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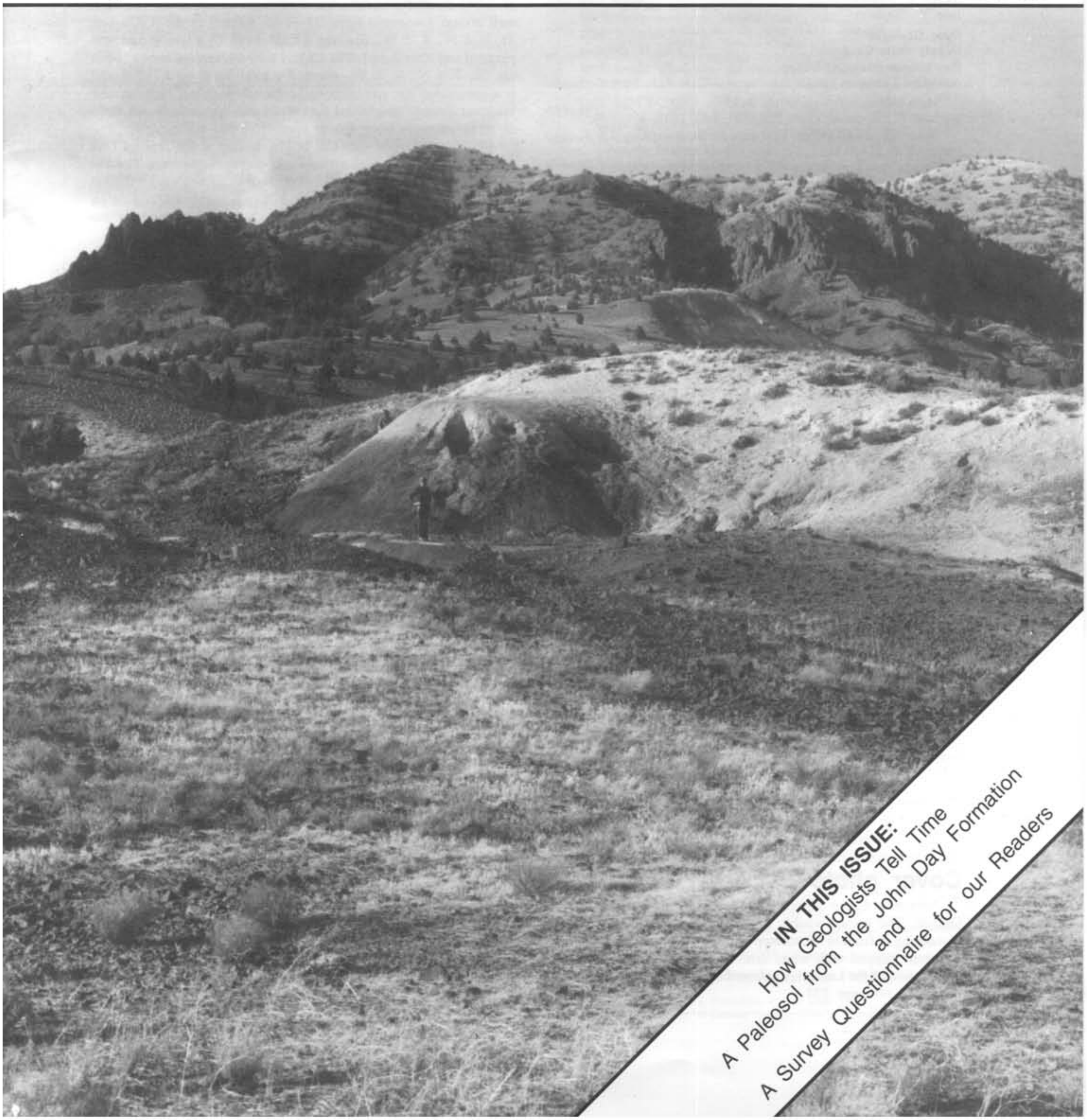

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The style to be followed is generally that of U.S. Geological Survey publications. (See the USGS manual *Suggestions to Authors*, 7th ed., 1991 or recent issues of *Oregon Geology*.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Names of reviewers should be included in the acknowledgments.

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of the Oregon Department of Geology and Mineral Industries.

Cover photo

Area near Camp Hancock in Wheeler County, central Oregon. The person visible near the center of the photo is standing in front of an outcrop of red John Day Formation claystone capped with white ash. This prominent knoll is the location of the Luca clay paleosol described in the article beginning on page 131.

