ASTRO 101A

AN INTRODUCTION TO THE ICE AGES

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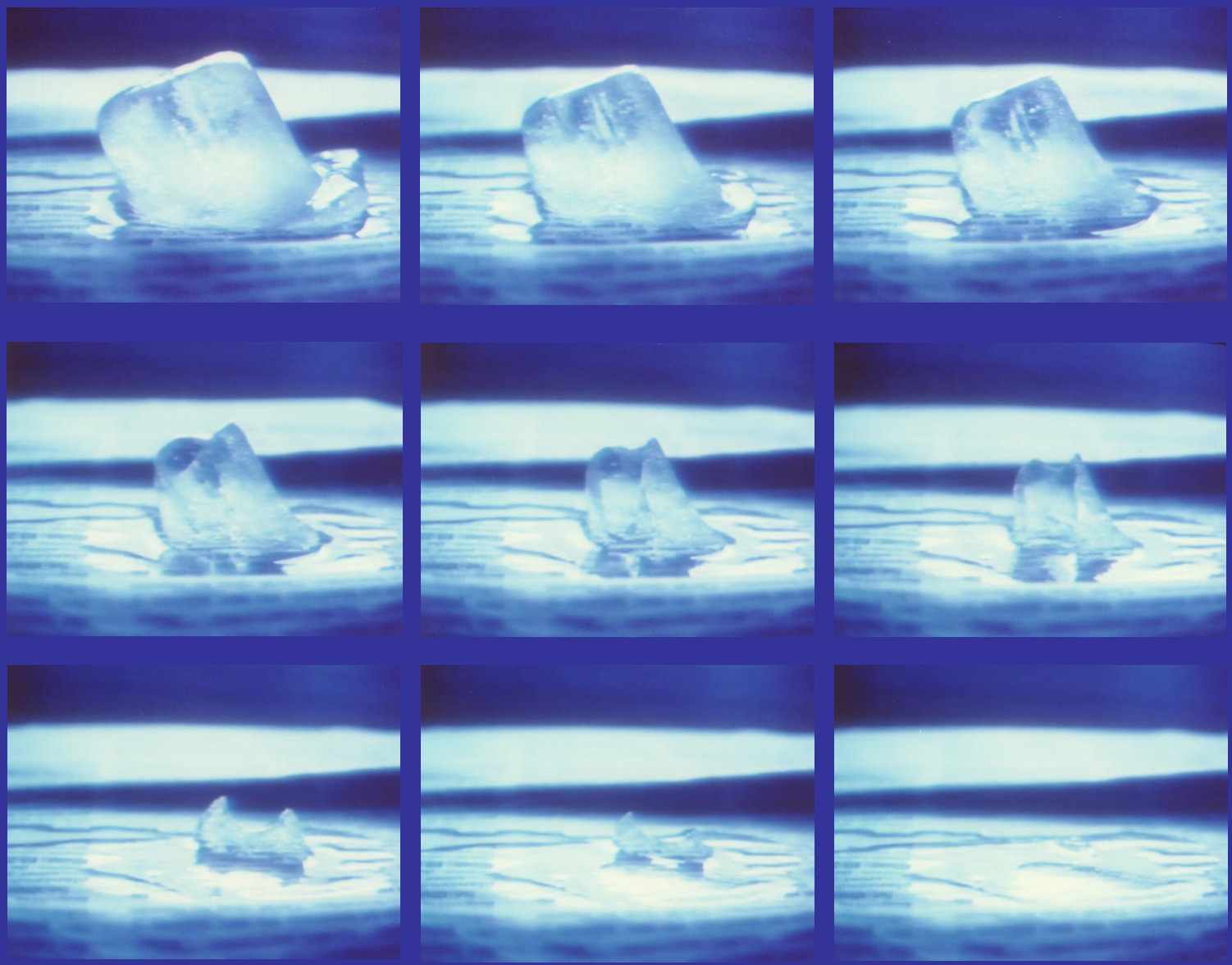

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Notes from the authors

This course is designed to introduce students to the basic idea of the astronomical aspects of the ice ages. It covers elementary explanations regarding the formation of ice ages and proceeds to present the evolution of the astronomical theories that describes the origination of ice ages.

Teachers should be aware that this is only a brief compilation of materials and that more supplementary details should be sought as an effort to enhance the student's learning.

A Sample Lesson Practices for Students is included in this teaching booklet. Each lesson has its unique set of questions that students should attempt to further understand the material. Teachers could reproduce these quizzes at their convenience if they so choose. However, please be aware that this Sample is by no means exhaustive. A sample answer key is attached separately in the following section. A supplementary section at the end of this teaching booklet serves to equip students with general knowledge that are relevant to ice ages but of no astronomical significance.

This course package also comes with a complementary compact disc (CD) containing essential multimedia illustrations designed to facilitate learning. Instructions to refer to the program are put as footnotes in this teaching booklet. A multimedia version of the Sample Lesson Quizzes for Students is also available in this CD.

The authors hope to make learning as fun an experience as possible. Suggestions for improvement and any kind of feedback are welcome. Please email your comments to ice_age@astro.com.

Sincerely,
The Authors.

Thank-yous from the Authors

The authors would like to express their utter appreciation to all those who have contributed to make this course package possible. The compilation process was greatly facilitated by these contributors, and the authors sincerely thank them for all their effort. The authors would also like to think their family members for their support and patience during the long working hours.

Forever Indebted,
The Authors.

RECOMMENDED LESSON PLAN AND CONTENTS

TOPIC 1: THE DISCOVERY OF ICE AGES

Lesson 1: The Formulation of Glacial Theory

Learning Objective: To acquaint students with the history of the discovery of the ice age and the origination of the glacial theory.

Formulation of Glacial Theory

It all started with Jean-Pierre Perraudin, a mountaineer from the southern Swiss Alps. Through his own observations, he came to a conclusion as early as 1815 that glaciers, which then occupied only the higher, southern portion of the Val de Bagnes, had once filled the entire valley. He deduced that the marks or scars occurring on hard rocks were caused by the pressure or weight of the glaciers.

Fig. 1

Fig. 2

Pictures of Val de Bagnes.

*(Pictures courtesy of **www.ccrt.ch/archivestv/ 020901unamourdemontagne.html**)*

Perraudin found an ear in Ignace Venetz, a highway and bridge engineer, who was slow to accept Perraudin's theory until 1829. He fully developed the ideas he had gleaned from Perraudin at the annual meeting of the Society at the Hospice of the Great St. Bernard. This was met with many rejections from scientists. At that time, the accepted explanation of erratics as the deposit of a great flood was deeply entrenched. Some other scientists investigated into the matter, notably, Jean de Charpentier, a naturalist who eventually gave the glacial theory an unshakeable foothold in scientific fact by organizing and classifying the evidence that supported it. Charpentier then convinced a fellow naturalist Louis Agassiz. Agassiz developed the famous "Agassiz' Discourse" that successfully aroused strong emotions among supporters and debaters of the glacier theory.

Glacial Theory

It was commonly believed that the history of the earth was divided into several epochs, each one of which had terminated in a catastrophe powerful enough to deform existing layers of sediment and rock, set off floods of incredible magnitude, uplift mountains, and to destroy all plant and animal life on the planet. At the beginning of each succeeding epoch, new life was breathed into the ravaged world. And this life would survive only until the next great cataclysm occurred.

Agassiz himself supported the idea of catastrophism, but challenged the nature of the last great catastrophe, which he believed was not a flood but an ice age.

In 1821, a number of strange bones were discovered in a cavern in the Vale of Pickering. Reverend William Buckland of England, a strong supporter of the flood theory, traveled to Yorkshire to investigate. He concluded that the cavern was an antediluvian hyena den that had been submerged in Noah's flood. He argued that the manner in which the bones are covered in silt indicated that the animals are drowned. From the quantity of post-diluvian stalagmites that had covered the floor of the cavern, he judged that the flood had occurred 5000 or 6000 years ago.

