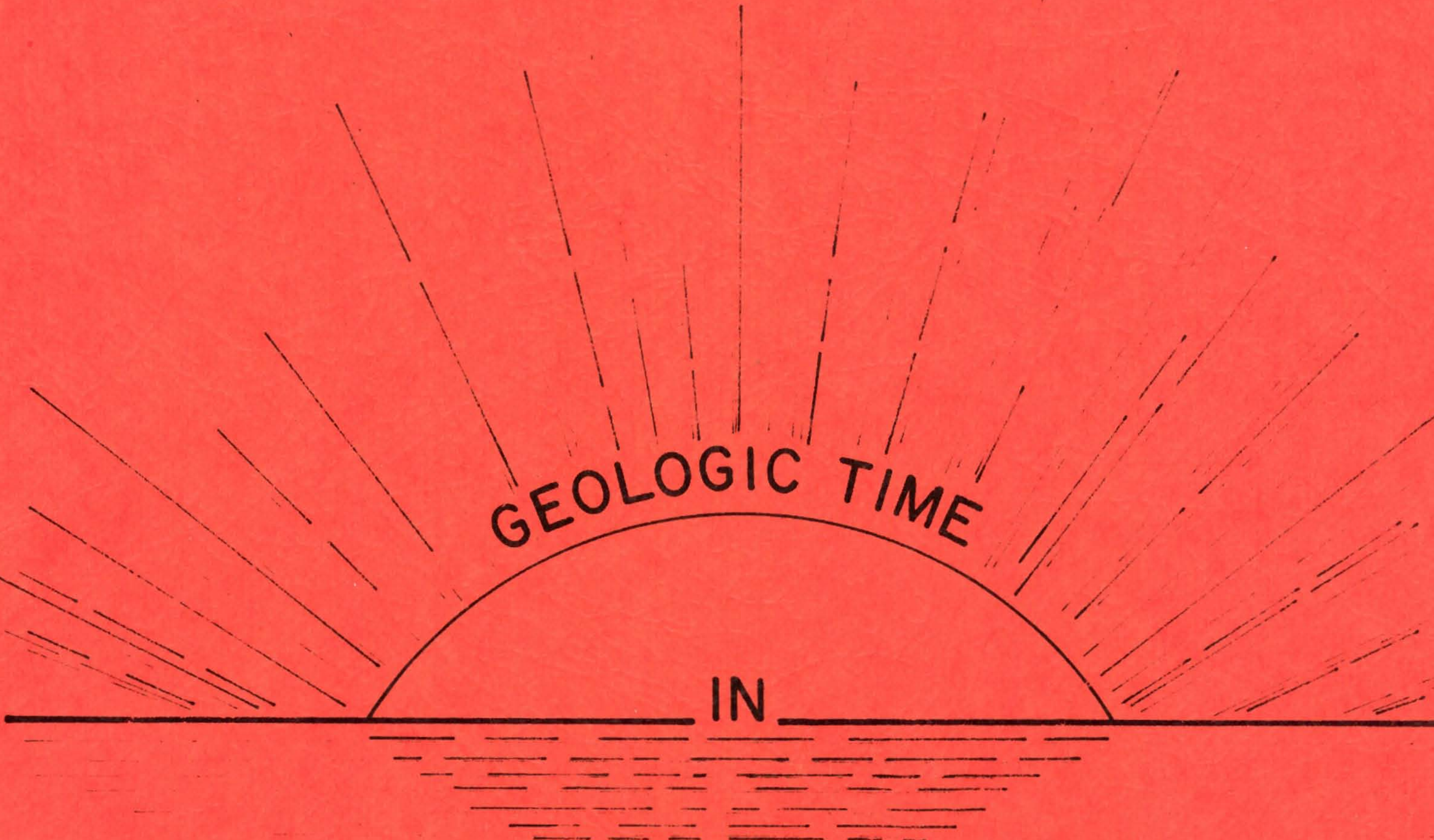

GEOLOGIC TIME IN NORTH DAKOTA

by

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Educational Series 14
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Don L. Halvorson, State Geologist
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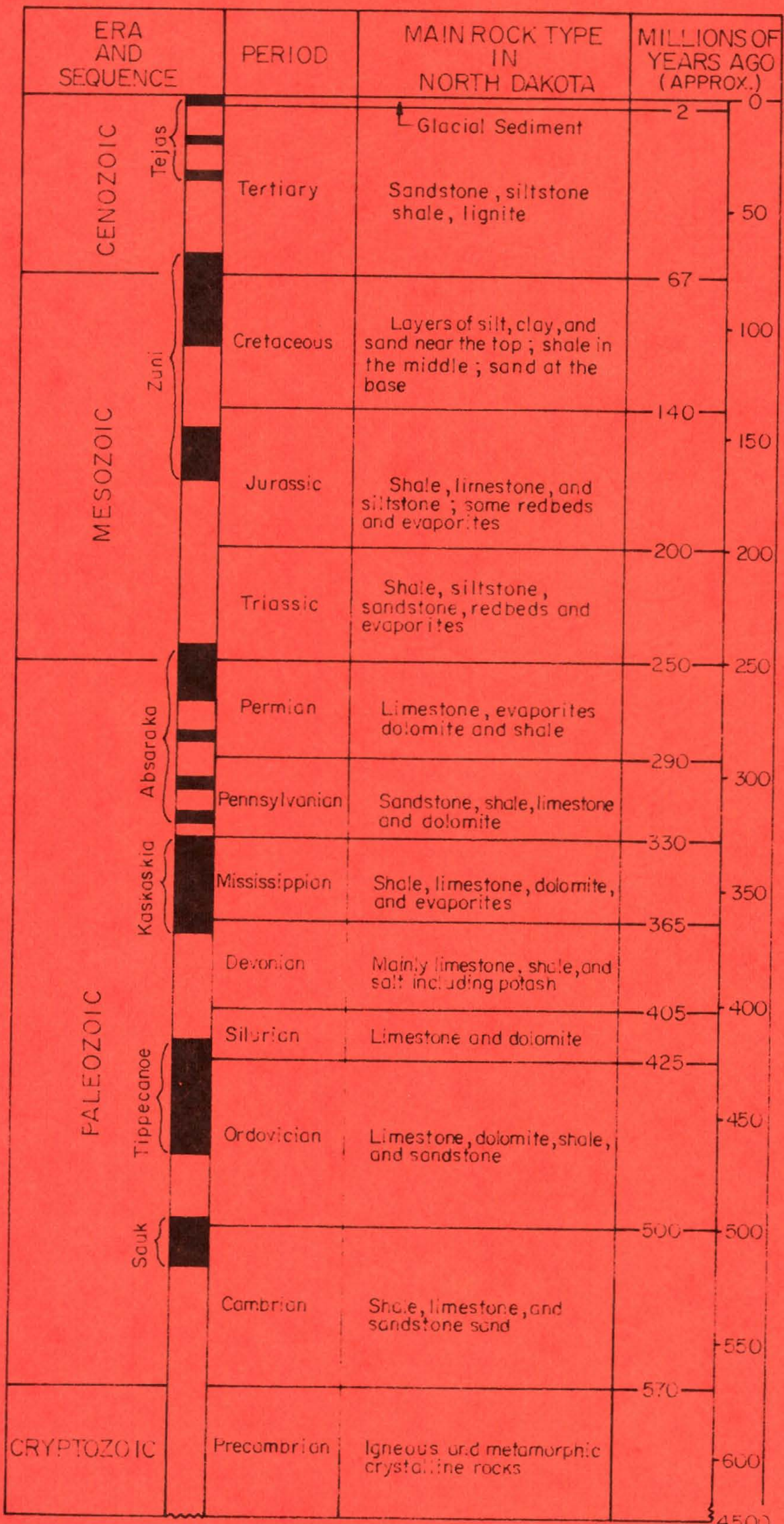
	Millions of Years Ago	Geologic Events	Era		System
Rock and sediment found at the surface in North Dakota	0.01	The glaciers melted as climates moderated. Grass became the dominant vegetation of the Great Plains. Many large land mammals became extinct; human cultures continued to develop.	Cenozoic ("recent life")	Quaternary	Holocene
	1.8	Glaciers repeatedly spread over North America; climates were cold when the glaciers spread, but warm during interglacial times. Herbs and grass increased in importance as trees decreased. Mammals grew large and varied; early man evolved.			Pleistocene
	5.2	The Rocky Mountains formed in Paleocene time; seas were drained from the continents during most of Tertiary time; there was an overall tendency toward more continental climates (hot summers; cold winters). Land plants became more like modern plants; grasses developed in Miocene time; coal formed in North Dakota in Paleocene time. Mammals became common and varied on land; sharks and bony fish were plentiful. Modern types of corals, clams, and snails became dominant in the seas; ammonoids and belemnoids died out, but squids and octopi became common.		Tertiary	Pliocene
	25				Miocene
	38				Oligocene
	55				Eocene
	67				Paleocene
	140	The land was generally low; climates were mild. Flowering plants became important and conifers decreased. Marine reptiles and bird-hipped dinosaurs were varied and abundant, but reptiles were generally decreasing. North Dakota was flooded by a shallow sea during much of Late Cretaceous time.	Mesozoic ("middle life")		Cretaceous
Rock and sediment known only from well and test-hole data in North Dakota	200	The land was low with deserts, volcanoes, and swampy forests in western North America. The first known flowering plants appeared as conifers and cycads dominated the vegetation. Ammonoids, belemnoids, and marine reptiles were common; dinosaurs dominated; the first birds appeared. North Dakota flooded during Late Jurassic time.			Jurassic
	250	Shallow seas covered many areas; but, except for Early Triassic time, North Dakota was emergent and being eroded. Conifers became important and the first cycads appeared. Ichthyosaurs and early plesiosaurs evolved as the reptiles became more important; the first primitive mammals may have appeared; lizard-hipped dinosaurs became common, but they were still small.			Triassic
	290	Mountains formed in eastern North America; glaciers spread in South Africa. Ancient plant types dwindled as large amphibians and reptiles lived in swampy lowlands and reptiles on land; shark-like fish and early ammonoids were common.	Paleozoic ("ancient life")		Permian
	330	Coal was deposited in tropical swamps over much of North America. Amphibians dominated on land and reptiles became good-sized and common; crinoids became less abundant. Repeated flooding by seas in North Dakota throughout Pennsylvanian and Permian time.			Pennsylvanian
	365	Seas covered much of North America; mountain-building took place in the east. First known mosses, seed ferns, and conifers; early coal forests. Sea lilies and sea buds (crinoids and blastoids) were abundant, brachiopods and trilobites less common; insects became more important. Much oil formed in North Dakota.			Mississippian
	405	Most of North America was flat and low, covered by shallow seas. The first forests developed on low deltas; the first known liverworts, ferns, and horsetails. Wide radiation occurred in the early fishes; first amphibians appeared.			Devonian
	425	Most of North America was flat and low, covered by shallow seas. The first known land plants, the club mosses, evolved. Marine life was abundant; jawless fish continued to evolve; invertebrates became more varied.			Silurian
	500	Seas covered most of North America, but mountains formed in the east. Marine algae were the dominant life form. Early fish developed and brachiopods and trilobites became abundant.			Ordovician
	570	Most of North America was low after mountain building in the Great Lakes region at the end of Precambrian time. Marine invertebrates such as brachiopods and trilobites became common as did algae, fungi, and bacteria.			Cambrian
	Probably more than 4,500 my	Many changes occurred in lands and seas; mountain building took place in various parts of the world and great volcanic eruptions occurred; important ore deposits formed. Traces of bacteria, fungi, and algae and a few primitive invertebrates are found in Precambrian rocks.	Precambrian or Cryptozoic ("hidden life")		

