

## SAP 1.2 GLOSSARY OF TERMS

Italicized terms within a definition refer to other entries in this glossary. Terms appearing in this glossary appear in bold type in the body of this SAP. All definitions supplied in this glossary refer to the use of these terms within the context of paleoclimate science.

**<sup>137</sup>Cs** – a radioactive isotope of the element Cesium utilized in dating modern sediments. It has a half-life of approximately 30 years. <sup>137</sup>Cs is a by-product of nuclear weapons testing (in conjunction with <sup>239, 240</sup>Pu and <sup>241</sup>Am). Its concentration in the environment peaked between the post-WWII years and 1980 when atmospheric nuclear weapons testing ceased. Therefore its detection in peak amounts (especially in conjunction with <sup>241</sup>Am and <sup>239, 240</sup>Pu) indicates that the sample being analyzed dates from that time period.

**<sup>210</sup>Pb** – a radioactive isotope of the element Lead used in dating modern sediments. It is one of the last elements in the decay chain of Uranium 238 and it has a half-life of approximately 22 years. <sup>210</sup>Pb accumulates naturally in sediments and rocks that contain Uranium 238 and also forms in the atmosphere as a by-product of Radon decay.

**<sup>239, 240</sup>Pu** – radioactive isotopes of the element Plutonium utilized in dating modern sediments. <sup>239</sup>Pu has a half-life of 24,110 years and prior to the production of nuclear weapons was virtually nonexistent in nature. It is one of the two fissile materials used in nuclear weapons and some nuclear reactors. <sup>240</sup>Pu has a half-life of approximately 6,600 years and is a by-product of the manufacture of <sup>239</sup>Pu and is produced in nuclear reactors as part of the fuel cycle. About 10,000 kg of Plutonium were released into the atmosphere during atmospheric nuclear weapons testing during the post-WWII years through the 1970's and became part of the stratigraphic record as fallout from these tests. Detection of peak Plutonium concentrations in a sample therefore indicates that the sample being analyzed dates from that time.

**<sup>241</sup>Am** – a radioactive isotope of the synthetic element Americium utilized in dating modern sediments. It has a half-life of approximately 432 years and is a byproduct of plutonium production as well as a component in fallout from nuclear weapons. It is also currently used in tiny quantities in smoke detectors. Its concentration in the environment peaked in during the years of nuclear weapons testing (post-WWII to 1980), therefore its detection in peak amounts (especially in conjunction with <sup>137</sup>Cs and <sup>239, 240</sup>Pu) indicates that the sample being analyzed dates from that time period.

**“α” parameter** – the relation between a change in stable isotope composition of oxygen or hydrogen in precipitation or in accumulated snow, and the associated change in temperature, usually expressed as a per-mil per degree. The isotopic composition in the comparison is the difference between the heavy:light ratio of the specified species and the corresponding ratio in a specified standard, divided by the ratio in the standard.

**$\delta^{18}\text{O}$**  – a measure of the ratio of the stable isotopes of oxygen,  $^{18}\text{O}$ : $^{16}\text{O}$  in water or a biomineral. The definition is  $\delta^{18}\text{O} (\text{‰}) = 10^3[(R_{\text{sample}}/R_{\text{standard}})-1]$ , where  $R_x = (^{18}\text{O})/(^{16}\text{O})$  is the ratio of isotopic composition of a sample compared to that of an established standard, such as ocean water. It is commonly used as a measure of the temperature of precipitation, the temperature of ocean surface waters, or the volume of freshwater sequestered as ice on the continents, and as an indicator of processes that show isotopic fractionation.

**$\delta\text{D}$**  – a measure of the ratio of the stable isotopes of hydrogen,  $^2\text{H}$ : $^1\text{H}$  in water. The definition is  $\delta\text{D}(\text{‰}) = 10^3[(R_{\text{sample}}/R_{\text{standard}})-1]$ , where  $R_x = (^2\text{H})/(^1\text{H})$  is the ratio of isotopic composition of a sample compared to that of an established standard, such as ocean water. It is commonly used as a measure of the temperature of precipitation, and when compared to the  $\delta^{18}\text{O}$  in the same water sample provides information on sources of water vapor or the extent of evaporation during transport or after precipitation. “D” is the chemical abbreviation for deuterium, the name given to hydrogen that contains one extra neutron.

**accelerator mass spectrometer (AMS)** – an analytical tool that permits the detection of isotopes of the elements to very low concentrations by accelerating the ions of the substance being analyzed to very high kinetic energies (energy of motion) prior to mass analysis.

**ACEX** – Arctic Coring Expedition. A multi-national scientific research effort to better understand both the climate history of the Arctic region and the role that the Arctic has played and continues to play in the Earth’s ongoing climatic variations; work is based on recovery and analysis of sediment cores from the Arctic Ocean.

**alkenone** – long-chain organic compound produced by certain *phytoplankton*, which biosynthetically control the number of carbon-carbon double bonds in response to the water temperature. The survival of this temperature signal in marine sediment sequences provides a time-resolved record of sea surface temperatures that reflect past climates.

**amplification** (with respect to climate) – phenomenon by which an observed change in a climate parameter in a particular area of the Earth is larger in magnitude than the global average. Climate amplification is typically connected to a *climate feedback mechanism*.

**anthropogenic** – effects, processes, objects, or materials that are derived primarily from human activities, as opposed to those occurring in natural environments without human influence.

