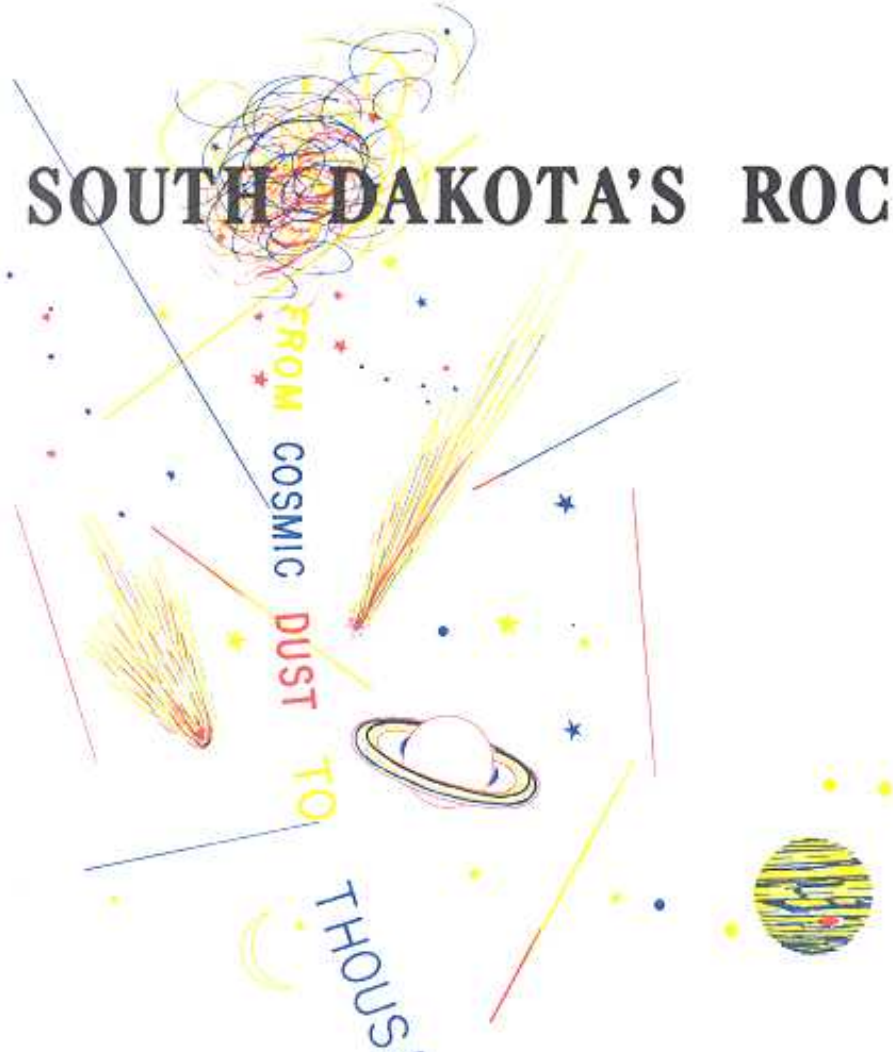
SOUTH DAKOTA'S ROCK HISTORY



BY
BRUNO C. PETSCH
&
DUNCAN J. MC GREGOR

EDUCATIONAL SERIES 3

SOUTH DAKOTA'S ROCK HISTORY

ERRATA SHEET

Page

iii Change **mantel** to **mantle.**

3 Line 10, change **ions** to **atoms.**

5 First paragraph, line 3, change **ejects** to **ejecta.**

8 First paragraph, line 1, delete the letter **a** before **2000.** Second paragraph, line 1, delete **If** (first word) and capitalize **O** on word **one.** Insert word **that** after word **eddies.**

14 Change word **mantel** on this page to **mantle.**

15 Line 4, change **gabro** to **gabbro.**

16 Third paragraph, line 11, insert word **to** before word **tan.**

17 Change **Pierrie** to **Pierre** in illustration. Paragraph 3, line 4, change **is** to **are.**

19 Change **Bell** to **Belle** in illustration (Belle Fourche Shale).

20 Fourth paragraph, line 2, change **metamorphose** to **metamorphosed.**

21 Opposite Pennsylvanian, change **Kibby** to **Kibbey.**

24 Second paragraph, change **Pennslyvanian** to **Pennsylvanian.**

25 First paragraph, line 2, change **rich** to **red.** Fourth paragraph, line 3, change **grapolites** to **graptolites** and change **tralobites** to **trilobites.**

27 First paragraph, line 5, change **are** to **is.** Fourth paragraph, line 3, add word **upon** after word **encroached.**

34 In first illustration change **pegmtite** to **pegmatite.** Change **deposite** to **deposit** (under first illustration).

37 First paragraph, line 4, change word **million** to **thousand.** Third paragraph, line 2 delete sentence beginning **"However, only deposits..."** and insert sentence reading as follows: **"Deposits left by the four ice advances are recognizable in South Dakota."**

38 Second paragraph, line 10, delete phrase **by radioactivity** and add word **from.**

PREFACE

Although much has been written about the geology of South Dakota few works are available to which readers not skilled in geology can turn for some general account of rocks and their origin. Possibly this present attempt to help correct this deficiency will not be wholly unacceptable.

This booklet is written particularly for the non-specialist interested in geology. Thus technical terminology is used as sparingly as possible.

The material used in the preparation of this booklet has come in the main from the great stock of common geologic knowledge. Therefore the reader is not burdened with numerous reference citations.

The paleogeographic maps were modified and redrawn using as a reference source the work of Charles Schuchert and Carl Dunbar, *Historical Geology*, published by John Wiley and Sons in 1933. The picture on page 24 and the drawing on pages 33 and 34 were taken from the geologic atlas of the United States, Folio No. 219, entitled *Central Black Hills*, written by N. H. Darton and Sidney Paige, published by the United States Geological Survey in 1925. The picure on page 36 was donated by the Museum of Geology, South Dakota School of Mines and Technology, Rapid City.

CONTENTS

Pages of the Past

And Nature, the old nurse, took
The Child upon her knee
Saying: "Here is a story book
Thy father has written for thee."

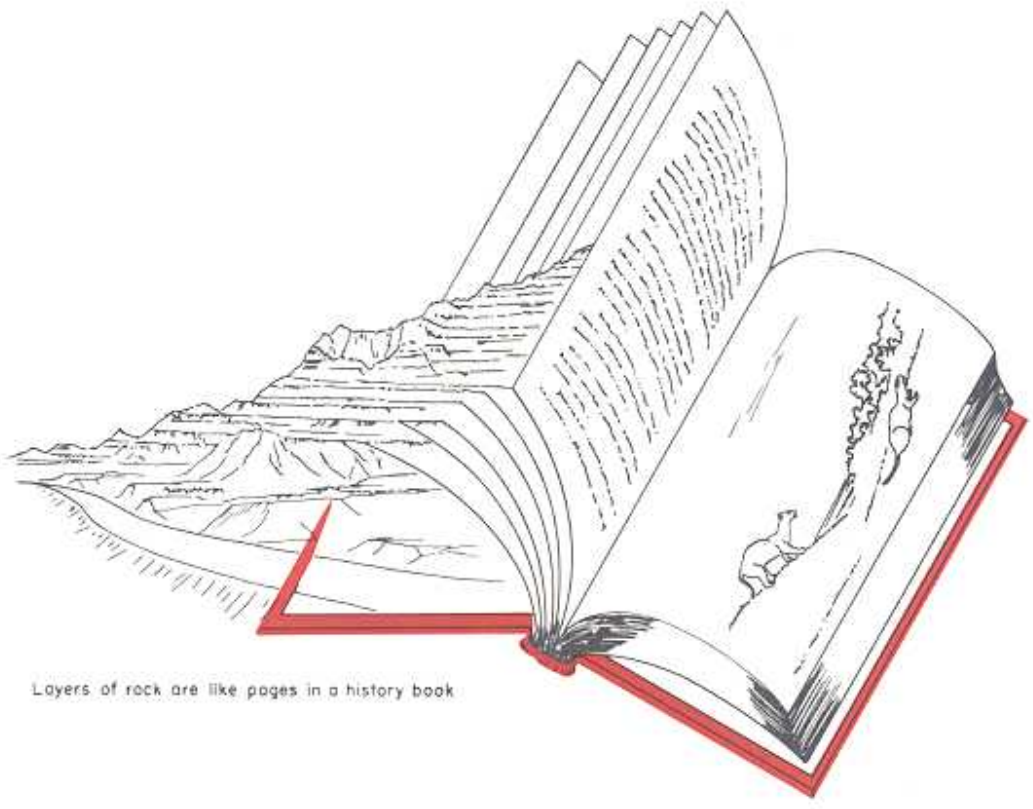
'Come wander with me,' she said,
'Into regions yet untrod;
And read what is still unread
In the manuscripts of God.'

And he wandered away and away
With Nature, the dear old nurse,
Who sang to him night and day
The rhymes of the Universe.

And whenever the way seemed long,
Or his heart began to fail,
She would sing a more wonderful song,
Or tell a more marvelous tale.

Henry Wadsworth Longfellow
"The Fifteenth Birthday of Agassiz"

Layers of rock are like the pages in a history book and like those pages,



Layers of rock are like pages in a history book

rock layers when put together in an orderly way reveal the history of the geologic past. Rock history is written in a language foreign to many people because the language used is that of fossils, rock fragments, mineral grains, cementing materials, color, and a variety of other rock features. For many generations geologists have studied rocks and out of their study of the contained extinct organisms and lifeless mineral matter, they have been able to translate meaningful messages. Man finds much that connects him with the earth whereon he treads, and through his mind's thoughts he has been able to write a fascinating story of earth history.

A knowledge of geologic history enables man to stand in his own backyard and see himself in the dimension of time. Suddenly he begins to appreciate the enormous amount of time it took to evolve the landscape that surrounds him.

For one to think in terms of the history of his own backyard may seem trite when compared to what he reads daily about the space-age accomplishments in piecing together the history of the universe. But lest one is mislead, let him be reminded that over one hundred years ago a renowned American geologist, James Dwight Dana, stated that a detailed knowledge of the history of the earth gives one an excellent background for deciphering the history of the entire universe.

No more fitting words can summarize the pages of the past than a part of William Wordsworth's poem, "The Excursion."

> He who with pocket-hammer smites the edge
> Of luckless rock or prominent stone, disguised
> In weather-stains or crusted o'er by Nature
> With her first growths, detaching by the stroke
> A chip or splinter, to resolve his doubts;
> And, with that ready answer satisfied,
> The substance classes by some barbarous name,
> And hurries on; or from the fragments picks
> His specimen, if but haply interveined
> With sparkling mineral, or should crystal cube
> Lurk in its cells, and thinks himself enriched,
> Wealthier, and doubtless wiser, than before!

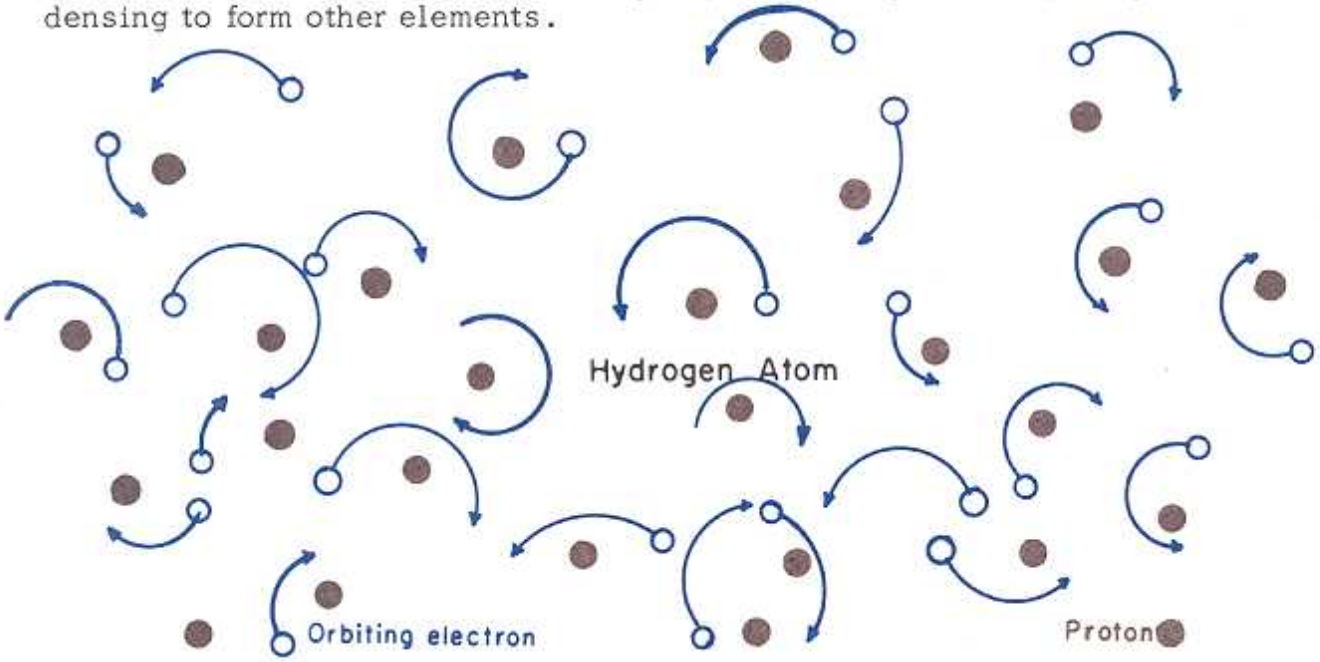
Certainly in reading the words of Wordsworth, rocks can tell us many romantic stories as one looks through the pages of the past.