This chart shows the changes that have taken place in the geology and living things in North Dakota and nearby areas over the last 600 million years.



This generalized geologic column of North Dakota is drawn with a vertical linear time scale of about 80 million years to the inch. It represents only the last 600 million years of the earth's history. To include all of the time that has elapsed since the formation of the earth, the column would have to be extended downward another 4 feet. It would have to be extended to a total length of about 16 feet if it were to include all of the time since the universe formed (fig. 1).

The ages given for the boundaries between each of the geologic periods (e.g.: the Cretaceous began 140 million years ago) are based on the latest available estimates (Amos Salvadore, The University of Texas at Austin, for American Association of Petroleum Geologists, COSUNA Project, November, 1981).

The era and sequence column shows those periods of time that are represented by preserved sedimentary rock section in North Dakota; these are shown as the darkened parts of the column (Sauk, Tippecanoe, etc.). The blank parts of the column, between the named sedimentary sequences, indicate periods of time not represented by a rock record in North Dakota. The lack of rocks of these ages is due either to nondeposition or the removal by erosion of rocks that may once have been present. Less than half of geologic time since the beginning of the Cambrian is represented by a preserved rock section in North Dakota. The most complete record is found in the central part of the Williston Basin in western North Dakota. It should also be pointed out that, even during those periods of time for which rocks do exist today (times represented by the black bars), innumerable disconformities (short-lived periods of nondeposition) occurred that are not shown on the chart. Probably only a quarter to a third of geologic time is actually represented in North Dakota by the existing rock record.

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GEOLOGIC TIME IN NORTH DAKOTA

Introduction

The intent of this publication is to give North Dakotans a better concept of geologic time. I have attempted to show the immense amount of time it has taken for our state to become the place it is today. A series of time-flow charts (figs. 1 through 7) show events that have occurred throughout the earth's history. Each successive chart represents a tenth of the geologic time shown on the preceding chart. Thus, the first chart is a very general accounting of the events that occurred over the entire 15 billion-year history of the universe, the second chart amplifies and details the last 1.5 billion years on earth, etc. The final chart (fig. 7) zeros in on the last 15,000 years of North Dakota's history. Beyond that, geology becomes "transformed" into recorded history, a study I leave to archaeologists and historians. Incidentally, the concept of using successive time charts to show contemporaneous geologic events in various parts of the world is borrowed from similar methods sometimes used by historians.

North Dakota's climatic and vegetative history during and since the Ice Age, especially since the most recent glacial epoch, the Wisconsinan glaciation, is of particular interest to many people and this is treated in a little more detail. (fig. 8).

The Length of Geologic Time

Geologists, like historians dealing with the development of civilization, need some method of relating important events to one another. Unlike the historian, however, the geologist thinks in terms of millions of years, not years or centuries. Time is a fundamental consideration in all geological research, but it is difficult for many people to comprehend the immensity of geologic time.

Early speculations about the nature of the earth inspired much of the lore and legend of ancient civilizations. At times, ancient people had considerable insight. The Greek historian, Herodotus, in the fifth century B.C., made one of the earliest recorded geological observations. After finding fossil shells far inland in what are now parts of Egypt and Libya, he correctly inferred that the Mediterranean Sea had once extended much farther to the south. Few people believed him, however, and his idea did not catch on. In the third century B.C., Eratosthenes depicted a spherical earth and even calculated its diameter and circumference, but the concept of a spherical earth was beyond the imagination of most men. Less than 500 years ago, sailors aboard the Santa Maria begged Columbus to turn back lest they sail off the earth's edge. Similar opinions and prejudices about the nature of the earth have waxed and waned down through the centuries; however, most people appear to have traditionally believed the earth to be quite young, that its age might be measured in terms of thousands of years, but certainly not in millions.

The evidence for an ancient earth is found in the rock record, the materials that form the earth's crust and surface. The rocks and sediments are not all the same age, or even nearly so, but, like the pages in a long and complicated history book, they record the earth-shaping events of the past; however, the record is incomplete. Many "pages" are missing and many others are tattered, torn, or difficult to decipher. Even so, enough of the record is preserved to allow geologists to determine that the earth is many millions of years old.

Two time scales are used to date geologic events and to measure the age of the earth: a relative time scale, based on the sequence of layering of the rocks and sediments; and an atomic time scale, based on the natural radioactivity of chemical elements in some of the rocks. The relative scale evolved along with the science of geology; the atomic scale is a recent development borrowed from physicists and chemists and applied to geologic problems.