**archives** – sources of information about the past.

**Arctic amplification** – the result of interactive feedback mechanisms in the Arctic. Owing to interactive feedback primarily from sea ice and snow cover, greenhouse-gas-induced warming is expected to be accelerated in the Arctic region in comparison with

that for the Northern Hemisphere or entire globe. This effect is referred to as *Arctic amplification*.

**bed** – the materials on which a glacier or ice sheet rests. These materials may be solid rock, or unconsolidated sediment. The term is sometimes applied to water between the ice and rock materials, but usually it is reserved for the rock materials.

**benthic foraminifera** – see *foraminifer*

**biomarkers** – residual organic molecules indicating the existence, past or present, of living organisms with specific climate or environmental constraints.

**biome**– an ecological community of organisms adapted to a particular climate or environment; that community dominates the large geographic area in which it occurs.

**Bølling** – a term used primarily in Europe for a warm interval (*interstadial*) of late-glacial time centered at about 12,500 years ago when climate warmed sufficiently to permit northward extension of vegetation on land and sea level rose approximately 20 meters relative to the colder period immediately preceding it.

**boreal** – pertaining to the northern regions of the Northern Hemisphere (from Boreas, god of the North Wind in Greek mythology).

**boundary condition** – in climate science this term refers to a prescribed state of Earth's surface at a particular point in time, often at the start of a climate model experiment. Examples include the topography of Earth, or the extent of sea ice.

**boundary current** – ocean currents whose dynamics are determined by a coastline. For example, the Gulf Stream is a warm, fast moving, and strong western boundary current along the east coast of North America.

**calving** – the breaking off of ice from the front of a glacier that, typically, extends into a lake or sea; in the sea, calved ice forms icebergs.

**calving flux** – the rate at which ice breaks off the front of a glacier. Most typically, *calving flux* will be expressed as either the rate of mass loss per unit width of the glacier per unit time (e.g., kilogram per meter per second (kg/m/s)) or the rate of volume loss per unit width per unit time (e.g., cubic meter per meter per second (m<sup>3</sup>/m/s), which is also square meter per second (m<sup>2</sup>/s)).

**CAPE Project** – Circum-Arctic PaleoEnvironments Project. A research program within the International Geosphere-Biosphere Program (IGBP)–Past Global Changes (PAGES) the focus of which is integration of paleoenvironmental research on terrestrial environments and adjacent margins covering the last 250,000 years of Earth history.

**carbon dioxide** – CO<sub>2</sub>. An atmospheric greenhouse gas with many natural and

*anthropogenic* sources, it is the second most abundant greenhouse gas in the atmosphere after water vapor. Natural sources of carbon dioxide include animal and plant respiration, release at the sea surface, and volcanic eruptions. Anthropogenic sources include the combustion of fossil fuels, biomass burning, and specialized industrial production processes. It is the principal anthropogenic greenhouse gas that affects Earth's radiative balance.

**carbon ketones** – functional chemical groups characterized by a carbonyl group (O=C) linked to two other carbon atoms.

**CCSP** – United States Climate Change Science Program; a consortium of federal agencies carrying out scientific research in the field of climate change. The primary objective of the CCSP is to provide the best science-based knowledge possible to support public discussion and government- and private-sector decisions about the risks and opportunities associated with changes in climate and in related environmental systems. See also *U.S. Climate Change Science Program*.

**Cenozoic** – the period of Earth's history encompassing the past 65 million years. The Cenozoic is subdivided into seven series or epochs: (oldest to most recent) *Paleocene*, *Eocene*, *Oligocene*, *Miocene*, *Pliocene*, *Pleistocene*, and *Holocene* (the current epoch).

**CFCs** – chlorinated fluorocarbon compounds, a family of man-made chemical compounds composed of carbon, hydrogen, chlorine, and fluorine. With respect to climate change, this term usually refers to manufactured CFCs used as refrigerants, aerosol propellants, and solvents and in insulation. When released into the lower atmosphere, these compounds act as greenhouse gases. However, because they are not destroyed in the lower atmosphere, CFCs drift into the upper atmosphere where, given suitable conditions, they break down ozone. Prior to industrialization these gases did not exist in the atmosphere; they now exist in concentrations of several hundred parts per trillion.

**CH<sub>4</sub>** – see *methane*

**chironomids** – the informal taxonomic name for non-biting members of the Diptera (true flies) family of insects commonly known as midges.

**climate** – the average weather over a particular region of the Earth. Climate originates in recurring meteorological phenomenon that result from specific modes of atmospheric circulation. The averaging period is conventionally a 30-year interval as promulgated by the World Meteorological Organization (WMO). Typical characteristics include mean seasonal temperature and precipitation, storm frequency, and wind velocity.

**climate analogue** – generally used to describe a climate state that is reasonably well known and that is similar to or has the same characteristics as the climate of a particular ancient time period under study.

**climate change** – a statistically significant variation in either the mean state of the climate or the mean variability of the climate that persists for an extended period (typically 10 years or more). Climate change may result from such factors as changes in solar activity, long-period changes in the Earth's orbital elements (*eccentricity*, *obliquity*, *precession of equinoxes*), natural internal processes of the climate system, or *anthropogenic* forcing (for example, increasing atmospheric concentrations of carbon dioxide and other greenhouse gases).

**climate feedback mechanisms** – processes that amplify the effects of a change in the controls on global temperature. Feedbacks are said to be positive when they increase the size of the original response or negative when they cause it to decrease.

**CO<sub>2</sub>** – see *carbon dioxide*

**coccolithophorid algae** – tiny single-celled marine algae, protists and phytoplankton, that are distinguished by special calcium carbonate plates called coccoliths. Coccoliths serve as important marine paleoclimate proxies relevant to past characteristics of the ocean's surface layer.