In the Beginning

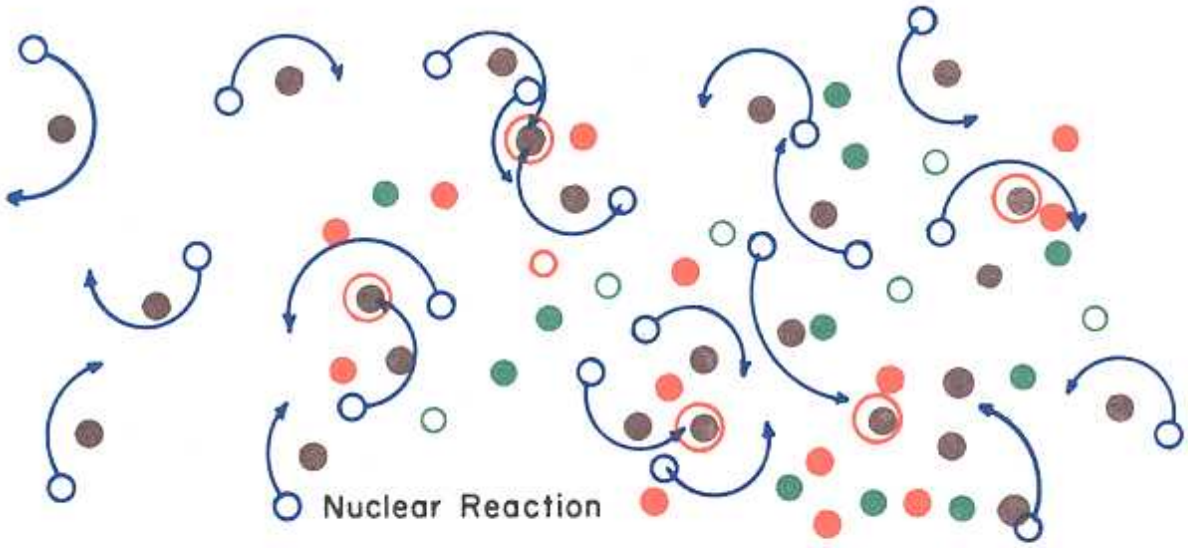
Story of Creation

> They say
> The solid earth whereon we tread
> In tracts of fluent heat began,
> And grew to seeming-random forms,
> The seeming prey of cyclic storms,
> Till at the last arose the man.
>
> Tennyson, "In Memoriam"

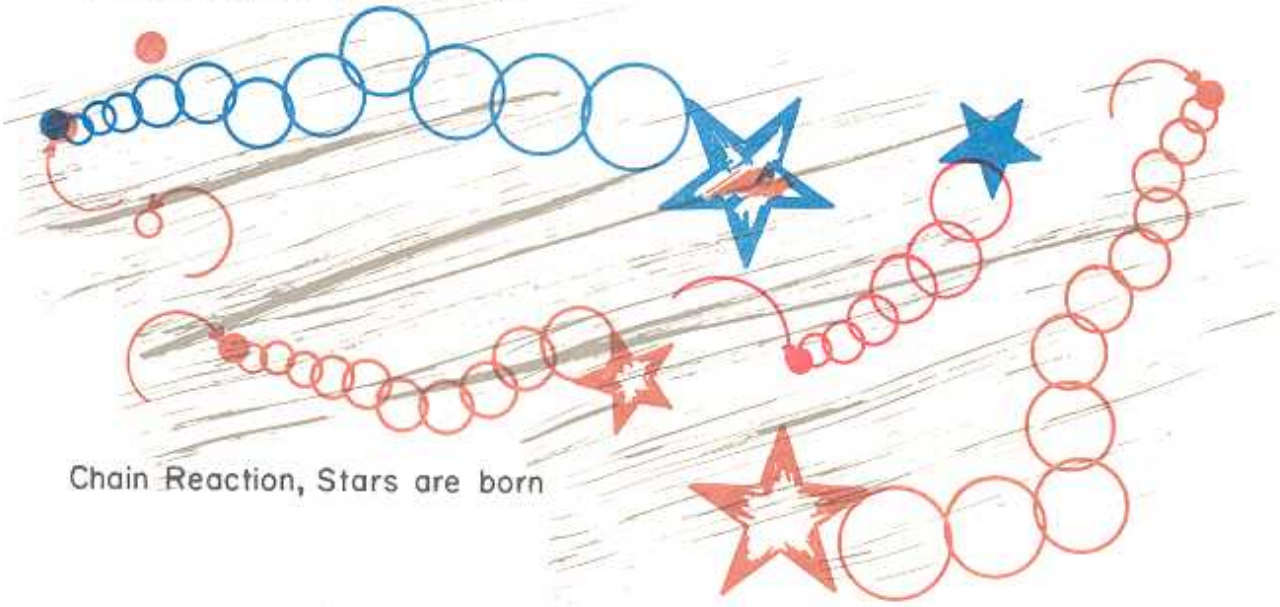
The material with which the earth was made is closely linked to the history of the universe. The first created elements in various mixtures formed the earth, planets, sun, and stars. The true beginnings, however, are cloaked in uncertainty, as even the early history of the observed universe presents problems which at present seem to be beyond the reach of the imagination. If, at the outset, one makes the assumption that at the dawn of time, the simplest element was hydrogen, each atom of which possessed a nuclear proton and an orbiting electron, and that hydrogen was in great abundance, then the astro or nuclear physicist can give a plausible account of how the many dispersed hydrogen ions may be changed by condensing to form other elements.



When the hydrogen atom encounters intense heat it may undergo a series of nuclear reactions, whereby the atoms of heavier and more complex elements are made.

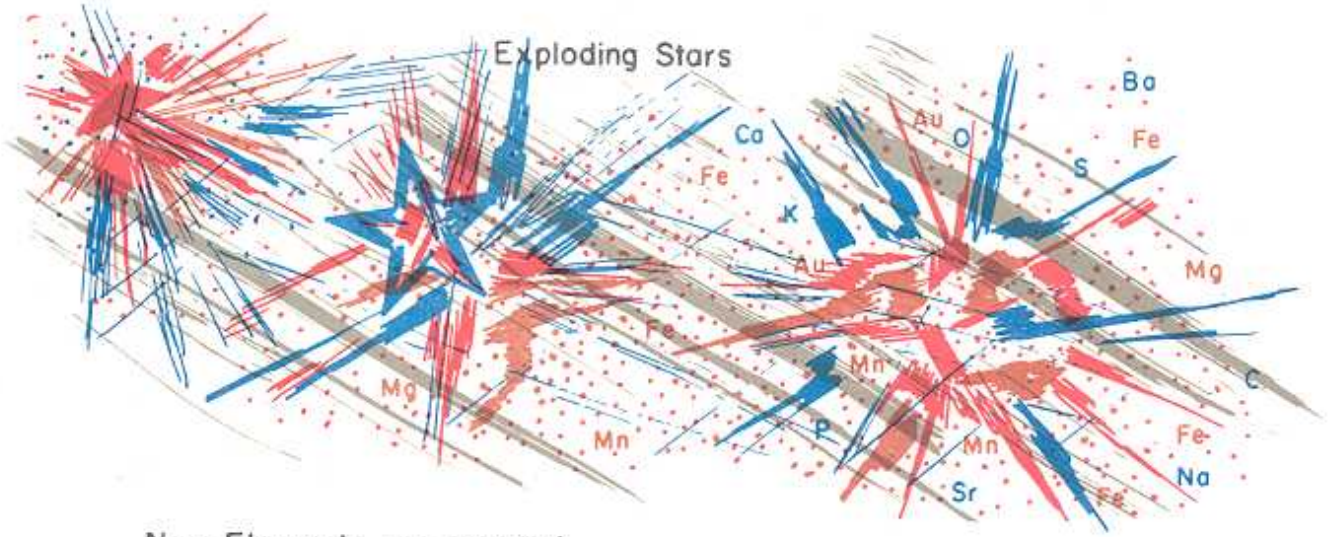


The heat required to cause that very first nuclear reaction may have come from the energy created by gravitational forces. The created heat is released when the mass of the hydrogen atoms are condensed. Once a nuclear reaction takes place, it triggers a chain reaction, whereby additional heat is made. Such nuclear reaction may be cyclic and therefore cause a substaining source of energy.



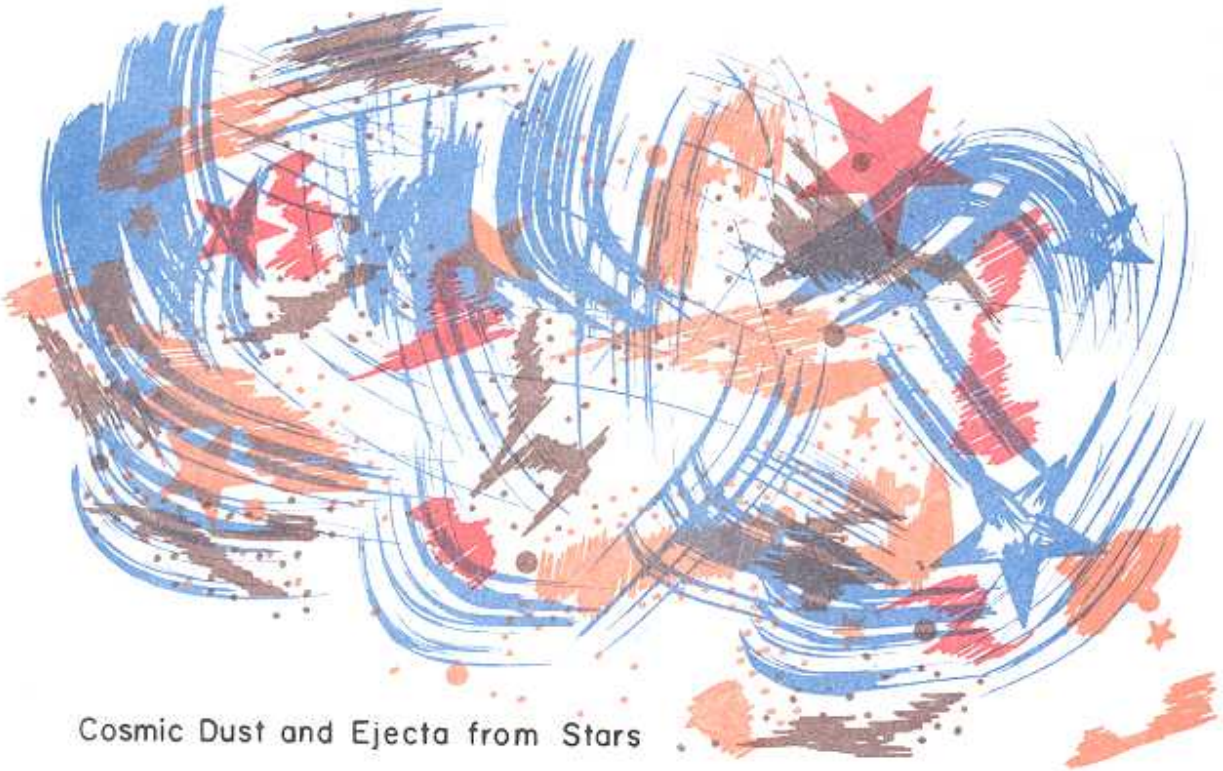
Chain Reaction, Stars are born

We can assume that the above takes place, and that in time a star is created, wherein nuclear reactions are still taking place in the hot interiors--and are happening in our present-day stars, including our sun--and furthermore we can assume that these reactions have been going on ever since a star came into existence. Although stars have been in existence for a long time, they are gradually undergoing change. Eventually a stage of instability is reached, because most of the nuclear fuel has been exhausted. When this unstable stage is reached, the star may explode and in the process, various heavy elements, before unknown, are produced in the star. It may well be that such continued processes of various stars going through the instability stage has created all the elements that we now know in the universe.



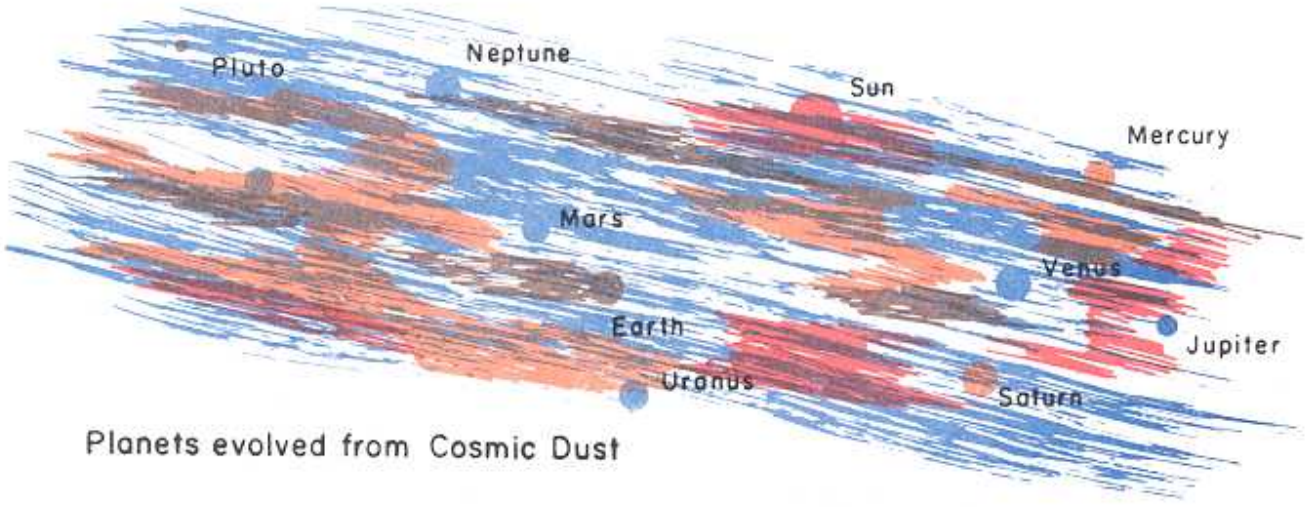
New Elements are created

Astronomers are fairly certain that stars eject part of their substance into outer space, either by an outright explosion or through conditions whereby material is lost at the surface. Such ejects from the star is known as cosmic dust, and is widely dispersed throughout space.

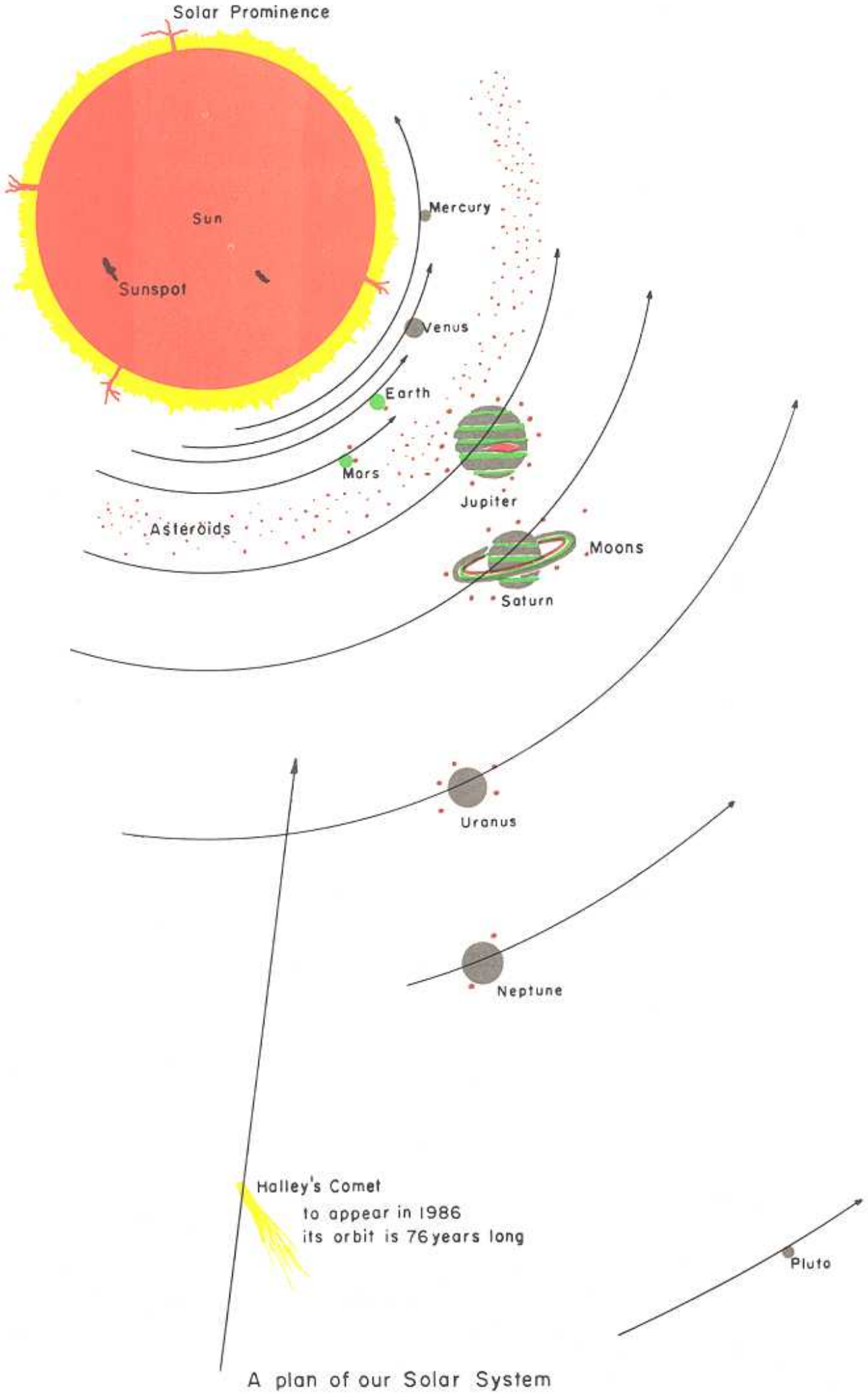


Cosmic Dust and Ejecta from Stars

Scientists believe that it is from cosmic dust that other components of our observable universe, such as the younger stars and planets, including members of our present-day solar system, may have been evolved. Scientists are rather certain that none of the happenings took place at any one time; that in fact, the universe came into existence through a very slow process.



