. . . . . .	∞
Lewisi Sow.	. . . . .	. b	. . . .	. . . .	. . .	. . . . . .	. .
tenuis Murch.	. . . . .	. b	. . . .	. . . .	. . .	. . . . . .	. .
ammonius Edw.	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
† gracilis Sandb.	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
omphalodes Edw.	. . . . .	. . c d . . .	. . . .	. . . .	. . .	. . . . . .	. .
minutus Portl.	. . . . .	. . . d . . .	. . . .	. . . .	. . .	. . . . . .	. .
Valvata Edw.	. . . . .	. . . .	. . k .	. . . .	. . .	. . . . . .	. .
complanatus Mü.	. . . . .	. . . .	. . . .	m . . .	. . .	. . . . . .	. .
planorbiformis Edw.	. . . . .	. . . .	. . . .	. n^5 . .	. . .	. . . . . .	. .
rotula Edw.	. . . . .	. . . .	. . . .	. . . .	. r ſ	. . . . . .	. .
conulus	. . . . .	. . . .	. . . .	. . . .	. . ſ	. . . . . .	. .
anfractus Edw.	. . . . .	. . . .	. . . .	. . . .	. . ſ	. . . . . .	. .
lituitis Defr.	. . . . .	. . . .	. . . .	. . . .	. . ſ	. . . . . .	. .
subcarinatus Edw.	. . . . .	. . . .	. . . .	. . . .	. . .	s	. .
conoideus Lk.	. . . . .	. . . .	. . . .	. . . .	. . .	. t	

FIG. 4. An example of Bronn's tabular data format. *Source*: Bronn, *Index palaeontologicus* (ref. 54), 546.

horizontal axis of the table. This represents the stratigraphic location of the taxa, from early to recent, and it is divided into geological periods. Within each period Bronn has designated subperiods with lower-case letters, which loosely correspond to epochs and ages in the modern geological timescale (although in

Bronn's usage they refer more to the particular formation of which the fossils are characteristic). Finally, Bronn also noted with upper-case letters E, S, F, M, U whether the fossils are found in Europe, Asia, Africa, the Americas, or Australia, respectively—this is indeed a global compendium. Reading down the table, then, a user could locate a particular species within a Class or Sub-Class, and then learn when the species appears in the fossil record. (Bronn helpfully marks this with the lower-case letter corresponding to the geological subperiod so the reader does not have to trace up the page.) From a single glance, a reader could gain a rough appreciation of the diversity of species within a particular group (in this case, genera and species of annelid worms), as well as the pattern of species diversification throughout geological time. Since certain patterns would only become visible when presented in this tabular format, tables were not just tools for communication—they were essential tools for knowledge production.[58]

But although these 745 tables were a useful initial visual aid, they were still far too unwieldy to clearly demonstrate broad patterns or trends. For this reason, in the final section of the *Index* Bronn converted all of the taxonomic records to numerical format, and compiled a series of tables presenting sums, ratios, and averages that reflected broader patterns of development, such as the number of all the species and genera ever fossilized, and the relationships between the living and extinct organisms or between genera and species (Fig. 5).

Here Bronn followed the cameralist example in naming what he saw as a new discipline "paleontological statics" (*paläontologische Statik*), which aimed at studying the relationships between the numerical entries presented in tables, thus distinguishing it from "mere statistics." Specifically, Bronn treated the earth's layers as a well-balanced system and calculated the number of extinct and living animals within it, much as other branches of cameralistic statics—say, agriculture or forestry—attempted to identify balance in the forces that act on crops or forests in order to maximize state revenue. Rather than seeking profit, though, Bronn's paleontological statics presented the numerical relations among the fossils in lists, charts, and tables in order to construct a broader narrative about the history of life. For instance, Bronn compared the fossilized plant and animal species at the beginning and at the end of every geological formation in order to illustrate the richness and changes in species diversity over geological time.

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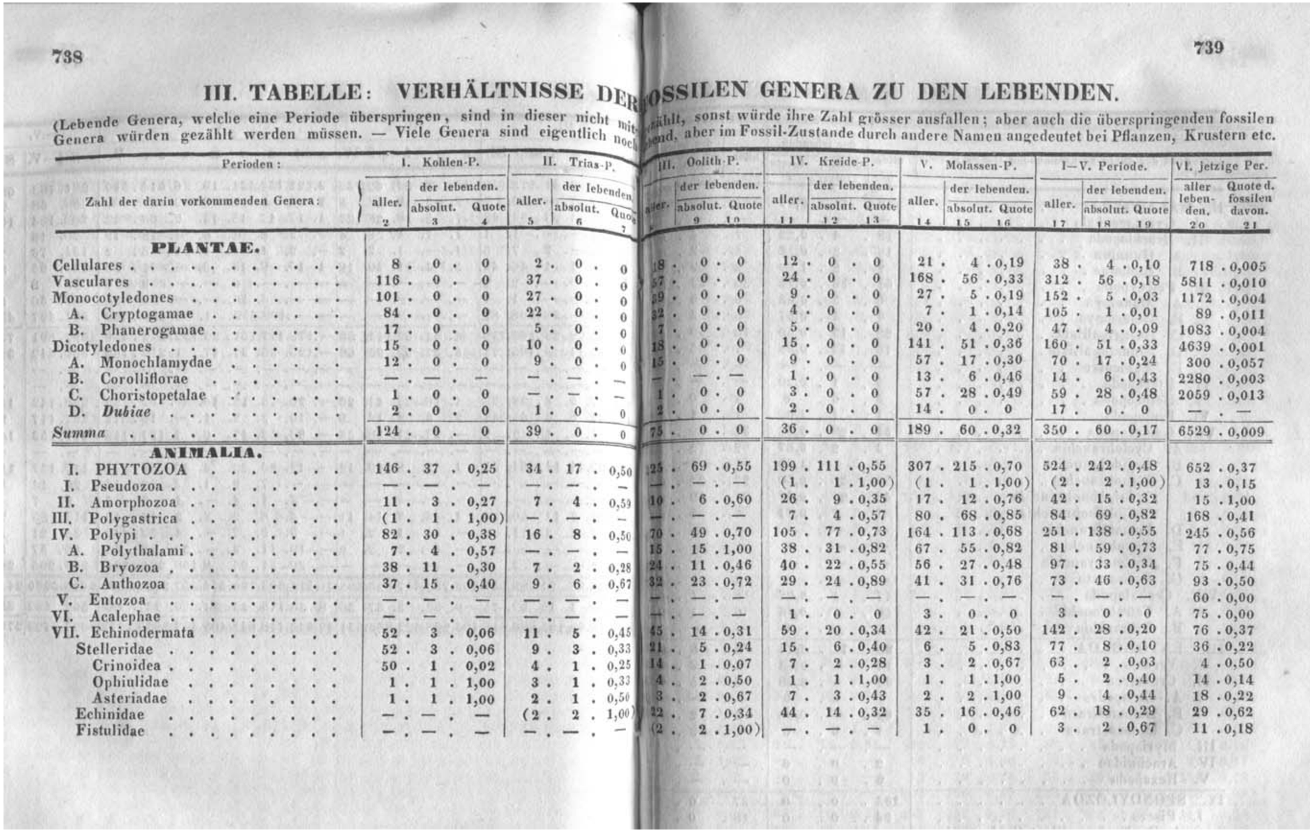
[58] See Sepkoski, "The Database Before the Computer?" (ref. 6), for a more detailed analysis of Bronn's data organization.



738 739

III. TABELLE: VERHÄLTNISSE DER OSSILEN GENERA ZU DEN LEBENDEN.

(Lebende Genera, welche eine Periode überspringen, sind in dieser nicht mit- ählt, sonst würde ihre Zahl grösser ausfallen; aber auch die überspringenden fossilen Genera würden gezählt werden müssen. — Viele Genera sind eigentlich noch bend, aber im Fossil-Zustande durch andere Namen angedeutet bei Pflanzen, Krustern etc.

