Article Title: Earth in Four Dimensions: Development of the Ideas of Geologic Time and History

Full Citation: R F Diffendal, Jr, "Earth in Four Dimensions: Development of the Ideas of Geologic Time and History, *Nebraska History* 80 (1999): 95-104

URL of article: http://www.nebraskahistory.org/publish/publicat/history/full-text/NH1999GeologicTime.pdf
Date: 3/08/2013

Article Summary: Nebraska's geologic history extends from rocks billions of years old buried beneath the surface to sediments accumulating today.

Cataloging Information:

Names: John Harrison; Nils Steensen (Nicolaus Steno); Georges Leclerc, Comte de Buffon; James Ussher; James Hutton; William Smith; Charles Darwin; William Thompson, Lord Kelvin; G DeGeer; Ernest Rutherford; Frederick Soddy; John Boellstorff

Place Names: Keith County, Nebraska; Sioux County, Nebraska; Greenwich, England; Lyme Regis, Dorset, England

Laws of Strata Formation: superposition, original horizontality, lateral continuity, cross-cutting relationships, floral and faunal succession

Dating Techniques: dendrochronology, fluorine dating, human cultural debris dating, fission track dating

Keywords: perspective art, chronometer, Nils Steensen (Nicolaus Steno), James Ussher, James Hutton, William Smith, strata, Charles Darwin, natural selection, sediments, varve, radioactive decay, isotope, mass spectrometer; Carbon-14 dating, dendrochronology, volcanic ash, Ogallala Group

Photographs / Images: (Fig 1) prime meridian, Royal Observatory, Greenwich, England; (Fig 2) cross sections showing Steno's principles and Hutton's Principle of Cross-cutting Relationships; (Fig 3) volcanic ash beds deposited in an ancient gully; (Fig 4) earthquake fault in Sioux County, Nebraska; (Fig 5) tilted strata along the Front Range, Colorado; (Fig 6) folded strata, Appalachian Mountains, western Maryland; (Fig 7) Cambrian trilobites, Nevada; (Fig 8) dinosaur footprints, Jurassic Morrison Formation near Denver, Colorado; (Fig 9) Jurassic marine ammonite cephalopod shell in shale, Lyme Regis, Dorset, England; (Fig 10) geologic bedrock map of Nebraska; (Fig 11) Varved lake sediments from Lake Diffendal, Keith County, Nebraska; (Table 1) dates of inventions and development of absolute dating techniques; (Fig 12) tree rings

FOREWORD

The Place of Time

Does time pass, or does it take place? This was one of a series of spontaneously emerging questions that led me to propose this exploratory theme issue of *Nebraska History* quarterly. Though the timing is later than originally intended—and the scope somewhat different—we might now just as well allow the synchronous juxtaposition of this number of the quarterly with the turn of the millennium. Whatever the fascination with the appearance of so many zeros in a date, this conjunction certainly provides an opportunity to reflect upon the concept of Time.

On the surface, time is the special province of history. But it is also a special concern of us all. We all exist in time and our time becomes an intimate part of us. While we mark our personal times using the same numerical system as historians, and we might even think in terms of personal histories, few us us will probably consider our lives as history, at least in the same sense as we have, say, Willa Cather's or William Jennings Bryan's.

But neither history nor time, as such, were the impetus for this project. One impulse is outlined in my own essay in this collection; another came about from a realization that my memory of time past—the internal "record" of my own personal history—was set in places, not in times. At least it wasn't set in the absolute Time that is measured by clocks and calendars. Recognizing that there could be many reasons why I do not remember experiences in terms of dates, the question that opens this introduction was nonetheless one that emerged. The phrasing of the question does seem to capture two quite different but fairly common ways of characterizing time: Is it just a "passing" out there somewhere that we have somehow figured out how to measure with clocks and calendars, or is it instead a kind of emplacement?

I posed the question, "Is there a place for time?," to a few people of varied perspective to see if I might elicit some interest in this theme. The essays of those who were in a position to write their thoughts are presented here. They are diverse enough, and they raise some provocative issues.

Bob Diffendal recounts the evolution of western perceptions of time in his historiographical essay on the development of various means of measuring Earth history through geology He concludes with graphic examples that show how the context of history has been changed by the accumulated spatial evidence of time in Earth. Paul Olson turns his essay on the Proustian notion of simultaneity and uses a personal experience to peer into the essence of time, which he concludes is spatial. He then investigates four historical visions of time, noting how Plains architecture either directly reflected a time-space simultaneity, or attempted to establish such a sense through the use of "quotation" from buildings of other times. His narrative establishes a context within which to review our current paradigm of absolute Time as a linear progression. Finally, I summarize how western culture created the artifact of linear time from the cosmic cycles—and the concept of flat space from the Euclidian geometry—then attempt a non-mathematical explanation of the Einsteinian concept of spacetime. I conclude by searching for ways to bring the spacetime notion "down to Earth," and find that place, as an experiential matrix of spaces-and-times, provides an authentic point-of-departure for further exploration of this new paradigm.

Interspersed with the major essays are two others that were initially conceived as sidebars. Their topics worked so well with the thematic question of this issue, as it developed, that they were expanded into historical articles. One by Janet Jeffries shows how space was used to mark time in Crete, Nebraska, after nationwide Standard Time had replaced local time and rendered local synchronization obsolete. Her article provides a brief history of the Boswell Observatory at Doane College, the functions of its various clocks, and the use of its time ball. In the other, Gene Thomsen shows how time was used by U.S. Government surveyors to establish their location in space. His article details how stars were used as timing signals, and the role that they played in laying Nebraska's western borders down upon the land.

I want to thank all of the authors for many interesting exchanges, and for enduring the longer-than-anticipated process of assembling this issue. Much deserved thanks is also due to my colleagues here—including individuals whose discussions unwittingly raised the question—but primarily to those in the Research and Publications Division. Special appreciation goes to James E. Potter, editor of the quarterly, and assistant editor Patricia C. Gaster. Their patience with this project has been extraordinary, not only in dealing with delays but in working these articles to completion.