Planets evolved from Cosmic Dust



A plan of our Solar System

A Ripe Old Age

"Some drill and bore
The solid earth and from the strata there
Extract a register by which we learn
That he who made it and revealed its date
To Moses, was mistaken in its age."

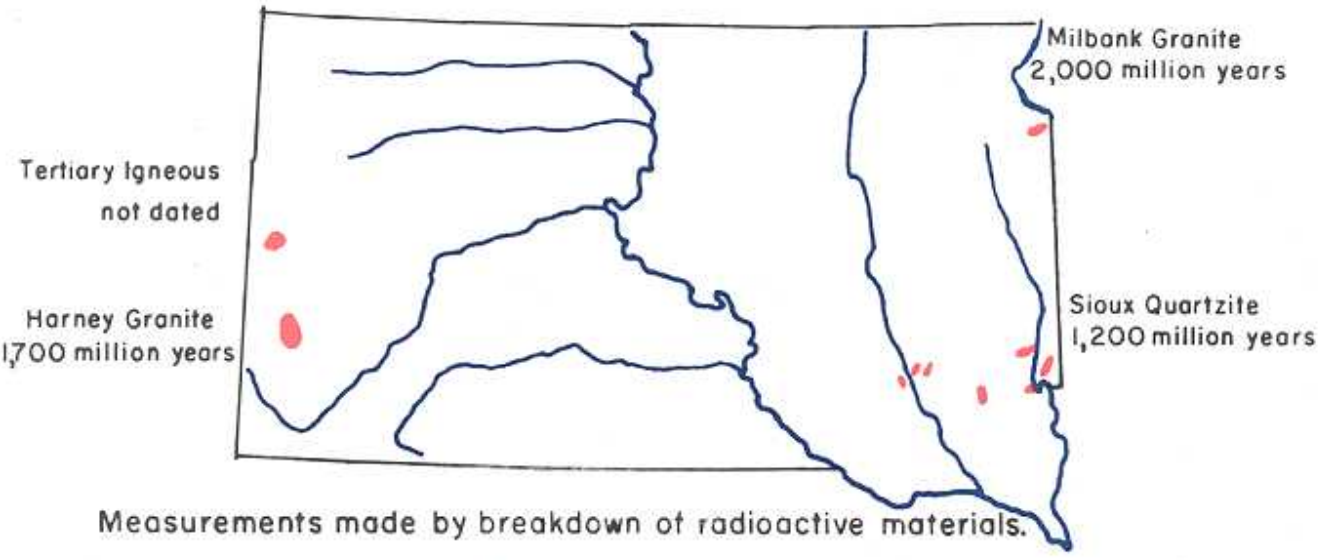
Cowper

If the history of creation of the universe was as stated above, and if all the component parts did not come into existence at the same time, then this implies that there must be a difference in the age of the solar system. Actually, according to most astronomers, the oldest stars known which populate the heavens are at least 10,000 million years old and possibly older.

Oldest stars are at least 10,000 million years old.

At the other extreme, we have some very young stars that are just in the stage of being born. If one were to assign a general age to our solar system, one might say that it has reached middle age and estimate that the universe is about 6,000 million years old.

When it comes to giving an age for our planet, earth, one can be more certain of its possible age. Natural radioactivity phenomena provide a means by which dating can be obtained. From known measurements made by the breakdown of radioactive materials, the oldest dated mineral on the continent is about 3,000 million years old. And to be on the safe side,

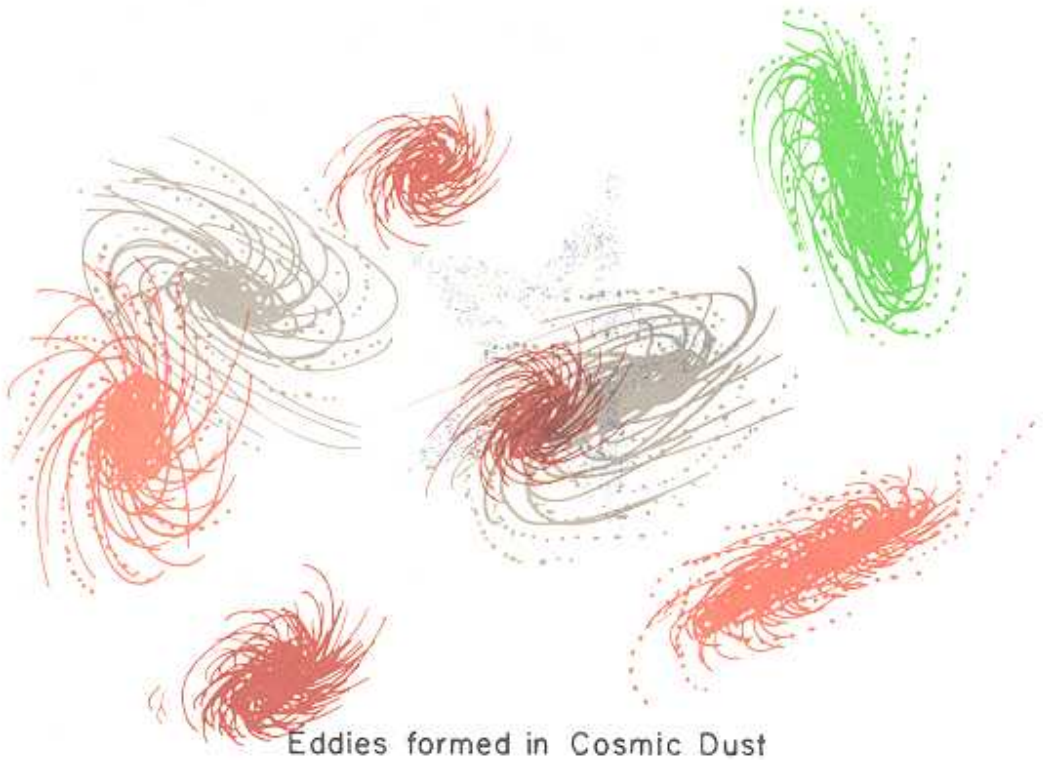


Measurements made by breakdown of radioactive materials.

if we applied the factor of a 2,000 million years to include the time which preceded the formation of the oldest rocks and minerals, one can arrive at an age of the earth at approximately 5,000 million years.

Earth Parentage

If one can assume that some 5 or 6 thousand million years ago eddies formed in cosmic dust created gravitational forces. Such forces caused dust particles to cling together, to form a cloud-like mass. In time, due



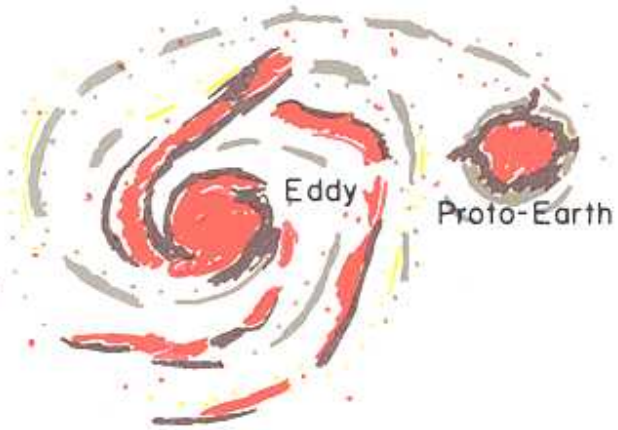
Eddies formed in Cosmic Dust

to nuclear reaction, the major portion of the accreted dust cloud would condense and ultimately form our fiery sun. That material left over, estimated probably somewhere around five percent, became dispersed in the form of rotating disc-like shapes, about the central mass. Again, one can assume that the rotating disc-like masses broke up into irregular sizes with sizes decreasing away from the central mass. Eventually, eddies of irregular size came together to form proto-planets.

Proto-Planet formed by Eddies

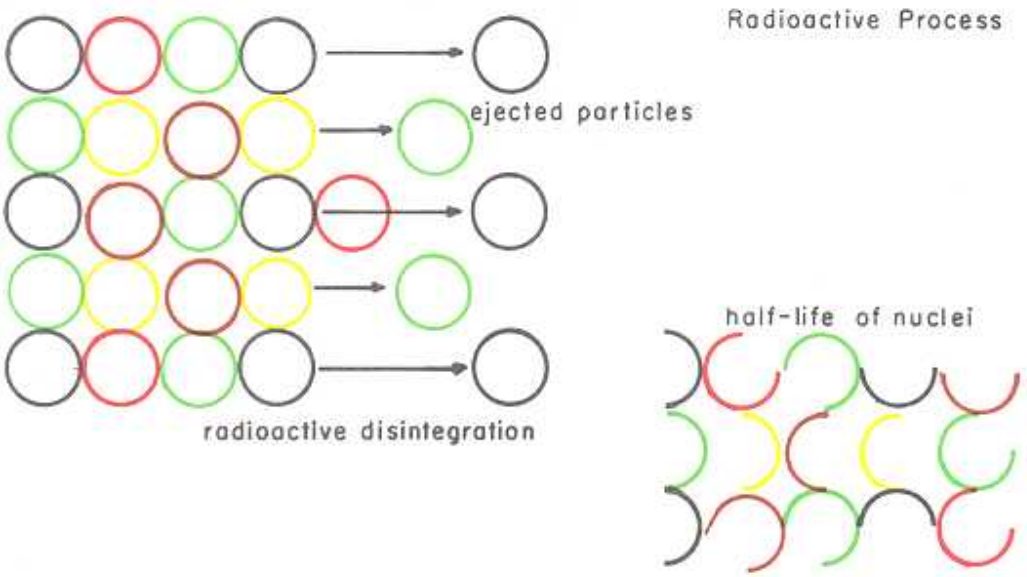
Proto-Sun

As we look at the further development of the solar system, one can again assume that at the time proto-planets were formed, the proto-sun had not yet reached the development of a true sun. In fact, it was rather dark and cold. The proto-earth at about this time was nothing more than a large quantity of dust and gases composed of hydrogen, helium, neon,



methane and possibly water vapor. From what is known, the cosmic material from which the proto-earth was formed was thought to be cool but when the dust particles began to condense to a considerable degree, the proto-earth mass began to heat up. The source of the heat could be by nuclear reaction, but it is thought that a large part of the heat was derived through radioactivity. Using this line of thought, one can say that the radioactivity was far more intense 5,000 million years ago than it is today.

In the radioactive process heat is formed, when through nuclear breakdown, ejected particles strike surrounding matter. As time moves on, the breakdown increases resulting in activity becoming progressively less. Thus heat generated by radioactivity decreases. In radioactive disintegration, one speaks of the half-life of nuclei--that is, the time taken for a given number of nuclei to reduce to half the original number. Radioactive



elements are small compared with the magnitude of the age of the earth. However, radioactivity continues to exist and there comes a time when activity would be exceedingly high and heating more intense.

If cosmic dust condensed, say 10,000 million years ago, heating due to radioactivity would have been so intense that the entire mass would have melted and vaporized. At a younger age, however, say 5,000 million years ago, heat from radioactivity would have been great but not so intense that the whole of the embryonic planet would be melted or vaporized. Suffice to say that heat derived from radioactivity and possibly other sources did cause some of the total planets to melt, and in this process some chemical reactions would have begun. Because it is known that the melting point of materials increases with pressure, which in turn increases with depth, it is believed that melting in the embryonic planet would have begun near the surface of the mass.

As radioactivity diminished, thereby resulting in less heat, the temperature of the proto-planet earth would begin to drop. When such a point was reached, a series of significant events began to take place, and these culminated in forming the solid part of the earth as we know it today.

As was mentioned before, the proto-sun in its early stages was thought to be dark and cool, but once the temperature started to rise, a true fiery sun came into existence. The intense heat was capable of driving off a major portion of the primitive proto-earth's atmosphere. Today, only a small portion of the early atmosphere remains and one should not think that the present atmosphere is a remnant of the primitive atmosphere that once was associated with the proto-earth. Many events have happened since the early days of the earth's birth.

Air and Water Flowing

Roll on, thou deep and dark blue Ocean - roll!
Thou glorious mirror, where the Almighty's form
Glasses itself in tempests; in all time, -
Calm or convulsed, in breeze, or gale, or storm,
Icing the pole, or in the torrid clime
Dark-heaving - boundness, endless and sublime,
The image of eternity,.....

Lord Byron

The present components of the atmosphere as well as the waters in the oceans apparently were generated by a degassing process of volatile materials that included water vapor from the interior of the earth. It is thought that volcanic activity persisted in varying degrees throughout geologic time, and was the mechanism that created the degassing process. This process is thought to have taken place about the same time as the consolidation of the proto-earth into a solid earth mass. One cannot assign to volcanic activity the total source from which the components of the atmosphere were created because atmospheric oxygen produced through photosynthesis and atmospheric argon (the third most abundant gas in the atmosphere) owes its origin to the breakup of potassium by radioactivity.

Primitive oceans were much fresher than the oceans of today. But as the earth grew older, the fresh water began grinding away at the rocks and dissolving their mineral content. The dissolved material, called salts, was carried by streams flowing over the earth's surface to the sea. And since the very beginning, water in the oceans has worked on Old Mother Earth trying to smooth out her roughness. Water, however, is not the only force working within the earth. Other forces cause mountains to form. If this were not so, the earth would eventually be covered by one big body of water.

Water in the oceans has worked on Old Mother Earth

FROM THE INSIDE TO THE OUTSIDE

The earth is by no means a hollow sphere. It is made up from a variety of minerals and rocks that are divided into three major zones: the core, mantel and crust.