OIL AND GAS NEWS

Drilling activity at Mist Gas Field

Drilling activity continues at the Mist Gas Field, Columbia County. Nahama and Weagant Energy continued the multi-well drilling program that began during July. The Columbia County 34-31-65, located in the SE¼ sec. 31, T. 6 N., R. 5 W., reached a total depth of 2,064 ft, was plugged and redrilled to a depth of 1,902 ft, and is now a successful gas completion. The next well drilled, Longview Fibre 22-31-65, located in the NW¼ sec. 31, T. 6 N., R. 5 W., reached a total depth of 1,991 ft and was plugged and abandoned. The CER 14-26-64, located in the SW¼ sec 26, T. 6 N., R. 4 W., reached a total depth of 2,702 ft and is a successful gas completion. So far for the year, Nahama and Weagant Energy has drilled five wells and one redrill, and three of these attempts have led to successful gas completions.

Northwest Natural Gas Co. began drilling at the Natural Gas Storage Project at the Mist Gas Field during September. The IW 13b-11 is a gas injection-withdrawal service well being drilled in the Bruer Pool. Upon completion of this well, drilling of an injection-withdrawal service well, IW 23d-3, is planned for the Flora Pool.

Seismic surveys conducted in Oregon

Two seismic surveys were completed in Oregon during September and October. The first was by Cimmaron Land Services, which conducted a wide-range refraction/reflection seismic survey in Wasco, Jefferson, and Wheeler Counties. The survey is located in the western Columbia River Basin and intended to define areas with stratigraphic and structural conditions necessary for potential oil and gas accumulations. The U.S. Geological Survey conducted a seismic refraction survey in western Oregon with the intent of helping scientists assess earthquake hazards in the Pacific Northwest more accurately. This seismic survey is a portion of a total project that extends north from western Oregon through Washington into southern British Columbia, Canada.

NWPA Kyle Huber luncheon scheduled

The annual Kyle Huber luncheon will be held by the Northwest Petroleum Association (NWPA) on November 8. At this luncheon, the Kyle Huber Award will be presented to the individual or company that has been selected to have made the most significant contribution to energy resource development in the Pacific Northwest during the year. Paul Dudley, independent geologist from Bend, will be the speaker. Details on the luncheon can be obtained from Shelley at (503) 220-2573.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
468	Nahama and Weagant CER 24-22-64 36-009-00293	SW¼ sec. 22 T. 6 N., R. 4 W. Columbia County	Permit; 2,600.

□

REMEMBER TO RENEW

Many of you will find that the code number on your address label ends in "1291," which means your subscription expires with the December issue of 1991. If so, or if your expiration date is anywhere near this, please use the renewal form on the last page to make sure you will continue receiving *Oregon Geology*. And while you are at it—why not consider a gift subscription for a friend?

How geologists tell time

*by Evelyn M. VandenDolder, Editor, Arizona Geological Survey. *

The following article was originally published as a two-part article in the winter 1990 (v. 20, no. 4) and spring 1991 (v. 21, no. 1) issues of *Arizona Geology*, published by the Arizona Geological Survey, 845 N. Park Avenue, Suite 100, Tucson, AZ 85719. With the publisher's permission, Part 1 is reprinted here, and Part 2 will appear in the next issue of *Oregon Geology*. In a few cases, the original illustrations had to be replaced with other, similar illustrations. —*Editors*

Part 1: Introduction and relative dating techniques

INTRODUCTION

The Shroud of Turin, revered for centuries as the burial garment of Christ, retains the imprint of a man who was apparently scourged and crucified. The first recorded exhibit of the shroud was at Lirey, France, in the 1350's. After passing through many hands and cities, it was ultimately enshrined in 1694 in the Royal Chapel of Turin Cathedral (Damon and others, 1989).

In the spring of 1988, as requested by the Vatican, owner of the shroud, radiocarbon laboratories in Oxford, England; Zurich, Switzerland; and Tucson, Arizona (Laboratory of Isotope Geochemistry, University of Arizona) dated the shroud by accelerator mass spectrometry. Each of the three laboratories dated four samples: one 50-milligram whole-cloth sample from the shroud and three control samples from other fabrics, the ages of which were known from previous radiocarbon measurements or from historical evidence. The age of the shroud was determined to be A.D. 1260-1390, with at least 95-percent confidence. The shroud, therefore, is medieval (Damon and others, 1989).

Radiocarbon dating has been widely used to date cultural artifacts, such as the Shroud of Turin and charcoal from late Pleistocene (11,000-year-old) fires built by early hunters in southeastern Arizona (Haynes, 1987). The radiocarbon technique has also been used to date ground water in the Tucson basin to determine its recharge rate. Because it has been popularized by the media in stories of archaeological discoveries, the radiocarbon method is the best known dating technique. It is, however, only one of many methods that scientists use to date objects (Figure 1). Other techniques that are also based on the rates of radioactive decay allow geologists to date rocks that are millions or even billions, not just thousands, of years old.