Perioden:	I. Kohlen-P.			II. Trias-P.			III. Oolith-P.			IV. Kreide-P.			V. Molassen-P.			I—V. Periode.			VI. jetzige Per.	
Zahl der darin vorkommenden Genera:	aller.	der lebenden.		aller.	der lebenden		ler.	der lebenden.		aller.	der lebenden.		aller.	der lebenden.		aller.	der lebenden.		aller leben-den.	Quote d. fossilen davon.
		absolut.	Quote		absolut.	Quo		absolut.	Quote		absolut.	Quote		absolut.	Quote		absolut.	Quote		
	2	3	4	5	6	7		9	10	11	12	13	14	15	16	17	18	19	20	21
PLANTAE.																				
Cellulares	8	0	0	2	0	0	18	0	0	12	0	0	21	4	0,19	38	4	0,10	718	0,005
Vasculares	116	0	0	37	0	0	57	0	0	24	0	0	168	56	0,33	312	56	0,18	5811	0,010
Monocotyledones	101	0	0	27	0	0	39	0	0	9	0	0	27	5	0,19	152	5	0,03	1172	0,004
A. Cryptogamae	84	0	0	22	0	0	32	0	0	4	0	0	7	1	0,14	105	1	0,01	89	0,011
B. Phanerogamae	17	0	0	5	0	0	7	0	0	5	0	0	20	4	0,20	47	4	0,09	1083	0,004
Dicotyledones	15	0	0	10	0	0	18	0	0	15	0	0	141	51	0,36	160	51	0,33	4639	0,001
A. Monochlamydae	12	0	0	9	0	0	15	0	0	9	0	0	57	17	0,30	70	17	0,24	300	0,057
B. Corolliflorae	—	—	—	—	—	—	—	—	—	1	0	0	13	6	0,46	14	6	0,43	2280	0,003
C. Choristopetalae	1	0	0	—	—	—	1	0	0	3	0	0	57	28	0,49	59	28	0,48	2059	0,013
D. *Dubiae*	2	0	0	1	0	0	2	0	0	2	0	0	14	0	0	17	0	0	—	—
Summa	124	0	0	39	0	0	75	0	0	36	0	0	189	60	0,32	350	60	0,17	6529	0,009
ANIMALIA.																				
I. PHYTOZOA	146	37	0,25	34	17	0,50	25	69	0,55	199	111	0,55	307	215	0,70	524	242	0,48	652	0,37
I. Pseudozoa	—	—	—	—	—	—	—	—	—	(1	1	1,00)	(1	1	1,00)	(2	2	1,00)	13	0,15
II. Amorphozoa	11	3	0,27	7	4	0,59	10	6	0,60	26	9	0,35	17	12	0,76	42	15	0,32	15	1,00
III. Polygastrica	(1	1	1,00)	—	—	—	—	—	—	7	4	0,57	80	68	0,85	84	69	0,82	168	0,41
IV. Polypi	82	30	0,38	16	8	0,50	70	49	0,70	105	77	0,73	164	113	0,68	251	138	0,55	245	0,56
A. Polythalami	7	4	0,57	—	—	—	15	15	1,00	38	31	0,82	67	55	0,82	81	59	0,73	77	0,75
B. Bryozoa	38	11	0,30	7	2	0,28	24	11	0,46	40	22	0,55	56	27	0,48	97	33	0,34	75	0,44
C. Anthozoa	37	15	0,40	9	6	0,67	32	23	0,72	29	24	0,89	41	31	0,76	73	46	0,63	93	0,50
V. Entozoa	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	60	0,00
VI. Acalephae	—	—	—	—	—	—	—	—	—	1	0	0	3	0	0	3	0	0	75	0,00
VII. Echinodermata	52	3	0,06	11	5	0,45	45	14	0,31	59	20	0,34	42	21	0,50	142	28	0,20	76	0,37
Stelleridae	52	3	0,06	9	3	0,33	21	5	0,24	15	6	0,40	6	5	0,83	77	8	0,10	36	0,22
Crinoidea	50	1	0,02	4	1	0,25	14	1	0,07	7	2	0,28	3	2	0,67	63	2	0,03	4	0,50
Ophiulidae	1	1	1,00	3	1	0,33	4	2	0,50	1	1	1,00	1	1	1,00	5	2	0,40	14	0,14
Asteriadae	1	1	1,00	2	1	0,50	3	2	0,67	7	3	0,43	2	2	1,00	9	4	0,44	18	0,22
Echinidae	—	—	—	(2	2	1,00)	22	7	0,34	44	14	0,32	35	16	0,46	62	18	0,29	29	0,62
Fistulidae	—	—	—	—	—	—	(2	2	1,00)	—	—	—	1	0	0	3	2	0,67	11	0,18

FIG. 5. Bronn's general table about the relationships between the living and extinct genera. *Source*: Bronn, *Index Palaeontologicus* (ref. 54), 738–39.

Bronn's conception of statics did not, however, imply that he thought the history of life was unchanging. It rather viewed the system under investigation as existing in a state of dynamic equilibrium, where changes to one side of the balance would be reflected by a predictable reaction on the other. He described the earth as a well-balanced system in which "greater or smaller oscillations both in a horizontal [i.e., geographical] and vertical [i.e., temporal] direction are not excluded."[59] The fundamental unit of these oscillations, which Bronn considered the primary object of paleontological statics, is the "life of species." Here Bronn invoked a conception that had been popularized by the Italian geologist Giambattista Brocchi (1772–1826) and popularized in Charles Lyell's *Principles of Geology*: that species or higher taxonomic units could be considered "individuals" with discrete "births" and "deaths" identifiable in the fossil record.[60] Building on his statistical conclusion that species of marine invertebrates tended to persist for roughly similar lengths of time, Bronn argued that there have been approximately thirty generations or "lives of a species" in the history of life. This was a relative conception; since Bronn had no way of absolutely dating fossils, he could not fix any definite length of time to these generations. What he could claim with assurance, though, was that "in each of these 'lives of a species,' each group was represented by as many species and genera as at present," or in other words that "despite minute oscillations up and down of individual groups," relative diversity has not changed significantly over time.[61]

Hence, paleontological statics represented the full flowering of Bronn's cameralist training as applied to paleontology. The approach revealed not just "how much" or "how many," but rather sought causal understanding of the "lives of species," that is, of the entire history of life. Indeed, it was only by after presenting his data in this summarized, numerical form that Bronn felt comfortable making his strongest argument: that "a gradual change of the organisms took place" over time.[62] This may not seem like a radical claim today—and indeed, only a decade later Darwin would present a much more detailed and influential theory of historical organic change—but Bronn's work provided the

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59. Bronn, *Handbuch einer Geschichte Der Natur* (ref. 56), 794.

60. See, for instance, Niles Eldredge, *Eternal Ephemera: Adaptation and the Origin of Species from the Nineteenth Century Through Punctuated Equilibria and Beyond* (New York: Columbia University Press, 2015); and Stefano Dominici and Niles Eldredge, "Brocchi, Darwin, and Transmutation: Phylogenetics and Paleontology at the Dawn of Evolutionary Biology," *Evolution: Education and Outreach* 3, no. 4 (2010): 576–84.

61. Bronn, *Handbuch einer Geschichte der Natur* (ref. 56), 795.

62. Ibid.

first truly systematic, quantitative demonstration that the history of life followed strong directional trends. Furthermore, it equipped Bronn to make tentative conclusions about causal factors that governed the development of life, which he set out in his final, most explicitly theoretical work, the *Untersuchungen* of 1858. Drawing on his analysis of data in the *Index*, Bronn drew up a lengthy series of general conclusions, culminating in the statement of three basic "laws" of organic development: "All the most important appearances in the various divisions of the organic kingdoms can be explained from the previously developed laws, which for the most part can be summarized in these three: (a) adaptation to the external conditions of existence, (b) Terripetal movement, and (c) progressive development."[63]

Bronn's approach, then, is far from what Browne has dismissively referred to as "botanical arithmetic" or even Bronn's own contemporaries derided as *Tabellenstatistik*. Rather, it was a fairly sophisticated attempt to convert natural phenomena to numerical data in order to produce a genuine causal understanding of broad patterns and processes. In this way, it flowed directly from his cameralistic training. Bronn did not just want to count and tabulate fossils, he wanted to "narrate in detail the history of the organisms."[64] Here he followed the cameralistic notion that the mere creation of tables was not the aim of scientific research, but rather that tabular data is only the starting point for further quantitative analysis. He wanted to transcend the mere presentation of empirical and local regularities as tables of data, and rather to uncover global biological laws.

A NEW VISUAL LANGUAGE FOR HISTORICAL STATISTICS

Despite Bronn's success in translating his cameralist, tabular-statistical aggregative methodology to the practice of paleontology, in one respect his cameralist training fell short. As it turned out, the explication of statistical regularities as narrative patterns in the history of life required a more intuitive mode of representation than a complex numerical table, and here is where Bronn's innovative use of pictorial visualization is the final component of our story. In this regard, Bronn went beyond the cameralist statics of the Heidelberg and Berlin schools, ultimately transforming cameralistic practices into a new visual

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[63] Bronn, *Untersuchungen* (ref. 1), 489.

[64] Bronn, *Index Palaeontologicus* (ref. 54), 1.

language for quantitative natural history. Bronn's numerical analysis had, in a sense, defined a new kind of aggregate, statistical object in life's history: "diversification." But how to represent an object that exists only as the aggregate of many individual data points, and furthermore that requires a temporal, as well as a quantitative, dimension? The well-established visual culture of geology tended strongly toward diagrams (or maps) that draw the eye along linear paths representing temporal or geographical space. As Martin Rudwick has argued, such a visual language "embodies a complex set of tacit rules and conventions that have to be learned by practice," and that "imply a social community which tacitly accepts these rules and shares an understanding of these conventions."[65] Bronn belonged to two such visual cultures—cameralistic and geological—but his paleontological work needed to combine the visual and epistemic conventions of each. So Bronn effectively merged these languages, creating a hybrid form that translated the static, numerical language of cameralism into a visual idiom suited to dynamic temporal narrative.

In doing so, he drew on a third visual culture: the visual narrative of the historical timeline. This, we argue, presents a strong—though as yet primarily circumstantial—case for the origin of the visual form of Bronn's spindle diagrams. As Daniel Rosenberg and Anthony Grafton have shown, the assumption that space can stand in for time in visual representations of history is a relatively recent concept.[66] In their innovative study of the history of the "timeline," Rosenberg and Grafton argue that only during the eighteenth century did the now commonly accepted visual trope emerge wherein time is represented as a (usually horizontal) line spanning measured space.[67] Moreover, the notion that complex historical relationships could be conveyed more effectively as visual images than through narrative texts did not achieve widespread acceptance until well into the nineteenth century.[68]

The most important early innovator in this regard was the English chemist and polymath Joseph Priestley (now famous for his "discovery" of phlogiston and debate with Antoine Lavoisier), who in 1764 published a short work titled *A Description of a Chart of Biography*. Priestley's quite simple convention was to present the life spans of noteworthy historical figures as

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[65] Martin J. S. Rudwick, "The Emergence of a Visual Language for Geological Science, 1760–1840," *History of Science* 14, no. 3 (1967): 149–95, on 151.

[66] Daniel Rosenberg and Anthony Grafton, *Cartographies of Time: A History of the Timeline* (Princeton, NJ: Princeton Architectural Press, 2010).

[67] Ibid., 113.

[68] Ibid., 71.