The Core

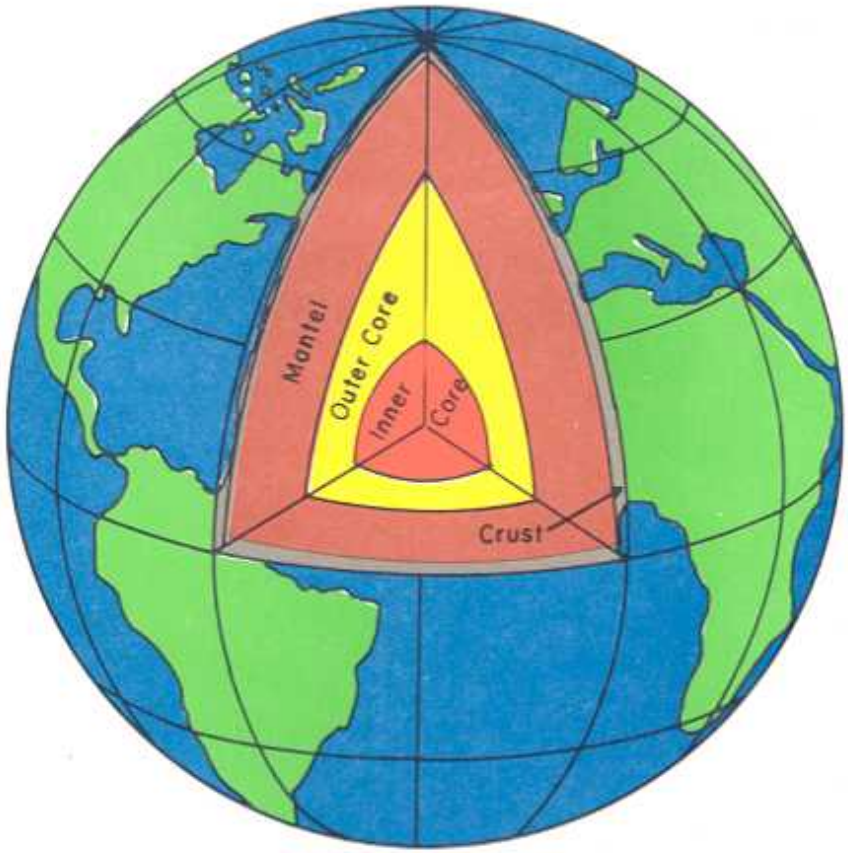
The core forms the innermost zone of the earth. It is not completely homogeneous and possibly has an inner zone that is solid, surrounded by an outer core that is a liquid. The inner core is composed chiefly of metallic elements--namely iron, nickel, cobalt, and possibly some gold and platinum. The outer core contains these same minerals but they are in a liquid phase.

The Mantel

Surrounding the core is a group of rocks containing much iron and magnesium. These rocks make up the second major zone, or mantel. Most of these iron-magnesium rich rocks are not as dense as the rocks in the core, and are silicates rather than metals.

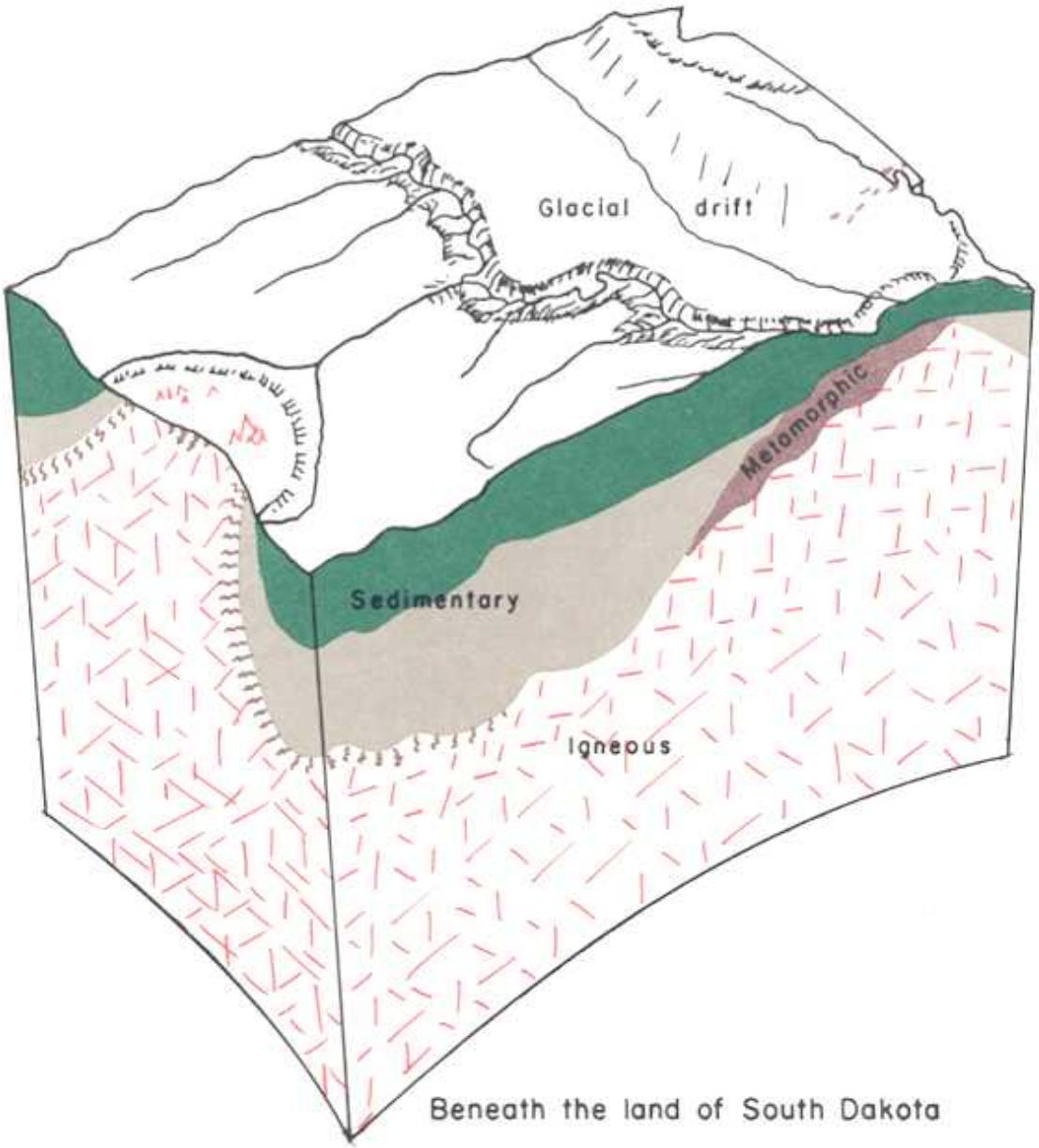
The Crust

The outermost zone, the crust, surrounds, of course, the mantel. Compared to the thickness of the core and mantel, the crust of the earth is but a thin skin no more than 6 to 30 miles thick. It is upon the crust of the earth that one walks, and the minerals and rocks familiar to all are found in the crust. Most of these rocks are not as dense as those in the core and mantel, and do not have as great an iron content.

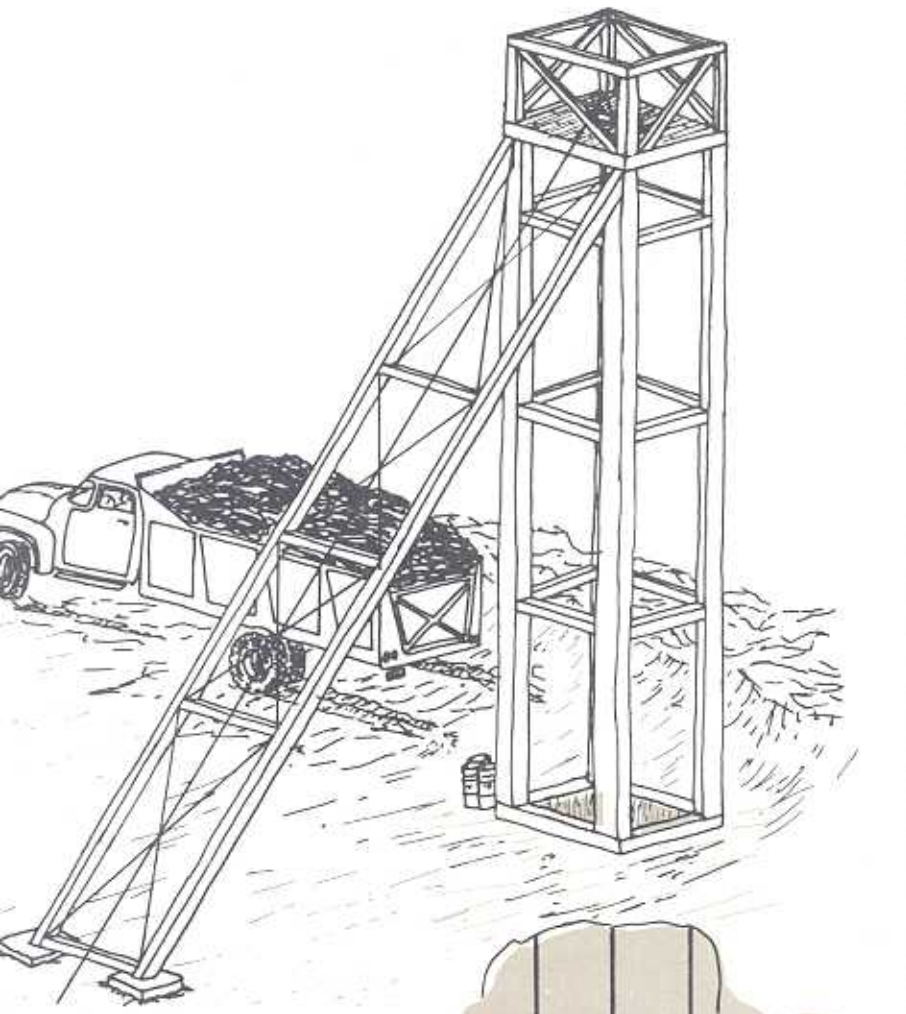


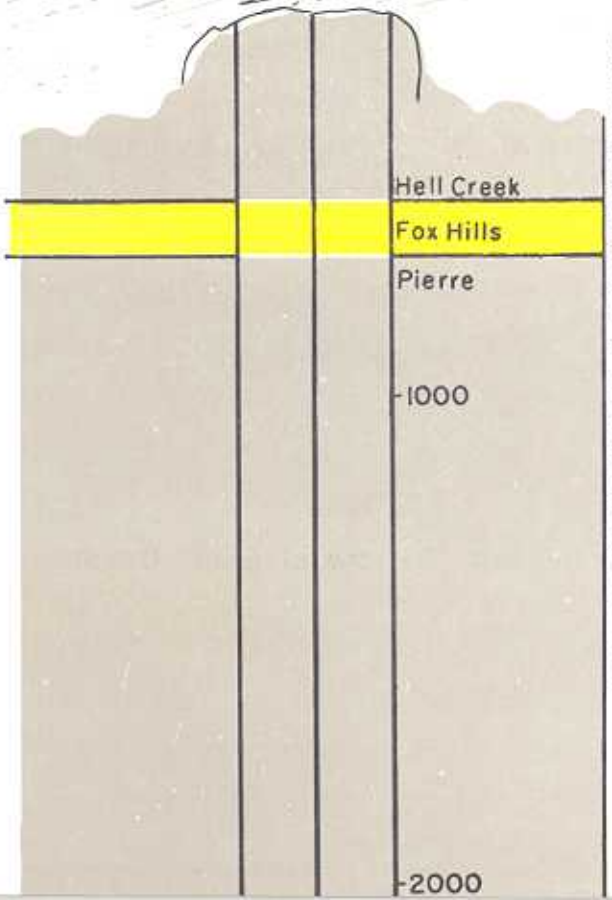
The Earth is not a hollow sphere

Beneath the land of South Dakota, the rocks of the crust are composed of sedimentary rocks (limestone, sandstone, shale and glacial drift), that were deposited either by wind, water or glacial ice; igneous rocks, formed by the liquid materials that have become hard (granite, gabro, basalt); and metamorphic rocks or altered materials (created from pre-existing sedimentary, igneous and metamorphic rocks) gneiss, schist, quartzite, slate. Above many of these rock types is a thin layer of material called soil that is derived from the weathering of the rock.



Beneath the land of South Dakota





A DOWNWARD DESCENT

Let's imagine that in northwestern Perkins County, where the Shell #1 Homme oil test was drilled in the $NW\frac{1}{4}NW\frac{1}{4}SE\frac{1}{4}$ sec. 13, T. 20 N., R. 12 E., that this hole was excavated for use as an elevator shaft. When one looks through a window in the elevator he sees rocks. Now pretend that one can get on an elevator and be lowered slowly down the shaft. Let's begin the downward descent and look at the rocks.

As one begins his downward journey, he notices in the wall a gray to tan rock that contains many black specks that are the carbon residues of plants. Also present are flakes of the mineral, muscovite, commonly called mica. The rock is a sequence of siltstone, shale and sandstone. As the elevator proceeds downward to a depth of 520 feet, one may note consistent black streaks, some as much as an inch or so thick. These are thin layers of lignite coal.

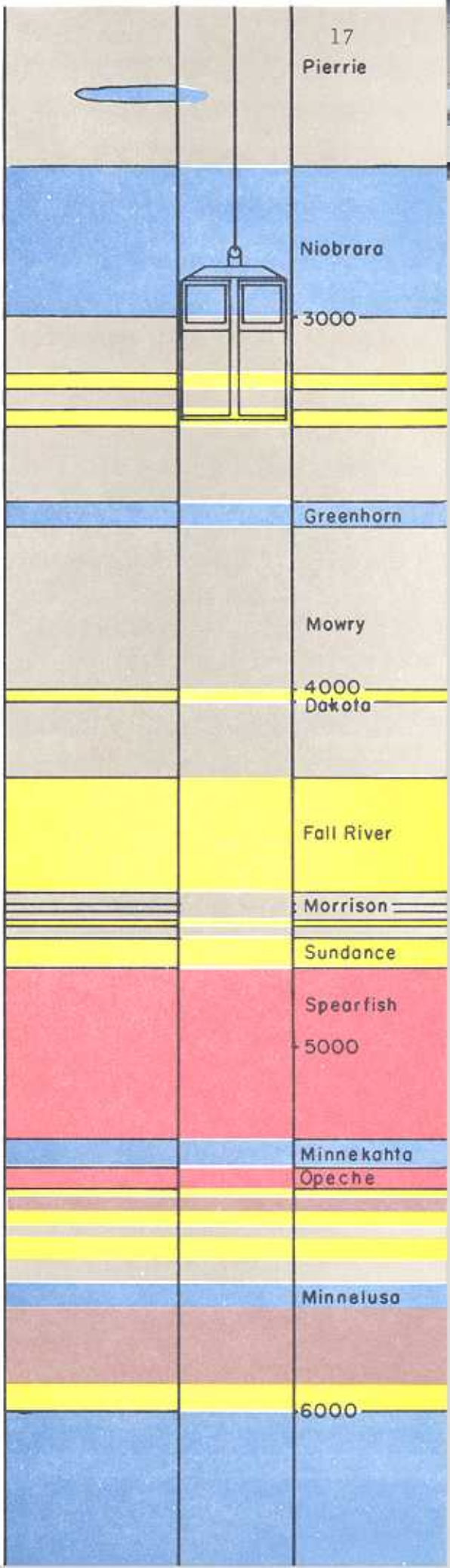
At 490 feet is the geologic time break between the Cenozoic and Mesozoic age rocks. For the untrained eye, the break is not apparent, and in many places the break is placed on the basis of fossils. Below 520 feet, as the elevator continues downward, one again sees layers of siltstone, sandstone, shale and lignite coal. Colors of sandstone vary from shades of brown, tan and gray. The siltstones and shales also exhibit variable colors, such as grays, greens, tans, brown and black. The elevator will continue to pass through the above type rock to a depth of 3,500 feet. The last 2,000 feet was through the gray Pierre Shale that one sees at the surface when driving west of Pierre to Rapid City.