However, other features of the diluvium were not as easily explained. Erratic boulders, the size of small houses, had been transported from their original locations hundreds of miles away. In addition, scratches and grooves[1] displayed by the bedrock surface underlying these deposits, and the unsorted nature of the deposits themselves were puzzling. Buckland was the first to admit that neither Lyell's iceberg-drift theory nor the classical diluvial theory could provide explanations for all of the evidence.

On a field trip to study drift in Scotland and northern England in 1840, Buckland was finally convinced by Agassiz about the glacial theory. It was only another twenty years later that majority of British geologists had accepted the ice-age theory.

After careful examination of later geological evidences, geologists recognized the significance of the glacial theory. Many scientists thus set out to postulate the cause of ice ages.

Glacial ice was formed by the piling up layer after layer of snow. When this pile grew thicker than about 100 feet, the sheer weight of the snow converted the bottom layers to ice. This ice then flowed sluggishly downhill, picking up loose

[1] **Topic One → A scratch rock pavement.**

material in its path and breaking off and assimilating huge chunks of solid bedrock. Stones and boulders that were frozen into the lowest layer of the glacier smooth and polish, and sometimes scratch the rock pavement over which the ice move.

For any given climate, a glacier will maintain a certain size. When the climate warms, the glacial margin seeks a new equilibrium position. In the case of an ice sheet, the equilibrium position is towards the centre of the sheet.

There were strong hints that the earth was glaciated several times before[2]. Sustained intervals of warm climate intervened between the glacial ages. In 1863, Scottish geologist Archibald Geikie argued that plant fragments found between layers of Scottish tills were clear evidence that this happened. Therefore, by 1875, geologists concluded that there had been a succession of ice ages, each separated by warmer, interglacial ages similar to the present one.

Vocabulary

Glaciers	: A huge mass of ice slowly flowing over a land mass, formed from compacted snow in an area where snow accumulation exceeds melting and sublimation
Antediluvian	: Bible. Occurring or belonging to the era before the Flood.
Postdiluvian	: Existing or occurring after the Flood
Diluvian	: Of, relating to, or produced by a flood.
Staglamite	: A conical mineral deposit, usually calcite or aragonite, built up on the floor of a cavern, formed from the dripping of mineral-rich water.

[2] **Topic One → Evidence of multiple Ice Ages.**

TOPIC 2: EARLY ASTRONOMICAL EXPLANATIONS FOR ICE AGES

Lesson 2: Early Refuted Theories

Learning Objectives: To familiarize students with early theories and the reasons leading to their refutation. This would also provide students some idea of scientific processes to formulating a theory.

Early Attempts at Explaining Ice Age

Early Theory 1: Solar Theory

According to the solar theory, ice age may be a result of a decrease in the amount of energy given out by the sun. The sun powers the climatic condition; hence, a drastic fall in the amount of sun's radiation will bring about ice age. However, there has not been any substantial evidence to prove that a significant decrease in the amount of radiation released by the sun occurred during any ice age. Observations in the past have shown that the number of sunspots was correlated with changes in rainfall and temperature. In addition, small advances of valley glaciers in mountainous regions were correlated with changes in solar activity. However, such observations were not sufficient to prove that solar fluctuations were the cause of ice ages.

Early Theory 2: Dust Particles Theory

The dust particles theory states that the uneven distribution of dust particles in space brought about the climatic changes that set off an ice age. One version of this theory suggests that when the sun passed through an area filled with dust particles, much of the sun's energy is screened out to produce a cooling trend. Another version of this story suggests that when more dust particles fall into the sun; it glowed more brightly, thus bringing about a rise in temperature. However, to date, astronomers have been unable to accurately predict how the concentration of dust particles between the sun and the earth has changed over the course of the geologic history. This leads one to question the validity of the dust particles theory.

Vocabulary

Sunspot : Any of the relatively cool dark spots appearing periodically in groups on the surface of the sun that are associated with strong magnetic fields

Lesson 3: Adhémar's Explanation

Learning Objective: To introduce to students the earliest form of the present-day astronomical explanation for ice ages.

Birth of the Astronomical Theory

Joseph Alphonse Adhémar, a mathematician tutor in Paris, was that first to suggest that the main cause of ice age was a result of variations in the way the movement of the earth around the sun. He argued that the southern hemisphere had more hours of darkness each year than daylight. Therefore, it followed that the southern hemisphere must be getting colder. Evidence for this could be seen in the Antarctic Ice Sheet in the southern hemisphere[3].

Yet, Adhémar felt that in the past, ice age should have also occurred in the northern hemisphere. His theory was based on the fact that over long periods of time, variations occurred in the direction of the earth's axis. The evidence was seen from the way the North Pole does not always point in the same directions. Instead, the axis of rotation moved in such a way that the North Pole appeared to be drawing a circle in space. This movement was known as precession of the equinox[4].

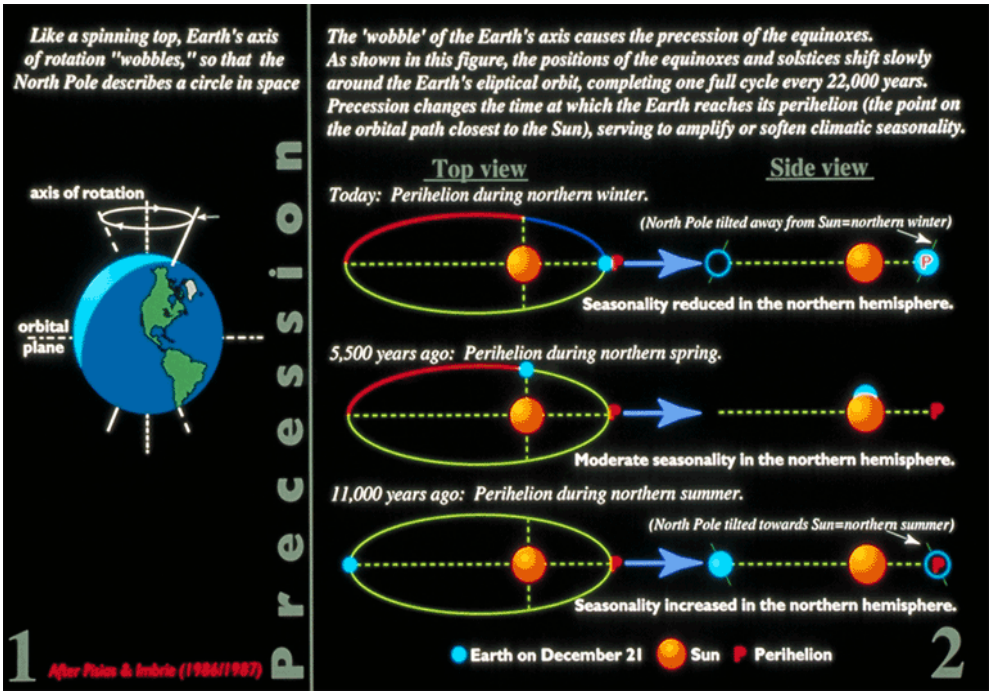

Fig. 3

Picture taken from http://www.ngdc.noaa.gov/paleo/slides/slideset/11/11_184_bslide.html

[3] **Topic 2 → Evidence of an Ice Age**
[4] **Topic 2 → Precession of the equinox**

The precession of the equinox was a slow occurring process. It took 26 000 years before the axis moved back to the same point on the circle. Precession occurred as a result of the gravitational pull that the sun and moon exert on the earth's equatorial bulge. This causes the movement of the four cardinal points (solstices and equinoxes) on the earth's orbit to move slowly along the orbital path. The movement of the four cardinal points was in a clockwise direction, as seen from the North Pole. The clockwise rotation of the four cardinal points, together with the counterclockwise rotating elliptical orbit resulted in shifts in the cardinal plane along the orbit. The shifts represented the climatic effect of the precession of the equinox. The shifting of the equinox along the orbit, as a result of the two combined effects, completes a cycle every 22 000 years.