At the close of the eighteenth century, the haze of fantasy and mysticism that tended to obscure the true nature of the earth was being swept away. Careful studies by geologists showed that rocks have diverse origins. Some rock layers, containing clearly identifiable fossil remains of fish and other forms of aquatic animal and plant life, originally formed in seawater. Other layers, consisting of sand grains winnowed clean by the pounding surf, formed as beach deposits that marked the shorelines of ancient seas. Some layers are in the form of sand bars and gravel bands, which consist of rock debris spread over the land by streams. Some rocks were once lava flows, or beds of cinders and ash thrown out of ancient volcanoes; others are portions of large masses of once-molten rock that cooled very slowly beneath the earth's surface. Still other rocks were so transformed by heat and pressure during the heaving and buckling of the earth's crust in periods of mountain building that their original features are obliterated. Some sediments were deposited by glaciers, like those that once flowed over North Dakota, or by the lakes and streams that formed from the melting ice.

From the results of studies on the origins of the various kinds of rocks (petrology), coupled with studies of rock layering (stratigraphy), and the evolution of life (paleontology), geologists reconstruct the sequence of events that have shaped the earth's surface. Their studies show, for example, that during a particular episode, the land surface was raised in one part of the world to form high plateaus and mountain ranges. Following the uplift of the land, the forces of erosion attacked the highlands and the eroded rock debris was transported and redeposited in the lowlands. During the same interval of time in another part of the world, the land surface subsided and was covered by the seas. With the sinking of the land surface, sediments were deposited on the ocean floor. In this way, sand, silt, and clay eroded from areas like the North Dakota badlands by the Little Missouri River were carried by the Little Missouri, Missouri, and Mississippi Rivers to the Gulf of Mexico, which has subsided to receive the sediments. The evidence for the existence of ancient mountain ranges lies in the nature of the eroded rock debris, and the evidence of the sea includes fossils that accumulated with the sea-bottom sediments.

The discovery of the natural radioactive decay of uranium in 1896 by Henry Becquerel, the French physicist, opened new vistas in many fields of science. In 1905, the British physicist, Lord Rutherford, after defining the structure of the atom, made the first clear suggestion for using radioactivity as a tool for measuring geologic time directly. Shortly thereafter, in 1907, Professor B. B. Boltwood, radiochemist at Yale University, published a list of geologic ages based on radioactivity. Although Boltwood's ages have since been revised, they did show correctly that the duration of geologic time would have to be measured in terms of millions, not thousands of years.

The next 40 years was a period of expanding research on the nature and behavior of atoms, leading to the development of nuclear fission and fusion as energy sources. A by-product of this atomic research has been the development and continuing refinement of the various methods and techniques used to measure the age of the earth materials. The most precise dates have become available since 1950.

A chemical element consists of atoms with a specific number of protons in their nuclei, but different atomic weights, owing to variations in the number of neutrons. Atoms of the same element with differing atomic weights are called isotopes. Radioactive decay is a spontaneous process in which an isotope (the parent) loses particles from its nucleus to form an isotope of a new element (the daughter). The rate of decay is conveniently expressed in terms of an isotope's half-life, or the time it takes for one-half of the nuclei in a sample to decay. Most radioactive isotopes have rapid rates of decay (that is, short half-lives) and lose their radioactivity within a few days or years. Some isotopes, however, decay slowly, and several of these can be used as atomic clocks.

Dating rocks by using these radioactive timekeepers is simple in theory, but the laboratory procedures are complex. The numbers of parent and daughter isotopes in each specimen are determined by various kinds of analytical methods. The principal difficulty lies in precisely measuring extremely tiny amounts of isotopes.

At the present time, the potassium-argon method is one of the most useful dating methods available to the geologist because it can be used on rocks as young as a few thousand years as well as on the oldest rocks known. Potassium is found in most rock-forming minerals. The half-life of its radioactive isotope, potassium-40, is such that measurable quantities of argon (daughter) have accumulated in potassium-bearing minerals of nearly all ages. The amounts of potassium and argon isotopes can be measured accurately, even in very small quantities. Where feasible, two or more methods of analysis are used on the same specimen or rock to confirm or verify the results.

Another important atomic clock used for dating purposes is based on the radioactive decay of the isotope carbon-14, which has a half-life of 5,730 years. Carbon-14 is being produced continuously in the earth's upper atmosphere as a result of nitrogen-14 isotopes being struck by neutrons that have their origin in cosmic rays. This newly formed radioactive carbon becomes uniformly mixed with the nonradioactive carbon in the carbon dioxide of the air, and it eventually finds its way into all living plants and animals. In effect, all carbon in living organisms contains a constant proportion of radioactive or carbon-14. After the death of the organism, the amount of radioactive carbon gradually decreases through radioactive decay as it reverts to nitrogen-14. By measuring the amount of radioactivity remaining in organic materials, the amount of carbon-14 in the materials can be calculated and the time of the organism's death can be determined. For example, if carbon from a sample of wood is found to contain only half as much carbon-14 as that from a living plant, the estimated age of the old wood would be 5,730 years; if it contained a fourth as much, the age would be 11,460 years.

The radiocarbon clock has become an extremely useful tool in dating the important episodes in the recent prehistory and history of man but, due to the relatively short half-life of carbon-14, the clock can be used for dating events that have taken place only within about the past 50,000 years.

Some of the oldest known rocks found in North America are in southwestern Minnesota. The Morton Gneiss appears to have formed about 3½ billion years ago. Other rocks with similar ages occur in South Africa, Finland, and Australia. Estimates of the age of the earth are based on the decay rates of radioactive isotopes. One such estimate is based on two long-lived isotopes, uranium-238 and uranium-235. It places the maximum age of the chemical elements that make up the earth at about 6 billion years. The reasoning behind this estimate involves theoretical concepts about the origin of uranium, which stipulate that not more than half of the first-formed uranium consisted of the uranium-235 isotope. But, because of the changes in isotopic composition that have taken place throughout geologic time as a result of radioactive decay, uranium today contains only about 0.7 percent of the uranium-235 isotope. Calculations based on the known decay rates for these two isotopes indicate that a span of about 6 billion years is required for the isotopic composition of uranium to have changed from 50 percent to 0.7 percent uranium-235. Had uranium originally consisted of more than half of the uranium-235 isotope, the calculated age of uranium would exceed 6 billion years.

Another estimate of the earth's age is based on the progressive build-up in the earth's crust of lead isotopes that have been derived from radioactive decay of uranium-238, uranium-235, and thorium-232. Studies of the relative abundance of these radiogenic leads suggest that the earth is not older than 5.5 billion years.

Finally, it is interesting to try to visualize just what 4 or 5 billion years really means. Suppose that the earth is 5 billion years old and then suppose that all of those 5 billion years could be compressed into a single imaginary year. At that scale, each second of our contemporary time would be equivalent to 160 years of geologic time, each day to 14 million years. Using this time scale, dinosaurs did not come on the scene until mid-December, and then they lasted six days. The Ice Age began in North Dakota at about 6:45 p.m. on December 31 and ended only one minute before midnight. Primitive man arrived on earth between 10 and 10:30 p.m. in the midst of the Ice Age. At 13 seconds before midnight, Christ was born, and at 6 seconds, Bjarni Herjolfsson discovered America.* The United States of America, now over two centuries old, has existed for less than two geologic seconds.

NOTES

*At the risk of starting an Italian/Scandinavian feud, I will point out that Bjarni Herjolfsson (a Viking) discovered (but did not land on) the North American continent in the year 985 or 986. He told Leif Ericson about it, and Ericson was the first European to set foot in North America. In 1492, Christopher Columbus discovered the West Indian Islands, and in 1499 he was the first person to land in South America (if Amerigo Vespucci didn't get there first, perhaps in 1498 or 1499). John Cabot discovered North America in 1497. Assorted Welshmen and Phoenicians have also been credited with the European discovery of the New World, but these are not documented.

Clovis Man (and woman) entered Alaska from Asia sometime during the Wisconsinan Epoch (earlier than 12,000 years ago) at a time when the Bering Strait was a land bridge due to the lowered sea level resulting from glaciation. Clovis Man migrated southward into North Dakota about 11,700 years ago, as soon as the glacier receded away from the Rocky Mountain front, allowing easy passage southward. These people were the ancestors of the Native American population that lived throughout the Americas when Europeans arrived much later.