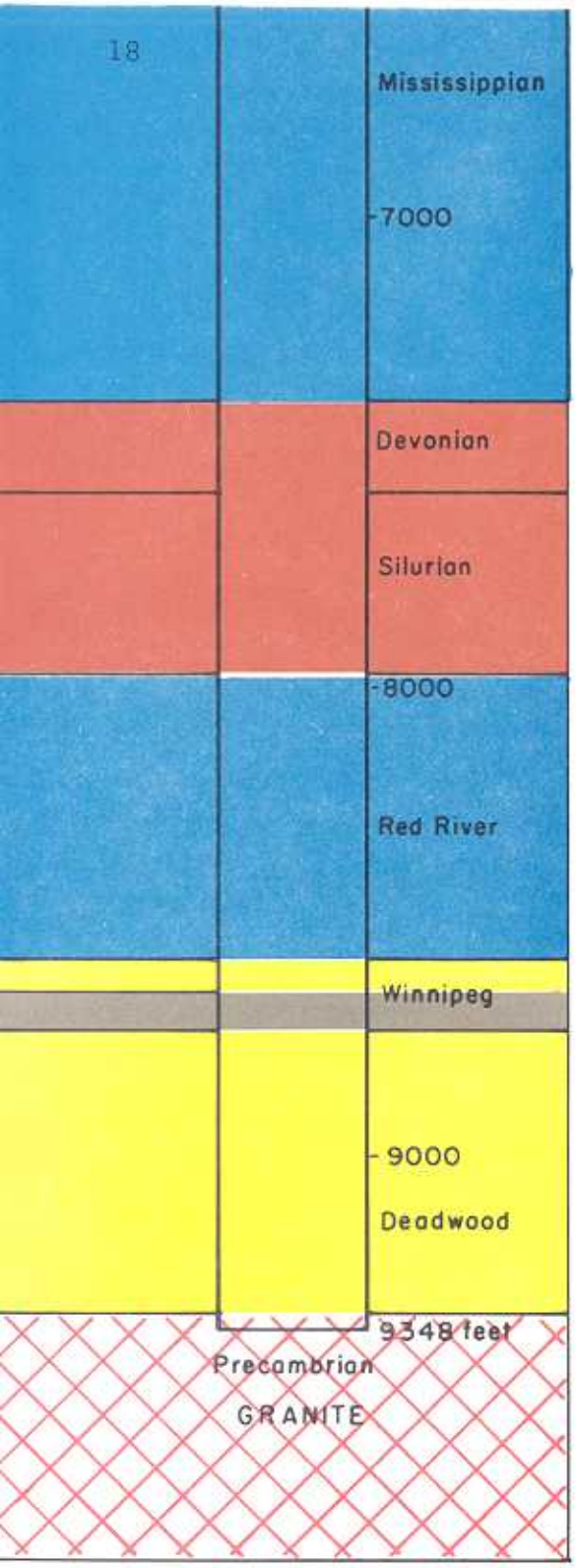
A good marker bed, as geologists commonly refer to readily identifiable rock layers that are persistent over wide areas, is seen at the 3,500 foot level. It is called the Greenhorn Limestone. The limestone has thin shale and sandstone beds interlaid with it. The Greenhorn Limestone is about 40 feet thick. Below the Greenhorn is seen again layers of sandstone and shale to a depth of 4,015 feet, where one sees another marker bed called the Dakota Sandstone. The Dakota is a rock unit composed of alternating layers of sandstones and shales. Beginning at a depth of 4,274 feet is seen a rather thick interval of sandstone called the Fall River that extends to a depth of 4,375 feet. The Fall River looks very much like the Dakota Sandstone.

Downward to a depth of 5,260 the rocks are mostly shale, siltstones, and clays with a few thin sandstone beds. The shales are green, gray, and red in color and a few fossils may be noted. Two rock types seen for the first time at a depth of 5,000 feet are gypsum and anhydrite. These rock types show up well because they are gray or bluish-white in color. Some beds are as much as 40 feet thick.

If one drives on Interstate 90 from Rapid City to Sturgis, South Dakota, the white rocks seen associated with the brilliant red shales is gypsum.

Another major geologic time break in the rock record is seen at a depth of 5,260 feet, which separates the Mesozoic from the Paleozoic rocks. Again one does not see a distinct break because age relationships were defined by the study of fossils found in the rocks.





When the imaginary elevator reaches the 6,000 foot level, one sees a decided change from the sequence of shales, siltstones, and sandstones to that of chiefly limestones and dolomites with a few thick units of gypsum and anhydrite. Because limestones and dolomites were formed in the waters of the seas, fossils commonly are abundantly present, at times making up the major portion of the rock. Thus, the geologist is able to separate one limestone layer from that of another strictly on the age of fossils. For example, at a depth of 6,005 feet the Mississippian, one of the subdivisions of the Paleozoic, can be identified as being younger than the limestones and dolomites belonging to the Devonian, another division of the Paleozoic, seen at a depth of 7,250 feet. The fossils in the Devonian rocks are younger than those found in the Ordovician rocks, still another division of the Paleozoic at a depth of 8,045 feet.

As the elevator passes the 8,600 foot level, one sees another change in the rock. Limestones and dolomites almost disappear and siltstones and shales again come into view. Continuing downward to the 8,700 foot level, a whitish sandstone is seen, and marks the top of the Cambrian system, the lowest subdivison of the Paleozoic rocks.

The imaginative elevator must stop at 9,348 feet, because this is the depth of the hole drilled for oil, or the depth of the excavation for the elevator shaft. If one looks out of the window and downward, one sees that the elevator rests on a pink granite. The Precambrian rocks have been reached and our downward descent ends.

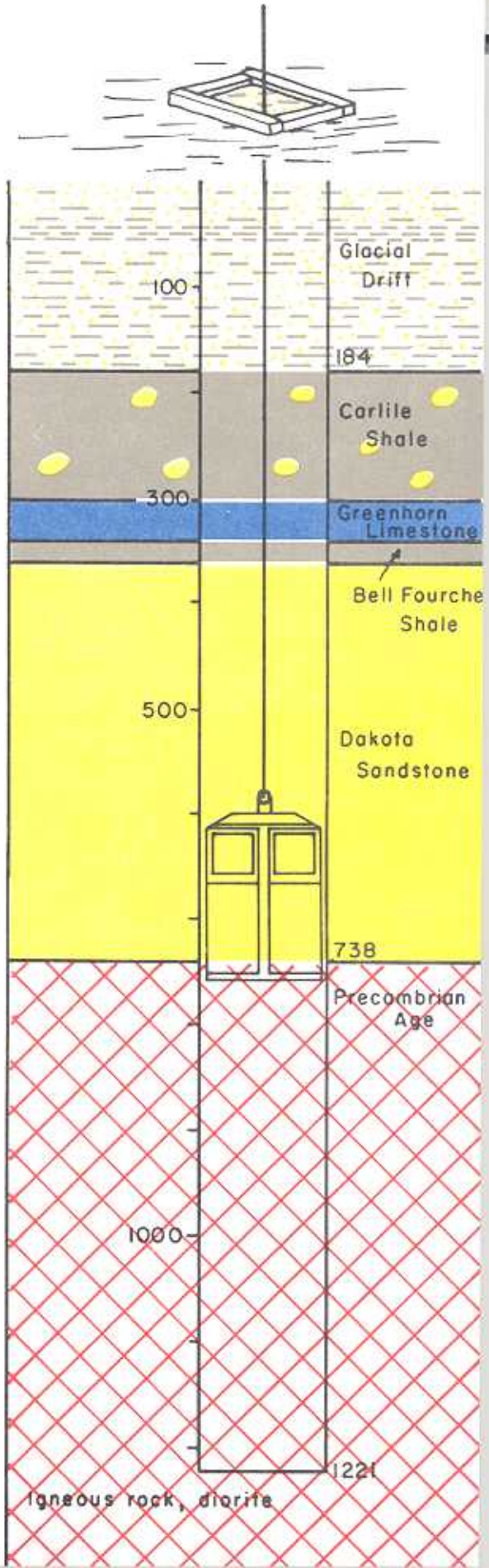
ANOTHER SHAFT--A DIFFERENT STORY

Lest one gets the impression that rocks beneath the land of infinite variety are the same everywhere, an oil test drilled in Yankton County in the NW$\frac{1}{4}$SW$\frac{1}{4}$, sec. 29, T. 96 N., R. 56 W., known as the Rittershaus #1 Jamesville Colony Well reveals a different story. Again imagine that this hole was excavated for an elevator shaft. Upon descending downward in the elevator one sees layer upon layer of sand and gravel that looks much like the material one sees in the banks of local streams in the surrounding area. This material, called glacial drift, was laid down when a thick layer of ice that once covered the land melted. The ice contained within it much sand and gravel that was picked up when the glacial ice moved southward across the land. Geologists say that the sediments are of Pleistocene age.

At a depth of 184 feet, the elevator leaves the deposits of glacial drift. One sees a distinct contrast between the glacial drift and the Mesozoic rock identified as the Carlile Shale. The Greenhorn Limestone marker bed is seen at a depth of 300 feet, and the Dakota Sandstone, at 360 feet. As the elevator continues down, one notes that sandstone is the dominant type of rock to a depth of 738 feet.

The excavated shaft for the imaginary elevator did not go through any Paleozoic rocks because they are not present. Mesozoic rocks rest directly upon Precambrian sediments. From a depth of 738 feet to 1,221 feet, the rocks seen are of Precambrian age and consist of dark-colored igneous rock. The chief rock type is called diorite. It is a rock containing a large amount of dark minerals, one of which is an iron oxide called magnetite. A magnet readily picks up pieces of this rock or if one could place a magnet on the wall of the elevator shaft, a decided "pull" would be felt.

The elevator stops at a depth of 1,221 feet, but the rocks continue at depth. What they are can only be a guess, but it is certain that most are of igneous origin.



A ROMANTIC ROCK HISTORY

The center-fire heaves underneath the earth,
And the earth changes like a human face;
The molten ore bursts up among the rocks,
Winds into the stone's heart, outbranches bright
In hidden mines, spots barren river-beds,
Crumbles into fine sand where sunbeams bask--

Browning, "Paracelsus"

Now that something is known about the geologic materials found beneath the land of infinite variety, a return trip up our imaginative elevators to the surface will permit one to read from the rocks the geologic history recorded there.

After the birth of planet earth, some six billion years ago, when it was cooled to a solid form, the earth was left with high mountain ranges and ocean basins. The natural geologic processes, such as the work of water, wind, and ice, gradually began to wear away the land, much as one sees these same processes acting today.

As is known now, no life existed on earth for at least 4 billion years. The only changes were physical ones. Mountain ranges were heaped up in response to the large contracting forces created by cooling, and high areas were worn down by various agents of weathering and erosion and waters of the sea advanced and retreated over many parts of the earth.

Some of the sediments laid down on the ancient sea floor became deeply buried and because of intense pressure became metamorphose (changed). Limestone and dolomite became marble; shale became slate; sandstone changed into quartzite. Beneath South Dakota, the record of Precambrian is revealed by granite and diorite, which are solidified molten rocks, and by quartzite, a metamorphic rock.

Budding of Life

When the four billion lifeless years had passed and possibly in the last two billion years of the Precambrian eon, only microscopic life existed. Then suddenly organic life in all its glory and wonder broke forth. The seas swarmed with plant and animal life, ever increasing in size and variety. Some had hard parts that became preserved in the rocks, and one sees them today. These early forms of life, now fossils, are found in Cambrian rocks, and ushered in the beginning of the Paleozoic era which by definition means "ancient life." The other subdivisions of the Paleozoic era are shown in the columnar section on the following page.

COLUMNAR SECTION OF THE BLACK HILLS

		FORMATION	SECTION	THICKNESS IN FEET	DESCRIPTION
QUATERNARY		PLEISTOCENE		0-50	Sand, gravel, and boulders.
TERTIARY	PLIOCENE	OGALLALA GROUP		0-100	Light colored sand and silts.
	MIOCENE	ARIKAREE GROUP		0-500	Light colored clays and silts. White ash beds at base.
	OLIGOCENE	WHITE RIVER GROUP		0-600	Light colored clays with sandstone channel fillings and local limestone lenses.
	PALEOCENE	FORT UNION FORMATION		0-425	Light colored clays and sands, with coal-beds farther north.
				0-225	Green marine shales and yellow sandstones, the latter often as concretions.
				0-350	Somber-colored clays and sandstones with thin beds of lignite.
	?	HELL CREEK FORMATION		425	Somber-colored soft brown shale and gray sandstone, with thin lignite lenses in the upper part. Lower half more sandy. Many loglike concretions and thin lenses of iron carbonate.
CRETACEOUS		FOX HILLS FORMATION		25-200	Grayish-white to yellow sandstone.
	UPPER	PIERRE SHALE		1200 to 2000	Principal horizon of limestone lenses giving teepee buttes. Dark-gray shale containing scattered concretions. Widely scattered limestone masses, giving small tepee buttes. Black fissile shale with concretions.
		NIOBRARA FORMATION		100-225	Impure chalk and calcareous shale.
		CARLILE FORMATION		400-750	Light-gray shale with numerous large concretions and sandy layers. Dark-gray shale.
		GREENHORN FORMATION		(25-30) (200-350)	Impure slabby limestone. Weathers buff. Dark-gray calcareous shale, with thin Orman Lake limestone at base.
		BELLE FOURCHE SHALE		300-550	Gray shale with scattered limestone concretions. Clay spur bentonite at base.
	LOWER	DAKOTA SANDSTONE		150-250 20-60	Light gray siliceous shale. Brown to light yellow and white sandstone.
		SKULL CREEK SHALE		170-270	Dark-gray to black shale.
		FALL RIVER SANDSTONE		10-200	Massive to slabby sandstone.
		LAKOTA FORMATION		10-188 0-25 25-485	Coarse gray to buff cross-bedded conglomeritic sandstone, interbedded with buff, red, and gray clay, especially toward top. Local fine-grained limestone.
JURASSIC		MORRISON FORMATION		0-220	Green to maroon shale. Thin sandstone.
		UNKPAPA SANDSTONE		0-225	Massive fine grained sandstone.
		SUNDANCE FORMATION		250-450	Greenish-gray shale, thin limestone lenses. Glauconitic sandstone; red sandstone near middle.
		GYPSUM SPRING		0-45	Red siltstone, gypsum, and limestone.
TRIASSIC	?	SPEARFISH FORMATION		250-700	Red sandy shale, soft red sandstone and siltstone with gypsum and thin limestone layers. Gypsum locally near the base.
PERMIAN		MINNEKAHTA LIMESTONE		30-50	Massive gray, laminated limestone.
		OPECHE FORMATION		50-135	Red shale and sandstone.
		MINNELUSA FORMATION		350-850	Yellow to red cross-bedded sandstone, limestone, and anhydrite locally at top. Interbedded sandstone, limestone, dolomite, shale, and anhydrite.
PENNSYLVANIAN		KIBBY FORMATION			Red shale with interbedded limestone and sandstone at base.
MISSISSIPPIAN		PAHASAPA (MADISON) LIMESTONE		300-630	Massive light-colored limestone. Dolomite in part. Cavernous in upper part.
DEVONIAN		ENGLEWOOD LIMESTONE		30-60	Pink to buff limestone. Shale locally at base.
ORDOVICIAN		WHITEWOOD (RED RIVER) FORMATION		0-60	Buff dolomite and limestone.
		WINNIPEG FORMATION		0-100	Green shale with siltstone.
CAMBRIAN		DEADWOOD FORMATION		10-400	Massive buff sandstone. Greenish glauconitic shale, flaggy dolomite and flatpebble limestone conglomerate. Sandstone with conglomerate locally at the base.
PRECAMBRIAN		METAMORPHIC and IGNEOUS ROCKS			Schist, slate, quatzite, and arkosic grit. Intruded by diorite, metamorphosed to amphibalite, and by granite and pegmatite.

modified from South Dokota School of Mines, Dept. of Geology.

In South Dakota, the Cambrian seas advanced over a flat Precambrian surface and covered the Black Hills area. The seas slowly retreated northwestward leaving behind deposits consisting of limestone, shale, and sandstone, referred to as the Deadwood Formation.