**continental drift** – the slow motion of the continents on the surface of the Earth. Continents ride on underlying segments of the Earth's crust which fit together like pieces of a jigsaw puzzle and are in constant motion, sliding over, under, past or away from each other at their boundaries. The underlying physics of plate motions is referred to as *plate tectonics* and encompasses an understanding of the deep internal structure and motions of the Earth.

**continentality** – characteristic of regions near the centers of large continents, where daily and seasonal variations of temperature and precipitation are relatively large compared with lands closer to the oceans (maritime lands) where such variations are moderated by the adjacent oceans. Continentality increases inland, away from ocean coastlines.

**conveyor belt circulation** – colloquial term for that part of the modern ocean currents (circulation) in which near-surface waters of the Atlantic flow northward, sink into the deep ocean, then flow southward, circulate around Antarctica, flow northward again but now in the deep parts of the Pacific and Indian Oceans, mix up to near the surface, and return to the surface flow of the Atlantic. The term is especially applied to that part of this globe-girdling circulation in the Atlantic.

**Crenarcheota** (taxonomy) –microscopic water-living organisms belonging to the kingdom of Archaea originally thought to thrive only under extreme conditions of heat, acidity, and high sulfur concentrations. However, recent studies indicate a much broader environmental distribution and pelagic (surface dwelling) crenarchaeota are now understood to be probably the most abundant group of archaea on Earth.

**Dansgaard-Oeschger events** – see *D-O events*

**deep -water formation** – the sinking of water from near the surface into the depths of the ocean, followed by lateral movement of that water. In the modern world, this process occurs only in restricted regions in the North Atlantic Ocean and around Antarctica.

**dendroclimatology** – the science of determining past climates from trees (primarily tree rings).

**diachronous** – “cutting across time”; said of a single geologic unit whose age differs depending on the location in which it is found. Such deposits are formed when the location of active deposition migrates, such as during the gradual melting of an ice sheet or the inland advance of seawater. Synonymous with *time-transgressive*.

**diffusion** – general name for the motion of mass or energy from regions of higher concentration to regions of lower concentration through a large number of small events that do not depend directly on each other. For instance, in a room with absolutely no wind, a new type of gas released in one corner will eventually spread throughout the room by the random motions of the individual molecules, and this spreading is called diffusion.

**D-O events** – widespread climate events seen as anomalously warm times in the northern hemisphere and especially around the north Atlantic Ocean, during most recent ice-age (from about 110,000 to 11,500 years ago), with large and rapid terminations and very large and rapid onsets, often persisting for a few centuries and spaced about 1500 years apart.

**driving stress** – as used in glaciology, the gravitational impetus for the flow of ice as it spreads under its own weight. The *driving stress* is calculated as the product of the ice density, ice thickness, ice surface slope, and the acceleration of gravity. Glaciers that are thicker or have a steeper surface thus have a greater tendency to spread or flow.

**eccentricity** – out of roundness (ellipticality) of the Earth’s orbit around the sun. The magnitude of Earth’s orbital eccentricity completes a full cycle about every 100,000 years and varies between a minimum departure from circularity of 0.0034 to a maximum departure of 0.058.

**elastic** – characterized by experiencing changes in shape or size in response to applied stress, but returning to the original shape or size when the stress is removed.

**elastic deformation** – changes in shape or size experienced by a material or body in response to applied stress that will be reversed when the stress is removed. See *elastic*.

**Eocene** – the geological epoch spanning 55.8 Ma to 22.9 Ma.

**equilibrium line** – an imaginary line on the upper surface of a glacier, separating the accumulation zone (the region in which mass supply to that surface exceeds mass loss)

from the ablation zone (the region in which mass supply is less than mass loss). (Mass supply is typically dominated by snowfall and mass loss by runoff of meltwater, although drifting snow, *sublimation* and other processes may contribute.) Almost always, the accumulation zone is higher in elevation than the ablation zone.

**equilibrium line altitude** – The elevation above sea level of the *equilibrium line*.

**far field** – the region at a sufficiently great distance from the source of a disturbance that some physical processes known to be important near the disturbance are no longer important because their influence has dropped greatly with increasing distance. For example, the initial growth of the ice sheet on Greenland lowered sea level globally (because water that evaporated from the ocean was stored in the ice sheet), but the weight of the ice pushed Greenland down farther than the globally averaged lowering of the sea surface; thus, sea level rose in the *near field* just beyond the growing ice sheet where sinking under the ice weight was important, whereas sea level fell in the *far field* where the influence of the weight of the growing ice sheet was small.

**firn** – old snow during transformation to glacier ice. The name *firn* is often applied to any snow on a glacier that is more than one year old. *Firn* becomes glacier ice when the interconnected pore spaces of the *firn* become isolated from the atmosphere above to form bubbles.

**foraminifer** (benthic, deep-sea) – a microscopic single-celled organism that lives on the sea floor and secretes calcium-carbonate shells in equilibrium with the sea water. The analysis of the stable isotopes contained in foraminifer shells found in sea floor sediment cores is the most commonly used method for determining ocean paleotemperatures.

**forcing** – with respect to climate, processes and factors external to the climate system which, when changed, generate a compensatory change in the climate system. Examples of climate forcings include variability in solar output, in the amount of sunshine received by a region of the Earth due to orbital changes, volcanic eruptions that inject particles and gases into the atmosphere, and changes in the positions of continents.