Figures 1 through 8

The Time Charts

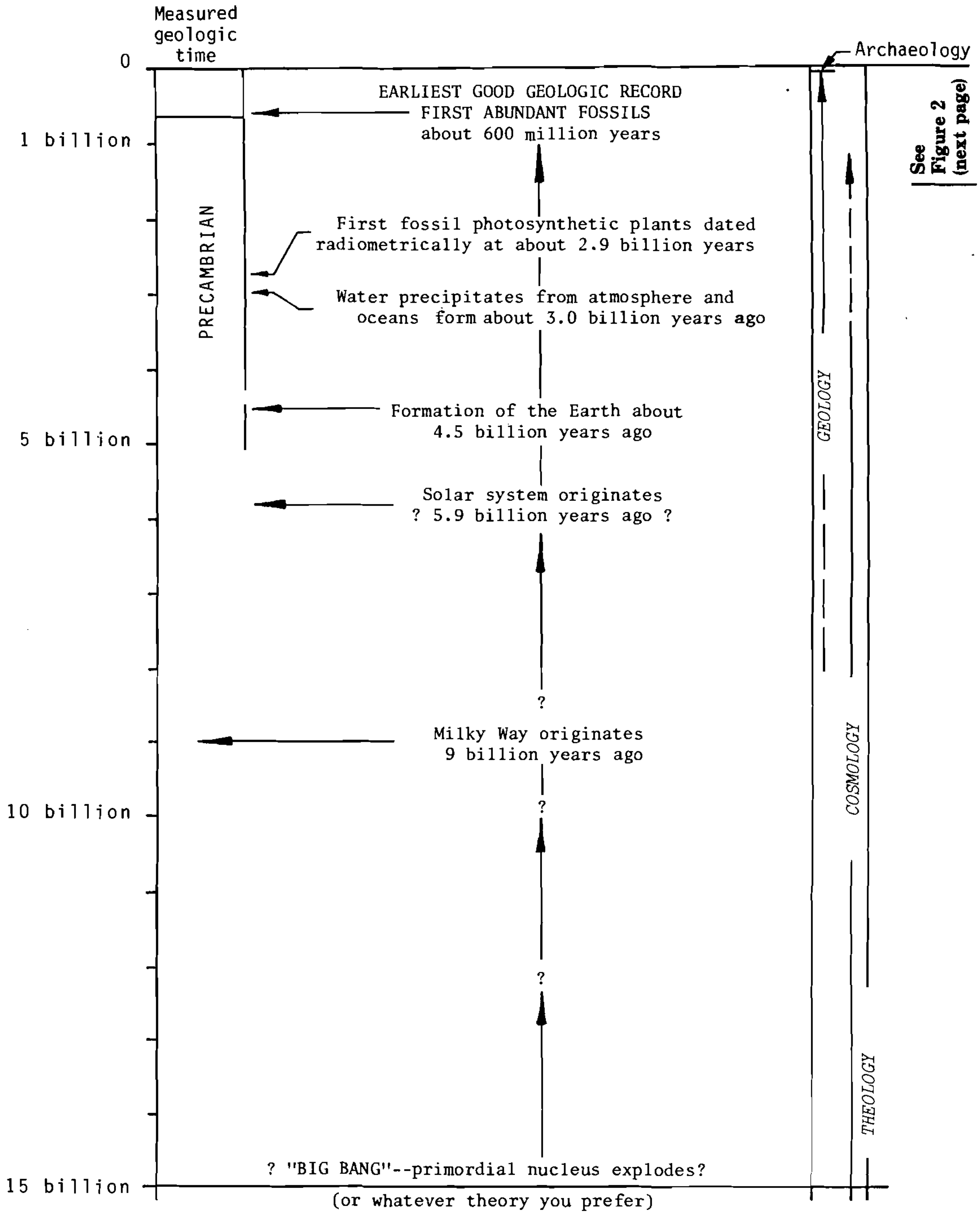

Figure 1. The past 15 billion years in North Dakota and the world.

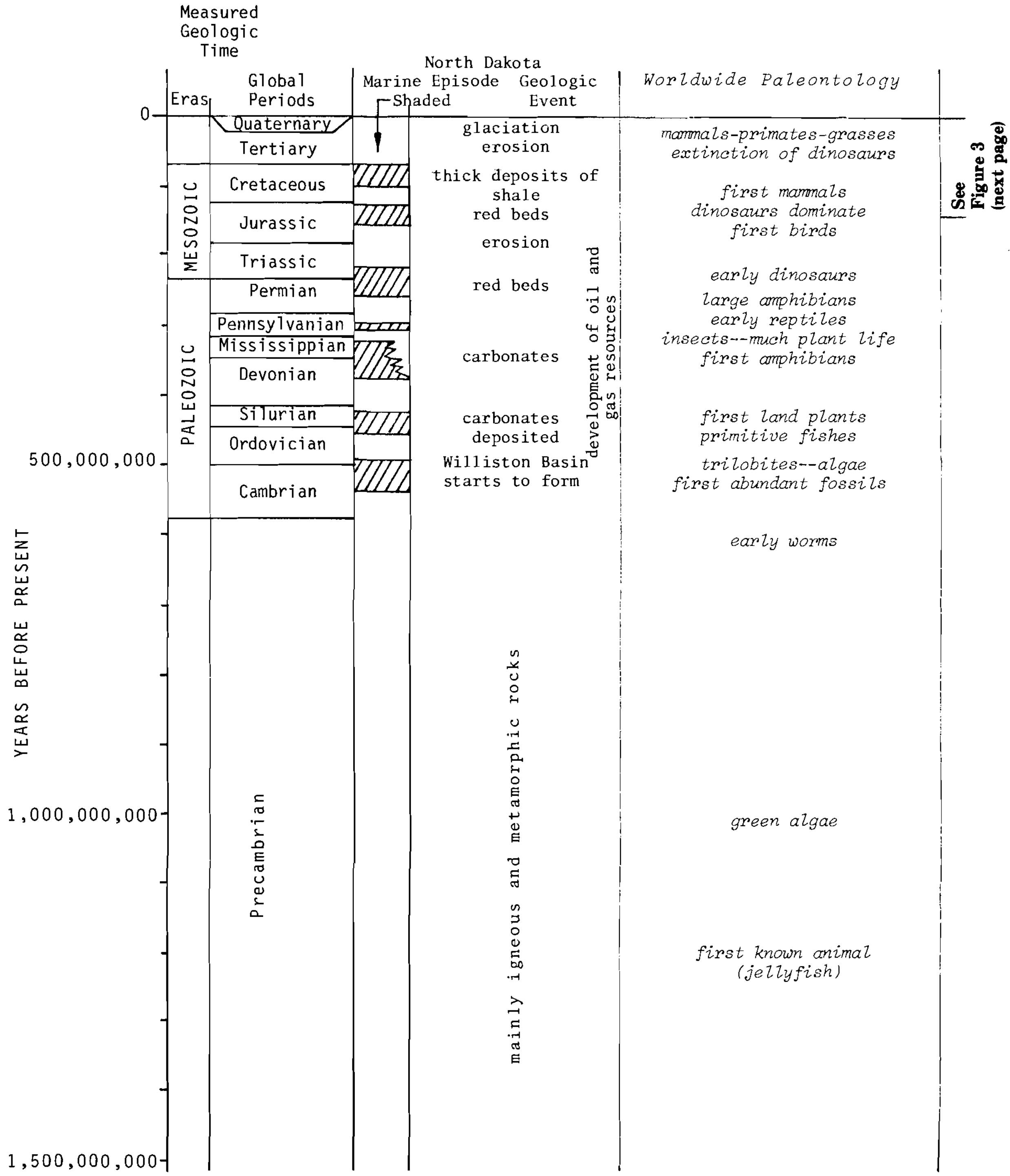

Figure 2. The past 1.5 billion years in North Dakota and the world.