Adhémar theorized that glacial climate occurred as a result of this 22 000 years cycle, and that the hemisphere with a longer winter would experience ice age. Every 11 000 years, an ice age would occur in alternating hemisphere (see Fig. 3 for detail).

Adhémar claimed that the gravitational attraction of the Antarctic Ice Sheet was large enough to drain water from the northern hemisphere, and create a sea level bulge in the southern hemisphere. As temperature in the southern hemisphere rises, the Antarctic Ice Cap would melt. This would cause the entire Ice Sheet to collapse into the sea, thus creating a huge iceberg-laden tidal.

Criticisms

Yet, convincing as Adhémar's theory might be, there were still criticisms to his theory. One such critic came from Baron Alexander von Humbolt. He felt the average temperature of both hemispheres was controlled by the amount of solar energy received by the earth each year. It was not decided by the number of hours of darkness and daylight. Furthermore, it was discovered that the real reason behind the increased coldness of the southern hemisphere was a result of its location. The Antarctic continent in the southern hemisphere was located far from the warm ocean currents. As a result, the continent was cold enough to support a permanent ice sheet. The ice sheet resulted in lowering of temperature in the region by reflecting large amounts of solar energy back into space.

Vocabulary

Precession	: (i) Precession of the equinoxes. (ii) A slow gyration of the earth's axis around the pole of the ecliptic, caused mainly by the gravitational pull of the sun, moon, and other planets on the earth's equatorial bulge.
Equinox	: (i)Either of two points on the celestial sphere at which the ecliptic intersects the celestial equator. (ii) Either of the two times during a year when the sun crosses the celestial equator and when the length of day and night are approximately equal; the vernal equinox or the autumnal equinox.
Cardinal Points	: (i) (Geol.) The four principal points of the compass, or intersections of the horizon with the meridian and the prime vertical circle, north, south east, and west. (ii) (Astrol.) The rising and setting of the sun, the zenith and nadir.

TOPIC 3: THE CONTRIBUTION OF JAMES CROLL

Lesson 4: James Croll's Astronomical Theory

Lesson Objective: To provide students with in-depth knowledge of the evolution of astronomical ice-age theory and the significance of the development of James Croll's theory.

James Croll's Background:

The next person who tried to formulate and build upon an astronomical theory of the ice ages was James Croll[5]. Born into modest surroundings on the farm of Little Whitefield, near Wolfhill (Perth and Kinross), Croll was largely self-educated through a passion for reading. He became an apprentice wheelwright at Collace, but gave that up due to ill-health. He was then, successively, a tea merchant in Elgin, manager of a temperence hotel in Blairgowrie and an insurance agent in Edinburgh and Glasgow, before being appointed as a janitor in the museum at Anderson's Institution (Glasgow) in 1859.

Fig. 4

http://www.ngdc.noaa.gov/paleo/slides/slideset/11/11_182_slide.html

Croll corresponded with Sir Charles Lyell, sending his ideas of links between ice ages and variations in the earth's orbit. This gained Croll a clerical position in the Geological Survey of Scotland. Later, Charles Darwin also corresponded with Croll and benefited from his ideas.

James Croll's Astronomical Theory

In 1867, James Croll compiled information from a variety of sources – including Adhémar's theory of seasonal precession. His work led to the development

[5] **Topic 3 → James Croll**

of a sound astronomical theory supporting the idea of cyclical ice ages. Croll's goal was to geologically predict when ice ages would occur and to explain the mechanism that caused them. .

Building upon Adhemer's focus on the precession[6] of the equinox, Croll proposed 2 more ideas to explain his theory that the ice ages were a result of the earth's changing orbital pattern around the sun – eccentricity[7] and obliquity[8]. His first thought was that gradual changes in earth's orbital eccentricity (more elliptical than circular) might be responsible. He proposed that a gradual change to a more severe ellipse might result in less overall light and heat – sort of like walking further away from a flashlight. The effect turned out to be very small. After additional research he further predicted that cyclical changes in the earth's precession will also cause tiny changes in our relative tilt (obliquity) toward the sun. This in turn would affect the amount of solar energy that the Earth received.

Eccentricity of the Earth's Orbit

Croll proposed that the disturbances of the Earth as a planet by the moon and the sun cause a periodic shift in the eccentricity of the Earth's orbit between 1%(more circular) to 6% (more elliptical). The shift has a period of a little more than 21,000 years. This shift affects the distribution of solar heat received by the Earth, though it does not affect the total amount received. The result will be that any given point at high latitude in the northern hemisphere will be affected accordingly.

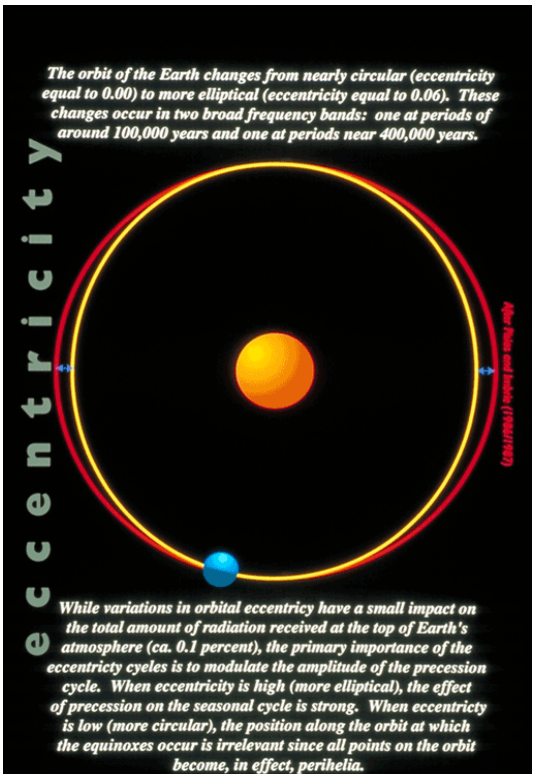

Fig. 5
http://www.ngdc.noaa.gov/paleo/slides/slideset/11/11_185_bslide.html

James Croll proposed that this eccentricity was important and that when combined with precession, it could cause an ice age. He decided that winter in the

[6] **Topic 3 → Precession of the Equinox**
[7] **Topic 3 → Eccentricity**
[8] **Topic 3 → Obliquity**

northern hemisphere was the important season. His idea was that when eccentricity was high and precession caused winter in the northern hemisphere to fall on the farthest point of the orbit, there were very cold winters and an ice age would begin in the northern hemisphere.

Taking together both the precession of the equinoxes and the eccentricity changes into account, Croll concluded that the occurrence of ice glacier alternated between the hemispheres when the orbit was highly eccentric and inter-glacials (little or no ice) occurred during periods of low eccentricity.

Obliquity of the Earth's Axis

In 1875, Croll published a paper entitled "Climate in Time" where he predicted that as a result of the cyclical changes in the earth's precession, a wobble effect is created giving rise to tiny changes in our relative tilt (obliquity) towards the sun. It is this inclination of the Earth's axis that causes the main difference in temperature between polar and equatorial regions. The Sun's rays striking the Earth obliquely are forced to pass through a much greater thickness of atmosphere, thus dissipating their warming effect, than those rays that strike in a more perpendicular direction and are thus required to penetrate a lesser amount of the atmosphere. Less tilt equals less light at the poles annually (according to Isaac Newton's Theory of Radiation) and causes a predisposition toward an ice age. The angle of this tilt is currently at 23.5° but was proposed by Croll to be a cyclical variation between 22° to 24.5°.