David Murphy
Senior Research Architect

EARTH in Four Dimensions

Development of the Ideas of Geologic Time and History

By R. F. Diffendal, Jr.

Forward and backward I have gone, and for me it has been an immense journey.
Loren Eiseley
The Immense Journey

Geology is an historical science. It deals with the three-dimensional Earth and its development through time, the fourth dimension of this piece. I cannot remember when I was first introduced to the idea of geologic or deep time, but the introduction occurred early in my childhood. I know that this was unusual in my hometown in western Maryland, and probably was unusual in most American hometowns in the 1940s and 1950s. My interest in geology and its subdisciplines was first sparked in the spring of 1950 by an accidental find on the grounds of a local industrial plant, before the advent of the EPA and the ban on open dumps and open burning. By the age of ten, several friends and I had developed interests in science. We thought that the sciences were extremely interesting ("neat," as we said in those days) and tried to find ways to conduct all kinds of experiments. After school we often stopped at a factory that made science sets for children. In back of the factory was an open dump where the business discarded old, flawed, and, to it, no longer saleable chemicals, glassware, microscope parts, and all sorts of other materials that were useful to us. We acquired hundreds of dollars worth of chemicals and equipment from that dump that none of us had the money to buy on our own.

One day we happened upon an inverted, conically shaped mound of pieces of what we took for "rock." The mound, as I remember it, was about four or five feet in diameter and about three feet high. There were many different kinds of "rocks" in the pile, and most of these had small pieces of paper with numbers pasted to their sides. I thought they were very interesting and took home as many different kinds as I could find over the next few days. I then stopped by the factory salesroom to see what I had collected. The pieces of "rock" turned out to be minerals, and the factory still stocked them and sold a book explaining how to identify them.[1] I saved my money, bought the book, and became an instant expert at school on mineral and rock identification, subjects that no teachers taught in the local schools in those days. I soon started on the Boy Scout geology merit badge, and must have had my first introduction to geologic time at some point between the first day with my book and the work on the badge. From my reading, I had no trouble understanding the notion of a very long earth history. It seemed like a perfectly reasonable idea.

Changes in ideas and in technology can come about as slow incremental modifications, as well as by major paradigm shifts. In the case of the development of the ideas of geologic history and time, I will try to present these changes broadly and then look at how some of these have affected interpretation of Nebraska geology. Changes of view on three fronts were important in the development of geologic history and time concepts.

First is the question of the nature of time.[2] Is time cyclic or is it linear? The Greco-Oriental cultures had a world view based on cosmic cycles, but the Judeo-Christian world view was more linear and reflected the historical nature of the Bible. Cosmic cycles had a repeating pattern with no beginning or end to the cycles. In the linear view time, the universe, the Earth, and its creatures had a beginning point and are moving to an end. The age of the Earth differed in these two views as well. Cosmic cycles were multiple and repetitious. Each took a long time (12,000 years in one Indian cycle).

In contrast the Judeo-Christian view of the Earth started with the Creation and ended with the Last Judgment.[3] The age of the Earth in this view was only about 6,000 years, calculated in the seventeenth century using Biblical accounts of the numbers of generations since the Creation. The time and date of the Earth's creation were calculated as noon on October 23, 4004, B.C.E. (derived in 1650 by James Ussher, archbishop of Armaugh, according to Stephen Gould), or 9:00 a.m., October 26, 4004 B.C.E. (derived in 1654). However, other similar dates were also circulating.[1] All of these had in common a short duration and linear history of the Earth. Ussher's latter date was included as a marginal note in an early edition (and in subsequent editions) of the King James Version of the Holy Bible, and thus came to be the most widely cited. (Readers interested in questions about when a millennium ends, or

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thoughts on the significance of new millennia, may find Gould, *Questioning the Millennium*, of interest.)

Second, the development of modern geologic thought originated in Europe partly as a result of the long development there of perspective art. Multipoint and aerial perspective were mastered by northern European artists during the Renaissance.[5] This mastery of a three-dimensional technique and way of viewing things had a major impact, beginning in the mid-1600s, on the thinking of early scientists there who contributed to the development of three-dimensional views of the transformation of the Earth through time.

Third, the seventeenth and eighteenth centuries witnessed the development of ideas regarding how to find places on the Earth. Observations of the apparent movement of the Sun and other celestial bodies had been used to determine latitude position north or south of the equator with some precision long before this. But determining longitude reliably, particularly at sea, remained impossible until solar tables and chronometers (clocks that would lose only a few seconds a month) were developed in the 1700s.[6] Knowing that the earth averages one complete rotation about its axis in respect to the sun in twenty-four hours, the distance east or west of any north-south imaginary line passing across the Earth's surface from the North to the South Pole could be determined (Fig. 1) To do this the chronometer was set at noon at the departure point and the ship then departed. After sailing a distance, noon time on the ship was determined by noting the time when the sun reached its zenith and comparing this time to the time at the prime meridian. If the two times were the same, the ship was still located on the prime meridian, but if the times differed, then the difference in position east or west of the prime meridian could be calculated. If the chronometer was running fast or slow the calculated position could be off by many miles, so the timepiece had to keep almost perfect time to be useful.

John Harrison, a self trained clockmaker, invented the first successful chronometer (from Greek words meaning "measure of time") and used it in a sea trial to determine the longitude of a ship for the first time in 1736. From this date on, locating oneself geographically and making maps became increasingly accurate and precise.

Fig. 1 **Prime meridian, Royal Observatory, Greenwich, England, UK. The imaginary 0° north-south line of longitude was chosen to run through this place in 1884.** All illustrations courtesy of author, except where noted.

By the 1600s, European scholars were seeking answers to all sorts of questions regarding measuring space and time, and northern European artists were creating landscapes and portraits with perspective rather than flat looking, two-dimensional renditions. Among them was a natural scientist, Nils Steensen, a Dane who changed his name to Nicolaus Steno. In 1671 he published some observations on the formation of strata and fossils which have become guiding principles of geologists to the present.[7] Three of these are commonly known as the principles or laws of superposition, original horizontality, and lateral continuity (Figs. 2A–D; 3).