Cambrian Time

Later, during Ordovician time, (time scale) the seas again invaded the State laying down sandstones and shales, called the Winnipeg Formation. As far as is known, the Winnipeg rocks are found only in the area of the northern Black Hills and if these rocks were more widespread, they have disappeared because of the processes of weathering and erosion.

After the Winnipeg sea withdrew, a readvancing sea from the north deposited rocks, called the Red River Formation. These rocks are found in the same general area as the Winnipeg rocks. The oil fields in Harding County northwest of Buffalo pump oil from the Red River rocks at a depth of 8,700 feet.

Ordovician Time

During Silurian and Devonian time, the seas came in again from the north depositing limestone and dolomite. It is thought that the seas never reached the Hills area until late Devonian. Pink shaly limestone, called the Englewood Formation, contained fossils of Devonian age in its lower part.

Silurian-Devonian Time

The upper part of the Englewood Formation contained fossils of early Mississippian age. Following the deposition of the Englewood, pure limestone and dolomite of Mississippian age were formed and given the name Pahasapa Limestone. As one drives through Spearfish Canyon, in the northern Black Hills, the high steep walls of rocks seen along the road are the Pahasapa Limestone. Beneath the surface, the Pahasapa is known by the name Madison Limestone.

The seas in which Mississippian rocks were deposited covered a wide area in South Dakota that extended from the west border of the State almost to the present-day Missouri River.

Mississippian Time

In late Mississippian time, the seas withdrew to the north. While sediments that formed the Kibbey Sandstone were deposited in the sea, land to the south was subjected to weathering and erosion. Sinkholes and caves developed in the limestone and red clay and soil filled in the low spots.

At the start of the Pennslyvanian period, the seas invaded the land again from the south in which was deposited sandstones, limestones, dolomite, anhydrite, gypsum, and many varicolored shales that are assigned to the Minnelusa Formation. At times, part of the Hills area rose slightly above sea level and then would disappear beneath the sea only to later rise again. Such unstable conditions continued into the Permian period, and resulted in a hodgepodge relationship among the various rock types.

Pennsylvanian Time

Finally, when the seas withdrew, shallow areas of water were left in which accumulated much rich shale, with patches here and there of anhydrite or gypsum. These sediments are referred to as the red beds of the Opeche Formation. For awhile the seas again invaded the land and deposited the Minnekahta Formation, chiefly composed of thinly banded, gray and red limestones.

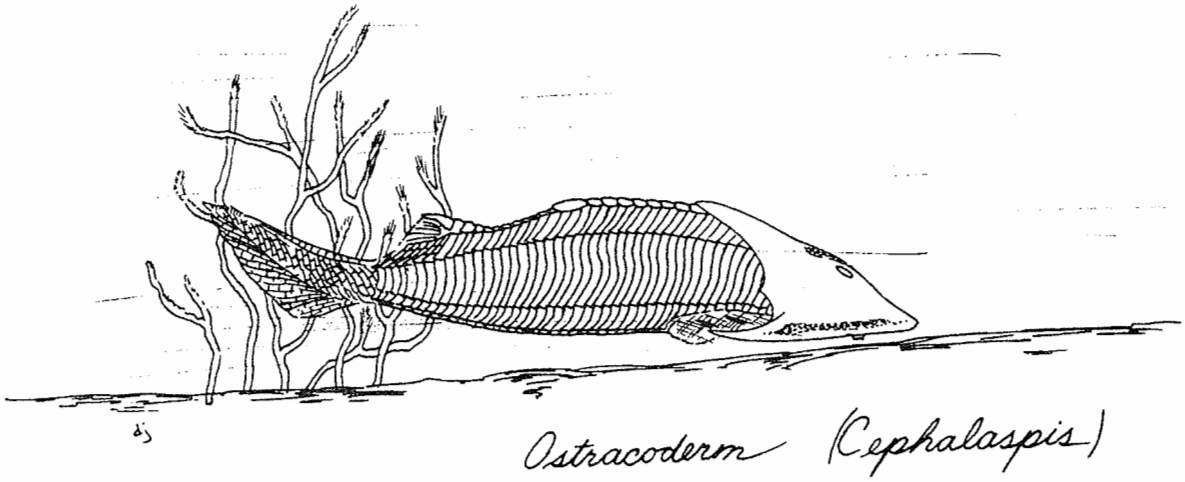
The Paleozoic era ended rather quietly in South Dakota, but elsewhere tremendous forces caused mountains to form, such as in the Appalachian regions of the United States.

End of Paleozoic Era.

Therefore, to draw a distinct line between the Paleozoic era and the Mesozoic era is most difficult to do in this State. When such is encountered, we say that the time line transgresses from Paleozoic into the Mesozoic.

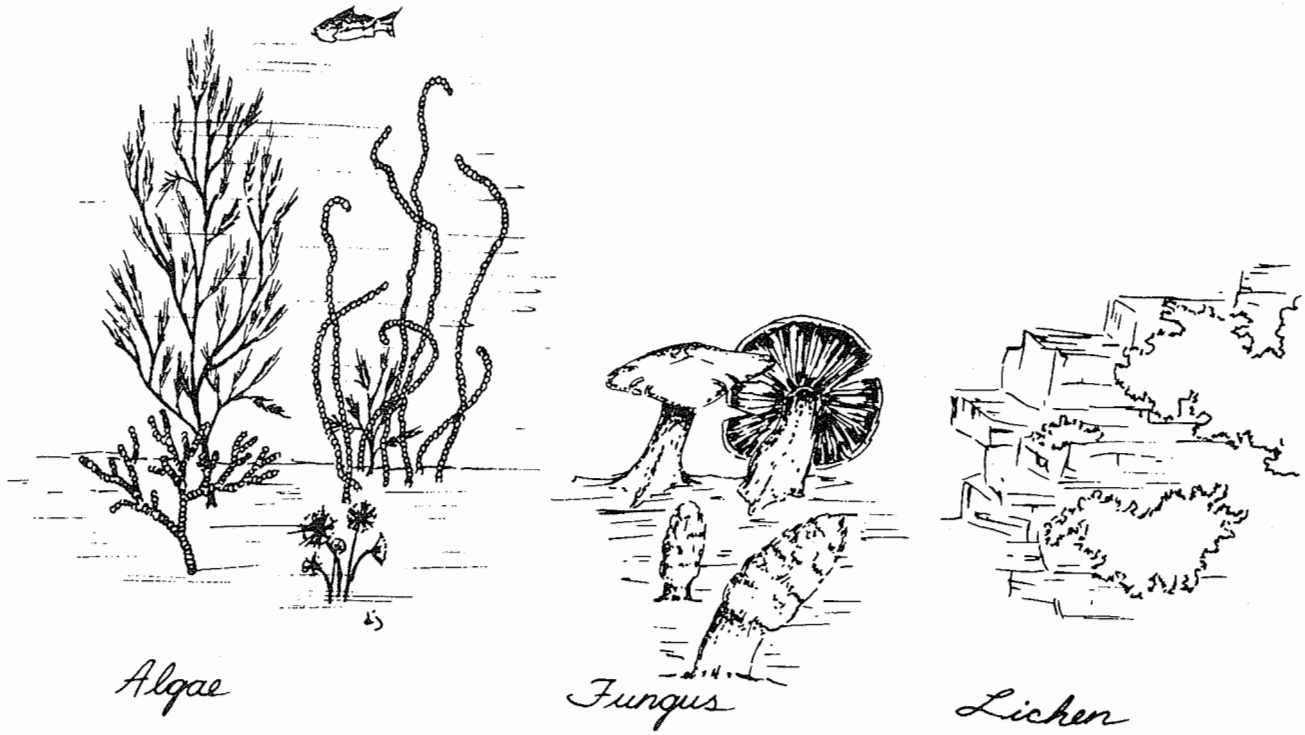
As mentioned previously, life began to blossom forth with the onset of the Paleozoic era. Invertebrate life, including pelecypods, gastropods, cephalopods, grapolites, and tralobites dominated life form of the early Paleozoic. Life forms continued to grow and become more specialized.

The first vertebrates were formed in early Paleozoic in the form of fish-like creatures, until by late Paleozoic times the seas were teeming with fish. Amphibians came into existence in mid- to late-Paleozoic times, as did the first reptiles.



Ostracoderm (Cephalaspis)

Plants were not to be denied their rightful place among the biological kingdom, as they came into being also in early Paleozoic time and continued to flourish throughout the Paleozoic era.



Algae

Fungus

Lichen

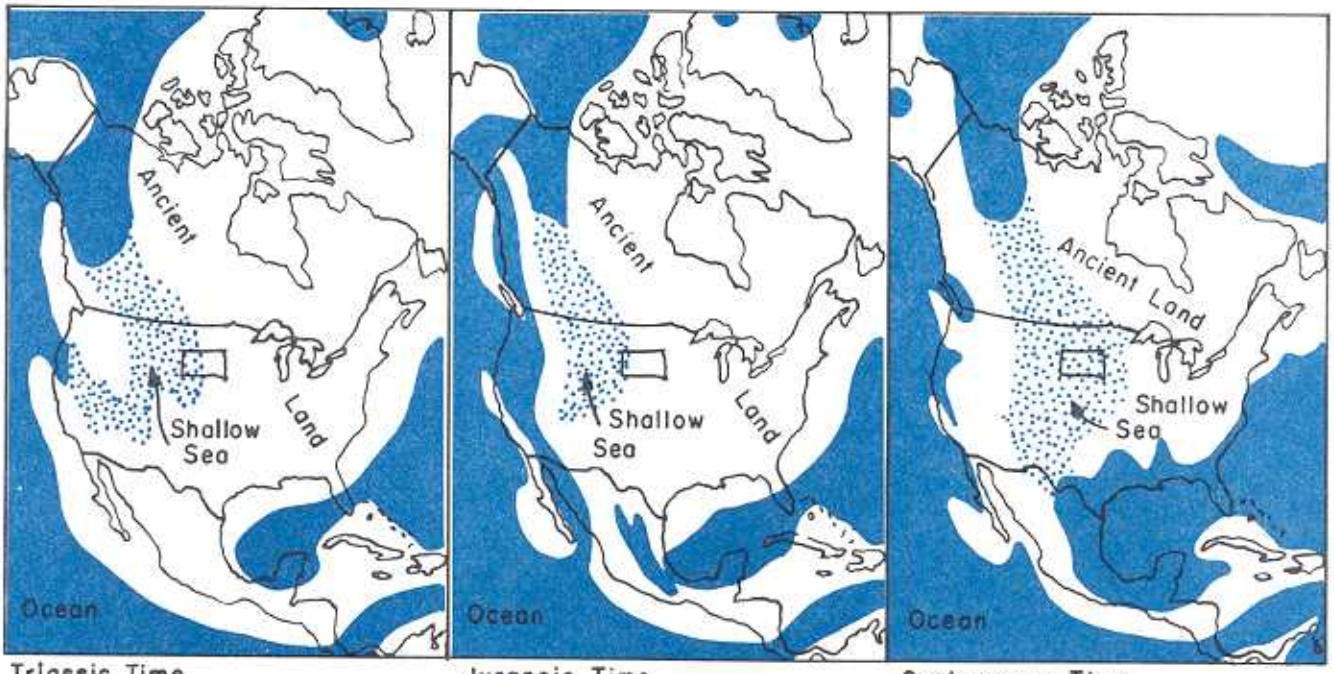
The Reptiles Grow Large

The Mesozoic era came in quietly in South Dakota. Early Mesozoic sediments consisted of brilliant red beds with layers of gypsum and anhydrite. Such deposits indicated a shallow sea environment where the land and sea relationships were unstable. The Spearfish Formation is composed of the above rocks and are thought to transgress the time boundary from the Paleozoic era into the Mesozoic era. The Triassic Spearfish (see time chart) sediments are found in subsurface over a fairly wide area in western South Dakota.

Jurassic rocks are represented by the Gypsum Springs Formation that is composed of red sandstones, gypsum and anhydrite, and varicolored shales. The Gypsum Springs, like the Spearfish, was formed in a shallow sea environment.

A greenish-gray shale and fine sand accumulated in late Jurassic time to form the Sundance Formation. Later, a fine-grained, white to highly varicolored sandstone, called the Unkpapa Sandstone was laid down in the southeastern part of the Hills area. On a vast floodplain that covered the western part of the State, the shale, sand and limestones of the Morrison Formation were formed.

At the beginning of Cretaceous time, the land rose to the east and the meandering streams blanketed the area with sand, silts, and clay, thus creating the Lakota Formation. As the early Cretaceous seas encroached the State, additional fine sand accumulated to form the Fall River Formation.



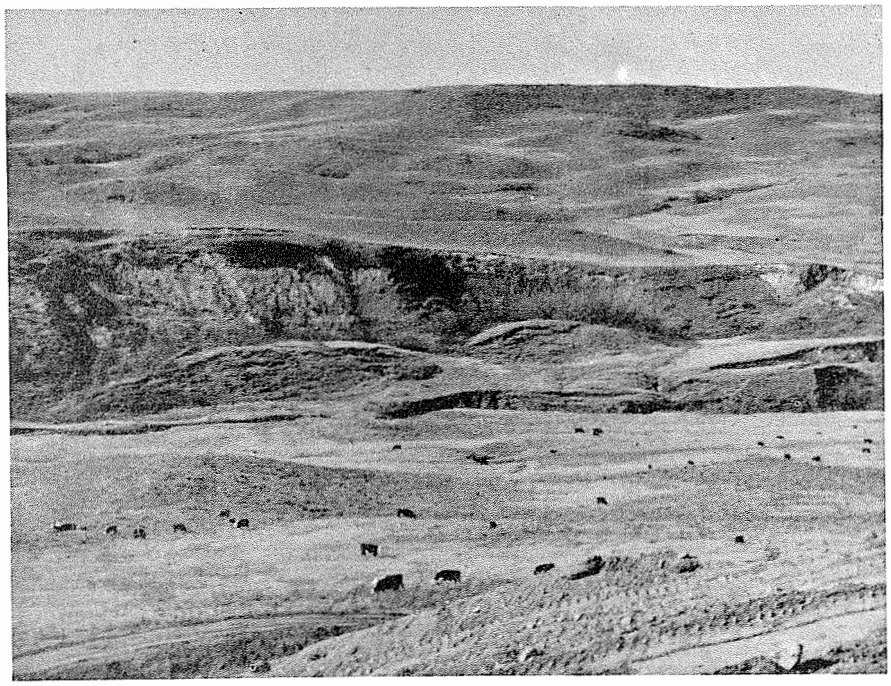
Triassic Time Jurassic Time Cretaceous Time

When the seas became deeper and advanced eastward, sand followed by dark-colored mud formed the Skull Creek Shale. In time, the seas withdrew rather rapidly. Inshoring of the sea let streams distribute fine sands in irregular patches, creating the Newcastle Sandstone. During this period of time, much shale was being deposited in the hills, and streams built up large deltas, composed of sands and clays in central and eastern South Dakota. The sand wedges into shale and brings out a relationship characteristic of the Dakota Sandstone.

The delta eventually became submerged beneath an invading sea in which was deposited the black shales of the Belle Fourche Formation. A brief period of quiet water resulted in the deposit of a limestone known as the Greenhorn.

When the waters became riled, the silty, dark shales of the Carlile Shale were formed, followed by another period of quiet waters wherein the Niobrara Limestone came into existence.