**gigatons** – in the International System of Measurement (Système International d'unités, or SI), a gigaton is 1,000,000,000 tons ( $10^9$  tons, or 1 billion tons in U.S. usage); a ton is 1,000 kilograms, and 1 kilogram is the mass equivalent of 2.2 pounds.

**GISP2** – acronym for the Greenland Ice Sheet Project 2 location and ice core in central Greenland (see map for location). Deep drilling at this site began in 1989 and was completed to bedrock at a depth of 3053 meters in 1993.

**glacial** (interval) – an interval of time during the past 2.6 million years in the Earth's history when the average global temperature was colder than it is currently and during which ice sheets expanded substantially in the northern hemisphere.

**glacial isostatic adjustment** – changes in the shape and elevation of Earth’s surface in response to growth and shrinkage of glaciers and ice sheets. For example, just as the surface of a water bed sinks beneath someone who sits on it but bulges up around that person, adding the load of an ice sheet causes sinking of the Earth’s surface beneath and near the ice sheet but bulging up beyond (*peripheral bulge*). Changes in global sea level associated with loss of that water stored in an ice sheet or gain of water as an ice sheet melts also cause rising or sinking of the seabed beneath. Taken together, these changes are *glacial isostatic adjustment*.

**glacier** – a mass of ice that persists for many years and notably deforms and flows under the influence of gravity. The term is especially applied to relatively small ice masses that flow down the sides of mountains, but it may also be applied to a fast-moving region of a larger ice mass or even to the larger ice mass itself.

**greenhouse gas** – gaseous constituents of the atmosphere that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by Earth’s surface, the atmosphere, and clouds. The primary greenhouse gases in the atmosphere are water vapor (H<sub>2</sub>O), carbon dioxide (CO<sub>2</sub>), nitrous oxide (N<sub>2</sub>O), methane (CH<sub>4</sub>), and ozone (O<sub>3</sub>), all of which have many natural and *anthropogenic* sources.

**grounded ice** – ice that remains on land and is not floating. The term is especially applied to nonfloating portions of *glaciers*, *ice caps*, or *ice sheets* that flow into lakes or seas and could have floating portions.

**Heinrich events** – intervals of anomalously rapid deposition of sand-sized and coarser materials in the open North Atlantic Ocean, formed by an anomalously rapid supply of icebergs carrying debris. Six or seven events are identified during the most recent ice-age cycle (from about 110,000 to 11,500 years ago), and older events have occurred as well. Characteristics of the debris in most of the events indicate that ice in Hudson Bay was a dominant source. Large and widespread climate anomalies were associated with the Heinrich events, such as cool conditions in the north and especially around the North Atlantic, and warmth in the far south.

**Holocene** – the current geologic epoch that began about 11,500 years ago when the climate warmed at the end of the most recent glacial period. The most recent epoch (subdivision) of the *Quaternary* period.

**hot-spot volcanic chains** – linear arrays of volcanoes produced by a single source, especially seen as lines of islands in the ocean. A ‘hot spot’ is a rising column of hot rock that rises from relatively deep in the Earth. The upper, cold layer of the Earth involved in continental drift typically moves horizontally much faster than a hot-spot does. The hot spot will poke through the overlying layer and form a volcano, then that volcano ceases to erupt as it is carried away by the drifting layer, while the hot spot pokes through to make a new volcano. The Hawaiian Islands are the younger part of such a *hot-spot volcanic chain*, which also includes the generally-undersea Emperor Seamounts to the northwest of Hawaii.

**ice cap** – a flowing mass of ice (*glacier*), moving away from a central dome or ridge, and notably smaller than an otherwise – similar *ice sheet*, which normally is of continental or subcontinental scale.

**ice dynamical model** – as used here, a representation of the physical behavior of a glacier, ice cap or ice sheet, developed with the use of a computer to solve mathematical equations approximating the important physical processes.

**ice sheet** – a flowing mass of ice (*glacier*), moving away from a central dome or ridge, normally of continental or subcontinental scale and notably larger than an otherwise similar *ice cap*.

**ice shelf** – a floating extension of a *glacier*, *ice cap* or *ice sheet*, nourished in part by flow from nonfloating (*grounded*) ice. An ice shelf may gain or lose mass on its upper surface (usually by snowfall or melting) or lower surface (usually by freezing or melting). Normally, an ice shelf loses mass into the adjacent water body by iceberg *calving*. The term ‘ice shelf’ is sometimes applied to relatively small ice masses that largely or completely lack flow from adjacent grounded ice and that thus are nourished by snowfall above or freezing beneath; these “ice shelves” typically are thicker and more persistent than features called *sea ice*, but they could be classified as *sea ice*.

**ice stream** – a faster moving ‘jet’ of ice flanked by slower flowing parts of an *ice sheet* or *ice cap*.

**Innuitian sector** – the ice sheet that covered the Queen Elizabeth Islands of northern and northeastern Canada. The term was originally proposed as the Innuitian Ice Sheet (Blake, 1970; Blake Jr., W., 1970. Studies of glacial history in Arctic Canada. Canadian Journal of Earth Sciences 7, 634–664), and was applied to the ice mass that formed during the most recent glaciation. The Innuitian Ice Sheet was joined to the *Laurentide Ice Sheet* to the south and to the Greenland Ice Sheet to the east when the ice sheets were largest; the term “*Innuitian Sector* of the Laurentide Ice Sheet” is often used. The term is also often applied to relict ice in the indicated region from earlier glaciations.