This paper, the first section of a two-part article, gives an abbreviated history of dating rocks and minerals, describes the geologic time scale, and summarizes several relative dating techniques. Part 2 of the article focuses on absolute dating techniques based on tree rings, varve sequences, and radioactive decay. Used together, relative and absolute dating methods en-

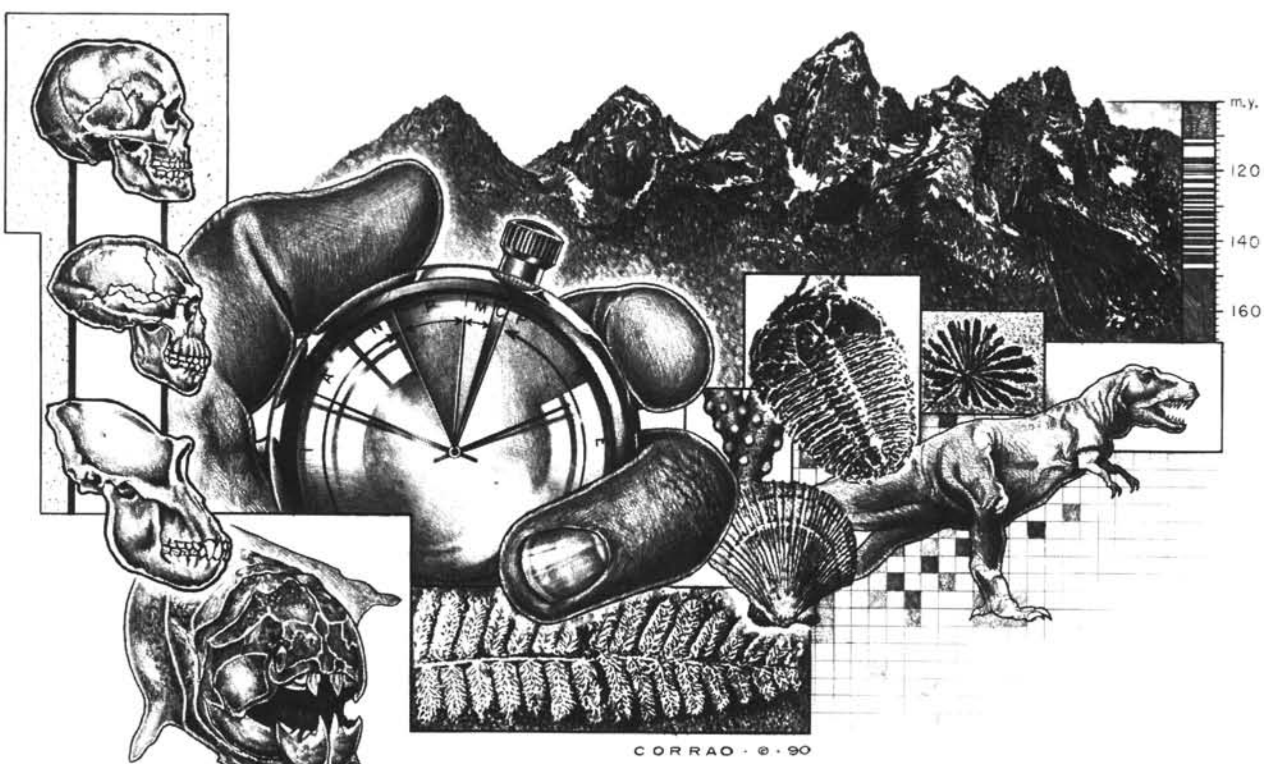

Figure 1. Today's geologists rely on several relative and absolute dating techniques, such as those based on fossils, paleomagnetism, and radioactive decay, to determine the ages of rocks and the order of geologic events. Drawing by Peter F. Corrao, Arizona Geological Survey.

able geologists to date fossils and rock formations and to establish a "calendar" of past geologic events.

HISTORY OF DATING

One of the most important contributions to modern scientific thought is the concept of geologic time. Humans have pondered the age of the Earth and the rocks that compose it for thousands of years. Eastern and western cultures, however, have held very different concepts of time. The Hindus, for example, view time as cyclical, a continuing process of birth, life, death, and rebirth, whereas Judeo-Christian cultures generally conceptualize time as linear, with a beginning and an end. Ancient Hindu philosophers believed that one cycle of the universe equaled one day in the life of Brahma, the creator god, or approximately 4.3 billion years (b.y.). Hindu scriptures postulated that the Earth was almost halfway through one cycle, or 2 b.y. old (Sawkins and others, 1978). This ancient estimate is amazingly close to the actual age of the Earth.

The science of geology, however, evolved in the western world, as did the concept of geologic time. Some ancient Greeks deduced (from observation) that geologic processes took considerable amounts of time. Xenophanes of Colophon (570-470 B.C.) was the first of the early Greek philosophers to recognize the antiquity of both fossils and sedimentary rocks. Around 450 B.C., Herodotus, the Greek historian, concluded that the Nile delta was built from the deposits left by countless floods and thus took thousands of years to form. Other Greek and Roman philosophers, such as Aristotle, and early Christian scholars, such as St. Augustine, continued to explain natural phenomena through deductive reasoning (Press and Siever, 1982).