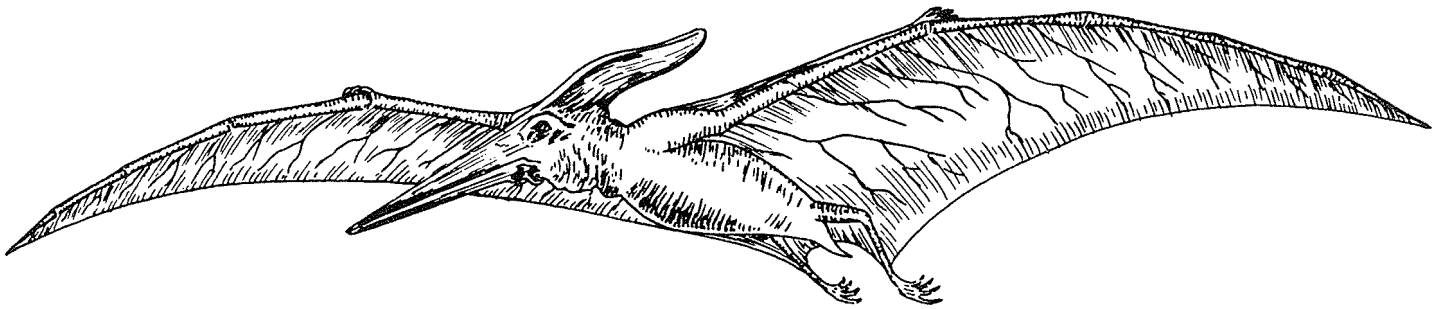
Again the disturbance of the sea water permitted the laying down of a dark shale and clay stone known by the familiar name, the Pierre Shale.



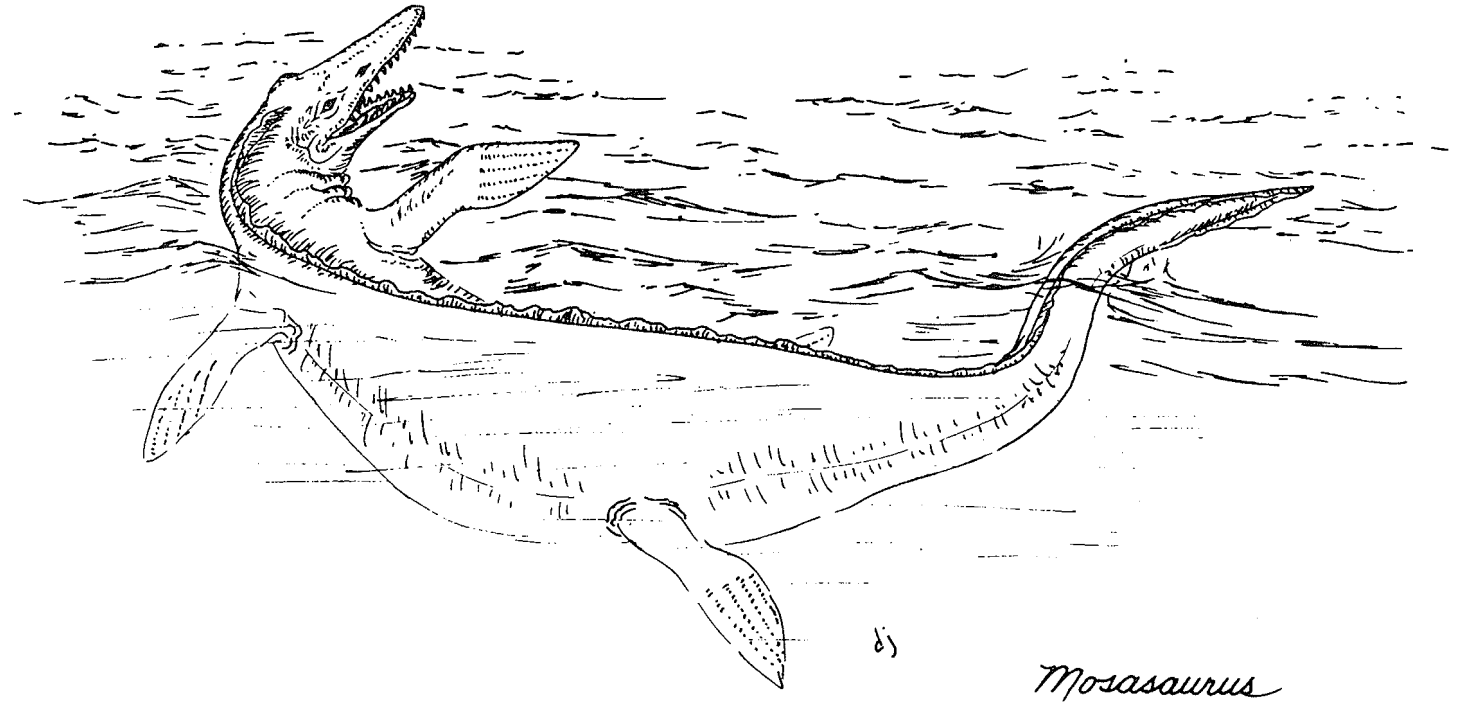
Finally, this period of alternating quiet - riling water ceased, and the waters withdrew to the southeast leaving behind a near shore deposit called the Fox Hills Sandstone. Sluggish streams traversing the lands spread sand and clay over the flat area left by the retreating sea. The sand and shales were deposited to form the Hell Creek Formation. Thus came to an end Mesozoic time.

During the Mesozoic era the largest beasts known lived on land and in the sea. One formation, the Morrison, was laid down over a vast flood-plain left by the retreating seas on which many small freshwater lakes existed, creating an ideal environment for the burial and preservation of bones of numerous dinosaurs.

Geologists have found in the Niobrara Formation large sea monsters and flying reptiles that characterize the beasts in the water and sky.



Pteranodon



Mosasaurus

THE DINOSAUR

Behold the mighty dinosaur,
  Famous in prehistoric lore,
Not only for his power and strength
  But for his intellectual length.
You will observe by these remains
  The creature had two sets of brains--
One in his head (the usual place)
  The other at his spinal base.
Thus he could reason "A priori"
  As well as "A posteriori."
No problem bothered him a bit
  He made both head and tail of it.

So wise was he, so wise and solemn,
  Each thought filled just a spinal column.
If one brain found the pressure strong
  It passed a few ideas along.
If something slipped his forward mind
  'Twas rescued by the one behind.
And if in error he was caught
  He had a saving afterthought.
As he thought twice before he spoke
  He had no judgment to revoke.
Thus he could think without congestion
  Upon both sides of every question.
Oh, gaze upon this model beast,
  Defunct ten million years at least.

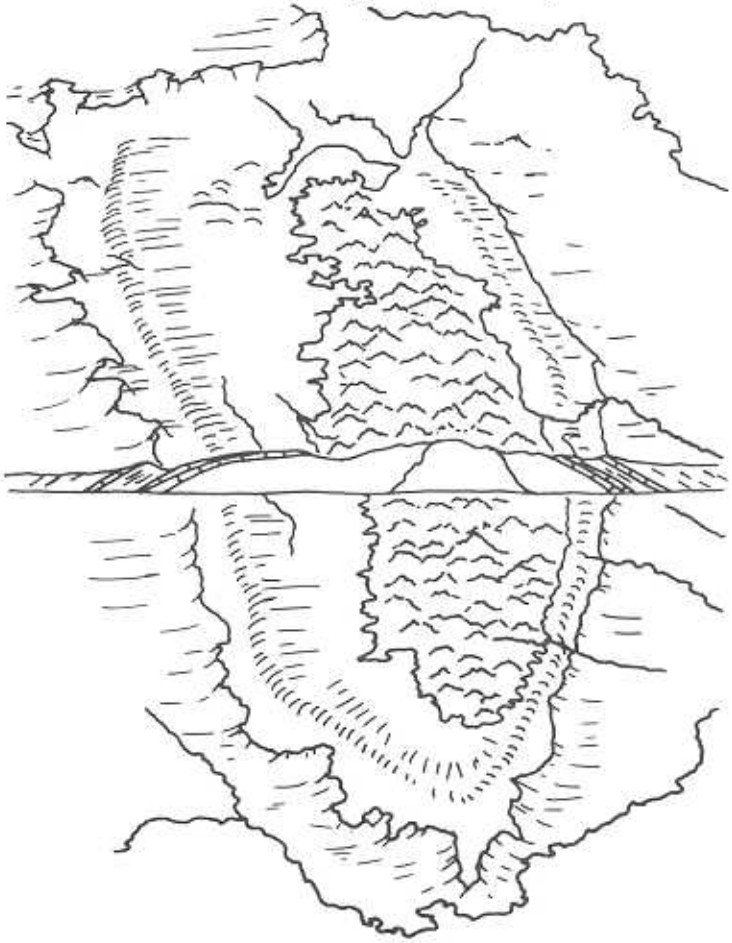
Bert Leston Taylor
Chicago Tribune

Plant life flourished during the Mesozoic and provided food for many animals. Plant life that became quickly buried eventually turned into the soft coal, thus streaks of coal are common in late Mesozoic rocks.

Near the end of the Cretaceous period, the seas retreated and accompanying the withdrawals of the sea were forces within the earth that caused an upheaval to form the Black Hills.

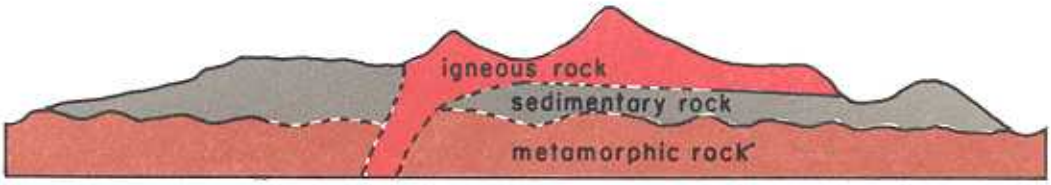
End of Cretaceous Time.

The upheaval was not sudden, but took place over many years. As the land rose, erosion attacked all rock types, and began to wear them down.



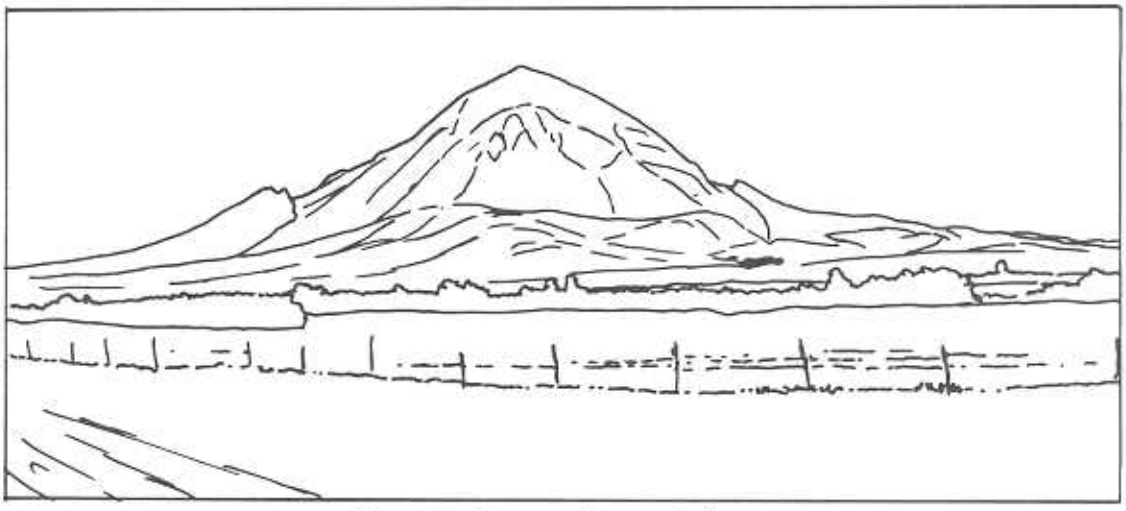
A relief map of the Black Hills illustrating erosion.

Later, in the northern Black Hills, igneous activity forced molten rock from depths upward toward the surface and in between layers of sedimentary rock. One sees this phenomena in Custer and Crow Peaks and in Deadman, Vanocker, and Green Mountains.



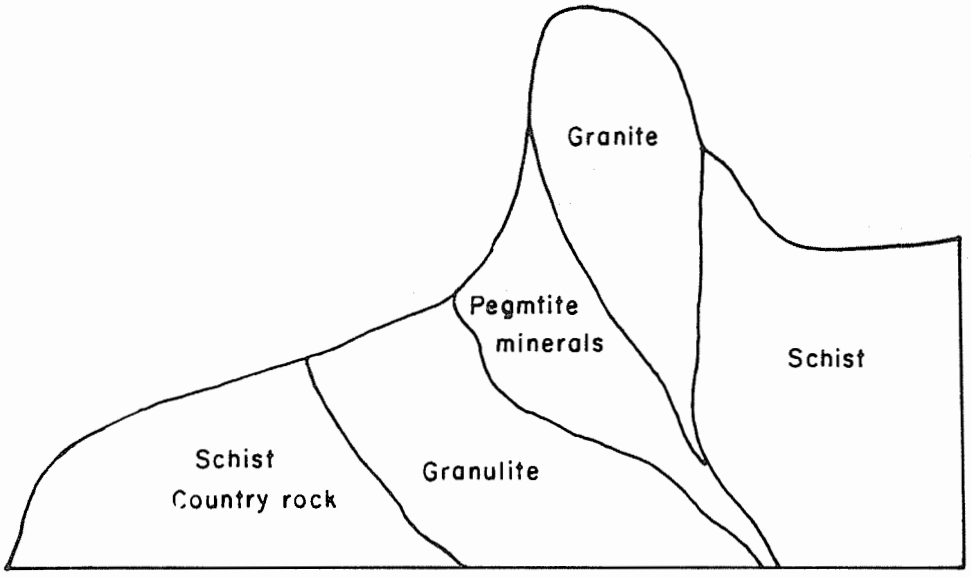
Profile of Custer Peak.

As the sedimentary rocks were forced apart, blister-like shaped mounds were formed that are called laccoliths. Bear Butte, a laccolith, was formed when the molten rock forced its way up into a steep-sided, plug-like form.



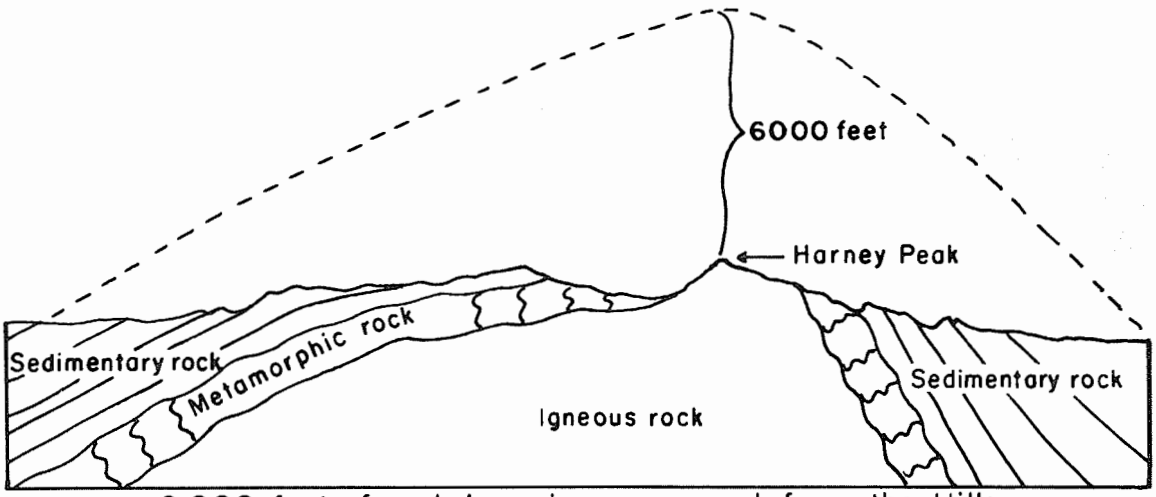
Bear Butte, a Laccolith.