Steno recognized that strata were deposits of fluids and that they contained fossils or remains of past life. He observed that when any stratum was deposited, its lower and lateral surfaces corresponded to the surface of the depression upon which it rested, but that its upper surface was horizontal or nearly so. All strata above this lower one were deposited as horizontal or nearly horizontal layers upon the first (law of original horizontality). He also noted that strata which are perpendicular to or inclined from the horizontal were at one time horizontal. Steno further observed that when the lowest stratum was formed none above it existed (law of superposition). Finally he remarked that, when a stratum was formed, it was either enclosed on the base and sides by another solid substance, or else covered the earth's surface (law of lateral continuity).

Steno's work laid the foundations for all later work of geologists trying to piece together the history of the stratified Earth. Since the principles were first introduced exceptions have been found to each. Superposition has an exception when a molten layer is intruded between sedimentary strata. In that case a younger stratum would underlie an older one. Some strata were deposited with sometimes considerable original inclination as for example sediments deposited on the floor of a steeply sloping valley. And some strata are continuous, but were deposited from one place to another over a long time span and thus are not the same age everywhere. Geologists have learned what these and other exceptions are and can recognize them.

By the mid-1700s scientists had observed the stars and planets and noted many facts about them. Based on these observations some felt that the Earth was originally molten and cooled from that state to its present condition. In 1774 Georges Leclerc, Comte de Buffon (his name is often shortened to Buffon), published the results of experiments he

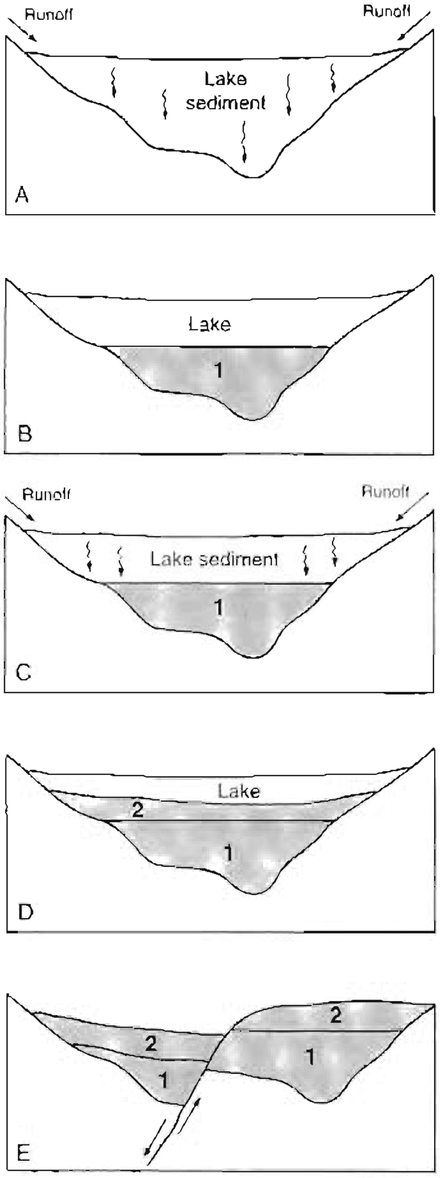

Fig. 3 Volcanic ash beds (whitish) deposited in an ancient gully illustrate Steno's principles; the hammer is positioned near the bottom of the gully.

Fig. 2 Cross sections showing Steno's principles and Hutton's Principle of Cross-cutting Relationships: A. Stream runoff carries sediment into a lake where it begins to sink to the lake floor; B. Sediment accumulates as layer 1 on the floor of the lake—Steno's Principle of Lateral Continuity (note bottom of layer 1 fits irregular lake floor, but top of layer 1 is nearly horizontal); C. Second period of stream runoff carries new sediment into waters of lake; D. New sediment accumulates on top of layer 1 and forms layer 2—Steno's principles of Superposition, Original Horizontality, and Lateral Continuity; E Movement along earthquake fault cuts rocks beneath lake and layers 1 and 2, offsetting them from one another across the fault (arrows indicate relative movement on either side of fault)—Hutton's Principle of Cross-cutting Relationships.

made on the cooling of molten bodies of different diameters and scaled these up to cooling of a molten object the volume of the Earth. He calculated that the Earth had taken 74,832 years to cool to its present state, thus suggesting an age for the Earth far older than any worked out from the Biblical chronology. The debate among scholars on the Earth's age from the time of Archbishop Ussher, which continued for more than two centuries, has been the subject of a number of excellent works.[8]

By the late 1700s there were many scholars discussing the Earth, its age, and other ideas about its origin and development. Many of these ultimately proved to be sidetracks that led nowhere, or were incorporated in part into other ideas. One idea, however, became a major contributor to the budding science that would be called geology James Hutton of Edinburgh, Scotland, studied the Earth and its development and published several works in the 1780s outlining his theory of the Earth.[9] Hutton viewed the Earth as if it worked like a machine. Rocks were formed, uplifted, and eroded. Their decomposition products were transported, deposited, hardened into rock, and uplifted again. Molten rock was intruded into these rocks and solidified at different times. This last idea led to the development of the principle or law of cross-cutting relationships (Fig. 2E), which states that any geologic feature that cuts across another must be the younger of the two. For example, an earthquake fault that disrupts rock is younger than the rock it cuts (Figs. 4–6).