Despite the insight of these early thinkers, for several centuries the concept of geologic time remained as constricted as the western notion of linear time. During the late Middle Ages, theology permeated scientific thought in Europe. The age of the Earth was determined by only one "proof": the book of Genesis. In the mid-1660's, Archbishop James Usher of Ireland and Dr. John Lightfoot, a Biblical scholar from Cambridge, England, concluded from scriptural analysis that the Earth was created at 9:00 a.m. on October 26, 4004 B.C. (Stokes, 1966; Press and Siever, 1982). Literal interpretation of the Bible was so common that many Christians, including scientists, believed that date, which was printed as an explanatory note in several editions of the Bible (Stokes, 1966). Before 1750, most scientists believed that all sedimentary rocks were deposited during the Great Flood of Noah's time. Other surface features, such as mountains, were believed to be the result of intermittent catastrophes (Faure, 1977). Until the late 18th century, most scientists did not question the orthodox tenets advocated by religious scholars to explain the age and origin of the Earth.

During the 18th and 19th centuries, scientific observations on depositional rates of sediments and the salinity of oceans gradually increased age estimates of the Earth to 100 million years (m.y.; Stokes, 1966; Press and Siever, 1982). In 1859, Charles Darwin published his magnum opus, *On the Origin of Species by Means of Natural Selection.* As the theory of evolution became more widely accepted, fossils were used to calibrate a stratigraphic time scale. Scientists made reasonable chronological assessments based on evolutionary theory; Darwin estimated that it had taken 300 m.y. for complex life to evolve. Increasing estimates of the Earth's age, however, ousted the human species from its egocentric position in the universe. Geologists were opposed, as were astronomers and evolutionary biologists before them, by religious believers who viewed scientific theories as antithetical to Biblical teachings.

While geologists and biologists were extending estimates of the Earth's age, physicists were lowering them. In the mid-18th century, Comte de Buffon of France calculated the age of the Earth based on the assumption that the Earth was solid and had cooled from a molten state. Because he believed that the Earth's interior was iron, Buffon used his measurements on the melting and cooling rates of iron balls to calculate how long it took the molten Earth to cool to its present temperature. He estimated that the Earth was 75,000 years old (Press and Siever, 1982).

In 1854, Herman von Helmholtz, a physicist who helped to establish the science of thermodynamics, theorized about the source of the Sun's light. He believed that it was created by gravitational contraction of the Sun's mass. Particles presumably fell into the center of the Sun, releasing energy in the forms of heat and light. Helmholtz estimated that the Sun began to collapse 20 to 40 m.y. ago (Press and Siever, 1982).

Late in the 19th century, William Thompson (Lord Kelvin), the British mathematician and physicist, applied Buffon's estimates of the Earth's cooling rate to Helmholtz's theories on the Sun's luminosity. Kelvin believed that the Sun was also cooling off and that the Earth would have been too hot to support life before the Sun began to collapse (Sawkins and others, 1978; Press and Siever, 1982). His estimate of the Earth's age (20 to 40 m.y.) was reasonable, based on the sources of energy known at that time. It did not, however, account for the internal heat of the Earth and Sun generated by radioactive decay. Kelvin's estimate caused a regression in scientists' understanding of geologic time. Not until the discovery of radioactivity, the energy within particles of matter, did estimates even approach the age of the Earth.

In the 1890's, three physicists made discoveries that dramatically changed the way scientists viewed the natural world: Antoine Henri Becquerel discovered radioactivity in uranium, Wilhelm Roentgen discovered X-rays, and Marie Sklodowska Curie discovered the radioactive element radium (Press and Siever, 1982). The British physicist Ernest Rutherford was the first to suggest that radioactive minerals could be used to date rocks. He, in fact, dated a uranium mineral in his laboratory in 1906. In that same year, B.B. Boltwood, an American chemist, discovered "ionium," an isotope of thorium; in 1907, he published a list of geologic ages based on radioactivity (Press and Siever, 1982; Newman, 1988). During the following decades, scientists determined the full series of decay products created by natural radioactive disintegration. Using a scientific instrument called a mass spectrometer, scientists were able to refine radiometric dating and establish that the Earth was not millions, but billions of years old. The oldest dated rocks on Earth are almost 4 b.y. old. The Earth, however, is estimated to be more than 4.5 b.y. old, based on the radiometric ages of meteorites and lunar rocks that are thought to record the age of the solar system, including the Earth (Newman, 1988). The earliest life forms preserved in the Earth's rock record (bacteria and blue-green algae) are about 3.5 b.y. old (Lambert and the Diagram Group, 1988).

GEOLOGIC TIME SCALE

Relative vs. absolute

Geochronology, the study and measurement of time as it relates to the history of the Earth, is based on two scales, relative and absolute. **Relative time scales**, defined by sedimentary rock sequences and their included fossils, arrange events in order of occurrence. A geologic event or rock unit is identified as being relatively younger or older than other events or units. **Absolute time scales**, measured in years before the present (B.P.; "present" is defined as A.D. 1950), give more definitive dates for events or units.* Absolute time, most commonly determined by radioactive decay of elements, is by no means "absolute": The precision and accuracy of dating techniques continue to be perfected (Duffield, 1990).