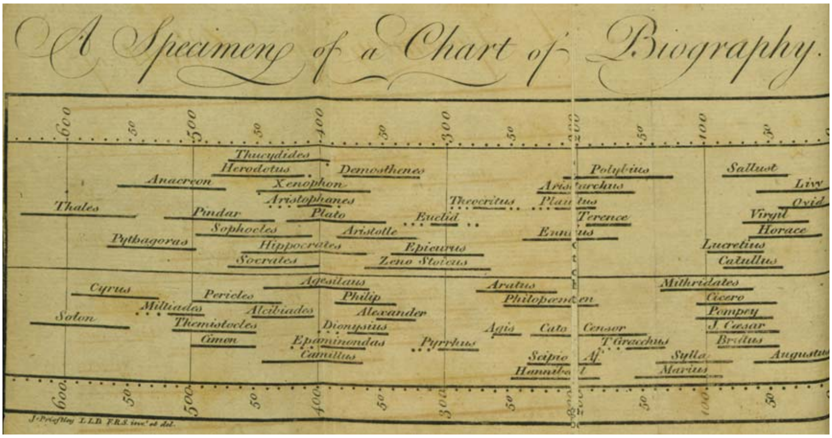

FIG. 6. Priestley's chart of biography. *Source*: Priestley, *A Description of a Chart of Biography* (ref. 69). Image provided courtesy of the University of Chicago Library's Special Collections Research Center.

horizontal lines measured against an absolute axis of time; Figure 6 is an example. As he explained it,

> Thus the abstract idea of TIME, though it be not the object of any of our senses, and no image can properly be made of it, yet because it has real quantity, and we can say a greater or less space of time, it admits of a natural and easy representation in our minds by the idea of a measurable space, and particularly that of a line; which like time, may be extended in length, without giving any idea of breadth or thickness.[69]

The great advantage of this method, he argued, is that it allows historical relationships to be absorbed intuitively: "They are the lines in this case which suggest the ideas, and this they do immediately and without the intervention of words: and what words would do but very imperfectly, and in a long time, this method effects in the completest manner possible, and almost at a single glance, when once it is known what life any line represents."[70]

An obvious limitation of Priestley's biographical chart is that the timelines are two dimensional; that is, the only meaningful information in the graph is on the horizontal axis. However, his next major historical visualization was more ambitious: the 1769 *A Description of a New Chart of History* was an attempt at nothing less than a graphical depiction of the waxing and waning fortunes of civilization's great empires (Fig. 7).

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69. Joseph Priestley, *A Description of a Chart of Biography* (London: J. Johnson, 1764), 5.
70. Ibid., 9.

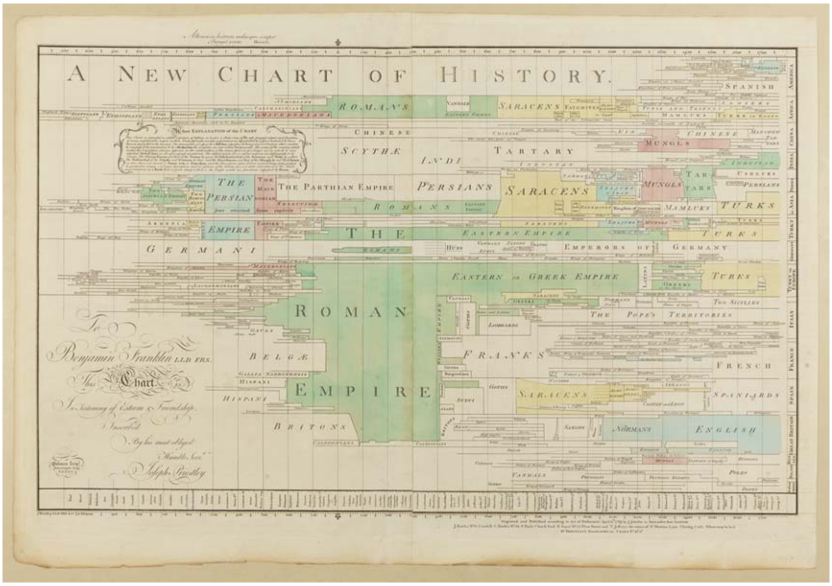

FIG. 7. Priestley's graphical depiction of the rise and decline of civilization's great empires. *Source*: Joseph Priestley, *A New Chart of History* (London: J. Johnson, 1769). Image provided courtesy of the University of Chicago Library's Special Collections Research Center.

Like the *Chart of Biography*, the new chart followed the convention of representing time on the horizontal axis, and the durations of various empires were juxtaposed visually in this way with one another. But the 1769 chart also introduced the new dimension of depth: the vertical axis represents the geographical spread of empires, making it possible to simultaneously assess the duration *and* the reach of empires, giving a rough indication of the relative importance of civilizations. Here Priestley commented, "If the reader carries his eye *vertically*, he will see the contemporary state of all the empires subsisting in the world, at any particular time. He may observe, which were then rising, which were flourishing, and which were upon the decline."[71]

The effect of Priestley's intervention on European historical consciousness was virtually immediate. According to Rosenberg and Grafton, Priestley's charts were widely distributed and imitated over the following decades, and by the early nineteenth century were considered "an essential part of a gentleman's library."[72] In Germany, for example, the physicist Johann Christian Poggendorff published a chart in 1853 explicitly modeled on Priestley's, which

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[71] Joseph Priestley, *A Description of a New Chart of History* (London: J. Johnson, 1770), 13.

[72] Rosenberg and Grafton, *Cartographies of Time* (ref. 66), 123.

depicted the lives of notable physical scientists since the middle ages as horizontal lines.[73] Priestley's charts also inspired new experiments with visualization: the economic statistician William Playfair, whose early line graphs represent some of the earliest examples of the genre in political economy, cited Priestley's charts as an important influence.[74] Although these conventions are now taken for granted, their revolutionary impact cannot be overstated: as Rosenberg and Grafton conclude, "After Priestley, most readers simply assumed the analogy between historical time and measured graphical space."[75]

This raises another issue, which is the appropriateness of graphical visualizations to represent statistical patterns. Again, although this convention is now taken for granted, at the beginning of the nineteenth century it was a new, and somewhat controversial, idea. Playfair's own graphs would have a profound influence on statistical practice, but that impact would be delayed until the second half of the 1800s, when innovation in statistical visualization experienced what has been described as a "golden age."[76] Prior to that time, statistical presentations in Britain and Europe tended to take the form of numerical tables, often of such compendious scope and volume that even a knowledgeable reader would have great difficulty extracting any meaningful patterns or regularities. Indeed, graphical visualizations of statistics had not been warmly welcomed into economic arguments. When, for example, the English mathematical economist William Stanley Jevons approached the noted statistician and publisher William Newmarch in the early 1860s about publishing a "Statistical Atlas" he was composing, he was taken aback by Newmarch's profound disinterest in his statistical visualizations. As the historian of economics Haro Maas puts it, "Apparently, it was not at all obvious for someone like Newmarch to present a table of numbers in a graph."[77] Maas and other historians have justifiably credited Jevons with ultimately influencing the acceptance of

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[73] Johann Christian Poggendorff, *Lebenslinien zur Geschichte der exacten Wissenschaften seit Wiederherstellung derselben* (Berlin: Alexander Duncker, 1853).

[74] William Playfair, *A Real Statement of the Finances and Resources of Great Britain* (London: Whittingham, 1796), v–vi.

[75] Rosenberg and Grafton, *Cartographies of Time* (ref. 66), 126.

[76] Michael Friendly, "The Golden Age of Statistical Graphics," *Statistical Science* 23, no. 4 (2008): 502–35.

[77] Harro Maas, *William Stanley Jevons and the Making of Modern Economics* (Cambridge: Cambridge University Press, 2005), 218.

graphical statistical visualization, but this was a development they locate only during the 1870s and beyond.[78]

Ultimately, Jevons' great innovation, according to Maas, was the marriage of statistical data to temporal graphical presentation. As Maas explains, "before graphs could reveal economic phenomena and feature in economic explanations. . . . Historical *events* had to be repackaged as *data*," something Maas labels "the timing of history."[79] Jevons also realized that, as Maas puts it, "To make graphs relevant to history, then, history has to be stabilized, not only along the horizontal axis, but also along the vertical axis," or in other words, that events must become "entities to which numbers can be affixed."[80] This was what Jevons achieved when he combined the horizontal axis of time with a vertical axis representing some variation in quantities of numerical data—in Jevons' case, economic data.

It is also almost precisely what Bronn had independently developed through his visual-statistical practice in paleontology some two decades or more earlier: in the first place, historical "events" (i.e., the individual life histories of organisms) were aggregated and converted to data points representing taxonomic units that could be counted and treated statistically. Here species became what Staffan Müller-Wille has, in the context of the development of Linnaean taxonomy, described as "entities to which numbers can be affixed," a process that we will call the "atomization" of taxonomy, which was a precondition to narrating deep time.[81] Secondly, those data were projected as a narrative progression in visual space, "stabilized" not only along the horizontal (temporal) axis, but also on the vertical, which represented change in quantity. The point here, however, is not to argue for Bronn's priority in "inventing" what Maas calls "the timing of history." Rather, it is to point out what a pervasive concern this was in the nineteenth century for a distinct but overlapping set of knowledge communities—in state administration, in human historiography, in natural history, and in economics—which were experimenting with and converging on a new mode of expressing temporal

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[78] In addition to Maas, see also Margaret Schabas, *A World Ruled by Number: William Stanley Jevons and the Rise of Mathematical Economics* (Princeton, NJ: Princeton University Press, 1990); and Tom Crook and Glen O'Hara, eds., *Statistics and the Public Sphere: Numbers and the People in Modern Britain, c. 1800–2000* (New York: Routledge, 2011).

[79] Maas, *William Stanley Jevons* (ref. 77), 220.

[80] Ibid., 223.

[81] Staffan Müller-Wille, "Names and Numbers: 'Data' in Classical Natural History, 1758–1859," *Osiris* 32 (2017): 109–28.

patterns and regularities using data and graphical visualization. That mode was grounded in the epistemological conviction that, as Porter has put it, "order is to be found in large numbers," and in the visual language of abstracted, graphical narrative.[82]

VISUAL STATISTICS IN PALEONTOLOGY

The very pervasiveness of this epistemic convention has often been missed in histories of individual disciplines. Maas, for example, comments that Jevons' "change in understanding would have transgressed the traditional boundaries between the moral and natural sciences in the early part of the century, but became unproblematic by the end."[83] In fact, geologists of Bronn's era were in a unique position to connect the visual metaphor of time-as-space with the statistical approaches of cameralism and the bureaucratic sciences. In the first place, during the early decades of the nineteenth century, geologists were developing their own visual analogies between time and space through stratigraphic depictions of ideal cross-sections of the earth's layers, like the famous illustration from Georges Cuvier and Alexandre Brongniart's 1812 *Description géologique des environs de Paris* (Fig. 8).