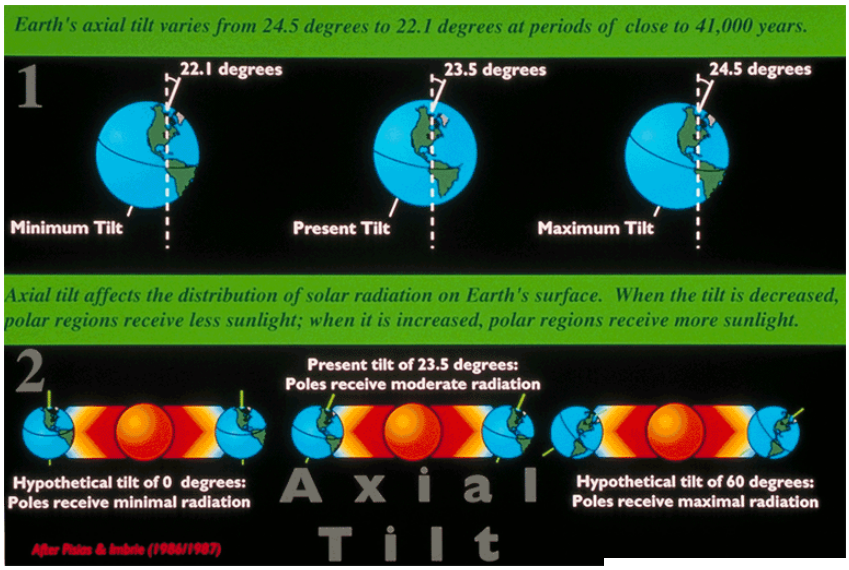

Fig. 6 *http://www.ngdc.noaa.gov/paleo/slides/slideset/11/11_183_bslide.html*

TOPIC 3: THE CONTRIBUTION OF
JAMES CROLL

Vocabulary

Eccentricity	: (i) The ratio of the distance of the center of the orbit of a heavenly body from the center of the body round which it revolves to the semi-transverse axis of the orbit.
Obliquity	: (i) The angle of tilt of the earth's axis of rotation.
Interglacial	: (i) A comparatively short period of warmth characterized by the absence of glaciers during an overall period of glaciation

Lesson 5: Debates over Croll's Explanation

Lesson Objective: To make students aware of the shortcomings and insufficiencies of James Croll's theory that leads to the overthrowing of this theory.

Many observers pointed to several key factors which discredited Croll's theory. These objections can be summarized by the following points:

- Croll's theory of the changing obliquity of the Earth was largely hampered by a lack of data available. He was aware of the changes in the earth's tilt but had no means of quantifying it and he did not know the period of this change. Croll died before any of his observations could be verified.

- Croll's theory of alternating glacial activity between the 2 hemispheres was not confirmed by geological evidence. Observers at that time proposed that southern hemisphere glaciers may actually be in phase with that in the northern hemisphere and ice ages did not occur alternately in one hemisphere and then in the other one. We now know that the glaciations were simultaneous in both hemispheres and did not alternate between hemispheres (but this was not known in the last century).

- Meteorologists found that the variations in solar heating described by Croll were far too small to have any noticeable effect on climate or bring about an ice age. Because of this, Croll had to further hypothesize that the climate system magnified these changes internally either by changing ocean currents or through the Ice Albedo feedback (another theory he proposed)

- Croll predicted that an ice age (a markedly elongate orbit and a winter solstice that occurs far from the sun) occurred about 250,000 years ago and ended about 80,000 years ago. However, geological evidence showed that the last glacial period ended not 80,000 years ago but around 6,000 to 10,000 years ago, as his theory would have it.

All these observations resulted in Jame's Croll's theory falling out of favour. However, even though Croll's theory was not correct, he had laid the groundwork for the 3 elements that were necessary for a successful astronomical theory of the Ice Ages – precession, eccentricity and obliquity. As we shall see in the next chapter, it would be the work of a Serbian mathematician Milutin Milankovitch to modify and unite all of these into one theory.

Vocabulary

Ice Albedo Feedback	: Croll's hypothesis of a positive feedback mechanism: cold winters lead to permanent snow fields at high latitudes. These produced even greater cooling by reflecting more sunlight and resulted in changes in atmospheric circulation.

TOPIC 4: THE ASTRONOMICAL THEORY OF MILANKOVITCH

Lesson 6: Milankovitch's Approach to Solution

Lesson Objective: To provide students with the background works of Milankovitch that lead to the formulation of his theory, and the detailed description of this theory.

http://www.ngdc.noaa.gov/paleo/slides/slideset/11/11_186_slide.html

Early Beginnings

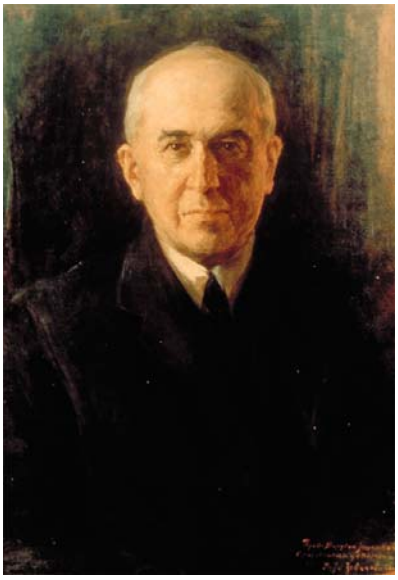

Fig. 7

Originally an engineer, Milankovitch[9] longed for a cosmic challenge of his lifetime. As he took up the position to teach applied mathematics in the University of Belgrade, he had decided on the goal worthy of his talent and life-long devotion – to develop a mathematical theory capable of describing the present, as well as the past, climates of Earth, Mars, and Venus. Though it seemed puzzling to many of his colleagues to have such an ambition, Milankovitch considered theoretical calculations the only means to investigate temperatures in areas beyond the reach of direct observations. To him, knowing the principles of temperature variations on Earth would shed light on the climates of other planets. In addition, the calculations done for the present climates of the planets also would provide a method to describe the climates in the past. He felt that the new theory would "make it possible for us to cross the boundaries of our direct observations in both time and space" (quoted in Imbrie & Imbrie, 1979, p. 99).

He first familiarized himself with what other researchers had done with regards to this topic and soon discovered that no one had accomplished what he set out to do. Current astronomers had only gone as far as determining the past and present shapes of the planetary orbits but not the distribution of radiation over the surfaces of the wobbling, tilting planets. Although James Croll had previously discussed extensively the effects of orbital variation on climate, he did not have the sufficient mathematical background to quantify the magnitude of these effects. Having realizing this, Milankovitch set course for his proposal that would take him 30 years to complete.

[9] **Topic 4 → Milutin Milankovitch**

The Process: Stage I

First of all he described the geometry of each planet's orbit and showed how the geometry had evolved over the past centuries. He found, just as Croll had before him, that three orbital properties determine the distribution of the sun's radiation over the surfaces of planets: the eccentricity of the orbit, the tilt of the axis of rotation, and the position of the equinoxes in their precession cycle. However, he had available the necessary astronomical calculations completed by the German mathematician Ludwig Pilgrim, something absent during Croll's similar quest. Pilgrim's calculations included the variations in all 3 key properties (eccentricity, tilt, and precession)[10] over the past 1 million years. Therefore Milankovitch had achieved his description of the orbits quite effortlessly.

The Process: Stage II

He then proceeded to calculate the amount of solar radiation striking the surface of each planet during each season at each latitude. Two centuries earlier, Isaac Newton[11] had deduced the factors affecting the planets' reception of solar radiation: the distance from the sun and the angle at which the sun's rays strike at particular parts of planet's surface. Since these factors can be deduced from Pilgrim's results, Milankovitch thought it was possible to mathematically describe the distribution of solar radiation onto the surface of the planets. He published his progress, demonstrating that the variations in orbital eccentricity and axial precession are large enough to cause ice sheets to expand and contract. He also showed that the climatic effect of the variations in the angle of tilt were even more profound than Croll had suggested. A few years later, he had successfully obtained the mathematical description of the present climates on Earth, Mars and Venus. The results demonstrated that astronomical variations were sufficient to incur ice ages by changing the geographic and seasonal distribution of sunlight. Furthermore, Milankovitch claimed that it would be possible to calculate the amount of sunlight reaching Earth for anytime in the past.