* Geologists use several abbreviations for units of geologic time. For example, "40 million years ago" might be written as "40 m.y. ago," "40 m.y.B.P.," or "40 Ma" (for "Mega-annum"). Similarly, "2 billion years ago" could be abbreviated as "2 b.y. ago," "2 b.y.B.P.," or "2 Ga" (for "Giga-annum"). Some geologists also abbreviate thousands of years as "ka" (for "kilo-annum"); e.g., "30,000 years" could be written as "30 ka."

There are advantages and disadvantages to each time scale. The relative scale based on fossils, used to chronologize the last 570 m.y. of Earth history, is a powerful and accurate method for correlating sedimentary rocks, but cannot be used by itself to assign ages in years. The absolute scale based on radiometric dating can provide dates for igneous and metamorphic rocks, but the date may not represent the true age of the rock if it has a complex thermal history. The two scales are, in fact, complementary: The relative scale determines the positional relationships among rock units; the absolute scale calibrates the relative scale. Generally, fossiliferous sedimentary rocks are dated by relative methods, and nonfossiliferous igneous and metamorphic rocks are dated by absolute techniques. Most sedimentary rocks cannot be dated radiometrically because the mineral grains within the sediments have typically been derived from the weathering of much older rocks and transported to the depositional site. The fossils, however, formed at about the same time as sedimentation. In 1913, the British geologist Arthur Holmes published *The Age of the Earth*, in which he plotted the ages of fossil-bearing sedimentary rocks against radiometrically dated ages of igneous rocks that crosscut them. He was the first to synchronize the relative and absolute time scales (Press and Siever, 1982).

From eons to ages

Geologists divide geologic time into the following main units, each of which is a smaller subdivision of time than the previous unit: eons, eras, periods, epochs, and ages (Figure 2).

Each of the three eons that encompass all of Earth history is a broad span of time distinguished by the general character of life that existed then. The Archean ("ancient") Eon, the earliest eon, is also the longest and least understood. During that time, the first microcontinents formed and primitive life forms appeared. ("Pre-Archean time" is an informal term without a specific rank that applies to the interval between the origin of the Earth and the formation of solid land masses.) The Proterozoic ("former life") Eon brought the first large continents and soft-bodied animals. These intervals, collectively known as the Precambrian, comprise more than 85 percent of geologic time and extend from the origin of the Earth more than 4.5 b.y. ago to the appearance of abundant (and well-preserved) life forms 570 m.y. ago. The Precambrian is radiometrically dated from episodes of igneous intrusion, metamorphism, and mountain building. The Phanerozoic ("visible life") Eon is the last, shortest, and best recorded eon. It is dated mainly from fossil-bearing sediments and includes the last 570 m.y. of Earth history. The Phanerozoic Eon is subdivided into the Paleozoic ("ancient life"), Mesozoic ("middle life"), and Cenozoic ("recent life") Eras (Lambert and the Diagram Group, 1988).

A period is a shorter span of time partly distinguished by evidence of major disturbances of the Earth's crust (Newman, 1988). The name of each period is derived either from the geographic locality where formations of that age were first studied or are well exposed or from a particular characteristic of those formations. The Pennsylvanian Period, for example, is named after the State of Pennsylvania, where rocks of this age are well exposed. The Cretaceous Period, named from the Latin word for "chalk" (*creta*), is named after the white chalk cliffs along the English Channel (Newman, 1988).

The names of epochs within the Cenozoic Era are based on the similarity of fossil molluscs to living molluscs. The Pleistocene Epoch, for example, is named from the Greek words *pleistos* ("most") and *kainos* ("recent") and includes rocks that contain 90- to 100-percent modern mollusc species. In contrast, the Paleocene Epoch, named from *palaios* ("ancient") and *kainos*, includes rocks that contain no modern mollusc species (Stokes, 1966). Ages within each epoch are named after geographic localities in which rocks of those ages are especially well exposed. Each unit of geologic time, from eons to ages, may also be partitioned into subunits through the use of the prefixes "early," "middle," and "late."