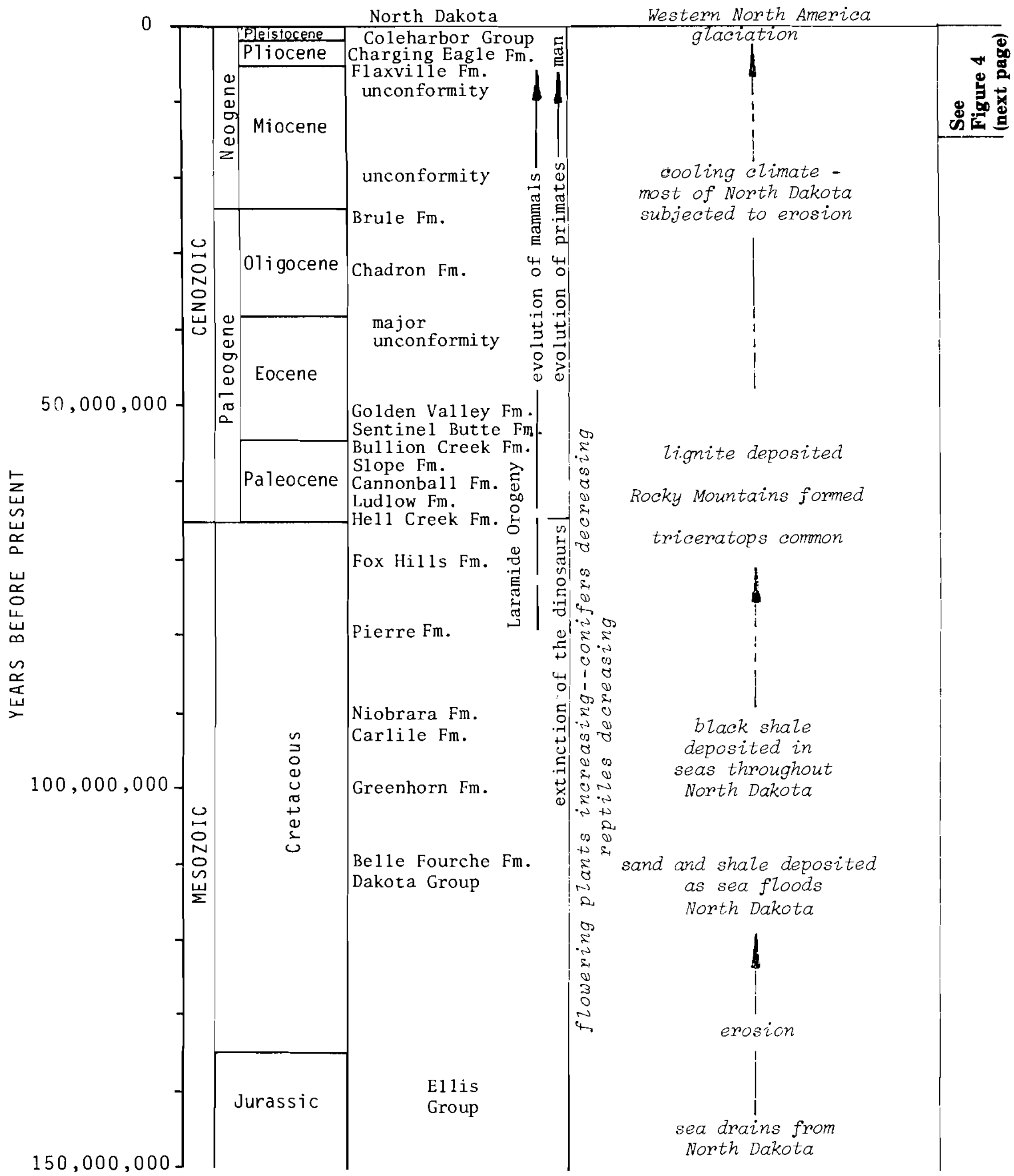

Figure 3. The past 150 million years in North Dakota and the world.

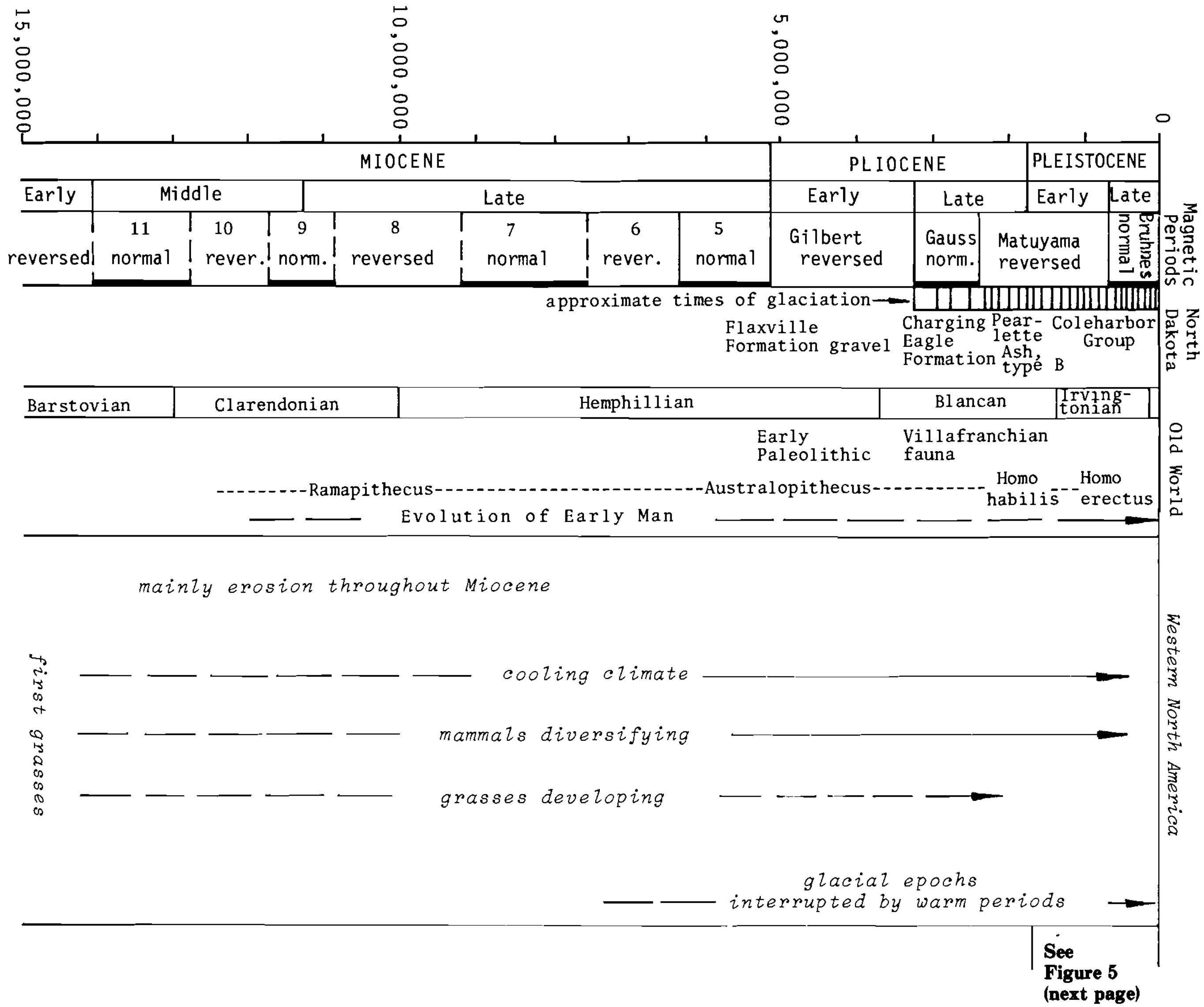

Figure 4. The past 15 million years in North Dakota and the world.