Fig. 4 **Earthquake fault in Sioux County, Nebraska.**

Fig. 5 **Tilted strata along the Front Range, Colorado.**

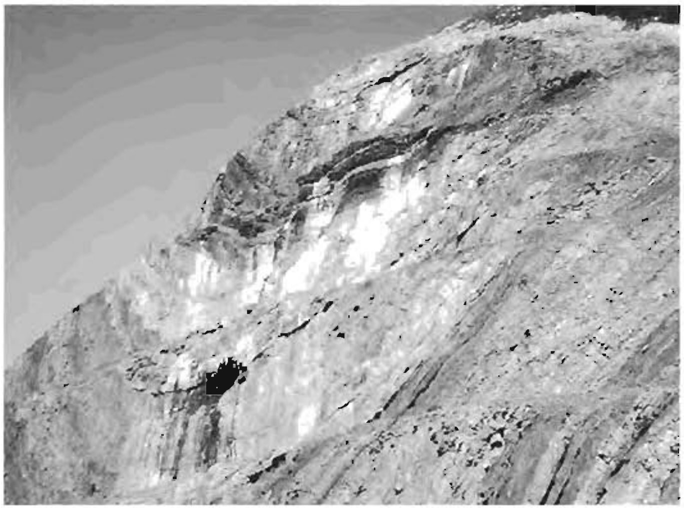

Fig 6 **Folded strata, Appalachian Mountains, western Maryland.**

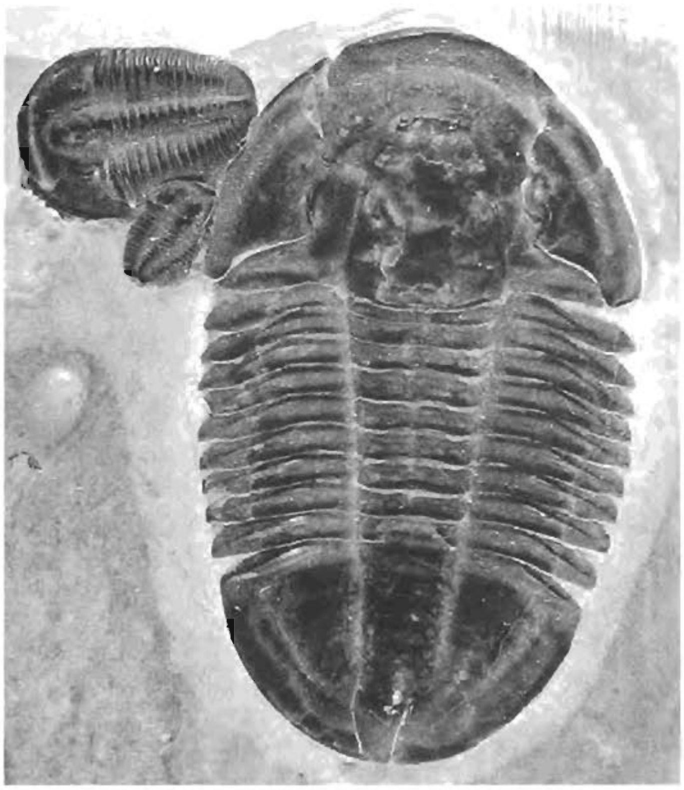

Fig. 7 **Cambrian trilobites, Nevada.**

Fig. 8 **Dinosaur footprints, Jurassic Morrison Formation near Denver, Colorado** (digitally modified).

The concluding paragraph of Hutton's 1788 article, "Theory of the Earth," is worth inspection because it led to other major ideas and contributed to the development of yet others.

> We have now got to the end of our reasoning; we have no data further to conclude immediately from that which actually is. But we have got enough; we have the satisfaction to find, that in nature there is wisdom, system, and consistency. For having, in the natural history of this earth, seen a succession of worlds, we may from this conclude that there is a system in nature; in like manner as, from seeing revolutions of the planets, it is concluded, that there is a system by which they are intended to continue those revolutions. But if the succession of worlds is established in the system of nature, it is in vain to look for any thing higher in the origin of the earth. *The result, therefore, of our present enquiry is, that we find no vestige of a beginning,—no prospect of an end* (emphasis added).[10]

These words were and are a powerful statement of a cyclical view of the Earth's history and of a very long history indeed. The theory behind the words was also powerful. Some geologists later hypothesized that the cycles were of uniform rate and duration while others defended the ideas that rates and durations varied. Either way, in these geologists' view the cycles occurred in sequence within a basically linear time line.

While these arguments were going on progress was being made in another area of geology. In 1799 William Smith described the succession of plant and animal fossils he observed in the strata of Great Britain. Certain fossils, Smith found, occurred only in a certain stratum or a sequence of strata and not in others (Figs. 7–9). The distribution of these fossils, combined with Steno's principles, could be used to place one's self within the stratified rock sequence across any given land area and to plot the surface distribution of the sequence on a map (Fig. 10). This principle, the law of floral and faunal succession, was used to develop a worldwide stratigraphic column of rock strata.[11] By this method a sequence of events is established. We know which event came first and so on to the last event, but not how much time was required for these events to happen. This is an example of relative, as opposed to absolute, geologic dating.

Fig. 9 **Jurassic marine ammonite cephalopod shell in shale, Lyme Regis, Dorset, England.**

Debate continued through the nineteenth century on the different concepts of Earth history.[12] But it was the naturalist, Charles Darwin, who added the next important theory to the mix that brought us to where we are today. Darwin proposed that species were not unchanging, that they changed through time into other species by means of natural selection processes. (This was not a new idea. See Eiseley, *Darwin's Century* [1961], for a wonderful review.) Darwin's *The Origin of Species* is a long work that is frequently referred to, but rarely read in total. Everyone who talks about Darwin's ideas should read the book to see that Darwin spent much time talking about breeding experiments on plants and animals and the results of those experiments. The concluding sentence of the book sums up Darwin's view of the history of life and of the Earth: "There is grandeur in this view of life with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved."[13]

Here again we have the difference between the strictly linear view and the view of cycles superimposed on a linear trend, shown well between the ideas of Smith and Darwin and those of Hutton.[14] These two views are both incorporated into today's outline of Earth history.

The time voyagers had to have vast eons in which to travel and they had, like the earlier voyagers, to bring back the visible spoil of strange coasts to convince their unwilling contemporaries.