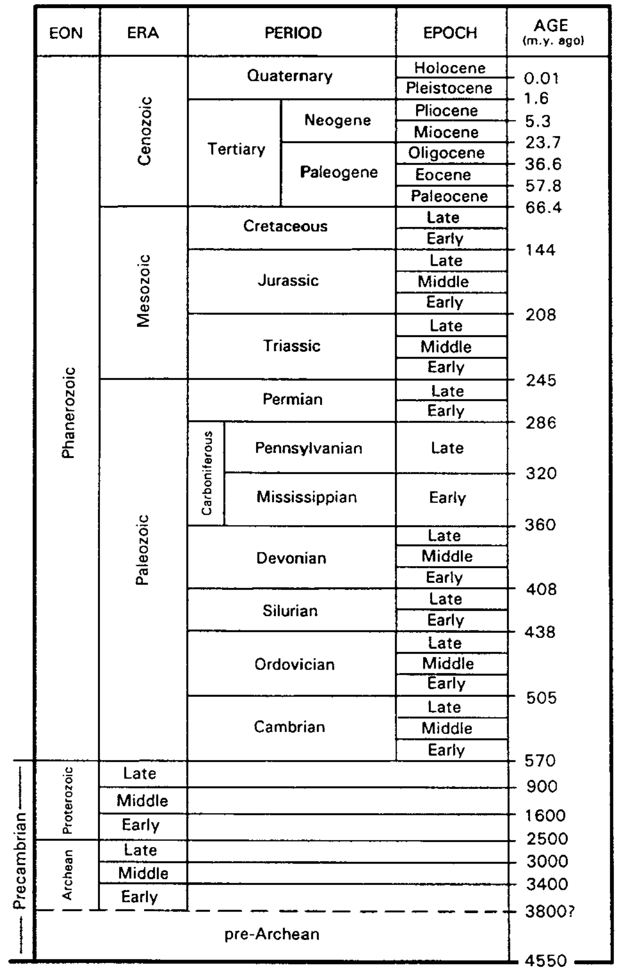

Figure 2. Geologic time scale. Age estimates of time boundaries are in millions of years (m.y.). Ages (subdivisions of epochs) are not shown. Sizes of time "slots" do not reflect proportionate lengths of time intervals. Rocks older than 570 m.y. are called Precambrian, a time term without specific rank. Geologic time prior to 3,800 m.y. ago is called pre-Archean, a term also without specific rank. The Mississippian and Pennsylvanian Periods, recognized in the United States, are collectively referred to as the Carboniferous Period, a term commonly used by geologists in other parts of the world. The Neogene and Paleogene are subperiods of the Tertiary Period. Modified from Palmer (1983), p. 504.

Scientists continue to refine the geologic time scale and revise the chronology of geologic events as more sophisticated technology provides more accurate radiometric dates for rocks and minerals (e.g., Odin, 1982; Palmer, 1983).

RELATIVE DATING TECHNIQUES

General principles

Three fundamental laws or principles of geology form the basis for interpreting the relative sequence of geologic events in an area. The **law of uniformitarianism**, proposed by James Hutton in 1795 and popularized by John Playfair in 1802 and Charles Lyell in 1830, states that the present is the key to the past (Stokes, 1966; Poort, 1980). The physical, chemical, and biological laws of nature that govern processes today controlled identical or similar processes during the past. Interpretations of the events of geologic history, therefore, are based on analyses of modern-day analogues. Uniformitarianism, however, does not imply that the rates of these events or processes were constant over time.

The **law of original horizontality**, proffered by the Danish court physician Nicolaus Steno in 1669, states that water-laid sedimentary rocks are originally horizontal, or parallel to the Earth's surface, because the sediments that compose them were deposited in horizontal layers on the bottoms of oceans, lakes, or rivers (Press and Siever, 1982). If a sedimentary rock unit is folded or tilted, therefore, it was disturbed after it was deposited.

The **law of superposition**, also proposed by Steno in 1669 and established by Hutton about 1795, states that in any undisturbed sequence of sedimentary strata, the oldest layer is at the bottom and the youngest is at the top (Poort, 1980; Press and Siever, 1982). In other words, each layer is younger than the underlying bed on which it was deposited (Figure 3). This law assumes that the strata have not been overturned by faulting or folding.

Faunal succession

The British geologist William "Strata" Smith (1769-1839) determined that each layer of fossil-bearing strata within a sedimentary sequence could be distinguished from the others by the fossils contained within it (Poort, 1980). Smith proposed the **law of faunal succession**, which states that assemblages of fossil organisms (both plants and animals) preserved in rock strata succeed one another in a definite and recognizable order. Evolutionary changes and changes in fossil assemblages are preserved in successive layers of sediments. In general, the older the rock is, the greater are the differences between fossil species within the rock and living species. The fossil content of rocks may, therefore, be used to determine the relative ages of sedimentary strata and to correlate them with rock formations in other geographic areas.

Index fossils are especially useful in correlating strata. An **index fossil** is a fossil from an organism that had a distinctive appearance, was widely distributed, and lived during a relatively short interval, such as an epoch or less. Trilobites and ammonites, for example, may be used as index fossils. Other fossils, such as shark teeth, are not very useful in dating rocks because the species lived during too long an interval of geologic time. Correlating **fossil assemblages**, or groups of distinctive fossils, is the best way to date rocks because the sediments must have been deposited when all the fossil species existed.