Stratigraphic depictions like Figure 8 one rely on the assumption that the deeper one penetrates into the earth, the older the layers are—they are literally "maps of time." Illustrations such as Cuvier and Brongniart's may well have been influenced by the visual idiom of Priestley's historical chronologies, but they also reflected a basic empirical reality with which geologists were well familiar. Secondly, geologists were conditioned to think of collecting data about the composition of geological formations with analogy to conducting bureaucratic surveys. For example, in his *Principles of Geology* (1830–33), Lyell explicitly

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[82] Tracing the reception of historical timelines in nineteenth century German visual culture is a task to which we are devoting further research toward the preparation of a book expanding the arguments of this paper into a broader case for overlapping visual and statistical cultures in nineteenth century natural and bureaucratic science. We are content, for now, to leave the direct influence of Priestley on Bronn as an open—though provocatively suggestive—question. However, it is certainly the case that, whatever his direct influences were, Bronn's visual idiom represents a shift in the visual application of statistical arguments that was taking place more broadly during the nineteenth century, which we feel has been amply documented by Grafton and Rosenberg, Friendly, Maas, and others. The key issue here is the projection of statistics onto measured graphical space, which was in the early nineteenth century still an emerging epistemic convention.

[83] Maas, *William Stanley Jevons* (ref. 77), 220.

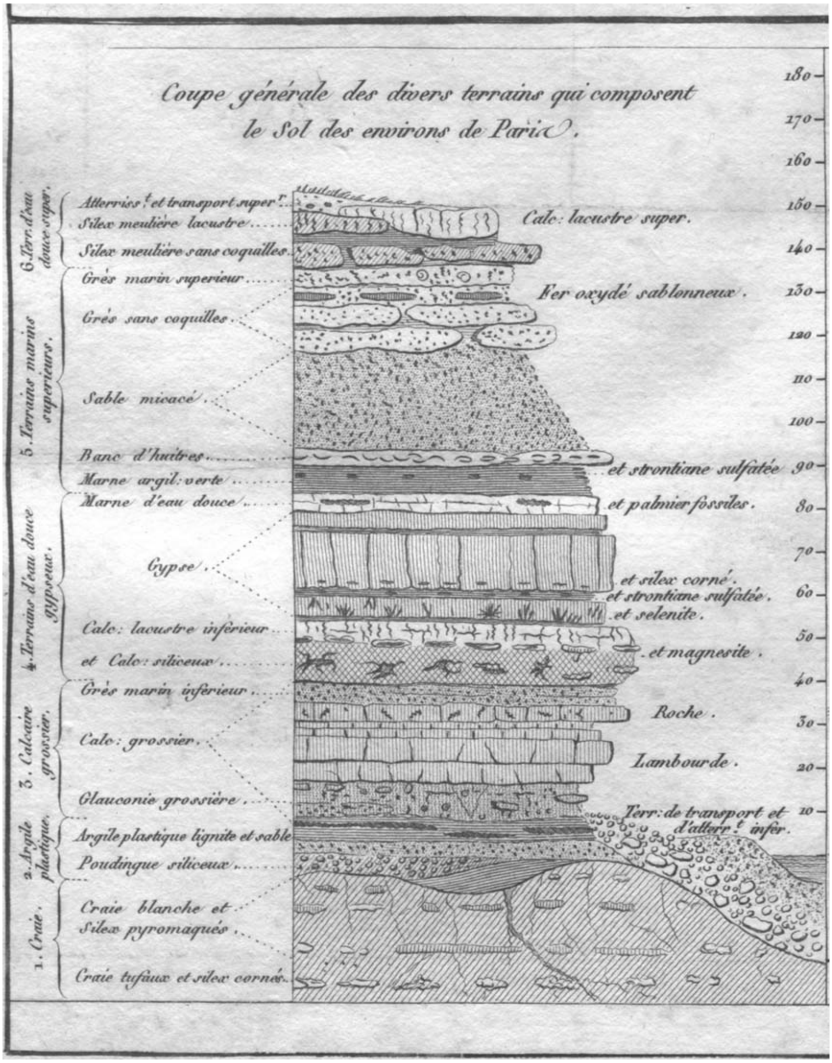

FIG. 8. A classical stratigraphic visualization of ideal cross sections of the earth's layers. *Source*: Georges Cuvier and Alexandre Brongniart, *Description géologique des environs de Paris* (Paris: G. Dufour et E. d'Ocagne, 1822), fig. 2.

compared the differential preservation of fossils in different regions and times with the activity of a census taker; as Rudwick explains, "Each preserved basin was thus like the 'statistical documents' that such [census] officials might leave behind them, to record the state of the population in a given province at

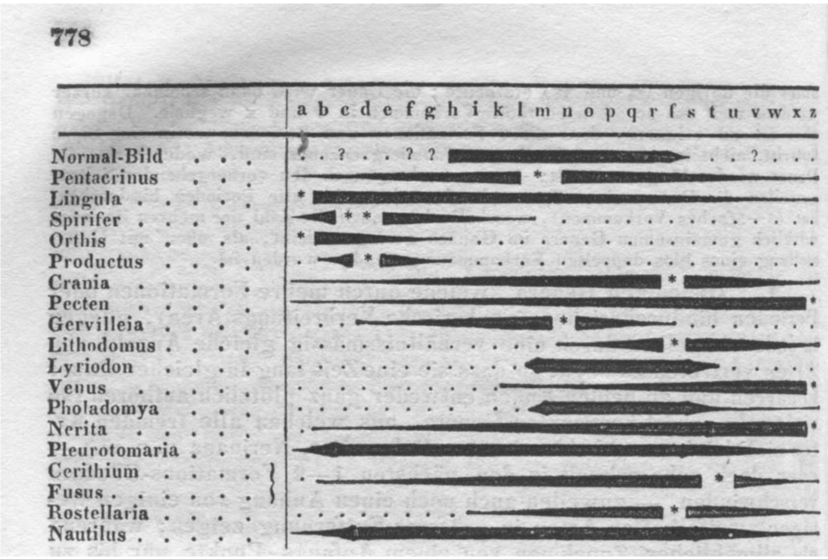

FIG. 9. One of Bronn's spindle diagrams, which depicts the relative changes in diversity among different groups of animals throughout geological time. *Source*: Bronn, *Index Paleontologicus* (ref. 54), 778.

a certain time."[84] Small wonder, then, that geologists were primed to "see" the narrative of life's history as a pattern of temporal data arranged in space.

But Bronn's spindle diagrams were not only illustrations of data: they were also tools of discovery. What Figure 9 shows is the relative diversification of different groups of fossil gastropods. The horizontal axis represents time (subdivided into geological periods), and the breadth of the line indicates the relative diversity of each taxon arranged on the vertical axis (e.g., the number of genera and species that compose it). It is a very simple visual narrative: at a glance one sees that as the *Lingula* brachiopods began a steady decline, others (for example, the snail *Nerita*) started a slow diversification in the opposite direction. But it is also a pictorial representation of a pattern in numerical data, since each of the lines are composed from the data points Bronn carefully tabulated and aggregated in the *Nomenclator* and *Enumerator* sections of the *Index*. It depicts, in strikingly clear form, an aggregate pattern that would be visible neither in the individual specimens themselves, nor in the numerical data presented in tables.

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[84] Rudwick, "Charles Lyell's Dream" (ref. 3), 237; Charles Lyell, *Principles of Geology; Being an Attempt to Explain the Former Changes of the Earth's Surface, by Reference to Causes Now in Operation*, vol. III (London: John Murray, 1833), 31–33.

Bronn prefaced this particular spindle diagram by commenting that it demonstrates the fact that lineages tend to follow a predictable pattern: "a gradual increase from an initial point to a culmination point [which Bronn indicates in the diagram with an *]—the center of the geological distribution—and a gradual decrease from thence to total disappearance," almost precisely as Priestley's *New Chart of History* revealed of human empires "which were then rising, which were flourishing, and which were upon the decline."[85] These visualizations, then, provided the evidence for the paleontological "laws" Bronn would articulate a decade later in the *Untersuchung*: for example, that "the progressive development concerns not only the fact that always more perfect types are added to the existing imperfect ones, but also the fact that the last of any point of culmination . . . reduces itself and gradually disappears."[86]

Bronn's spindle diagrams in the 1849 *Index* were not, however, the very first spindles to be published in natural historical context. In fact, the first known published spindle diagram appears in one of Bronn's earlier works, an 1837 atlas of tables that accompanied his multi-volume stratigraphic compendium *Lethaea Geognostica*.[87] In this image (Fig. 10), unlike Bronn's later published spindles, the orientation of the figure is vertical: on the left-hand side of the image is a schematic of the stratigraphic units between the early "Kohlen" (in modern terms, Carboniferous) period and the late "Molasse" (roughly the Tertiary period), proceeding upward from oldest to most recent, as in a traditional stratigraphic image. On the right, paralleling the stratigraphic table, is a spindle diagram depicting the representative organisms found in the layers or, as the heading explains, the "Distribution of the organic remains therein." Two observations are particularly noteworthy here: First, and most obviously, the orientation of the spindle diagram is vertical, indicating that Bronn was, at this point, still working within the established visual idiom of geology and stratigraphy. In the nineteenth century, the standard orientation for paleontological and geological diagrams was on the vertical axis, with time flowing from the bottom of the page to the top. This convention developed directly from the orientation of stratigraphic diagrams, like Cuvier and Brongniart's reproduced above (Fig. 8). Second, however, is the fact that it is impossible to read both the left- and the right-hand images together: the text in the stratigraphic table on

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[85] Bronn, *Index Paleontologicus*, vol. II (ref. 54), 777.

[86] Bronn, *Untersuchungen* (ref. 1), 489.

[87] Heinrich Georg Bronn, *XLVII Tafeln mit Abbildungen zur Lethäa Geognostica* (Stuttgart: E. Schweizerbart, 1837).