Loren Eiseley
Darwin's Century

Darwin and Hutton both called for a long Earth history. A few thousand or even a few hundred thousand years would not do to produce the cycles of the earth and the evolution of life. In 1862–64 William Thomson, better known

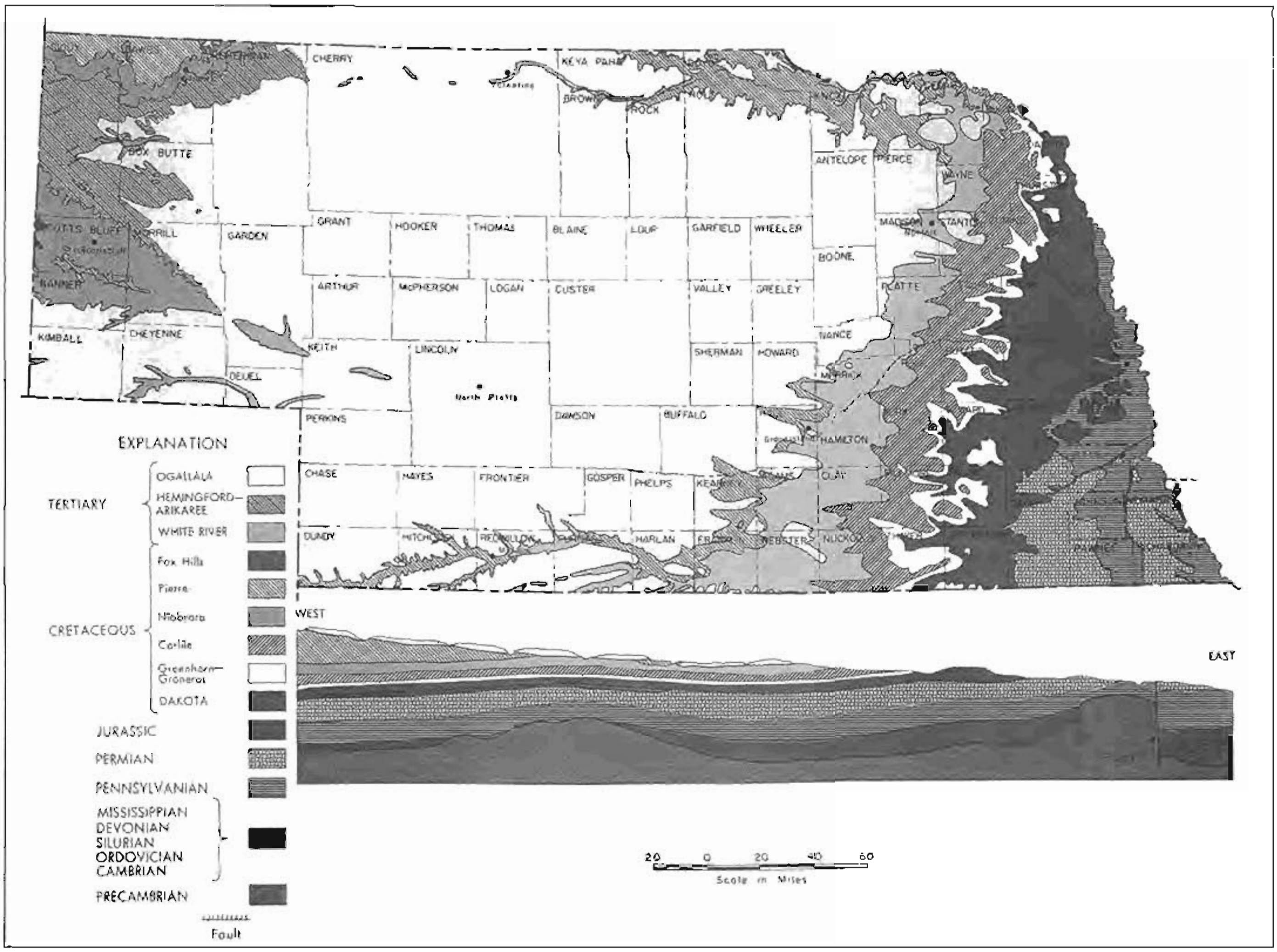

Fig. 10 **Geologic bedrock map of Nebraska, with a geologic cross section along the southern Nebraska border, 1991; compiled by Raymond R. Burchett and Roger K. Pabian, and drafted by Jerry P. Leach. The unconsolidated sediments of recent and Pleistocene age, which cover the bedrock throughout much of the state, are not indicated.** University of Nebraska-Lincoln, Conservation & Survey Division, and the Institute of Agriculture and Natural Resources

today as Lord Kelvin, began to publish works on the age of the Earth based on physical principles.[15] Kelvin, like Buffon before him, assumed that the Earth originated as a fully molten body and cooled to its present state. Using improved concepts of how fast this cooling proceeded, Kelvin initially calculated an age of 98 million years with a range from as little as 20 million years to as much as 400 million years for the Earth since its origin. Over the years Kelvin revised these figures downward and others went even farther, but the age was still in the multimillion year range. These dates were far too long for some Biblical scholars and far too short for most geologists and evolutionary biologists.

As noted earlier, John Harrison invented a good chronometer to help determine longitude in the early 1700s. A century and a half later, other researchers began a search for accurate and precise "chronometers" to determine the time that it had taken for the geologic rock column to accumulate and for the oceans to reach their present salinity; and to establish the dates when minerals and rocks formed.