[10] **Topic 4 →The three orbital properties**
[11] **Topic 4 → Isaac Newton**

The Process: Stage III

His next objective would be a mathematical description of Earth's past climates. He claimed to be able to accomplish this by drawing a curve[12] that would show the variations in radiation responsible for the succession of ice ages. But different circle of latitude at each season had a unique radiation history; Milankovitch therefore was facing the problem of distinguishing the latitude and season critical to the growth of ice sheets. According to some previous views, it was assumed that ice ages were triggered when the amount of radiation[13] received by Arctic regions was diminished in the winter period. However, Milankovitch thought that it was the diminishing heat during the summer period that is the decisive factor in glaciations. During winter, the change in radiation has small effect because the Arctic regions are cold enough for snow to accumulate even in present day. But during summer, present-day glaciers melt, therefore any decrease in the summer radiation would prevent melting, leading to an overall positive annual growth of the ice sheet and thus glacial expansion.

Milankovitch generated curves for latitudes 55^{o}, 60^{o}, and 65^{o} showing the variation of summer radiation for the past 600,000 years. He identified certain low points on the curves with the four known European ice ages. The publication of these curves was the landmark for geologists to understand the influence of 2 of the astronomical cycles on the pattern of incoming solar radiation. As Croll had foretold, a decrease in axial tilt causes a decrease in summer radiation and a decrease in the Earth-Sun distance at any season causes an increase in radiation at that season. With the addition of Milankovitch's results, it was clear that the degree of these effects varied systematically with latitude.

The tilt cycle, the oscillation of the inclination of Earth's axis with a period of 41,000 years, has a greater influence at the poles than at the equator. In contrast, the precession cycle, the 22,000-year oscillation of the Earth-Sun distance, has a smaller influence at the poles than at the equator. At any latitude and season, the amount of radiation received depends on the tilt angle and the Earth-Sun distance, therefore the shape of the radiation curve generated varies systematically from pole to equator. That is, the high-latitude curves are dominated by the 41,000-year tilt cycle, and the low-latitude curves are dominated by the 22,000-year precession cycle.

[12] **Topic 4 → Milankovitch's Radiation Curves**
[13] **Topic 4 → Radiation Charts**

The Process: Final Stage

Milankovitch's final step to his theory was to determine the response of ice sheets to changes in solar radiation. The main difficulty was estimating the importance of the feedback mechanism. This mechanism, in essence, works in such a way that amplifies any initial change in radiation by reflecting solar radiation (the amount of reflection depends on the initial size of the ice sheets). So far all attempts to quantitative analysis of this mechanism had failed. Milankovitch studied the altitude of snowline (the elevation above which there is at least some snow all year round) and formulated a mathematical relationship between summer radiation and the altitude of the snowline, thus determining the amount of increase in snow cover resulting from any change in summer radiation.

In 1941, Milankovitch completed his mathematical theory of radiation. He had applied his theory to the ice-age problem, with the emphasis on the effects of the tilt cycle and precession cycle.

Vocabulary

Cosmic	: Of or relating to the universe, especially as distinct from Earth
Eccentricity	: The ratio of the distance of the center of the orbit of a heavenly body from the center of the body round which it revolves to the semi-transverse axis of the orbit; ("a circle is an ellipse with zero eccentricity").
Orbit	: The path of a celestial body or an artificial satellite as it revolves around another body
Latitude	: The angular distance of a celestial body north or south of the ecliptic
Altitude	: The angular distance of a celestial object above the horizon

Lesson 7: The Controversy Surrounding The Milankovitch Theory

Learning Objective: To make students aware of the debates over the Milankovitch theory, and the reasons contributing to those debates.

With the publication of the Milankovitch theory, scientists once again focused on the ice-age problem. This theory was the one the geologists needed to integrate the facts about ice ages and provide a comprehensive explanation to their occurrence. To the scientific world, this theory's most valuable feature was that it was testable. It predicted how many ice-age deposits geologists would find and pinpointed the time these deposits were formed during the past 650,000 years.

The controversy arose with the gathering of more detailed geological facts from soil and fossils, especially among the American geologists. Further protests against the Milankovitch theory were from meteorologists, claiming that this theory ignored the role of the atmosphere and the ocean in heat transport. Others found inconsistencies in some of the calculations published by Milankovitch, which Milankovitch himself could not explain, e.g. in theory, temperatures in winter were calculated to have averaged 0.7^{o}C warmer than today.

Furthermore, the development of radiocarbon dating method[14] for dating fossils made most geologists reject Milankovitch's astronomical theory. The presence of fossils of relatively warm temperature coincided with the ice age that Milankovitch predicted and were found at numerous locations. Geological evidence dated by radiocarbon dating suggested time periods for different ice ages conflicting with the time periods concluded by Milankovitch's astronomical theory. By 1965, this theory of the ice ages had lost most of its supporters.

Vocabulary

Radiocarbon Dating Method : Dating the age of an organic matter by detecting its radioactive carbon content. Radioactive form of carbon is produced in small quantities in the atmosphere by cosmic rays. These radiocarbon atoms can be absorbed into the bodies of all living plants and animals. But organisms continue to acquire radiocarbon only as long as they live. After death, the organic tissues disintegrate, changing into inert atoms of nitrogen at a rate that can be measured. This rate is used to calculate the time of death for any fossils less than 40,000 years old (the half life of radiocarbons).

[14] **Topic 4 → Radiocarbon Dating Method**

Lesson 8: The Milankovitch Revival

Lesson Objective: To show students that scientific theories depend on the evidence discovered and that the Milankovitch theory does provide a good astronomical basis of explaining the ice ages.

Although the shorelines suggested the periodic oscillation of sea lever due to the melting and growth of ice sheets, they were qualitative and inconclusive as to which cycle this period of oscillation corresponded to. And because of the limitation of radiocarbon dating, the time period of these shorelines could not be determined. A new dating method was clearly called for. Thorium dating method was proven to be an accurate means to determine the age of sea levels. This method dated high sea levels that corresponded well with the maxima in Milankovitch's radiation curve.

In addition, because of the new geological evidences collected, geologists turned to focus on the radiation curves of lower latitudes as opposed to the higher latitudes from before, which were influenced by the 22,000-year precession cycle significantly enough to modulate the effect of the tilt cycle. This suggested that the precession cycle was more important than Milankovitch had believed. It was shown that the astronomical theory could account for the high sea level (the interglacial period) if modified to place more emphasis on the precession effect.

However, by the 1970s, the isotopic records[15] of the new geological evidences revealed a 100,000-year climatic cycle as well, something entirely absent from the Milankovitch theory. The dominant periodicity of Milankovitch's radiation curve was that of the tilt cycle – 41,000 years. Fortunately, Kenneth Mesolella at Brown University and George Kukla in Czechoslovakia found ways to modify the Milankovitch theory to account for the 100,000-year cycle by pointing out the dominant cycle in the eccentricity curves. They, too, emphasized the precession-cycle controlled intensity of radiation during any particular season, the amplitude of which is exactly proportional to eccentricity. When the orbit is unusually elongated, the contrast between seasons is correspondingly great. Therefore if the temperature during one particular season is critical to the expansion or retraction of ice sheets, the 100,000-year cycle must be reflected in the climatic record.

Most scientists up to this point were only convinced that the astronomical theory was correct it if could be shown that the small oscillations superimposed on

[15] **Topic 4 → The Isotopic Records**

the 100,000-year cycle were predicted by Milankovitch. If these shorter climatic cycles turned out to correspond to the 41,000-year cycle of axial tilt and to the 22,000-year cycle of precession, then the astronomical theory of the ice ages would be confirmed. However, this correspondence requires the climatic curves to be more detailed to exhibit the cycles. So the increasing accuracy of the geological time scale was inevitably important.