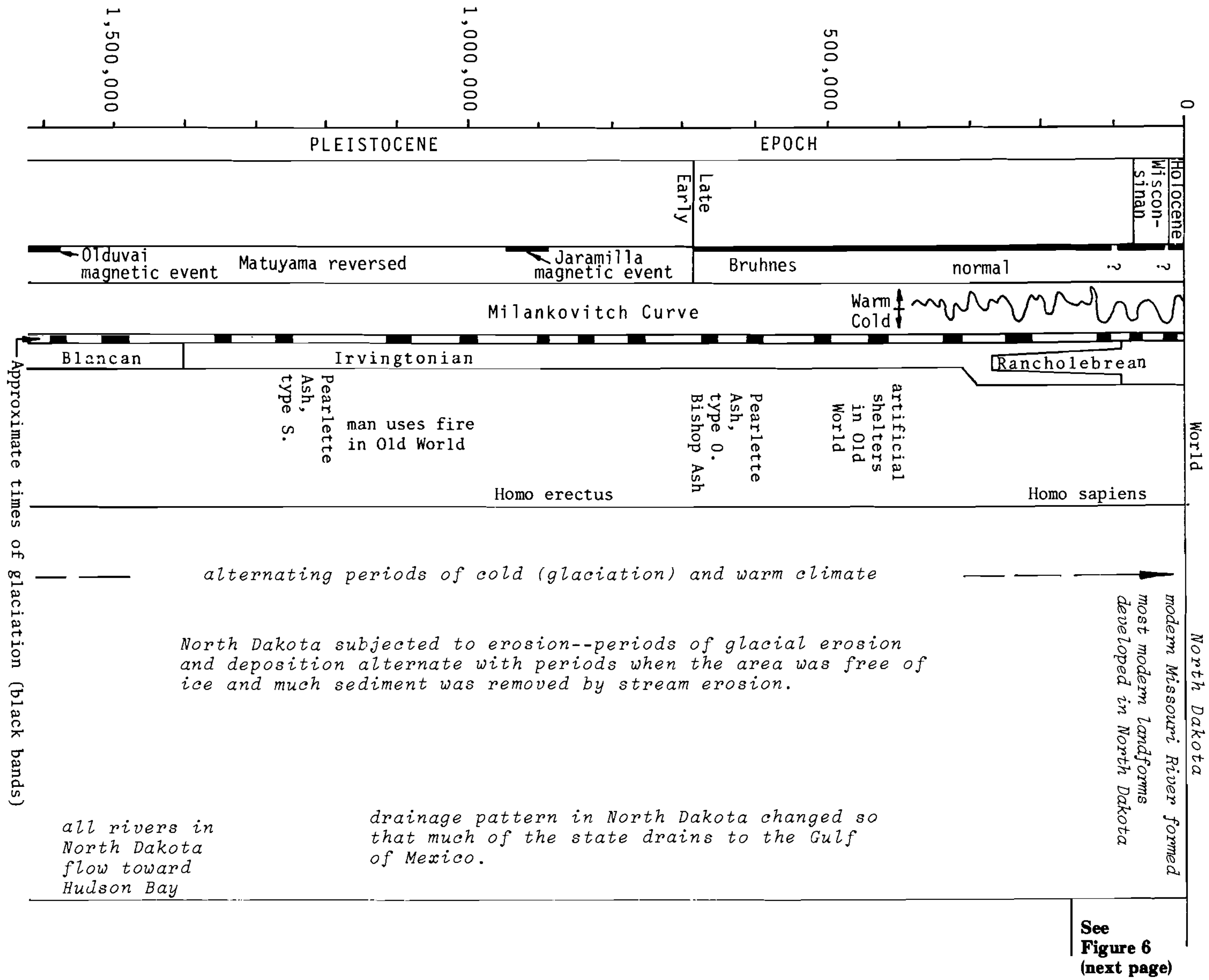

Figure 5. The past 1.5 million years in North Dakota and the world.

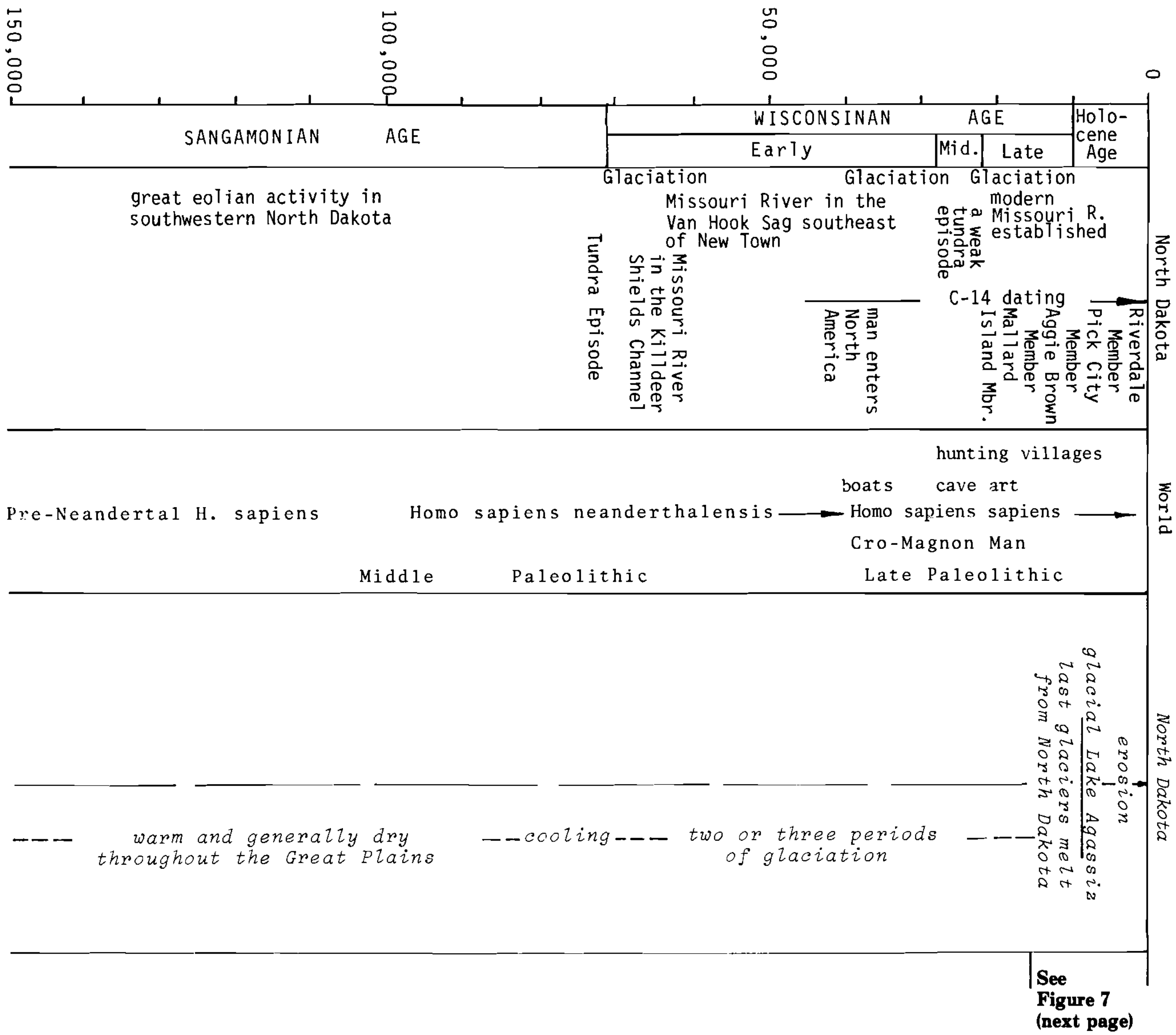

Figure 6. The past 150 thousand years in North Dakota and the world.