Sediment deposition rates might be one such measure by which to estimate the length of time required for the Earth's crustal strata to form. By the mid-nineteenth century, vast amounts of data were being recorded about many phenomena worldwide. Assuming that sediments were removed from the lands at a uniform rate and deposited in the seas and oceans, if you had an estimate

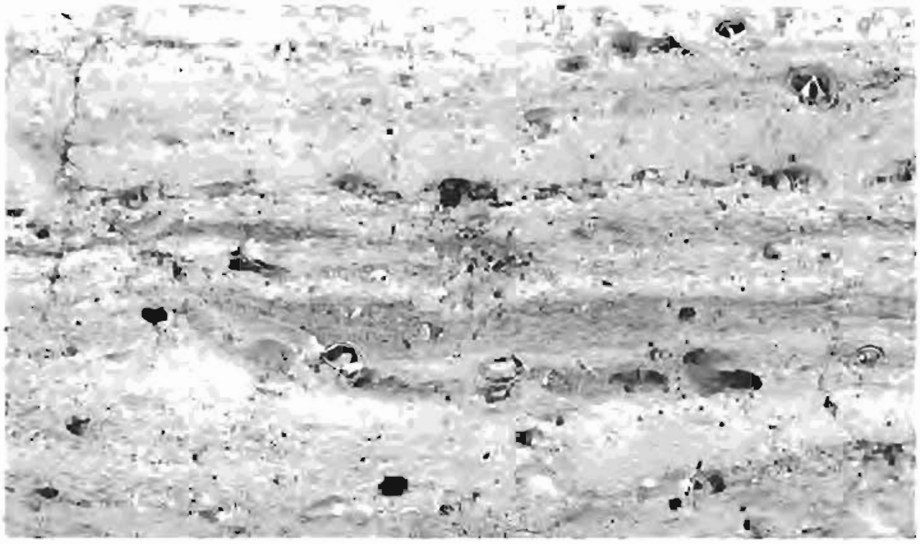

Fig. 11 **Varved lake sediments from so-called Lake Diffendal, Keith County, Nebraska.**

of the annual volume of these sediments deposited worldwide, and an estimate of the total thickness of such deposits of all geologic ages, the time required for the rocks of the geologic column to form could be calculated. Following this general approach, John Phillips of Great Britain used available data in 1860 to derive a very approximate estimate of 96 million years for the formation of the Earth's sedimentary rocks.[16] In 1878 Samuel Haughton, an Irish geologist, using somewhat different reasoning and data, reported an estimate of about 200 million years to accumulate all of the fossiliferous rock strata of the earth.[17] John Goodchild of Scotland in 1896, using different methods deemed appropriate for different parts of the geologic column, calculated an estimated time span for the accumulation of the column of over 700 million years.[18] Other contemporary estimates differed widely, some much less than those reported above, but all in the multimillions of years range. Unfortunately these efforts did not produce the needed "chronometer."

In 1884 G. DeGeer began a study of rhythmically layered lake sediment in Scandinavia.[19] Known as a varve, it consists of two layers of sediment: a thick coarser-grained, light-colored layer deposited during periods of high runoff and precipitation in spring and summer; and a thinner, finer-grained, dark-colored layer formed in the fall and winter, when the lake was frozen over and only sediments suspended in the water settled onto the bottom (Fig. 11). DeGeer found that these varves varied in thickness from year to year because of a number of factors, but in general the pattern of varve thickness change was similar from one lake to another. Comparison of varve sequences from extant lakes and from filled-in lakes could be used to date events in the lakes, and to correlate events from one lake to another. DeGeer first published the results of his studies of varves in 1912.[20]

Late in the last century, scientists began to ask how old the oceans were. If one assumed that the earth was cooled from a fully molten state, then at some point the surface would be cool enough for water vapor to begin condensing and precipitating as rain. The oceans would have formed as fresh water bodies and would become progressively saltier through time by dissolution of the components of salt, mostly sodium and chloride ions, from the decay of rocks on land. If you knew how much dissolved salt reached the oceans from land each year, assumed that all salt in the oceans came from decomposition of rocks on land, assumed that the land areas and runoff had been the same throughout earth history, assumed no recycling of salts, and knew the volume (which would remain constant) of the oceans, their age could be calculated by simple mathematics. John Joly, an Irish geologist, performed this calculation in 1899 and arrived at a general estimated range of 90 million to 99.4 million years for the age of the oceans.[21] Both Joly's assumptions and methods were attacked, and the idea was discarded soon after its presentation.

We have reached 1900, and scientists at that time were still looking for the elusive "chronometer," the measure of time, that would allow them to produce precise and accurate dates of geologic events. The clock was ticking down to the date of the invention of the first absolute dating technique. In 1896 Henri Becquerel discovered natural radioactivity. Shortly thereafter, the scientific view of the age of the earth was altered greatly. From 1900 to the present, devices have been invented to measure abundances of elements and their isotopes, and techniques have been developed to use these devices to date geologic materials (Table 1). The advent of dating can be traced to the Ernest Rutherford and Frederick Soddy discovery and announcement of the radioactive decay law in 1902–3, which was used to determine the half-lives of radioactive isotopes of elements. This law states that the number of atoms which decay during a given period of time is directly proportional to the number of atoms of the radioactive element present in the sample.[22] Atoms of an isotope of a radioactive element break down or decay into atoms of an isotope of a non-radioactive element at a set rate that does not vary through time. The time required for half of the atoms of a mass of a radioactive isotope to decay into non-radioactive products is known as the half life of the radioactive

Table 1 **Dates of Inventions and Development of Absolute Dating Techniques**

Date	Device Invented	Radiometric Dating Technique First Used
1907	First Mass Spectrometer	Uranium/Lead
1908	Scintillation Counter	
1912	Improved Mass Spectrometer	
1912	Geiger Counter	
1913		Uranium/Lead Methods Used to Make Time Scale
1928	Geiger-Müller Counter	
1938		Rubidium/Strontium ($^{87}Rb/^{87}Sr$)
1940s	Nuclear Magnetic Resonance	
1946		Carbon-14 (^{14}C)
1948		Potassium/Argon ($^{40}K/^{40}Ar$)
1952	Neutron Activation Analysis	
1962		Fission Track Dating
1970s	Accelerator Mass Spectrometer	
1975	X-ray Fluorescence	
1982	Laser Microprobe	
1983	Ion Microprobe	

isotope. When a mineral containing atoms of a radioactive isotope first forms, almost no atoms of the stable decay element are present in its structure; but at the end of the first half-life time the mineral has half of the original radioactive atoms still present and half of the stable decay element.