With the refinement of the geological time scale, it was shown that the smaller fluctuations in the climatic curve reflected the variations in the axial tilt and precession[16]. In addition to the 100,000-year cycle appearing as a dominant peak in the calculation, two smaller peaks were found to indicate the presence of climatic cycles about 40,000 and 20,000 years long. Further analysis, however, also showed 2 distinct precession cycles – a major one of a period of 23,000 years and a minor one of 19,000 years[17].

Vocabulary

Thorium Dating Method : Another radioactive dating method for fossils less than 150,000 years old. Therefore it is a more effective method for dating than radiocarbon method.

Amplitude : Greatness of size; magnitude.

[16] **Topic 4 →Variations – Tilt and Precession**
[17] **Topic 4 → Forecasting the Future**

Lesson 9: Conclusion

Lesson Objective: To provide the students with the final revision and the complete content of the Milankovitch theory for the ice ages.

An expanded version of the Astronomical theory developed by Mesolella and Kukla was therefore proposed by Hays, Imbrie and Shackleton in 1976: climatic oscillations occur as 4 distinct cycles – a 100,000-year cycle corresponding to variations in eccentricity, a 41,000-year cycle corresponding to variations in axial tilt, and 23,000- and 19,000-year cycles corresponding to variations in precession. This is supported by the spectrum of climatic variation over the past 500,000 years generated by the isotope records from the oceans.

If the astronomical theory were correct, it should be possible to discover how rapidly the ice sheets had responded to each type of astronomical variation. Climatic cycles should either occur simultaneously with the variation or followed regularly behind the variation. Filter analysis showed that the 41,000-year climatic cycle lagged behind tilt variations by about 8000 years; the 23,000-year climatic cycle lagged behind the precession variation systematically. These lags confirmed that variations in tilt and precession set the pace for climatic change.

Exactly how the motions of Earth in its orbit around the sun triggered the ice ages and why the 100,000-year cycle of orbital eccentricity appeared to so strongly impress on the climatic record of the last half-million years were still unknown. But for now Milankovitch had led the way to solving a major part of the ice-age mystery.

Vocabulary

Spectrum : A graphic or photographic representation of the distribution of a characteristic of a physical system or phenomenon.

TOPIC 5: THE FUTURE OF ICE AGES

Lesson 10: Predictions for the Future

Lesson Objective: To introduce to students different results of the predictions of the next ice age, and in doing so, show students that not only astronomy but other factors also contribute to the occurrence of ice ages.

Most scientists agree that Earth would experience another ice age, provided that there is no some fundamental and unforeseeable change in the climate system. What most geologists disagree on is the time when this upcoming ice age would occur. Some predict that the present interglacial age will last another 50,000 years while others believe that the ice age is already on its way, due within the next few centuries.

To a certain extent, the definition of the ice age needs to be clarified. What defines the *beginning* of an ice age? How extensive must an ice sheet be and how far must the global temperatures fall before the world is officially declared to be in an ice age? Viewpoints get rather subjective, depending on the location of the observer. An arbitrary definition is made on the basis of Pleistocene deposits in Central Europe. Interglacials begin with the arrival of deciduous trees and forests, and end when these trees are replaces by grassland. Thus ice ages end and begin accordingly.

Based on this definition, the present interglacial age began about 10,000 years ago. Statistical calculations based on the lengths of past interglacial periods predict the end of present interglacial within the next 2000 years. On the other hand, projections of current climatic trends into the future give another result. The gradual cooling of the present-day Earth makes the ice-age-equivalent global temperatures reachable in 18,000 years.

The astronomical theory of the ice ages provides a basis for forecasting the course of future climate, avoiding the uncertainties inherent in predictions based on trends. But the forecast is complicated by the fact that changes in eccentricity and tilt are now working to cool the climate, while the precession cycle is working to warm the climate. It turns out that the combined effects can be described mathematically. The cooling trend was calculated to have begun 7000 years ago and will continue into the future, leading to a maximum advance of the glaciers 23,000 years from now.

However potentially accurate this information, derived from astronomical theory, could be, the effect of climatic oscillations of much shorter period cannot be ignored. Many human activities undoubtedly influence climate, i.e. fossil fuel burning (pollution) contributing to global warming. This global warming, if continued, is likely to set Earth into a "super-interglacial age," melting away the Greenland and Antarctic ice caps, raising sea levels around the world etc. etc. Fortunately, the atmosphere eventually rids itself of the greenhouse gases. The long-term cooling cycles driven by changes in Earth's orbit would resume, and Earth would find itself going through the ice ages set apart by interglacial periods yet again every 23,000 years.

Vocabulary

Pleistocene : Of or pertaining to the epoch, or the deposits, from 11,000 to 2,000,000 years ago (following the Tertiary and immediately preceding man); extensive glaciation of northern hemisphere; time of human evolution.

Deciduous : Shedding or losing foliage at the end of the growing season.

SAMPLE LESSON PRACTICES FOR STUDENTS

PRACTICE 1

Lesson 1: The Formulation of Glacial Theory

Learning Objective: To acquaint students with the history of the discovery of the ice age and the origination of the glacial theory.

What you should know:

- **Formulation of Glacial Theory – Jean-Pierre Perraudin and his findings**
- **Flood Theory and criticisms**
- **Glacial Theory**

PRACTICE QUESTIONS

Please select True (T) or False (F) for each of the following questions (2 marks each).

1. Jean-Pierre Perraudin believed that glaciers had filled the entire valley of Val de Bagnes throughout history. T F

2. Jean-Pierre Perraudin had found that the marks or scars occurring on hard rocks were caused by the shape and size of the glaciers. T F

3. Glacier ice is formed by the piling of layers of snow, causing the bottom layers to be compacted into a chunk of ice. T F

4. When climatic conditions change, the size of glaciers changes. T F

5. The geologists do not believe that ice ages had ever occurred. T F

Your Grade	/ 10

PRACTICE 2

Lesson 2: Early Refuted Theories

Learning Objective: *To familiarize students with early theories and the reasons leading to their refutation. This would also provide students some idea of scientific processes to formulating a theory.*

What you should know:

- **Solar theory and how it works; its criticisms**
- **Dust particles theory and how it works; its criticisms**

PRACTICE QUESTIONS

For each of the following questions, please choose the correct answer (2 marks each).

1. According to (the) _____, ice age may be a result of a decrease in the amount of energy given out by the sun.

    a) glacier throey
    b) geologists
    c) solar theory
    d) astronomer's research

2. Past data showed that the number of sunspots is correlated with changes in _____ and _____.

    a) Light energy and motion of sun
    b) Pressure and heat
    c) Temperature and rainfall
    d) Impurities and light energy

3. Small advances of valley glaciers in mountainous regions have been found to be correlated with changes in _____.

    a) solar activity
    b) snow activity
    c) minute movements of glaciers
    d) movements of the plates of the earth's crust

4. The dust particles theory states that the _____ in space is brought about by climatic changes.

    a) amount of dust particles
    b) movement of dust particles
    c) uneven distribution of dust particles
    d) temperature changes

5. The concentration of dust particles between the sun and the earth can be easily determined _____.

    a) accurately
    b) using modern scientific and astronomical tools
    c) using results of the solar theory
    d) none of the above

Your Grade	/ 10

PRACTICE 3

Lesson 3: Adhémar's Explanation

Lesson Objective: *To introduce to students the earliest form of the present-day astronomical explanation for ice ages.*

What you should know:

- **Birth of the astronomical theory and its criticisms**

PRACTICE QUESTIONS

Please answer the following questions (2 marks each).