**insolation** – the amount of sunshine, measured in watts per square meter ( $W/m^2$ ), on one unit of horizontal surface. With respect to climate studies, insolation is typically evaluated at the Earth’s surface. The intrinsic latitudinal differences in the amount of sunshine that reaches the Earth’s surface (e.g at the equator and at the poles) depend on the seasons, but the total global value does not.

**interannual variability** – changes in a measured value from year to year. As an example, during the last 30 years, globally averaged surface temperatures have increased, with high statistical confidence. However, events such as an El Nino cause the average temperature for a year to plot off of the line that best represents the whole 30-year history. The difference between the annual average temperature and the best-fit line changes from year to year in response to this *interannual variability*.

**interglacial** (interval) – an interval of time during the past 2.6 million years in Earth’s history when the average global temperature was as warm or warmer than it is currently and during which ice sheets contracted substantially in the northern hemisphere.

**IPCC** – Intergovernmental Panel on Climate Change. A multinational group of experts in the field of climate change established (by the World Meteorological Organization and the United Nations Environmental Program) to provide decision-makers and other interested persons with an objective source of information about climate change. The IPCC does not conduct any research nor does it monitor climate-related data or parameters. Its role is to assess on a comprehensive, objective, open and transparent basis the latest scientific, technical and socio-economic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected effects and options for adaptation and mitigation.

**interstadial(s)** – a warmer period of time within an ice age marked by a temporary retreat of ice.

**irradiance** (solar) – the amount of intrinsic radiant energy emitted by the sun over all wavelengths that falls each second on 1square meter ( $W/m^2/s$ ) outside the Earth’s atmosphere. The current average value of solar irradiance is approximately 1,367 Watts per square meter. Small variations in irradiance attributable to a variety of internal solar process have been observed and have had small but detectable effects on global temperature over the past 65 million years.

**isochrone** – a line on a map or a chart connecting all points at which an event or phenomenon occurred simultaneously or which represent the same time value or time difference. In sediment or sediment core analysis, a point of known age that can be identified in mutiple locations that ties the datasets derived from the analyses to a common point in time.

**ka** – kiloannum; thousands of years ago (a point in time)

**k.y.** – thousands of years (a time interval)

**Laurentide Ice Sheet** – name proposed by Flint (1943; Flint, R.F., 1943, Growth of the North American ice sheet during the Wisconsin age. Geological Society of America Bulletin, v. 54, p. 325-362) for the great *ice sheet* that covered much of northern North America east of the Rocky Mountains during the most recent ice age (from about 110,000 to 11,500 years ago). Use of the term is widely extended to include older ice sheets that occupied the same general area.

**Little Ice Age** – a period of time during the last millennium (approximately 1500 to 1850 C.E.) during which summers globally, but particularly in the higher latitudes of the Northern Hemisphere, were colder than during the preceding millennium or the 20th

Century. The Little Ice Age is widely manifested by the advance of mountain glaciers and ice caps, as well as by periodic crop failures, especially in NW Europe.

**Ma** – mega-annum; millions of years ago (a point in time)

**marine isotope stage** – see *MIS below*

**mass flux** – rate at which material passes an observational site. The mass flux added to the surface of a glacier by snowfall may be reported as the ice added to an area during a time interval and thus measured in kilograms per square meter per second ( $\text{kg}/\text{m}^2/\text{s}$ ) or equivalent units; the mass flux per unit width for flow of a glacier may be reported as kilograms per meter per second ( $\text{kg}/\text{m}/\text{s}$ ).

**meristematic** – the tissue in all plants consisting of undifferentiated cells (meristematic cells) and found in zones of the plant where growth can take place.

**methane** –  $\text{CH}_4$ ; an atmospheric greenhouse gas with many natural and anthropogenic sources chief of which are decomposition of organic matter in the absence of oxygen (e.g., in wetlands and landfills), animal digestion and animal waste, and the production and distribution of natural gas, oil, and coal. It is the third most abundant atmospheric greenhouse gas after water vapor and *carbon dioxide*. The current lower-atmospheric concentration of methane at middle latitudes in the northern hemisphere is approximately 1,847 parts per billion and is stable. This concentration is substantially above the pre-industrial level of about 730 parts per billion.

**Milankovitch cycles, time scales** – The Milankovitch or astronomical theory of climate change is an explanation for cyclical changes in the seasons which result from cyclical changes in the earth's orbit around the sun. The theory is named for Serbian astronomer Milutin Milankovitch, who calculated the slow changes in the earth's orbit by careful measurements of the position of the stars, and through equations using the gravitational pull of other planets and stars. He determined that the earth "wobbles" in its orbit. The earth's "tilt" is what causes seasons, and changes in the tilt of the earth change the strength of the seasons. The seasons can also be accentuated or modified by the eccentricity (degree of roundness) of the orbital path around the sun, and the precession effect, the position of the solstices in the annual orbit. Together, the periods of these orbital motions [ 40,000 years for tilt, 90,000 – 100,000 years for eccentricity, and approximately 26,000 years for precession) have become known as Milankovitch cycles and their associated periodicities as Milankovitch time scales.

**millennial** – occurring or repeating every thousand years.

**m.y.** – millions of years (a time interval).

**Miocene** – the geological epoch spanning 23 Ma to 5.3 Ma.

**MIS** – commonly used acronym for *Marine Isotope Stage(s)*. A subdivision of recent geologic time, identified by number (e.g., marine isotope stage 1, or marine isotope stage 8); marine isotope stage 1 includes today, and numbers increase with increasing age. The marine isotope stages were defined from the oxygen–isotopic ratios of shells that accumulated on the ocean floor and were collected in sediment cores; shells that grew in cooler water, or at times when more water was stored on land in ice sheets, are isotopically heavier. Intervals of warmer water or smaller ice are labeled with odd numbers (marine isotope stage 1, or 5), and times of colder water or larger ice have even numbers. Marine isotope stages average a few tens of thousands of years long, but different stages have different durations.