Many species, however, have left no record because their remains have not been preserved in rock. This nonfossilization may be due to the species' lack of hardened skeletons, destruction of their hard parts by predators or waves, erosion or metamorphism of the fossilized rocks, or other factors. Scientists estimate that less than 1 percent of all species that ever lived have been identified (Sawkins and others, 1978).

Crosscutting relationships and included fragments

Any rock unit or fault that cuts across other rock units is younger than the units it cuts (Figure 3). Crosscutting units include igneous intrusions of solidified magma. Simply stated, crosscutting relationships indicate that a disrupted pattern (a rock sequence) is older than the cause of the disruption (an igneous intru-

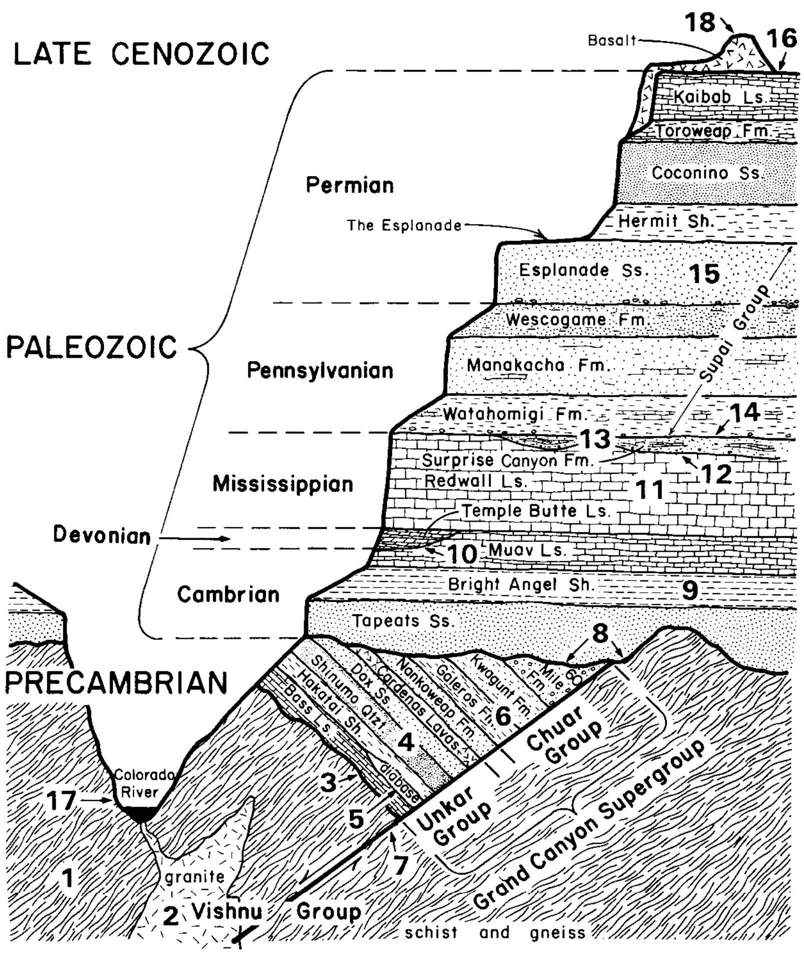

Figure 3. Generalized stratigraphic section of rock units in the Grand Canyon, illustrating superpositional, crosscutting, and unconformable relationships. Not all unconformities have been identified. The order of major geologic events and ages of rock units, from oldest to youngest, are as follows: (1) formation and metamorphism of Vishnu Group (schist and gneiss); (2) granitic intrusion; (3) erosion and formation of nonconformity (about 450 m.y. missing); (4) deposition of Bass Limestone, Hakatai Shale, Shinumo Quartzite, and Dox Sandstone; (5) intrusion of diabase sill; (6) deposition of rest of Grand Canyon Supergroup; (7) faulting and tilting of Grand Canyon Supergroup; (8) uplift and extensive erosion; formation of angular unconformity between Grand Canyon Supergroup and Tapeats Sandstone (at least 300 m.y. missing); formation of nonconformity between Vishnu Group and Tapeats Sandstone ("The Great Unconformity"; more than 1 b.y. missing); (9) deposition of Tapeats Sandstone, Bright Angel Shale, and Muav Limestone; (10) erosion and formation of disconformity (about 135 m.y. missing); (11) deposition of Temple Butte Limestone (in channels) and Redwall Limestone; (12) erosion and formation of disconformity (a few million years missing); (13) deposition of Surprise Canyon Formation in estuaries, caves, and collapsed depressions; (14) erosion and formation of disconformity (about 15 m.y. missing); (15) deposition of Supai Group, Hermit Shale, Coconino Sandstone, Toroweap Formation, and Kaibab Limestone; (16) uplift and extensive erosion; all Mesozoic and nearly all Cenozoic sedimentary rocks stripped away or never deposited (about 243 m.y. missing); (17) cutting of Grand Canyon (starting about 5 m.y. ago); and (18) volcanic eruptions. Modified from Potochnik and Reynolds, 1986, p. 2.

sion). Although a rock unit may not be intersected by an intrusion, it could still be identified as older than the intrusion if the unit is metamorphosed near the intrusion (i.e., if it was altered by the intrusion's heat). If fragments of one rock formation are contained within another, the former rock formation is older than the latter.