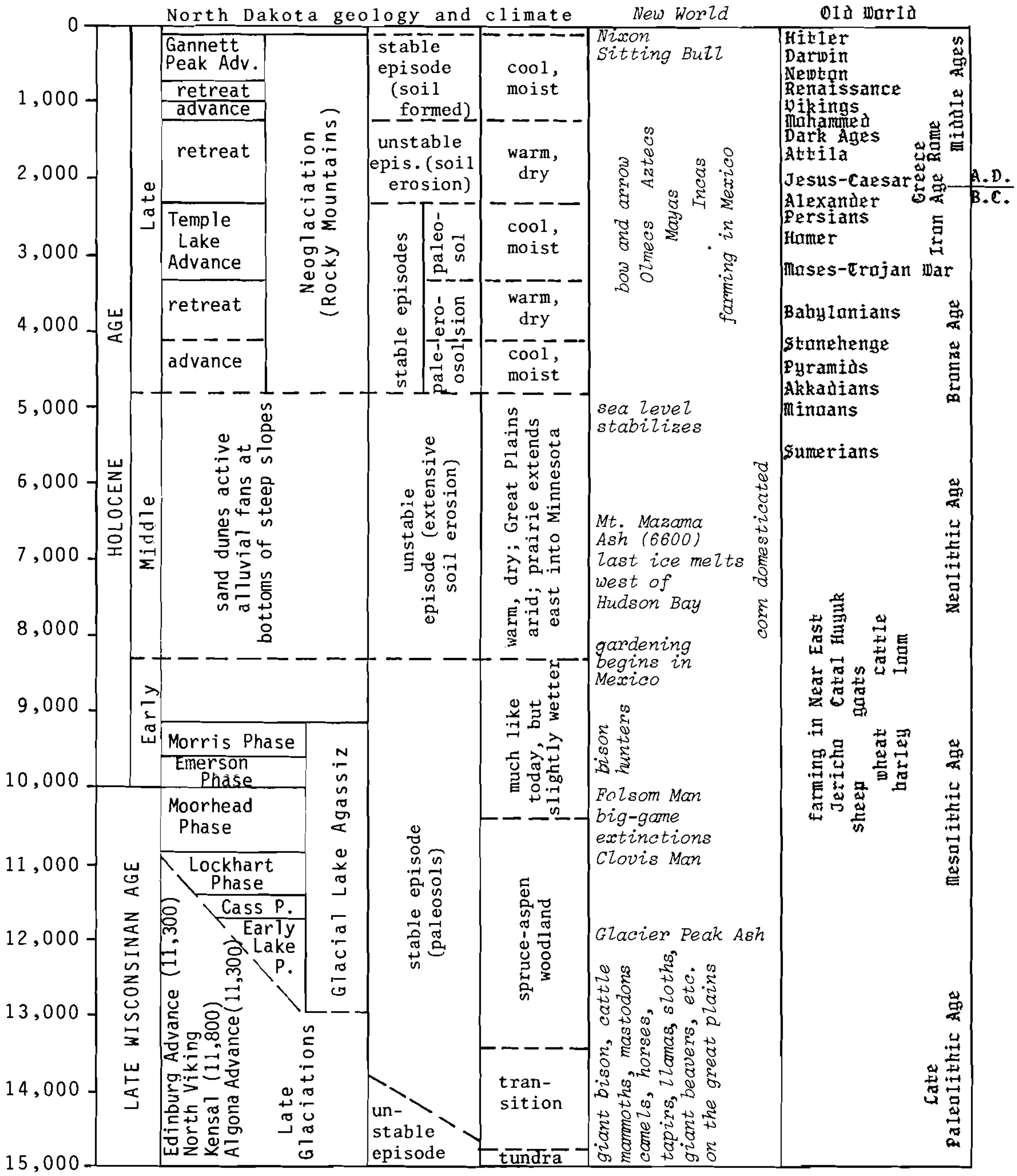

Figure 7. The past 15 thousand years in North Dakota and the world.

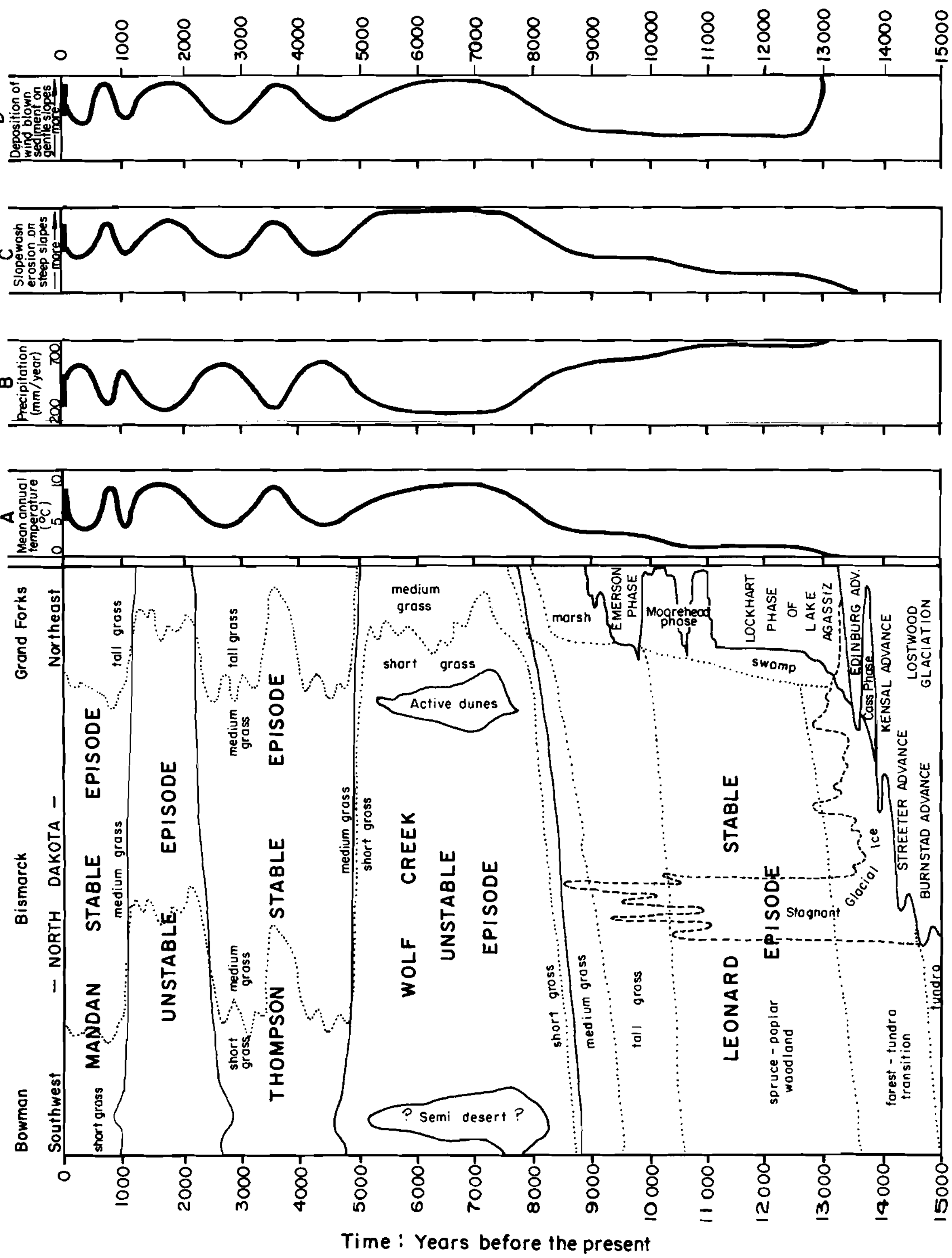

Figure 8. North Dakota's climatic history for the last 15,000 years. This is a time-distance diagram, time represented in a vertical direction, and distance, from southwestern to northeastern North Dakota, shown from left to right. The diagram illustrates when certain climatic events occurred in various parts of the state. For example, as conditions dried about 9,000 years ago, short-grass prairie first covered southwestern North Dakota (about 8,700 years ago) and advanced northeastward, although not into the easternmost part of the state, before giving way to medium-grass prairie over most of the state about 5,000 years ago as the climate again became more moist.

The Lockhart, Moorhead, and Emerson Phases, shown in eastern North Dakota between about 13,000 and 9,500 years ago, portray the history of Lake Agassiz. The Burnstad advance, and other advances, represent glacial advances of the last glacier that affected North Dakota. The "stagnant glacial ice" occurred mainly on the Missouri Coteau between about 14,000 and 9,000 years ago (it also was widespread over the Turtle Mountains and Prairie Coteau in southeastern North Dakota).

The four columns on the right (A, B, C, and D) represent, in a general sort of way, how various specific conditions changed over the past 15,000 years. Column A shows how the mean annual temperature varied; B shows how precipitation varied; C shows the relative amount of slope-wash erosion from the hillslopes; and D shows the amount of wind-blown sediment being deposited on gentle slopes and in low areas. In all four columns, the increasing amount is to the right, decreasing amount is to the left.

Most of what we know about past climatic conditions (fig. 8) we have learned from studies of pollen, and more recently, beetle assemblages, found in the sediments of lakes and bogs. Particularly valuable research is currently being done along these lines at the Fossil Beetle Laboratory at North Dakota State University in Fargo.