**model** – with respect to climate studies, a computer program designed to mimic a natural process or system of processes with the aim of aiding in understanding how the process or system behaves. The representation of the climate system is based on mathematical equations governing the behavior of the various components of the climate system and includes treatment of key physical processes and interactions.

**moraine** – landforms (typically ridges) composed of sediment deposited at or near the edge of a glacier; a *moraine* provides an outline of all or part of a glacier at some time. (Please note that the term “ground moraine” is sometimes used for a blanket of sediment deposited beneath a glacier, and the term “medial moraine” can be used for a band of debris on the surface of a glacier marking the junction of confluent flows; however, *moraine* normally is used as given in the main definition here.)

**N<sub>2</sub>O** – See *nitrous oxide* below.

**near field** – the region sufficiently close to the source of a disturbance that some physical processes must be considered that are unimportant at greater distance from the disturbance in the *far field*. For example, the initial growth of the ice sheet on Greenland lowered the sea level globally (because water evaporated from the ocean was stored in the ice sheet), but the weight of the ice depressed Greenland more than the globally averaged lowering of the sea surface; thus, sea level rose in the *near field* just beyond the growing ice sheet where sinking under the ice weight was important, whereas sea level fell in the *far field* where the influence of the weight of the growing ice sheet was small.

**negative feedback** – in climate studies, a process that acts to decrease the magnitude of the climate’s response to an initial *forcing*.

**NGRIP** – acronym for the North Greenland Ice Sheet Project location and ice core (see map for location). Deep drilling at the NGRIP site began in 1999 and was completed to bedrock at 3094 meters in 2003.

**N<sub>2</sub>O** – See *nitrous oxide* below.

**nitrous oxide** – *N<sub>2</sub>O*; an atmospheric greenhouse gas. It is the fourth most abundant greenhouse gas after water vapor, *carbon dioxide*, and *methane*. Natural sources include

many biological sources in soil and water, primarily through bacterial breakdown of nitrogen in soils and in the earth's oceans. Primary human-related sources of  $N_2O$  are agricultural soil management, animal manure management, sewage treatment, mobile and stationary combustion of fossil fuel, and the manufacture of adipic and nitric acid. The pre-industrial value of  $N_2O$  in the atmosphere was approximately 265 parts per billion; it has increased monotonically since that time. The current atmospheric concentration is approximately 319 parts per billion.

**NAO** – North Atlantic Oscillation (atmospheric phenomenon), a large-scale see-saw in barometric pressure between the vicinity of Iceland and the Azores. It corresponds to fluctuations in the strength of the main westerly winds across the north Atlantic Ocean and is the primary wintertime weather-maker for the North Atlantic region of the eastern United States and Canada, Greenland, and Europe. When this pressure difference is large the NAO is said to be in positive phase, when it is small the NAO is said to be in negative phase.

**North Atlantic Oscillation** – see *NAO* above.

**obliquity** – the angle between the rotational axis of the Earth and a line perpendicular to the plane containing Earth's orbit about the sun. Earth's obliquity varies predictably from  $22.1^\circ$  to  $24.5^\circ$  in a 41,000 year cycle. The fact that Earth's axis of rotation is not perpendicular to the plane of its orbit around the sun (i.e. Earth's *obliquity* is not zero) is the origin of the seasons.

**Oligocene** – the geological epoch spanning 33.9 Ma to 23 Ma.

**orbitally paced** – phenomena that are synchronous with cyclical features of the Earth's orbit are described as 'orbitally paced'.

**oscillation** (climate) – a cyclical change in value between two different states. The *North Atlantic Oscillation* is a particularly important cyclic variation in atmospheric pressure over the North Atlantic region that is the primary wintertime weather-maker in the North Atlantic region.

**outlet glacier** – a jet of ice flowing from an *ice sheet* or *ice cap*. Usage may be imprecise, but in general *outlet glacier* is the preferred term when the sides of fast-flowing ice are controlled prominently by bedrock (which usually is visible above the ice surface but also includes cases in which the fast-flowing ice occupies a deep bedrock trough but is flanked by a thin layer of slower-flowing ice); *ice stream* is usually applied when bedrock control is weak and the faster-flowing ice is flanked by a considerable thickness of slower-flowing ice.

**paleoceanographic archives** – sources of information about the past climate originating in records from the deep ocean, typically derived from an analysis of the stable isotopes of oxygen contained in the shells of marine microorganisms.

**Paleocene** – the earliest geological epoch of the *Cenozoic* spanning 65.5 Ma to 55.8 Ma.

**paleoclimate reconstruction** – the determination of past states of Earth’s climate (prior to historical or instrumental records) created by interpreting the climate signals contained in natural recorders such as tree rings, ice cores, deep sea and lake sediments, and cave deposits. Also, a reconstruction of past climates based on a *model* that uses paleoclimate data.

**paleoclimatology** – the science of reconstructing the past climate of Earth.

**paleorecord, paleoclimate record** – a data set constructed from a direct or indirect (*proxy*) recorder of climate. At their most useful, these records contain climate information that is unambiguous, continuous, and capable of being dated at a level of resolution sufficient to reveal climate changes at the scale of interest of the study.