Devices capable of measuring the amounts of a radioactive isotope and its stable decay element were soon invented and put to use in dating radioactive minerals. The first primitive mass spectrometer used to identify different isotopes and to measure their amounts was invented in J. J. Thomson's lab in 1907 and used to measure isotope ratios in samples. In the same year Bertram Boltwood reported a method of absolute age dating using uranium/lead ratios. In 1908 scintillation counters were invented, the Geiger counter (also for detection of radiation) and an improved mass spectrometer followed in 1912. Then Arthur Holmes of Great Britain began to test the theories and to use the hardware to devise the first absolute geologic time scale using uranium/lead dating in 1913. Soon other devices were invented and other dating techniques developed (Table 1).[23]

Dating and refinement of the time scale by Arthur Holmes and others has continued since 1913. $^{238}U/^{206}Pb$ (Uranium/Lead), $^{232}Th/^{208}Pb$ (Thorium/Lead), $^{40}K/^{40}Ar$ (Potassium/Argon), and ^{14}C (Carbon-14) dating methods were all devised from 1938 to 1948 and have been used to revise the geologic time scale since their development.[24]

I want to note four other forms of dating: tree-ring dating, an absolute dating technique; fluorine dating, a relative dating technique; human cultural debris dating, which can yield either relative or absolute dates; and fission track dating, which yields absolute dates for much older materials than tree rings yield. Tree-ring dating or dendrochronology was first applied in 1925 to studies of the ages of wood used in Native American dwellings and other sites in the western United States. Species of trees with well developed annual growth rings are studied (Fig. 12). Using wood from a long-lived living tree, rings that vary in width depending on growing conditions can be compared to rings from unknown samples to determine the oldest age of the unknown, rather like the varve dating mentioned earlier.

Fluorine dating was first used in 1949–50 to resolve the question of the authenticity of the so-called Piltdown Man of England.[25] Fluorine occurs naturally in groundwater, and bones buried in the ground have a natural affinity for absorbing the fluorine. The longer the bones are buried the more fluorine they contain. If the bones of a skeleton of an animal are all buried at the same time, they should all have about the same amounts of fluorine present in them per unit volume of bone. The bones of Piltdown Man did not.

Archaeologists have used artifacts for relative dating of sites for a long time. Charles Hunt wrote a nice little piece detailing how bottles and cans could be used to date mining camps. This method has also been usefully applied at sites in Nebraska.[26]

The method of fission track dating was first described in 1962 by Price and Walker.[27] As radioactive isotopes decay in minerals like zircon and in natural glasses erupted from volcanoes, they emit alpha particles that produce tubular openings in the glass. The older the mineral or glass the more of these tubes or fission tracks are present in the sample.

The door to the past is a strange door.
Loren Eiseley,
The Immense Journey

In the past one hundred years, a number of "chronometers" have been employed to tell Earth's "deep time," as the author John McPhee called it. Some have been used in studies of Nebraska's natural history with greater or lesser success. Steno's principles, Hutton's principle of cross-cutting relationships, and William Smith's principle of floral and faunal succession have been used to piece together the geology of the state and to fit it into the worldwide geologic column. Dendrochronology was used to work out a tree ring record of precipitation by Harry Weakley in the 1940s. More recently Lawson and others employed this method at eastern Nebraska sites. John Boellstorff used the fission track method to date volcanic ash beds in Nebraska and adjacent states. His work revolutionized our concepts of the ages and relationships of Ogallala Group and younger sediments here. Boellstorff calculated dates for the Ogallala ash beds ranging from 10.6 to about 5 million years and dates for Ice Age ashes ranging from 2.2 to 0.6 million years.[28]

Carbon-14 dating has been employed at Nebraska sites younger than 30–40,000 years old for many years. Recently my colleague, Jim Swinehart, reported C-14 dates of peat and other plant materials in Sand Hills lake sediments and beneath the dunes and used these to revise our thinking about the ages of the dunes and their relationships to the lakes.[29] Carl Swisher, formerly a student at the University of Nebraska-Lincoln and now at UC Berkeley Geochronology Lab, has dated volcanic ash beds from the White River and Arikaree Groups of western Nebraska, which resulted in major changes in our thinking about the ages of these strata and how quickly they were deposited.[30] Swisher's dates for these deposits ranged from 31.8 to 28.3 million years. Paul Johnsgard described reports on Lake Diffendal, a large natural dune-dammed lake hypothesized to have been in the North Platte Valley from about 8,000 to 10,500 years ago roughly in the position now occupied by Lake McConaughy. And most recently, Michael Perkins has studied the volcanic ash beds in the Ogallala Group in Nebraska and for the first time correlated them to specific eruptions of volcanoes on the Snake River Plain in Idaho.[31]

Astronomers estimate that Earth formed around 4.5 to 5.0 billion years ago. The oldest rocks on Earth dated so far using radioactive dating methods are about 3.8 billion years old. Visualizing time spans this great is difficult. Science writers often use the year as a model to explain how vast these dates are, in comparison to the length of human history. If one year represents 5 billion years, then human history fits into the last minute of that year.

Fig. 12 **Tree rings. Note variation in widths of ring couplets.**

Another way of visualizing this great span of time is to visit a big library system such as the one at the University of Nebraska-Lincoln (UNL). There are more than 2 million books and bound periodicals in that library's holdings. Let's estimate that the average length of each is 300 pages, making the total holdings more than 600 million pages. If the 5 billion years of Earth's history is represented by those 600 million pages, then the 6,000 or so years of recorded human history fills about 720 pages, or 2.4 books. The oldest fossils of recognizable *Homo sapiens* found so far were collected from deposits dated at about 150,000 years. Using the approach outlined above, this period of years is equivalent to about 18,000 pages or about 60 bound volumes in the UNL library system. Walk into the UNL library stacks and contemplate those ideas and the vastness of geologic time!