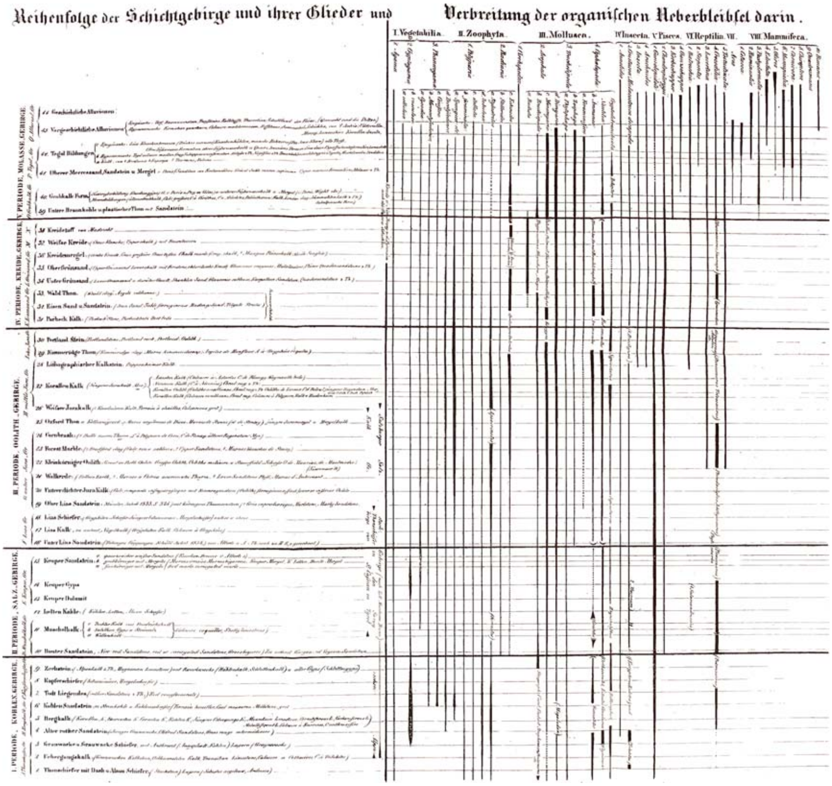

FIG. 10. Bronn's first published spindle diagram (and the first known spindle diagram published in a natural historical context). The left side of the image is a vertical stratigraphic chart, proceeding upward from early to later periods; the right side depicts the range and diversity of major lineages of organisms, corresponding to the stratigraphic intervals. *Source*: Bronn, *XLVII Tafeln* (ref. 87).

the left is oriented horizontally, while the text accompanying the spindles on the right is vertical—meaning, in other words, that the figure must be rotated horizontally to read the taxonomic information in the spindle diagram.

In this sense, the spindles in this 1837 work more closely resemble similar images published (slightly later) by contemporary geologists; for example, the Swiss naturalist Louis Agassiz published a graph of the diversification of fishes in his 1843 work *Researches on Fossil Fish*, which takes the basic form of a vertical spindle diagram (Fig. 11).[88]

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[88] Louis Agassiz, *Recherches Sur Les Poissons Fossiles* (Neucha?tel, 1833–1843). An even earlier drawing that has been cited (incorrectly, as it turns out) as the very first spindle diagram to be published accompanied the American geologist Edward Hitchcock's textbook *Elementary Geology*

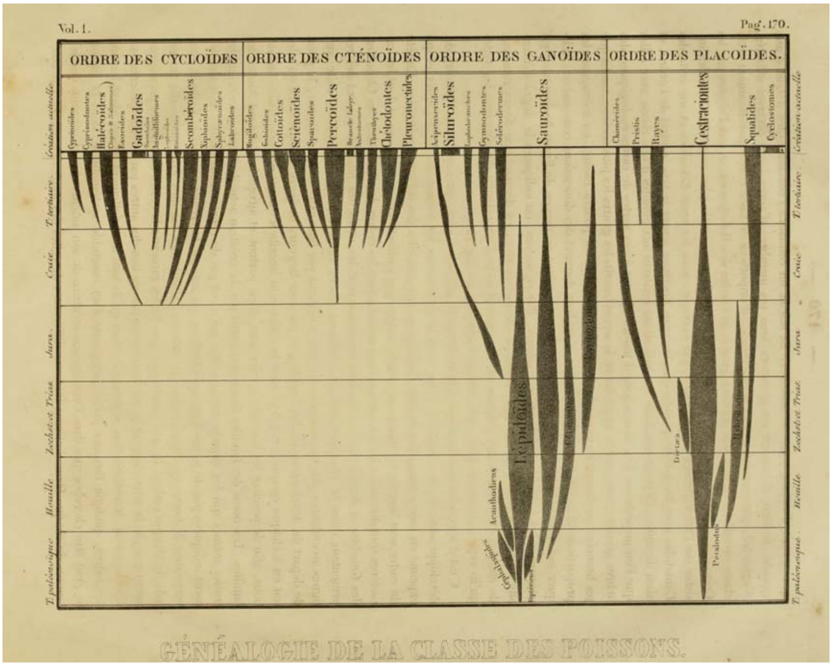

FIG. 11. Louis Agassiz's spindle diagram. Note that the thickness of the spindles was not based on a statistical accounting. *Source*: Agassiz, *Recherches* (ref. 88), 170.

Likewise, in 1852 the French paleontologist Alcide D'Orbigny published an appendix to his *Cours élémentaire de paléontologie de géologie stratigraphiques* containing a number of *tableaux* representing the temporal distribution of various taxa. These were represented not as spindles, but rather as vertical lines (see Fig. 12), much like those Priestley's *Chart of Biography*. Indeed, Bronn himself published several figures of the same type (although oriented horizontally), and such diagrams—now known as "range diagrams," since they show the temporal range of a taxon through time—and have become quite common ever since the mid-nineteenth century.

(1841), which (rather crudely) depicts the diversification of plants and animals as a tree-like diagram in which the thickness of branches roughly corresponds to the number of taxa that compose them. Hitchcock himself acknowledged that he found in the "Lethea Geognostica of Professor Bronn a Chart constructed on essentially the same principles." Edward Hitchcock, *Elementary Geology* (New York: Dayton & Saxton, 1841), 104. On Hitchcock, see J. David Archibald, *Aristotle's Ladder, Darwin's Tree: The Evolution of Visual Metaphors for Biolgoical Order* (New York: Columbia University Press, 2014).

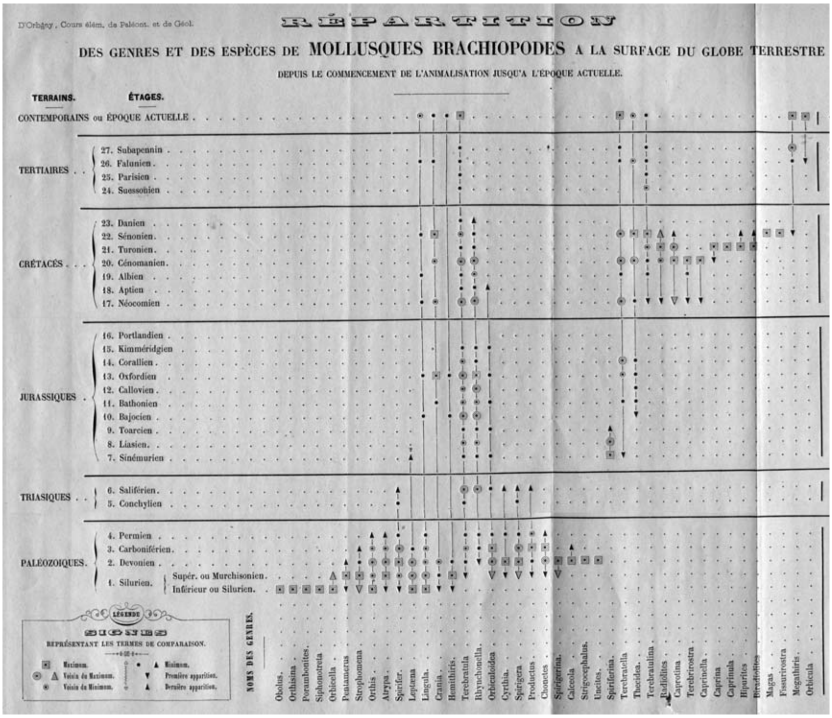

FIG. 12. A vertical range diagram from Alcide D'Orbigny's atlas of *Tableaux* to his *Cours élémentaire de paléontologie de géologie stratigraphiques* (Paris: Victor Masson, 1852), tableau 9.

What should we make of the difference between Bronn's 1837 spindles and his later diagrams, from the late 1840s and 1850s? We argue that Bronn's 1837 diagram is a hybrid of the vertical stratigraphic visual language of geology and the horizontal visual language of the timeline. In this sense, it represents a (perhaps uncomfortable) compromise between the epistemic goals of stratigraphic illustration and those of visual historical narrative. Returning to Bronn's 1837 diagram (Fig. 10), the "at a glance" information the 1837 image provides is keyed to the stratigraphic table: the lines on the right show roughly which major groups of plants, invertebrates, and vertebrates can be found in particular layers, information that is most useful for identifying the representative fossils in individual strata. Indeed, when oriented vertically the reader's eye is drawn from left to right across the page, encountering the spindles not as continuous lines, but rather as individual segments (indicating that a group either is or is not present in the layer being traced). It is only when the figure is turned on its side that the full picture of the waxing and waning of fossil organisms comes fully into view—or, in other words, that the visual information tells a kind of pictorial story about the history of life. Here the goal is not to assist geologists in identifying strata, but rather to narrate a pattern in the fossil record.[89]

It appears that, in the late 1830s, Bronn was still formulating his vision of what the primary epistemic goal of his paleontological work should be. His 1833 *Italiens-Tertirär* was fairly explicitly an attempt to collect and analyze numerical data for the purpose of conducting a census of Italian Tertiary fossils in order to correlate and date the region's strata, but it includes no pictorial representations of data. On the other hand, the 1837 *Lethaea Geognostica* (which is subtitled "or Descriptions and depictions of the petrified fossils that are most characteristic for rock formations") is a multivolume collection of stratigraphic taxonomy and description, but it is accompanied by very little numerical data.[90] Accordingly, the spindles in the 1837 work are mostly impressionistic, very much like Agassiz's in 1844—they are based on a rough tally of species numbers in his taxonomic catalog, but they are not reinforced by a rigorous statistical accounting.[91] In other words, they do not narrate history with data.