**paleothermometers** – a climate proxy (physical, biological or chemical) preserved in geological archives that provides either qualitative or quantitative estimates of past temperatures.

**perfectly plastic behavior** – a model for material behavior in which no permanent deformation occurs in response to small applied stress but, when stress is raised to the strength of the material, arbitrarily large and rapid deformation results, such that the stress cannot be raised above that strength. Perfect plasticity provides a useful approximation of real material behavior in some cases.

**peripheral bulge** – a raised region encircling the region pushed down by the weight of an ice sheet or other large mass placed on the surface of the Earth. See *glacial isostatic adjustment* above.

**permafrost** – ground that is permanently frozen below its uppermost layer, which thaws in summer.

**perturbation** – a change or deviation from the predicted, average or otherwise anticipated stable state; typically caused by a force or process outside the perturbed system.

**phytoplankton** – microscopic algae which inhabit the illuminated surface waters of both marine and freshwater bodies.

**plate tectonics** – the theory of the Earth that describes the outermost layer of Earth as comprising of a series of rigid pieces or ‘plates’ on which the continents ride that are in constant motion relative to each other and that interact with each other at their boundaries. Plate boundaries are typically the site of substantial seismic and volcanic activity.

**Pleistocene** – the geological epoch spanning 2.6 Ma to 11, 477 years ago. The Pleistocene was characterized by multiple cyclical episodes of cold and warm times during which ice sheets and glaciers grew and shrank in response to global temperature changes initiated by climate *forcings* originating from cyclical changes in Earth’s orbit around the sun.

**Pliocene** – the geological epoch spanning 5.3 Ma to 2.6 Ma.

**positive feedback** – in climate studies, a process that acts to increase the magnitude of the climate’s response to an initial forcing.

**Preboreal** – originally, the term applied to the approximately millennium-long interval occurring just after the end of the *Younger Dryas*, which is now known to have ended about 11,500 years before present. During the *Preboreal* interval, a short-lived cold event occurred between about 11,400 and 11,200 years before present. This event is often referred to as the *Preboreal Oscillation*.

**precession** (of the equinoxes) – the wobble of the Earth’s rotational axis expressed in degrees of arc. The Earth executes a complete precessional cycle once every 19,000 to 23,000 years.

**provenance** – the geological term for the site of origin of rock material that has since been transported elsewhere. The *provenance* of much of the material deposited in the North Atlantic during *HeinricheEvents* is the Hudson Bay region of Canada.

**proxy** – in paleoclimate studies, an indirect indicator of climate from which a record of change can be reconstructed once the relationship between the proxy and the desired parameter (e.g. temperature, precipitation) is understood. Many paleoclimate reconstructions are based on proxy records.

**Quaternary** – the geologic subdivision of the Cenozoic encompassing the past approximately 2.6 million years.

**radiocarbon reservoir age** – the number of years old (the age) of carbon-14 (radiocarbon) incorporated by a sample when it formed. In radiocarbon dating, the simplest approach is to use the carefully reconstructed history of radiocarbon abundance in the atmosphere, together with the known half-life of radiocarbon and the measured abundance of radiocarbon in a sample today, to estimate how long it has been since the sample formed. However, the radiocarbon in some environments contains less radiocarbon than would be expected based on equilibrium with the atmosphere, causing the simplest possible approach to overestimate the time since a sample formed, and motivating the use of a correction for the *radiocarbon reservoir age*. For example, water near the surface of the oceans exchanges radiocarbon with the atmosphere, and then sinks into the deep ocean, remaining there for roughly one millennium before returning to the surface to exchange radiocarbon again. While the water is deep in the ocean and out of contact with the atmosphere, some of the radiocarbon in the water decays. A creature

living in the deep ocean will thus incorporate less radiocarbon than an equivalent creature living at the same time near the ocean surface. This difference in initial radiocarbon abundance in the samples would lead to an error in estimating the age of the deep dweller if not corrected for; the correction is the *radiocarbon reservoir age*.

**radiogenic isotopes** – atomic species produced by radioactive decay.

**rifting** – as used here, the geological process associated with plate *tectonics* (which is the science of drifting continents; see *tectonics*) by which continents are split apart to make ocean basins.

**SAP** – Synthesis and Assessment Product; one of the 21 technical reports sponsored by the U.S. Climate Change Science Program that discuss aspects of climate change.

**sea ice** – any form of ice found at sea that has originated from the freezing of sea water (in contrast to floating ice at sea that has originated from glaciers on land ).

**sea level equivalent** – see *SLE* below.

**SLE** – sea level equivalent; as used here, a measure of a mass of ice, calculated as the rise in global sea level that would result if the ice were melted and the resulting water spread uniformly over the world's oceans.

**shelf break** – the continental shelf, the undersea extension of a continent, ends at the *shelf break*, where the continental slope begins its steep drop into the deep ocean.

**sill** – as used here, a narrow, shallow sea-floor region connecting continents or islands and separating two deeper basins.

**speleothem** – mineral deposits (most commonly calcium carbonate) found in caves where water seeping through cracks in a cave's surrounding bedrock carries dissolved compounds that precipitate when the solution reaches an air-filled cave. Speleothems accumulate slowly, often spanning decades to millennia.

**stage** – in paleoclimate studies, a time term for a major subdivision of a glacial epoch. See MIS above.

**step forcing** – a rapid jump from one sustained level to another in some environmental feature that controls a system. For an ice sheet after a long interval at one temperature, a rapid warming to a new and sustained level would constitute a *step forcing* on the ice sheet system.