1. What did Joseph Alphonse Adhémar suggest was the main cause of ice age? What did he propose?

2. What was his theory based upon and why was it so?

3. What does "precession" mean? Why does it occur?

4. What is an "equinox"? Explain specifically its meaning in terms of (i) being a place (ii) being time.

5. Explain why the astronomical theory has been criticized. Do you think there are valid reasons?

Your Grade	/ 10

PRACTICE 4

Lesson 4: Croll's Astronomical Theory

Lesson Objective: *To provide students with in-depth knowledge of the evolution of astronomical ice-age theory and the significance of the development of James Croll's theory.*

What you should know:

- James Croll's Astronomical Theory – it's propositions and predictions.

PRACTICE QUESTIONS

For each of the following questions, please choose the correct answer (2 marks each).

1. Croll's goal was to geologically predict _____ and to explain the mechanism that caused them. .

    a) when ice ages would occur
    b) how ice ages occur
    c) the factors that contribute to ice ages
    d) how glaciers are formed

2. Croll's propositions were built upon Adhemer's focus on the _____

    a) composition of glaciers
    b) tilt of the earth's axis
    c) precession
    d) precession of the equinox

3. What 2 factors did Croll propose to be responsible for the ice ages?

    a) prescession and elliptical orbits
    b) eccentricity and obliquity
    c) altitude and weather
    d) amount of tilt of earth's axis and its tilt

4a. According to Croll, disturbances of the Earth as a planet by the moon and the sun cause a periodic shift in the _____ between being more circular to being more elliptical.

    a) earth's tilt
    b) shadow of the earth
    c) eccentricity of the Earth's orbit
    d) precession of the earth

4b. The shift in question (4a) has a period of around _____.

    a) 210 centuries
    b) 120 centuries
    c) 210 decades
    d) 120 decades

4c. This shift affects the _____ received by the Earth, though it does not affect the total amount received.

a) distribution of solar heat
b) amount of dust particles
c) amount of ice
d) distribution of glaciers

Your Grade	/12

PRACTICE 5

Lesson 5: Debates Over Croll's Explanation

Lesson Objective: To make students aware of the shortcomings and insufficiencies of James Croll's theory that leads to the overthrowing of this theory.

What you should know:

- Criticisms of James Croll's theory and their basis.

PRACTICE QUESTION

Write a short summary about the various factors that contributed to the criticisms of the James Croll's theory (Total: 10 marks).

Your Grade	/ 6

PRACTICE 6

Lesson 6: Milankovitch's Approach to Solution

Lesson Objective: *To provide students with the background works of Milankovitch that lead to the formulation of his theory, and the detailed description of this theory.*

What you should know:

- **Similarities/Differences between Milankovitch's and Croll's theories.**
- **Milankovitch's propositions; the various factors that led him to his findings.**

PRACTICE QUESTIONS

For each of the following questions, please choose the correct answer (2 marks each).

1. What similarities do the properties of Milankovitch's theory have in common with James Croll's theory?

   a) eccentricity of the orbit
   b) tilt of the axis of rotation
   c) position of the equinoxes in their precession cycle
   d) all of the above

2. Milankovitch claimed that it was not possible to calculate the amount of sunlight reaching Earth for anytime in the past.

   T F

3. Wanting to invent a mathematical description of Earth's past climates, Milankovitch claimed to be able to accomplish this by drawing a curve that would show the variations in radiation responsible for the succession of ice ages.

   T F

4. Milankovitch thought that it was the diminishing heat during the summer period that is the decisive factor in glaciations

   T F

5. As Croll had foretold, an <u>increase</u> in axial tilt causes an <u>increase</u> in summer radiation and a <u>decrease</u> in the Earth-Sun distance at any season causes an <u>increase</u> in radiation at that season.

   T F

Your Grade	/10

PRACTICE 7

Lesson 7: The Controversy Surrounding the Milankovitch Theory

Lesson Objective: ***To make students aware of the debates over the Milankovitch theory, and the reasons contributing to those debates.***

What you should know:

- **Criticisms on Milankovitch's theory.**

PRACTICE QUESTION

Write a short summary about the various factors that contributed to the controversies of Milankovitch's theory (Total: 10 marks).

Your summary should include these help-points:

- Brief introduction of the Milankovitch theory
- The American geologists
- The meteorologists
- Possible inconsistencies in some of Milankovitch's calculations
- The radiocarbon dating method

Your Grade	/10

PRACTICE 8

Lesson 8: The Milankovitch Revival

Lesson Objective: *To show students that scientific theories depend on the evidence discovered and that the Milankovitch theory does provide a good astronomical basis of explaining the ice ages.*

What you should know:

- Why and how Milankovitch's theory came about a second time – it's new propositions/ modifications.

PRACTICE QUESTIONS

Please fill in the blanks with appropriate answers (1 mark for each blank).

1. After Milankovitch, it was discovered that compared to the _____ method, the _____ method was the more accurate means to determine the age of sea levels.

2. New geological evidences collected that focused on the radiation curves of lower latitudes as opposed to the higher latitudes from before suggested that the _____ was more important than Milankovitch had believed.

3. The _____ was then believed to be able to be responsible for the high sea levels (during the interglacial period) if the theory was modified to place more emphasis on the precession effect.

4. By the 1970s, isotopic records of the new geological evidences revealed a _____. This had previously been an element entirely absent from the Milankovitch theory.

5. Kenneth Mesolella and George Kukla then helped modify Milankovitch's theory by pointing out the dominant cycle in the eccentricity curves. Similar to Milankovitch, they emphasized the _____ controlled intensity of radiation during any particular season, the amplitude of which is exactly proportional to _____. When the orbit is unusually elongated, the contrast between seasons is correspondingly _____. Therefore if the temperature during one particular season is critical to the expansion or retraction of ice sheets, the 100,000-year cycle must be reflected in the climatic record.

Your Grade	/ 8

ANSWER KEY

LESSON 1

1. F
From text: The glaciers only once filled the valley of Val de Bagnes. They were no longer in the valley by the time Jean-Pierre Perraudin came up with his conclusions.

2. F
From text: Jean-Pierre Perraudin had found that the marks or scars occurring on hard rocks were caused by the pressure and weight of the glaciers.

3. T

4. T

5. F
From text: By 1875, geologists concluded that there had been a succession of ice ages, each separated by warmer, interglacial ages similar to the present one.

LESSON 2

1. c
2. c
3. a
4. c
5. d

LESSON 3

1. Variations in the way the earth moves around the sun.

   (From text) “He argued that the southern hemisphere had more hours of darkness each year than daylight. Therefore, it followed that the southern hemisphere must be getting colder. Evidence for this could be seen in the Antarctic Ice Sheet in the southern hemisphere.”

2. (Read text) “His theory was based on the fact that over long periods of time, variations occurred in the direction of the earth’s axis. The evidence was seen from the way the North Pole does not always point in the same directions. Instead, the axis of rotation moved in such a way that the North Pole appeared to be drawing a circle in space.”

3. A slow gyration of the earth's axis around the pole of the ecliptic. It is caused mainly by the gravitational pull of the sun, moon, and other planets on the earth's equatorial bulge.

4. (i)Either of two points on the celestial sphere at which the ecliptic intersects the celestial equator.

   (ii) Either of the two times during a year when the sun crosses the celestial equator and when the length of day and night are approximately equal; the vernal equinox or the autumnal equinox.

5. (i) Alexander von Humbolt felt the average temperature of both hemispheres was controlled by the amount of solar energy received by the earth each year instead of the number of hours of darkness and daylight.

   (ii) Increased coldness of the southern hemisphere is a result of location.

LESSON 4

1. a
2. d
3. b

4a. c
4b. a
4c. a

LESSON 5
(2 marks for each point)

- Changing obliquity of the Earth largely hampered by a lack of data available.
- Alternating glacial activity between the 2 hemispheres not confirmed by geological evidence. Glaciations have been believed to be simultaneous in both hemispheres and did not alternate between hemispheres
- Variations in solar heating described by Croll were found by meteorologists to be too small to have any noticeable effect on climate or bring about an ice age.

LESSON 6

1. D
2. F
3. T
4. T
5. F *Decrease; decrease; decrease; increase.*

LESSON 7
(2 marks for each point)

- Controversy arose with gathering of more detailed geological facts from soil and fossils, especially among the American geologists.