Nonetheless, by 1837, both elements of Bronn's later methodology were in place: the tabular, numerical data analysis of *Italiens-Tertirär* and the visual narration of *Lethaea*. It was only in his 1840s publications that Bronn joined the two modes, dropping the primarily stratigraphic agenda of earlier work, and at the same time changing the spatial orientation of his diagrams, because after 1837, *all* of Bronn's published spindle and range diagrams follow a horizontal

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[89] Indeed, studies of visual epistemology have emphasized that the orientation of diagrams constrains or enables the recognition of essential phenomena represented in images. In other words, adopting the "pictorial grammar" of a horizontal, left-to-right narrative image involved an epistemic as well as conventional turn away from the standard, vertical geological idiom. See, for example, Wolfram Pichler and Ralph Ubl, *Bildtheorie zur Einführung* (Hamburg: Junius, 2014); W. J. T. Mitchell, *Picture Theory: Essays on Verbal and Visual Representation* (Chicago: The University of Chicago Press, 1995); and Gottfried Boehm, ed., *Was ist ein Bild?* (Munich: Fink, 1994).

[90] H. G. Bronn, *Lethaea geognostica, oder Abbildungen und Beschreibungen der für die Gebirgs-Formationen bezeichnendsten Versteinerungen* (Stuttgart: E. Schweizerbart, 1835–38).

[91] Theodore Pietsch comments that the "spindles" in Agassiz's diagram "do not so much reflect the relative abundance of fossil material found with various geological strata through time, but only provide an indication of the initial increase and . . . eventually [*sic*] decrease of taxa contained within each group." Theodore W. Pietsch, *Trees of Life: A Visual History of Evolution* (Baltimore: Johns Hopkins University Press, 2013), 71. Intriguingly, Agassiz studied at Heidelberg with Bronn in 1826 and 1827, raising the possibility that he and Bronn may have discussed visual narration (alas, no documentation of any such exchange survives).

orientation. This may seem like a trivial point, but to a nineteenth-century geologist such a departure from standard orientation would have been a conscious and unusual choice—and not merely a matter of typesetting or layout determined by a publisher. The vertical orientation was ubiquitous throughout the nineteenth and early twentieth centuries not only in stratigraphic diagrams but also in the increasingly popular tree-like representations of organic development—for example, those published in the evolutionary works of Darwin and Ernst Haeckel.[92] Bronn's decision to orient his spindle and range diagrams horizontally—and moreover, to depict time as flowing left to right (rather than right to left, as in his rotated 1837 graph)—appears to be a deliberate adoption of the visual idiom of the popular historical timelines (and, of course, the sequential direction of Western books). The message behind this decision is somewhat ambiguous, but we suggest that this was a conscious reflection of the changing epistemic goal of his work: no longer an attempt to document stratigraphic succession, his project was, by the late 1840s, the pursuit of a history of life narrated though data, and the discovery of patterns of progressive historical development exhibiting law-like regularity. The visual language of the geologists was superseded by that of contemporary historians.

Although spindle diagrams have become a standard part of the visual language of paleontology, it should be remarked that the adaptation of the natural historical community to visual modes of representation was not immediate. For example, for all that Darwin is celebrated for having brought the visual image of the tree into evolutionary reasoning, he himself rarely employed visual images. Darwin was, in fact, well aware of Bronn's work, and he and Bronn exchanged correspondence. In the *Origin* Darwin acknowledged Bronn as among the paleontologists "whose opinions are worthy of much deference," and he cited Bronn's study of the relative emergence and extinction of different lineages as evidence of temporal geological succession.[93] Strikingly, in his chapter on extinction, Darwin essentially narrated a spindle diagram—although he neither explicitly cited Bronn nor provided an image:

> If the number of the species of a genus, or the number of the genera of a family, be represented by a vertical line of varying thickness, crossing the

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[92] For a representative overview of tree-like evolutionary diagrams, see Pietsch, ibid.

[93] "The secondary formations are more broken; but, as Bronn has remarked, neither the appearance nor disappearance of their many now extinct species has been simultaneous in each separate formation. Species of different genera and classes have not changed at the same rate, or in the same degree." Darwin, *Origin of Species* (ref. 51), 312–13.

> successive geological formations in which the species are found, the line will sometimes falsely appear to begin at its lower end, not in a sharp point, but abruptly; it then gradually thickens upwards, sometimes keeping for a space of equal thickness, and ultimately thins out in the upper beds, marking the decrease and final extinction of the species.[94]

Nonetheless, the visual method did slowly catch on, in Germany as well as in France and Britain. For example, in 1852, Joachim Barrande (another practitioner of statistical paleontology) produced a spindle diagram showing the diversity and range of trilobites in the Silurian Period—in which the spindles were actually depicted within the enclosing idealized stratigraphic sequences, effectively marrying the two visual idioms (Fig. 13).[95]

Likewise, in Britain the English geologist John Phillips published several diagrams in his 1860 treatise *Life on the Earth*, including a spindle diagram and one of the first line graphs (in the style of Playfair) to depict global changes in diversity over time (Figs. 14 and 15, respectively). Phillips' visualizations were based on a fairly extensive statistical analysis of British fossil invertebrates (although he did not publish or discuss his data analysis in any detail), and he described his diversity diagram as "a continuous curve, which corresponds to the numerical prevalence of life, and represents its rise and fall."[96] Both Barrande's and Phillips' diagrams were oriented vertically, perhaps reflecting the mainstream incorporation of Bronn's approach into geology and paleontology. Once accepted as a viable method for recording and visualizing the history of life, the statistical approach to paleontology lost some of the idiosyncratic touches that Bronn's cameralistic background had imparted.

Ultimately, these visualizations—spindle diagrams and line graphs—would become the standard idioms for presenting statistical analyses of diversity in the fossil record. Although they are distinct from one another, they share the analogy between time and measured space, and both follow the convention that diversity should be measured by distance along the axis perpendicular to time (horizontal in Bronn's case, vertical in Phillips'). In a sense, a line graph is simply the upper half of a spindle. Both formats became increasingly popular in the twentieth century, and spindle diagrams were widely popularized in particular through the work of the American

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[94] Ibid., 316–17.

[95] Joachim Barrande, *Systême Silurien, du centre de la bohême* (Paris, 1852). On Barrande's statistical approach see Tamborini, "Paleontology and Darwin's Theory of Evolution" (ref. 6).

[96] John Phillips, *Life on Earth* (London: John Murray, 1860), 65.

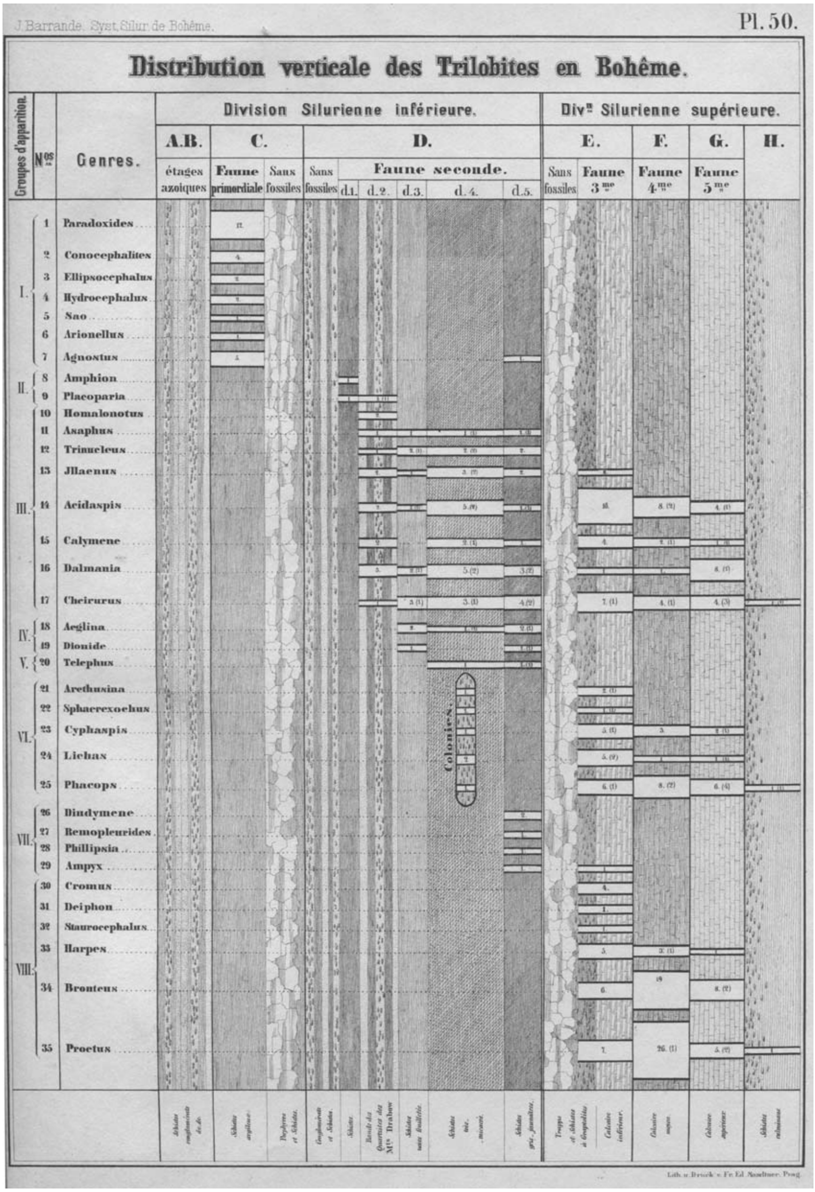

FIG. 13. Joachim Barrande's vertical spindle diagram—in which the spindles are "encased" in surrounding stratigraphic layers. *Source*: Barrande, *Systême Silurien* (ref. 95), table 50.

vertebrate paleontologist Alfred Sherwood Romer, who employed them widely in his articles and textbooks (to such an extent that they are now sometimes referred to as "romerograms").