The first three points are based on studies made beyond the limit of the glaciation in central Iowa:

1. Throughout Wisconsinan time: (70,000 to 10,000 years ago)

   Summers were generally more cool and moist over the midcontinent region than they are today; during much of this time, most of North Dakota, except for the southwest corner, was glaciated.

2. During Late Wisconsinan time: (25,000 to 10,000 years ago)

   The coldest conditions occurred about 17,000 years ago--at that time, central Iowa (at the edge of the glacier that covered North Dakota) had summer temperatures comparable to those at the treeline in Canada today, (a mean July temperature of about 10°C, compared to the 23°C of today (50°F vs. 73°F). North Dakota was heavily glaciated at that time and it is not known what the average temperature was here--certainly considerably colder than Iowa at that time.

3. By 13,000 years ago, summer temperatures in North Dakota had warmed by several degrees and they were comparable to those in the mid-Boreal Forest today. North Dakota was being deglaciated so we may assume that the average annual temperature was above freezing; however, changes in both annual temperature and annual precipitation have to be considered in determining when and at what rate deglaciation occurred.

The remaining points are based on studies made in bogs and sloughs in North Dakota, northern Minnesota, and Manitoba:

4. From 13,000 until 9,000 years ago, summer temperatures warmed slightly to those at the southern edge of the Boreal Forest today (fig. 8). The warming may have occurred gradually, or it may have been in steps--we don't know which. North Dakota became wooded as the ice melted away (mainly spruce-poplar woodland).

5. About 10,000 or 9,500 years ago, conditions became much drier (fig. 8) so that prairie grassland replaced much of the woodland in North Dakota, first in the west, then farther east. Temperatures also warmed.

6. Warming and drying continued, reaching a maximum between about 7,000 and 5,000 years ago (the time known as "hypsithermal" or "altithermal"). At that time, North Dakota was considerably drier and warmer than it is today (fig. 8).

7. Since about 3,500 years ago, the climatic patterns have been similar to today, although variations that may last for several hundred years at a time do occur.

GLOSSARY

Geologic Time Terminology

Precambrian: mainly complex metamorphic and igneous rock that makes up most of the volume of the earth's crust; very few fossils; Precambrian time makes up about 90% of geologic time.

Paleozoic Era: "ancient life"

Cambrian: a Latin word meaning "Wales"

Ordovician: a word derived from "Ordovices," an ancient tribe of Wales

Silurian: a word derived from "Silures," a tribe of Wales

Carboniferous: "coal-bearing"; in the United States:

"Pennsylvanian" (from the state of Pennsylvania where coal of this age is mined) and "Mississippian" from the upper Mississippi Valley (Iowa-Missouri-Illinois)

Permian: a word referring to rocks exposed over much of the province of Perm, Russia, just west of the Ural Mountains

Mesozoic Era: "middle life"

Triassic: a term that refers to the three-fold division of rocks overlying the Paleozoic rocks in Germany

Jurassic: refers to rocks of that age outcropping in the Jura Mountains in Germany

Cretaceous: a Latin word meaning "chalk"; refers to the chalk formations in France and England

Cenozoic Era: "recent life"

Tertiary: an old term held over from early attempts to subdivide the geologic record into three divisions ("Primary," "Secondary," and "Tertiary"); the first two terms have been discontinued.

Quaternary: refers to the very recent deposits that contain fossils which contain living representatives

We also use seven epochs, subdivisions of Tertiary and Quaternary time; they are based on the relationships between life forms:

Paleocene: "ancient recent"
Eocene: "dawn of recent"
Oligocene: "little recent"
Miocene: "less recent"
Pliocene: "more recent"
Pleistocene: "most recent"
Holocene: "recent"

Explanation of Some of the Terms Used on the Time-Flow Charts

Magnetic polarity. Recent studies of the magnetic properties of numerous samples of basalt from many parts of the world demonstrate that the earth's magnetic field has been reversed many times during the last 70 to 80 million years. That is, there have been periods of 1 to 3 million years during which the magnetic poles have been close to their present location, followed by similar periods during which the north and south poles have been reversed. At least nine reversals have occurred in the last 4.5 million years. The present period of "normal" (Bruhnes normal on figures 4 and 5) polarity began about 700,000 years ago and was preceded by a period of reversed polarity (the Matuyama reversed on figures 4 and 5) beginning 2.5 million years ago (two short periods of normal polarity occurred within the Matuyama reversed period). The major intervals of alternating polarity (about a million years apart) are termed polarity epochs, and intervals of shorter duration are termed polarity events. In short, the north and south poles remain in about their present positions during the reversals, but their polarity is reversed. The reversal seems to take place quite rapidly, over a period of only a few thousand years. Incidentally, the reversals have been especially interesting to paleontologists because the magnetic field is eliminated during each reversal, permitting increased cosmic radiation to reach earth. This increased radiation may cause spurts of evolution.

Milankovitch curve. Originally proposed by the Yugoslav scientist, M. Milankovitch, the Milankovitch curve is based on the premise that both the orbit and axial rotation of the earth vary through geologic time in a systematic way. The variations result in changes in the seasonal and latitudinal disturbances of the earth's insolation (the way it holds and reflects the heat it receives from the sun). The Milankovitch curve considers three main factors: 1) variations in the eccentricity of the earth's orbit through time--the period is 96,000 years and it results in about a 25% difference in the earth's heat-reflecting ability; 2) the "precession of the equinoxes"--the period is 21,000 years; today the earth is nearest the sun in January; in 10,000 years it will be nearest in June; 3) the oblicity of the ecliptic or the angle of the earth's orbit--the period is 41,000 years; the angle is 23.5° and the variation is about 2.5° but there is evidence that in early Tertiary time the angle was close to 0°. (The angle we are measuring is the inclination of the earth's axis to the orbital plane).

Milankovitch took all of these factors into account and constructed a curve to show how the earth's climate may have varied through geologic time. Presumably, if all three factors tended toward warming at the same time, then the overall effect would be marked warming. Most geologists accept the validity of the Milankovitch curve, but there is considerable disagreement about how important it is, what it really means, and whether all the necessary factors are included and their relative importance.

Terms used on Figures 3 and others

Formation. Geologic formations are the basic rock-stratigraphic units. They consist of a body of rock of sediment (limestone, shale, sandstone, sand, etc.) that has a certain amount of internal lithologic homogeniety or other distinctive characteristic or characteristics. For example, the Pierre Formation is mainly shale; the Red River Formation is carbonate rock. Generally, a formation has lateral continuity and covers a broad area.

Terms used on Figures 3 and others

Group. Groups, like formations, are rock stratigraphic units, but they consist of two or more formations that are in some way related to one another. For example, the Coleharbor Group consists of several similar formations, all of which are composed of glacier and glacier-related deposits.

Unconformity. A break or gap in the geologic record where a rock unit is overlain by another that is not next in stratigraphic succession is an unconformity. Most important unconformities represent an interruption in depositional continuity that spans a considerable length of time. Generally, the rocks below an unconformity are considerably older than those above and they have been eroded during the time when deposition was not taking place. North Dakota is currently undergoing erosion--deposition of sediment is only minor and is restricted to a few ponds, lakes, and streams--and therefore it can be said that we are now experiencing a time of unconformity.

Terms used on Figures 4 and 5

Rancholebrean, Irvingtonian, etc. Southern California mammal zones. The Rancholebrean zone is of upper Pleistocene (Wisconsinan) age and began about 80,000 to 100,000 years ago. It is probably best known for the tar pits that trapped a great variety of animals, including sabre-tooth tigers, dire wolves, etc. Other, older mammal zones shown on figure 4, are the Irvingtonian (also southern California), Barstovian, Clarendonian, Hemphillian, and Blancan. Older mammal zones are not included on the charts.

Terms used on Figures 4, 5, and 6

Pearlette Ash, Bishop Ash, Glacier Peak Ash, Mt. Mazama Ash. Volcanic ash falls are important because they help geologists to precisely correlate the ages of geologic events over wide areas. Thus, when Mt. Mazama erupted 6,600 years ago, the explosion formed a crater now flooded by Crater Lake in Oregon and the volcanic ash from the eruption fell over much of North America. The ash is of a specific chemical composition and, wherever it is identified, it is possible to say with certainty that the rock or sediment it is found in is 6,600 years old, thereby establishing regional age correlations.