To some extent the arguments about a short Earth history of a few thousand years versus a long history of billions of years are still going on today. Most natural scientists support the long history. However, some people including Richard Milton, John Whitmore, and Eddie Zacapa support the idea of a short one. Many also think and write about time and our place in it (e.g., G. G. Simpson in *The Dechronization of Sam Magruder*).[32]

My view, developed since the day that boy I was found a career on the discard pile of a Maryland factory, is that Nebraska's geologic history extends from rocks billions of years old buried beneath the surface to sediments accumulating today. It is a story of volcanism, faulting, flooding by ancient seas, erosion of emergent lands by rivers and glaciers, winds moving sands and silts, and shifting and ever-changing landscapes. To understand that geologic history, you must be willing to think in four dimensions and to take an immense journey.

Notes

[1] F. V. Rosevear, *Sciencecraft Mineralogy Manual* (Hagerstown, Md.: Porter Chemical Co., 1949).

[2] Francis C. Haber, *The Age of the World-Moses to Darwin* (Baltimore: Johns Hopkins University Press, 1959); Haber, "The Darwinian Revolution in the Concept of Time," in Julius T. Fraser, Francis C. Haber, and Gert H. Muller, eds., *The Study of Time*, v.1 (New York: Springer-Verlag, 1972), 338–401; and Loren Eiseley, *Darwin's Century* (New York: Anchor Books, 1961).

[3] Haber, *Age of the World*.

[4] Stephen J. Gould, *Questioning the Millennium* (New York: Harmony Books, 1997); Haber, *Age of the World*; Arthur Holmes, *Principles of Physical Geology*, 2d. ed. (New York: Ronald Press Co., 1965); Bernhard Kummel, *History of the Earth*, 2d. ed. (San Francisco: W. H. Freeman and Co., 1970); L. W. Mintz, *Historical Geology*, 2d. ed. (Columbus, Oh.: Charles E. Merrill Pub. Co., 1977); and Anthony Hallam, *Great Geological Controversies*, 2d. ed. (New York: Oxford University Press, 1992).

[5] Gary D. Rosenberg, "An Artistic Perspective on the Origin of Modern Geologic Thought," *Geological Society of America Abstracts with Programs* 28 (1996): 168.

[6] Dava Sobel, *Longitude: The True Story of a Lone Genius Who Solved the Greatest Scientific Problem of His Time* (New York: Penguin Books USA, 1995).

[7] Preston Cloud, ed., *Adventures in Earth History* (San Francisco: W. H. Freeman and Co., 1970); Kirtley F. Mather and Shirley L. Mason, eds., *A Source Book in Geology, 1400–1900* (Cambridge: Harvard University Press, 1970).

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[9] James Hutton, "Theory of the Earth: Or an Investigation of the Laws Observable in the Composition, Dissolution, and Restoration of Land upon the Globe," *Transactions of the Royal Society of Edinburgh* v. 1, pt. 2 (1788), 209–304, is recommended.

[10] Ibid.

[11] William B. N. Berry, *Growth of a Prehistoric Timescale* (San Francisco: W. H. Freeman and Co., 1968), provides an excellent history of this development. See also Maurice Gignoux, *Stratigraphic Geology* (San Francisco: W. H. Freeman and Co., 1955).

[12] Cloud, *Adventures in Earth History*; Hallam, *Great Geological Controversies*.

[13] Charles Darwin, *The Origin of Species* (New York: Washington Square Press, 1963 rpt. of 1859 ed.).

[14] See Gould, *Time's Arrow*.

[15] Holmes, *Physical Geology*; Joseph D. Burchfield, *Lord Kelvin and the Age of the Earth* (New York: Science History Publications, 1975).

[16] Hallam, *Great Geological Controversies*.

[17] Holmes, *Physical Geology*.

[18] Burchfield, *Lord Kelvin*.

[19] Holmes, *Physical Geology*.

[20] C. Schluchter, ed., *Moraines and Varves* (Rotterdam: A. A. Balkema, 1979).

[21] Burchfield, *Lord Kelvin*.

[22] Holmes, *Physical Geology*; Burchfield, *Lord Kelvin*.

[23] Kummel, *History of the Earth*. Use of many of the dating devices and techniques is described in detail by Mebus A. Geyh and Helmut Schleicher, *Absolute Age Determination* (Heidelberg: Springer-Verlag, 1990). E. I. Hamilton, *Applied Geochronology* (London: Academic Press, 1965), and Hamilton and Ronald M. Farquhar, eds., *Radiometric Dating for Geologists* (London: Interscience Publishers, 1968) also are useful references.

[24] Willard F. Libby, *Radiocarbon Dating*, 2d. ed. (Chicago: University of Chicago Press, 1955); Rainer Berger and Hans E. Suess, eds., *Radiocarbon Dating* (Berkeley: University of California Press, 1979).

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[27] Geyh and Schleicher, *Absolute Age Determination*.

[28] Harry E. Weakly, "A Tree-ring Record of Precipitation in Western Nebraska," *Journal of Forestry* 41 (1943): 816–19; Weakly, "Dendrochronology in Nebraska," in John L. Champe, Waldo W. Wedel, J. D. Jennings, W. C. McKern, and F. H. H. Roberts, Jr., *Proceedings of the Fifth Plains Conference for Anthropology, University of Nebraska Laboratory of Anthropology Notebook 1* (1949): 111–14; Merlin P. Lawson, R. Heim, Jr., John A. Mangimeli, and G. Moles, "Dendroclimatic Analysis of Burr Oak in Eastern Nebraska," *Tree Ring Bulletin* 40 (1980): 1–11; John Boellstorff, "The Succession of Late Cenozoic Volcanic Ashes in the Great Plains: A Progress Report," *Kansas Geological Survey Guidebook* 1 (1976): 37–71; Boellstorff, "Chronology of Some Late Cenozoic Deposits from the Central United States and the Ice Ages," *Nebraska Academy of Science Transactions* 6 (1978): 35–49; and Boellstorff, "North American Pleistocene Stages Reconsidered in Light of Probable Pliocene-Pleistocene Continental Glaciation," *Science* 202 (1978): 305–7.

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