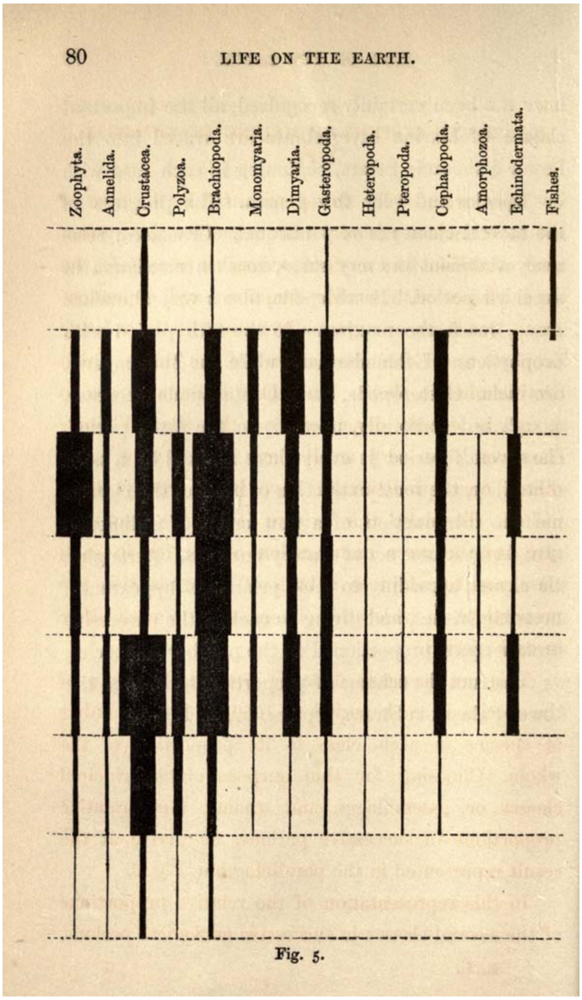

FIG. 14. An example of Phillips's spindle diagram of major groups of animals. *Source*: Phillips, *Life on the Earth* (ref. 96), 80.

With the advent of digital electronic computers, the statistical approach became even more prevalent after the 1950s, culminating ultimately in a highly technical quantitative "paleobiology" that flourished during the 1970s and 1980s and remains a dominant influence on the field to this day.[97] It may well be the case that while, as Rosenberg and Grafton have argued, "the rise of the modern timeline coincided with the decline of academic chronology," it

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[97] Sepkoski, *Rereading the Fossil Record* (ref. 7).

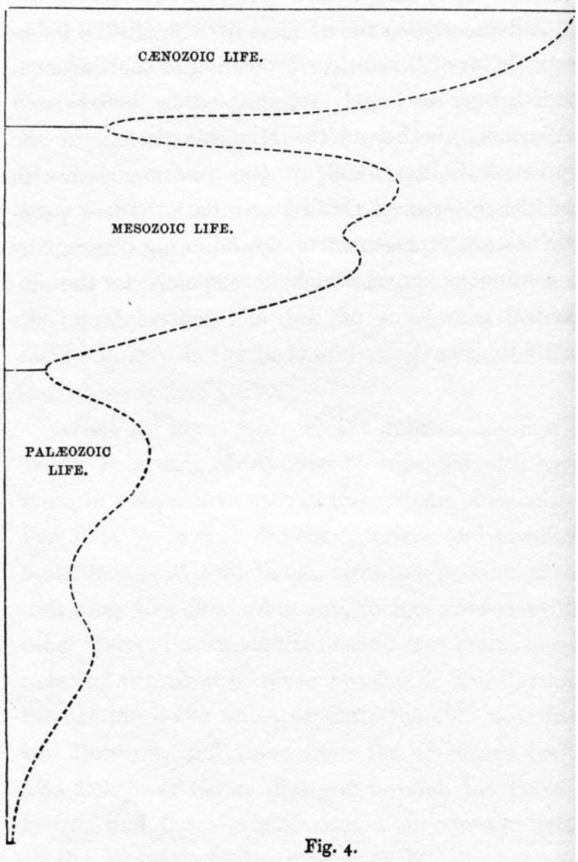

FIG. 15. Phillips' depiction of the history of the entire history of marine life as three successive curves. Note the vertical orientation (as with a stratigraphic column). *Source*: Phillips, *Life on the Earth* (ref. 96), 66.

simultaneously coincided with the rise of statistical historicism in natural history.[98] That is to say, although the convention of representing historical time as space became firmly established, the explanatory value of such graphical representations for understanding human history was eclipsed by other (usually textual) conventions. However, the value of this visual approach for understanding *natural* history has only increased, and naturalists like Bronn and Phillips stood right at the cusp of this transition. Scholars in the humanities may now be justifiably suspicious of constructing narratives based on

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[98] Rosenberg and Grafton, *Cartographies of Time* (ref. 66), 138.

numerical data and statistical generalizations, but it is now the primary way scientists narrate the deeper history of life on earth.

CONCLUSION: AN IMAGE OF SCIENCE

Studies of the relationship between data and visualization have become popular in science and technology studies in recent years, most prominently in scholarship that traces the rise and impact of so-called Big Data, a phenomenon associated in the natural sciences with the advent of powerful electronic digital computers and high-throughput technologies.[99] As a number of authors have shown, images have become a powerful tool for understanding a world increasingly defined by immense aggregations of data—in some cases, they may be the *only* way of "seeing" the phenomena that data describe.[100] As Hallam Stevens has observed in a recent essay, "Our relationship to data is constructed through images—pictures show us what data is and what it means."[101] But as a number of other scholars have also argued, our current Big Data moment is continuous with a longer history of data collection, analysis, and visualization that extends back long before the computer era.[102] This paper, then, may be read as a contribution to an archaeology of modern data practices. But we resist

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[99] On visual culture in science, see, for instance, Klaus Hentschel, *Visual Cultures in Science and Technology: A Comparative History* (Oxford: Oxford University Press, 2015); and Horst Bredekamp, Vera Dünkel, and Birgit Schneider, eds., *The Technical Image: A History of Styles in Scientific Imagery* (Chicago: The University of Chicago Press, 2015). On big data see, for example, Tony Hey, Stewart Tansley, and Kristine Tolle, eds., *The Fourth Paradigm: Data-Intensive Scientific Discovery* (Redmond, WA: Microsoft Research, 2009); Chris Anderson, "The End of Theory: The Data Deluge Makes the Scientific Method Obsolete," *Wired Magazine*, 23 Jun 2008; Sabina Leonelli, "Introduction: Making Sense of Data-Driven Research in the Biological and Biomedical Sciences," *Studies in History and Philosophy of Biological and Biomedical Sciences* 43 (2012), 1–3; Lisa Gitelman, *"Raw Data" Is an Oxymoron* (Cambridge, MA: MIT Press, 2013); Viktor Cukier and Kenneth Mayer-Schönberger, *Big Data: A Revolution That Will Transform How We Live, Work, and Think* (London: Murray, 2013).

[100] See, for example, Wiebe E. Bijker, W. Bernard Carlson, and Trevor Pinch, *Representation in Scientific Practice Revisited* (Cambridge, MA: MIT Press, 2014); Orit Halpern, *Beautiful Data: A History of Vision and Reason since 1945* (Durham, NC: Duke University Press, 2014); Hallam Stevens, *Life out of Sequence: A Data-Driven History of Bioinformatics* (Chicago: The University of Chicago Press, 2013).

[101] Hallam Stevens, "Seeing Data," *Historical Studies in the Natural Sciences* 46, no. 2 (2016): 252–59.

[102] See, for example, the 2017 volume of *Osiris* on "Data Histories," which explores epistemologies, technologies, and political cultures of data from the seventeenth to the late twentieth centuries. Elena Aronova, Christine von Oertzen, and David Sepkoski, eds., "Data Histories,"

any implication of teleology by pointing to the important role of contingency in our story; most of the techniques and approaches to data we have described arose out of transfers of knowledge—among bureaucratic cameralism, empirical natural history, and chronological visualization—that were highly contingent upon the idiosyncratic interests of individuals.

The particular contingent contours of this story do, however, allow us to make several conclusions of broad historical interest. In the first—and narrowest—sense, our study tracks the emergence of a powerful approach to analysis and interpretation of data in paleontology and natural history. Since at least the eighteenth century, naturalists had been coping with a "data deluge" brought about by the rapid contemporary increase in efforts to collect and document the natural world.[103] Although a number of early nineteenth-century natural historians—Browne's "Humboldtian" arithmeticians, for instance—experimented with quantitative approaches to numerical data about plant and animal distribution, Bronn's aggregative approach to interpreting the fossil record stands out for its ambition and broad influence. After Bronn, it became common practice for paleontologists to evaluate patterns in the history of life through analysis and interpretation of numerical taxonomic data, and to represent those patterns using distinctive visual imagery that Bronn had a major hand in inventing and popularizing.

The way Bronn developed his approach to data is also notable. While historians of science and quantification have long pointed to a close relationship between the natural and bureaucratic sciences during the eighteenth and nineteenth centuries, the particular role of cameralism in this story is something new. Naturalists like Linnaeus may have been influenced by some of the broad administrative perspectives of eighteenth-century cameralism, but here we have documented the specific transfer of both practices and theoretical goals from the Heidelberg school of *Kameralwissenschaft* to natural history, in the form of a quantitative cameralistic "statics" that was distinctive for its time. The table was a widely used tool in nineteenth-century bureaucratic and natural science, but Bronn's approach—reflecting his specific cameralistic training—saw a refinement of tabular methods toward the goal of producing data summaries that could yield regularities and even empirical laws.

Osiris 32 (2017); Bruno J. Strasser, "Data-Driven Sciences: From Wonder Cabinets to Electronic Databases," *Studies in History and Philosophy of Biological and Biomedical Sciences* 43 (2012): 85–87.

103. See, for instance, Staffan Müller-Wille and Isabelle Charmantier, "Natural History and Information Overload: The Case of Linnaeus," *Studies in History and Philosophy of Biological and Biomedical Sciences* 43 (2012): 4–15.

At an even broader level, our focus on the development of spindle diagrams in Bronn's work highlights the important role that early statistical visualizations played in the development of "trust in numbers" in nineteenth-century natural science. For large collections of data to be truly useful, those data had to be made to present some legible insight into phenomena of recognized scientific interest. The question of the historical development of life over time was one such area of burgeoning interest during the middle decades of the nineteenth century, and Bronn found a powerful way to combine quantitative techniques with simple visual imagery that helped establish directional patterns in life's history as an empirical fact. He accomplished this both with his careful collection and tabulation of taxonomic data and with his summarizing diagrams, establishing a methodology that would carry forward into successive generations of practice. What is perhaps surprising was that a major source of inspiration for Bronn appears to have come from the seemingly unrelated genre of the eighteenth-century historical timeline. The acceptance of the analogy between time and measurable graphical space seems to have been a precondition for the development of many of the now intuitive statistical visualizations that came to prominence during the "golden age" of statistical visualization in the later nineteenth century. But Bronn's deployment of spindle diagrams (and other paleontologists' use of similar devices) pushes the important connection between data and spatiotemporal visualization—the "timing of history," as Maas puts it—significantly earlier in the history of statistics than has been generally suspected. It also suggests that the relationship of influence between bureaucratic and natural sciences was complex and bidirectional at the time; Bronn's tabular and statistical practice was clearly influenced by cameralism, but the modes of statistical visualization he developed and helped popularize may well have influenced statistical practices in economics and social sciences as well.