- Meteorologists claimed Milankovitch's theory ignored the role of the atmosphere and the ocean in heat transport

- Inconsistencies in some of the calculations published by Milankovitch, of which Milankovitch himself could not explain, include temperatures in winter that had been calculated to have averaged 0.7^{o}C warmer than today.

- The development of radiocarbon dating method for dating fossils made most geologists reject Milankovitch's astronomical theory

- Geological evidence dated by radiocarbon dating suggested time periods for different ice ages conflicting with the time periods concluded by Milankovitch's astronomical theory

LESSON 8

1. radiocarbon dating; thorium dating
2. precession cycle
3. astronomical theory
4. 100,000-year climatic cycle
5. precession-cycle; eccentricity; great

APPENDIX A: THE GEOLOGICAL EVIDENCE & THE FORMATION OF ICE SHEETS

Works of the Ice Age

Glacial ice was formed by the piling up layer after layer of snow. When this pile grew thicker than about 100 feet, sheer weight converted the bottom to ice. This ice then flowed sluggishly downhill, picking up loose material in it path and breaking off and assimilating huge chunks of solid bedrock. Stones and boulders that were frozen into the lowest layer of the glacier smooth and polish, and sometimes scratch the rock pavement over which the ice move.

For any given climate, a glacier will maintain a certain size. When the climate warms, the glacial margin seeks a new equilibrium position. In the case of a valley glacier, the equilibrium is further uphill. In the case of an ice sheet, the equilibrium position is towards the centre of the sheet. But the lower part of the glacier becomes stagnant. It ceases to flow and melts away. Some of the stones, sand and other materials contained within this part of the glacier are then released directly from the ice. This layer called ablation till is superimposed on the lodgment till. The rest of the sediment is carried away and deposited as outwash by streams of melt water flowing within the stagnant glacier and along its margin.

Similar streams of melt water operated within the glacier- filling crevasses, subsurface tunnels, and caverns with irregularly shaped deposits of outwash sediment. The blanket of sediment that the glacier left behind when it finally retreated was a chaotic jumble of unstratified deposits (transported by ice and dropped helter-skelter over the landscape) and stratified deposits (carried away by water and sorted and deposited in neat layers).

Geologists were also able to determine the flow of the ice by recording the scratches and grooves that had been incised in the bedrock by moving glaciers. It was found that individual ice sheets had expanded from different spreading centers.

The ocean level was also of great interest. The drop in sea level postulated by Whittlesey was large enough to have brought about significant changes in the geography of the seashore. As waters retired, the configuration of all the continents would change. Groups of islands, like the West Indies, would unite, forming smaller number of islands, but of larger area. New points would appear above ocean level, and large shoals would become dry land.

The shorelines of glaciated regions speak of marine inundations. During the ice age, worldwide lowering of the sea level caused shorelines to move downward by about 350 feet. The weight of ice sheets depressed the land surface underneath them. When the ice sheet melted, there was an immediate response- a rise in sea level- and a gradual response- a slow uplifting of the land surface. Thus, in New England, Scandinavia, and other glaciated areas, deglaciation was followed immediately by flooding.

Land areas not covered by ice had been blanketed during the ice age with a layer of fine, homogeneous, yellowish sediment. This deposit is called ‘loess’. Loess is composed of minute, uniform grains of silt. When melting occurred at the southern boundary of the ice sheet, great quantities of silt were deposited by outwash streams. Deposits were neither covered with snow, nor held in place by vegetation. Hence, they were easily blown away by the high winds that swirled in front of the ice sheet. (Silt was blown southwards where is settled and eventually became the rich, easily cultivated, and well-drained soil of America’s farm belt.)

APPENDIX B: OTHER EARLY THEORIES

Theory 1: Carbon Dioxide Theory

Studies have shown that carbon dioxide has an important influence on global climate. Changes in the amount of carbon dioxide in the atmosphere leads to changes in the amount of heat reflected back to earth. The more carbon dioxide there is in the atmosphere, the more the environment warms up as more energy is being trapped on earth[18]. Scientists have predicted that a tremendous fall in the amount of carbon dioxide on earth would lead to a drop in temperature, thus resulting in the possibility of an ice age. Yet, several loose ends in the theory such as why and how the concentration of carbon dioxide in the atmosphere might have altered over the course of the earth's history have made it difficult to support the theory.

Theory 2: Ice Age as a Result of Volcanic Eruption

This theory speculated that ice ages occurred during epochs of frequent and explosive volcanic eruptions. During such epochs, the amount of volcanic dust in the atmosphere increased, and caused more of the sun's energy to be reflected back into space, thus resulting in a cooler climate. There has been evidence to show that large volcanic eruptions result in a lowered temperature on earth. The force of the East Indian volcano Krakatoa eruption in 1883 was so massive that large quantities of dust were injected into the atmosphere. This resulted in sunset all over the world to become redder for two years afterward. During this period, there was also a fall in the average global temperature. Hence, this led to the speculation that should the frequency of violent volcanic eruptions increase significantly; the resulting cooling effect might bring about ice age. However, there has not been enough accurate data to validate the theory.

Theory 3: Vertical Movement of the Earth's Crust

According to the English geologist Charles Lyell, ice ages were caused by vertical movements of the earth's crust. An increase in the uplift of the earth's land areas will lead to a fall in temperature[19]. This is because temperature tends to be lower at higher altitudes. However, this theory was rebutted by the Scottish geologist, James Geikie, who felt that the occurrence of large increases in land elevation within a short span of time was impossible. Moreover, the uplift of the land area in the

[18] **Topic Two → Carbon Dioxide Theory**
[19] **Topic Two → Uplift Theory**

northern hemisphere could not account for the glacial phenomena of the southern hemisphere.

Theory 4: Abrupt Sliding of Large Portions of the Antarctic Sheet

A New Zealand scientist, Alex T. Wilson proposed in 1964 that the abrupt sliding of large portions of the Antarctic Ice Sheet into the ocean would bring about climatic changes that would lead to an ice age. Under normal conditions, snow that accumulates on the surface of the Antarctic Ice Sheet flows outward towards its perimeter. Chunks of ice would then break off and float away as ice bergs. Wilson felt that the increasing weight of the glacier and the accumulated water along its base might cause it to collapse and flow rapidly into the ocean. Increasing surge occurrence of this kind would result in the surrounding ocean being covered with a highly reflective layer of floating ice. This would cause large amounts of sun's radiation to be reflected back into space. The resulting drastic fall in the earth's temperature would lead to the likely occurrence of an ice age. If such a surge were to occur, there would be a sudden rise in sea level. Hence, the onset of ice age would be accompanied by a rise in sea level. However, to date, there has been no evidence of that kind.

Theory 5: Increase in Snowfall

Maurice Ewing and William Donn argued, in 1956, that the low temperature in the Arctic region, together with an increased in snowfall brought about by an influx of moist air, were sufficient to promote the growth of ice sheets. The growth of ice sheets would lead to a fall in the atmospheric temperature. The increased snow cover would be able to reflect the sun's radiation back to space, thereby speeding up the glaciation process leading to an ice age. The deglaciation process occurred when temperatures on earth fell low enough to cause the Arctic Ocean to freeze again. With less moisture, the ice sheets shrinks causing sea level to rise. If this theory were to hold through, layers of sediment containing animal fossils would be formed on the ocean floor. However, evidence of this kind was not found. Thus, this questions the validity of the theory.

Theory 6: Stochastic Theory

The central assumption of the stochastic theory is that large scale variability is a natural and inherent property of climate. Random variations in climate took place in interval time periods. The stochastic theory claimed that the longer the time interval, the greater the magnitude of the climatic variations. According to the stochastic

theory, any ice age period did not require an explanation. Because the theory held that no particular event can bring about ice age, it is difficult to test to its validity.

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