**stochastic** – randomly determined; involving or containing a random variable. A *stochastic* process is one in which the current state does not fully determine the next.

**striated** – scratched. Glaciers typically entrain loose rocks at their base; the moving ice then drags those rocks over bedrock, which may be scratched (*striated*) by the entrained rocks; striations may occur in sets of parallel marks.

**striated boulders** – boulders scratched by being dragged across other rocks by the passage of overlying, moving glacier ice.

**sublimation** – evaporation of water molecules directly from ice without first melting the ice to make water and then evaporating the water. Water molecules also can condense on ice directly (forming frost or hoarfrost, for example), and this process is often referred to as a negative rate of *sublimation*.

**tectonic** – related to the large features and movements of geology. The outer, colder layer of Earth is broken into a few large plates, which drift around carrying the continents (hence the term *continental drift*). The interactions of these plates give rise to most of Earth's mountain ranges, volcanoes and earthquakes, and these motions and interactions are called *tectonic*.

**tectonic forces** – forces internal to the Earth that cause segments of its crust to move in ways that build mountains and open or close oceans.

**tephra** – anything thrown by eruption of a volcano.

**tetraether lipids** – biomarkers produced by *Crenarcheota* that preserve well in marine and lacustrine sediments and that have been used to reconstruct past temperature changes in surface waters.

**TEX<sub>86</sub> index** – a proxy related to surface water temperatures for marine and lacustrine (lake) systems, the index is based on membrane *tetraether* lipids of *crenarchaeota*, with 86 carbon atoms.

**thermohaline; thermohaline circulation** – deep circulation of the global ocean that is driven by density gradients established by differences in the temperature ('thermo') and salinity ('haline') of the water masses. Salty surface waters that lose heat in the polar regions become denser than underlying waters and sink, establishing a global network of deep ocean currents.

**tidewater glacier** – a mountain glacier that terminates in the ocean

**tidewater glacier cycle** – the typically centuries-long behavior of tidewater glaciers that consists of recurring periods of advance alternating with rapid retreat and punctuated by periods of stability.

**till** – a mixed deposit of unconsolidated clay, silt, sand, gravel and boulders deposited directly by and underneath a glacier. Till deposits that remain behind after the glacier has melted or retreated are characterized by a lack of stratification or layering.

**time-transgressive** – said of a single geologic unit whose age differs depending on location in which it is found. This nature is characteristic of geologic units created by processes that require a substantial time during which the location of active deposition migrates, such as the melting of an ice sheet or the recession of a shoreline. Synonymous with *diachronous*.

**troposphere** – the lowest layer of the atmosphere closest to Earth’s surface. It extends from the surface up to approximately 7 kilometers at the poles and about 17 kilometers in the equatorial regions. The troposphere is characterized by decreasing temperature with increasing height, significant vertical air movement and appreciable water vapor content.

**trough-mouth fans** – undersea deposits of sediment on a slope, narrow at the top and wider at the bottom (hence fan-shaped) that develop near the downslope ends (or mouths) of submarine canyons (or troughs) that cross the *continental shelf* and descend the continental slope. Rapid rates of sedimentation in trough-mouth fans makes them good sources of sediment cores for paleoclimatic analyses.

**tundra** – a treeless landscape on *permafrost* (ground that is permanently frozen below the uppermost layer, which thaws in summer), today restricted to high-latitude and high-altitude areas. The dominant vegetation is low-growing lichens, mosses, and stunted shrubs.

**U<sup>k</sup><sub>37</sub> index** – the relative abundances of long-chain C<sub>37</sub> *alkenones* in marine sediment that serve as a proxy for past sea-surface temperatures.

**U.S. Climate Change Science Program (CCSP)** – a consortium of Federal agencies that investigate climate. The primary objective of the CCSP is to provide the best science-based knowledge possible to support public discussion and government- and private-sector decisions about the risks and opportunities associated with changes in climate and in related environmental systems.

**viscoelastic deformation** – the general term for change in shape or volume (deformation) of materials in response to applied stress. It involves changes that will be reversed (returning the material to its original configuration) if the stress is removed (*elastic deformation*), and also as changes that are permanent and thus will not be reversed if the stress is removed (viscous deformation, broadly defined).

**viscoelastic structure** – distribution of the material properties of the planet that controls how it deforms in response to applied stress (*viscoelastic deformation*), especially referring to how these material properties vary with depth.

**yedoma** – a frozen, organic-rich, wind-blown accumulation, dominantly of silt-sized particles (loess), with ice content of 50–90% by volume. *Yedoma* is a frozen reservoir of carbon that will, if melted, release a substantial volume of carbon to the atmosphere and

contribute substantively to Earth's greenhouse effect. *Yedoma* covers more than one million square kilometers of Russia.

**yield strength** – the stress required to cause permanent deformation of a material. In many materials, if the applied stress falls below some level (the *yield strength*) then *elastic deformation* occurs but no permanent or viscous deformation, whereas for higher stresses permanent deformation occurs.

**Younger Dryas** – a climate event, that occurred between about 11,500 and 12,800 years before present (with uncertainties of a couple of centuries). The *Younger Dryas* was characterized by cool conditions in the northern hemisphere, warm conditions in the far south, a southward shift of the tropical circulation, reduction in monsoonal rainfall in Africa and Asia, extended sea ice and reduced sinking of surface ocean waters in the North Atlantic, and with a fast start (decades) and a very fast end (perhaps less than a decade) to the anomalous conditions.