This case also serves as a reminder of the close historical relationship between the study of human history and the historical natural sciences. Both emerged in their modern professional forms at the beginning of the nineteenth century, and there was considerable conceptual and methodological overlap between the two domains. As the connection to Priestley's charts demonstrates, the emergence of historical thinking in the natural sciences was deeply informed by contemporary approaches to the historiography of human history. It is well known, for instance, that not only Bronn, but Cuvier, Lyell, and even Darwin were well versed in and deeply influenced by some of the major historical philosophies of the day.[104] For example, the notion of the successive rise and decline of civilizations was well entrenched in what Peter Bowler labels a "conservative" nineteenth-century German historiography.[105] Analogies between the purported life cycles of individuals and species were frequent in contemporary developmental and paleontological literature (especially in the so-called orthogenetic evolutionary theories of Ernst Haeckel, Alpheus Hyatt, Carl Nägeli, Edward Drinker Cope, and others), as were analogies between individuals and civilizations in historical philosophies. Oswald Spengler, for example, was merely one of the last and most famous to invoke this parallelism, which he explicitly presented as a biological analogy.[106] And at the same time, Spengler's early twentieth-century contemporaries Karl Beurlen and Otto Schindewolf warmly acknowledged Spengler in advancing their typostrophic theories of the intrinsic life cycles of species.[107]

More proximate to Bronn was G.F. Hegel's philosophy of history, as expressed, for example, in his Lectures on the Philosophy of World History: "A nation makes internal advances; it develops further and is ultimately destroyed. The appropriate categories here are those of cultural development, over-refinement, and degeneration; the latter can be either the product or the cause of the nation's downfall."[108] We know that Bronn attended Hegel's

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[104] As Rudwick has put it in his most recent book, "it should be no surprise that [the source of Earth's deep history lay] in the contemporary understanding of *human* history, which was deliberately and knowingly transposed into the world of nature . . . the sense of historicity that was transferred from culture into nature, generating a new understanding of nature, and specifically of the Earth, as similarly historical." Martin J. S. Rudwick, *Earth's Deep History, How it was Discovered and why it Matters* (Chicago: The University of Chicago Press, 2014), 4. On Darwin's historicity, see Stephen Jay Gould, "Evolution and the Triumph of Homology, or Why History Matters," *American Scientist* 74 (1986): 60–69. See also Rudwick, *Bursting the Limits of Time* (ref. 49) and *Worlds Before Adam* (ref. 3), and Sepkoski, "Earth as Archive", in *Science in the Archives. Past, Presents, Futures*, ed. Lorraine Daston (Chicago: The University of Chicago Press, 2017), 53–85.

[105] Peter J. Bowler, *The Invention of Progress: The Victorians and the Past* (Oxford: Blackwell, 1989); Bowler, *Life's Splendid Drama* (Chicago: The University of Chicago Press, 1996), 435.

[106] Oswald Spengler, *Der Untergang des Abendlandes* (Munich: Beck, 1919–22).

[107] Olivier Rieppel, "Karl Beurlen (1901–1985), Nature Mysticism, and Aryan Paleontology," *Journal of the History of Biology* 45 (2012): 253–99.

[108] G. W. F. Hegel, "Second Draft" (1830), in *Lectures on the Philosophy of World History: Introduction*, trans. H. B. Nisbet (Cambridge: Cambridge University Press, 1975), 56. It should be also added that Kant's distinction between natural history (*Naturgeschichte*) and natural description (*Naturbeschreibung*) is important to understanding the broader philosophical framework of nineteenth-century natural history. On Kant's distinction see, for instance, Peter McLaughlin, "Actualism and the Archaeology of Nature", in *Kant und die Philosophie in*

lectures at Heidelberg in 1817, although we don't know the exact content of those lectures. Nonetheless, it is tempting to read another, quite different passage from Hegel's definition of "Universal History" as analogous to Bronn's approach to the history of life. As Hegel put it,

> A history which aspires to traverse long periods of time, or to be universal, must indeed forego the attempt to give individual representations of the past as it actually existed. It must foreshorten its pictures by abstractions; and this includes not merely the omission of events and deeds, but whatever is involved in the fact that Thought is, after all, the most trenchant epitomist.[109]

In short, and as Rudwick has convincingly shown, new understandings of historicity in both natural and human contexts emerged simultaneously during the late eighteenth and early nineteenth centuries. Their relationship was far from trivial, but too little is still known about the extent to which historians and naturalists—particularly on the continent—interacted and influenced one another's methodologies and assumptions.

While the professional historical community fairly quickly lost interest in quantitative and visual approaches such as the timeline—except, perhaps, in popular presentations and pedagogy—these tools became integral to the historical natural sciences from the mid-nineteenth century onward. Adoption of the characteristic visual modes of historical narration discussed in this paper shaped not only the practice of natural history, but its central phenomena and concepts as well. As Stevens has argued in his study of late twentieth-century bioinformatics, visualizations of data can "act to generate new and often unexpected relationships between biological objects," and even to create new entities or phenomena.[110] It appears that this was the case even back in the nineteenth century: Bronn's aggregative analysis of fossil data and his resulting visualizations of change over time helped to create awareness of the phenomenon of taxonomic diversification, which only emerged as an empirical pattern when presented as spindle diagrams or (in the case of Phillips) as line graphs. By the later twentieth century, phenomena such as diversification and mass extinction are often only detectible—and in some cases have been "discovered"—by generating such

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weltbürgerlicher Absicht: Akten des XI. Kant-Kongresses, ed. M. Ruffing, C. La Rocca, A. Ferrarin & S. Bacin (Berlin: de Gruyter, 2013): 159–70.

[109] Hegel, "Introduction to the Philosophy of History," reproduced in Aakash Singh and Rimina Mohapatra, *Reading Hegel: The Introductions* (Melbourne: re.press, 2008), 114–15.

[110] Stevens, *Life out of Sequence* (ref. 100), 200.

visualizations from large databases.[111] Moreover, the recognition of organic development over time—and even of the phenomenon of evolution—has relied greatly on distinctive visualizations of temporal change, such as evolutionary or phylogenetic "trees" that have a close family relationship to the spindle diagrams and line graphs encountered here.

In fact, it seems that some of the fundamental ways that biologists and paleontologists have come to interpret and narrate the history of life have their origin in the close associations among natural history, administrative practice, and emergent historicism in the late eighteenth and early nineteenth centuries. As Müller-Wille has noted, as a side-effect of the need among eighteenth- and nineteenth-century Linnaean taxonomists to keep orderly records, "Species became units that could be 'inserted' into collections and publications, reshuffled and exchanged, kept track of in lists and catalogues, and counted and distributed in ever new ways."[112] The notion that species are things to be numbered and counted rapidly took hold among nineteenth-century taxonomists, which is why naturalists like Bronn used terms like "Index" and "Nomenclator" in the titles of their compendia. This reinforces Müller-Wille's observation that "once names and taxa were reduced to labels and containers in order to enhance the exchange of information—once the system they formed became a system of relations of equivalence, rather than difference—species numbers began to take on new, empirical meanings."[113] We have referred to this as the "atomization" of taxonomy, and it is reflected in Bronn's observation that species can be considered to be independent units with "lives" in space and time.

It may be the case that a prerequisite for narrating the history of life against a background of truly deep time was the reconceptualization of organic history as a history of data. The nearly incomprehensibly vast stretches of the prehistoric past—which even twenty-first-century minds balk at fully confronting—would be impossible to narrate as a history of individual organisms and events. Deep history is qualitatively different from human history in that way. What Bronn and others recognized is the fact that only through statistical aggregation do recognizable patterns come into view: first, by converting individual

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[111] See, for example, J. John Sepkoski Jr., "A Kinetic Model of Phanerozoic Taxonomic Diversity. I. Analysis of Marine Orders," *Paleobiology* 1, no. 4 (1978): 223–51; David M. Raup and J. John Sepkoski Jr., "Periodicity of Extinctions in the Geologic Past," *Proceedings of the National Academy of Sciences* 81, no. 3 (1984): 801–04.

[112] Müller-Wille, "Names and Numbers" (ref. 81).

[113] Ibid., 126.

specimens to taxonomic units that can be counted and converted to numerical data; and second by aggregating those data—deliberately throwing away what is singular and unique in favor of averages and means—through statistical analysis. Aggregating taxonomic data and then visualizing them as patterns in measured graphical space has, ever since, been the dominant way of narrating the history of life—not to mention for representing many other kinds of temporal patterns in large data sets.

In the end, our goal has been less to celebrate the innovations of one particular scientist (Bronn) than to illuminate the complex influences on statistical knowledge-making in nineteenth-century natural history. We have called Bronn as our chief "witness" (*sensu* Hacking) to an epistemic change that was taking place more generally in the first half of the nineteenth century in a variety of contexts and disciplines.[114] The particular example of Bronn can, we suspect, be correlated with other similar cases, leading hopefully to a more detailed picture of knowledge transfer, disciplinary flexibility, and visualization strategy in nineteenth-century quantitative natural science. Bronn himself did not see his approach as being necessarily limited to one knowledge domain (paleontology), but rather viewed it as a universally applicable methodology. As he wrote in 1849, "although the results of the paleontological statics are still incomplete . . . they give us at least an image of science and therefore they will always have a value in themselves."[115] Bronn's modest contribution to understanding the history of life may now be mostly forgotten, but the "image of science" he proposed is still very much with us today.

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[114] Ian Hacking, *The Emergence of Probability* (Cambridge: Cambridge University Press, 1975), 57.

[115] Bronn, *Handbuch einer Geschichte der Natur* (ref. 56), 750.