The many mineral deposits in the area of the Black Hills owe their existence to the intense igneous activity that began at the close of the Mesozoic era, and extended into the early part of the Cenozoic era.



Pegmatite Dike, a mineral deposite.

During much of Cenozoic time the land was high and subject to intense weathering and erosion; streams became sluggish and could not carry the sediment load. As a result, deposits of mud, sand and gravel were formed. Many of the streams headed in the Hills area and recognizable pieces of rose quartz, tourmaline, feldspar, and other minerals have been found. It is estimated that as much as 6,000 feet of rock have been removed from the Hills and carried eastward by streams. The varicolored

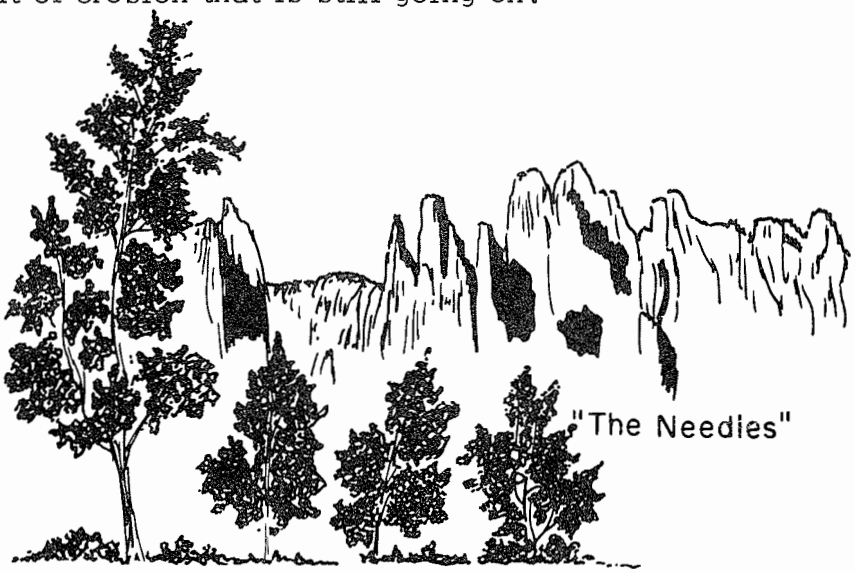


6,000 feet of rock have been removed from the Hills.

shales and sands of the Badlands area (White River Group) represent this type of deposit.

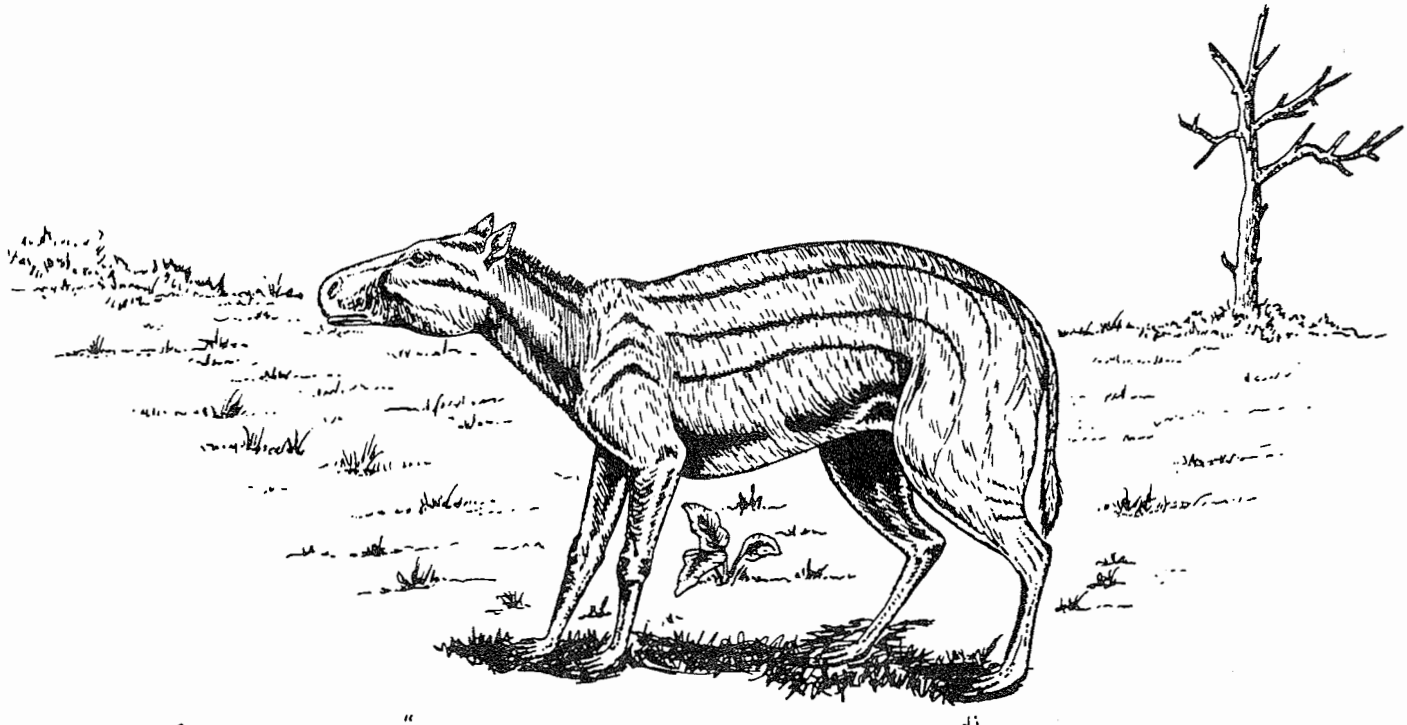
Later in the Cenozoic, the Hills area became partially buried by locally derived weathered materials, and from materials from the mountains to the west. To the west, possibly in Yellowstone Park, volcanic activity yielded large volumes of volcanic ash that was carried eastward by the wind.

Still later in the Cenozoic, because of a combination of climatic changes and earth movement, weathering and erosion were intense and gradually uncovered more and more of the Black Hills. What we see today is the result of erosion that is still going on.



Result of erosion that is still going on.

The beginning of the Cenozoic ushered in a new form of life known as the mammal. In rocks of Cenozoic age (Fort Union, White River, Arikaree, and Ogallala Groups), one finds representatives of the horse, camel, rhinoceros and dog. Many of these mammal forms can be seen in the excellent

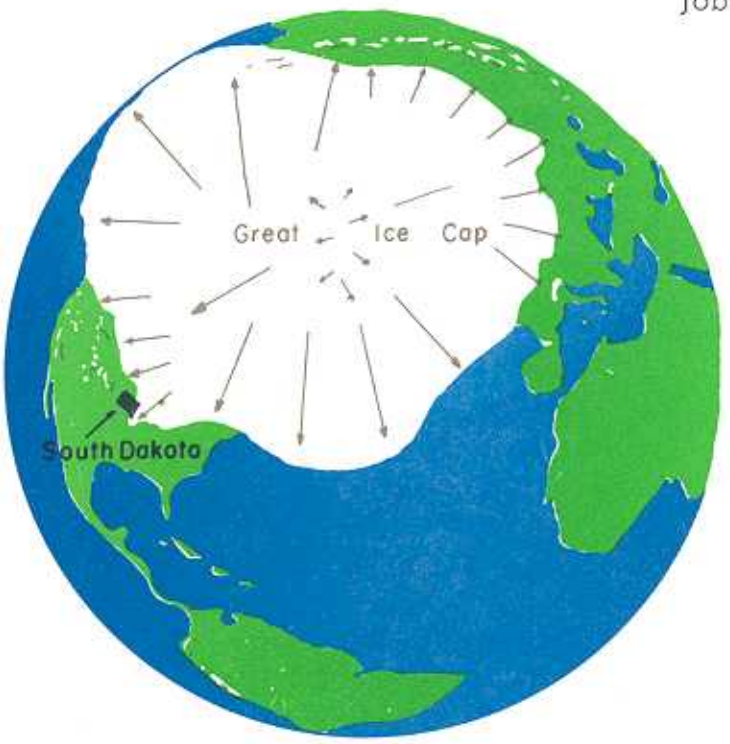


Eohippus or "Dawn Horse"

museum of geology housed at the South Dakota School of Mines and Technology in Rapid City. Those people who have not been in this museum and if they are in the Rapid City area should avail themselves of the opportunity to spend a few hours going through the excellent mineral and fossil collection on exhibit there.

Out of whose womb came the ice
And the hoary frost of heaven, who hath gendered it?
The waters are hid as with a stone,
And the face of the deep is frozen.

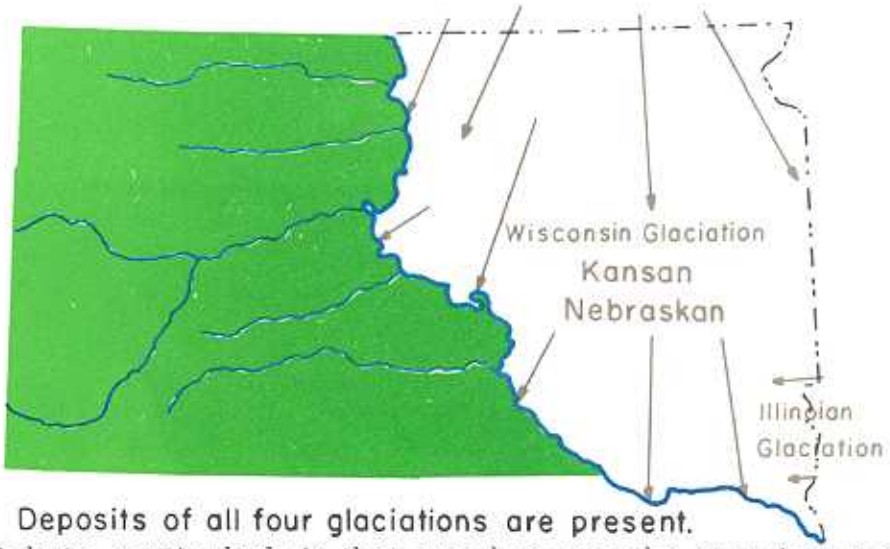
Job (1520 B. C.)



The ice first accumulated in Canada.

A climatic change took place later in the Cenozoic in which the air became cooled and ice began to form on land. This period of time has come to be known as the Pleistocene or the Great Ice Age, and began about 600 million years ago. The ice first accumulated in Canada and when it became sufficiently thick, over a large geographic area, the ice, now a glacier, began to move southward.

From studies made throughout the world, geologists know that four major periods of glaciation took place, each of which was followed by an interglacial period. Between glaciations, the climate was warmed, soils formed, and animal and plant life invaded the area.



Deposits of all four glaciations are present.

In South Dakota, particularly in that area known as the east river area, it is believed that deposits of all four glaciations are present. However, only deposits of Illinoian and Wisconsin are identified with certainty.

Glacial deposits, collectively called drift, range in composition from clean, uniform sized clays, sand and gravel, to a hodgepodge mixture of clays, sand, gravel and boulders.

Located near Sioux Falls, South Dakota, one can enter another imaginative elevator that sits on the Precambrian Sioux Quartzite. As one begins the ascent upward, the first material seen is unconsolidated rock derived from the weathering of the Precambrian Sioux Quartzite. It is difficult or next to impossible to divide a sequence of glacial deposits into respective age relationships. Because the material is unconsolidated, it has a tendency to cave, and thus representative samples at a precise depth cannot be obtained. Age relationships are based chiefly on observations and collections made at surface exposures in natural and artificial cuts. Age determinations are made chiefly by radioactive material such as wood and plant remains. Fossil snails are also used in age determination.

Proceeding upward from the weathered quartzite material at the 70-foot level, a dark-gray clay containing numerous pebbles of quartzite is seen up to the 47-foot level. Above this to the 25-foot level, more clay lighter in color and containing numerous pebbles, but not as many quartzite ones, is noted. Up to the 19-foot level is a coarse sand intermixed with gravel. A gray clay containing numerous pebbles is seen up to the 14-foot level, which in turn is overlain by gravel to the 8-foot level. A clay and sandy soil is seen from the 8-foot level to the surface.

Undoubtedly these deposits represent the invasion of ice into South Dakota, and whether or not we can break them down into more than one ice advance must be determined by further studies of the deposits, particularly where they are exposed at the surface. From our knowledge to date, we believe that these deposits at this location are of Wisconsin age, and represent the material laid down as a result of the melting of the last glacial ice.

'Say when, and whence, and how, huge Mister Boulder,
And by what wond'rous force hast thou been rolled here?
Has some strong torrent driven thee from afar,
Or hast thou ridden on an icy car?
Which, from its native rock once torn like thee,
Has floundered many a mile throughout the sea,
And stranded thee at last upon this earth,
So distant from thy primal place of birth,....'

Quoted by North, E. J., 1943, Centenary of the glacial theory: Proc. Geol. Assoc. v. 54, p. 21.

MAN'S DOMINION

Thus He dwells in all,
From life's minute beginnings, up at last
To man--the consummation of this scheme
Of being, the completion of this sphere
Of life: whose attributes had here and there
Been scattered o'er the visible world before,
Asking to be combined, dim fragments meant
To be united in some wondrous whole,
Imperfect qualities throughout creation,
Suggesting some one creature yet to make,
Some point where all those scattered rays should meet
Convergent in the faculties of man.

Browning, "Paracelsus"

Man has within his domain the world. The mental capacity of man now dominates the whole of the organic world and to man all creation is more or less subservient to him. Through technology man is able to control his environment. His future progress thus becomes dependent upon himself and upon whether he will learn to control his activities for the total benefit of human society.

As to man's future, the poet Browning sums it up very nicely by writing,

> The morn has enterprise, deep quiet droops
> With evening, triumph takes the sunset hour,
> Voluptuous transport ripens with the corn
> Beneath a warm moon like a happy face:
> --And this to fill us with regard for man,
> With apprehension of his passing worth,
> Desire to work his proper nature out,
> And ascertain his rank and final place,
> For these things tend still upward, progress is
> The law of life, man is not Man as yet.
> Nor shall I deem his object served, his end
> Attained, his genuine strength put fairly forth,
> While only here and there a star dispels
> The darkness, here and there a towering mind
> O'erlooks its prostrate fellows; when the host
> Is out at once to the despair of night,
> When all mankind alike is perfected,
> Equal in full-blown powers--then, not till then,
> I say, begins man's general infancy.
> For wherefore make account of feverish starts
> Of restless members of a dormant whole,
> Impatient nerves which quiver while the body
> Slumbers as in a grave? Oh long ago
> The brow was twitched, the tremulous lids astir,
> The peaceful mouth disturbed; half-uttered speech
> Ruffled the lip, and then the teeth were set,
> The breath drawn sharp, the strong right-hand clenched stronger,
> As it would pluck a lion by the jaw;
> The glorious creature laughed out even in sleep!
> But when full roused, each giant-limb awake,
> Each sinew strung, the great heart pulsing fast,
> He shall start up and stand on his own earth,
> Then shall his long triumphant march begin,
> Thence shall his being date,--thus wholly roused,
> What he achieves shall be set down to him.
> When all the race is perfected alike
> As man, that is; all tended to mankind,
> And, man produced, all has its end thus far.
> But in completed man begins anew
> A tendency to God.
>
> -- Browning, "Paracelsus"