Unconformities

An **unconformity** is a surface that represents a break or gap in the geologic record due to erosion or nondeposition. These gaps are recognized by abrupt and striking changes in the composition or orientation of the rocks and by a marked age difference between the rocks above and below the unconformity. Unconformities are commonly caused by uplift of an area, which induces erosion and removal of previously formed rock units.

Geologists classify unconformities into three types: nonconformities, angular unconformities, and disconformities. A **nonconformity** is a break between eroded igneous or metamorphic rocks and younger sedimentary strata (Figure 3). A nonconformity may be identified by the presence of an erosional surface composed of broken fragments of the underlying rock unit or by a lack of metamorphism in the strata overlying an igneous or metamorphic formation. Because intrusive igneous and metamorphic rocks form deep below the Earth's crust, a nonconformity generally indicates that deep or long-lasting erosion occurred before additional sediments were deposited (Poort, 1980).

An **angular unconformity** is an erosional surface between tilted or folded older sedimentary rocks and younger sedimentary strata that are oriented differently (Figure 3). This type of unconformity indicates that the underlying rocks were deposited, folded or tilted, uplifted, and eroded before the overlying rocks were deposited.

A **disconformity** is a surface that represents a gap between essentially parallel sedimentary strata (Figure 3). Because the strata have the same orientation and an erosional surface may not be apparent, a disconformity is the most difficult unconformity to detect. It is commonly identified by studying the fossils within the rock units and recognizing a substantial gap in the faunal succession. A disconformity implies that the area was uplifted, but not severely deformed or metamorphosed (Poort, 1980).

Because several geologic events could have taken place during these missing intervals, unconformities must be included in the reconstruction of an area's geologic history. Unconformities help geologists to determine the relative sequence, duration, and intensity of geologic processes within a particular region.

Paleomagnetic properties

The Earth is surrounded by a magnetic field believed to originate in the fluid part of its iron core. Heat generated by radioactivity in the Earth's core stirs the fluid into convective motion. A weak magnetic field interacting with the moving iron fluid generates electric currents, creating a stronger magnetic field and a self-sustaining magnetic system (Press and Siever, 1982).

The Earth's magnetic field, like a bar magnet, has a specific direction that is defined by the magnetic north and south poles. Geomagnetic north, the direction to which a compass needle points, is not the same as geographic or true north. True north coincides with the Earth's axis of rotation; geomagnetic north is presently inclined about 11° from true north. The direction of the geomagnetic field at any point on the Earth's surface includes its **declination** (its angle east or west of true north) and its **inclination** (its angle with respect to the Earth's surface). Declination varies with both latitude and longitude. In Flagstaff, Arizona, for example, the geomagnetic north pole is 13.5° east of true north, whereas in Tucson it is 12.5° east. Inclination varies primarily with latitude. At the magnetic poles, the inclination is vertical; near the magnetic Equator, it is horizontal. The intensity of the geomagnetic field also varies with latitude; it is strong at the poles, but relatively weak at the Equator. Both the intensity and direction of the geomagnetic field vary gradually with time, a phenomenon called **secular variation**. Despite this deviation, the average position of the magnetic pole over millions of years has centered on the Earth's rotational (geographic) pole (Press and Siever, 1982).

Rocks may contain a magnetic signature that reflects the orientation of the Earth's magnetic field when the rocks were formed. This signature is recorded when iron-rich minerals crystallize from a molten state, are deposited in calm bodies of water, such as an ocean, or crystallize within a rock during metamorphism or diagenesis (the processes that compact and harden sediments and turn them into rock). When molten materials cool and harden and when sediments lithify, the magnetic iron minerals are "frozen" in place, essentially pointing to the Earth's magnetic pole like a compass needle. This **remanent magnetization** has a fixed direction that is independent of the current magnetic field of the Earth. Remanent magnetization in rocks leaves a record of the Earth's ancient magnetic field, just as a fossil leaves a record of ancient life.

Paleomagnetism, the study of the Earth's magnetic field during the geologic past, involves measuring both the direction and intensity of remanent magnetization in rocks. By comparing the paleomagnetic properties of rocks of similar age on different continents, scientists discovered during the 1950's and 1960's that the positions of the magnetic poles inscribed in the rocks did not agree. If, however, the continents were reassembled on the globe by matching the shapes of their edges like the pieces of a puzzle, the directions of the paleomagnetic poles also coincided. Paleomagnetism thus provided evidence of continental drift. To reconstruct the positions of the continents during the geologic past, scientists had to determine the average position of the geomagnetic pole from numerous sample sets, each of which included rocks dated within a few million years of each other. If the average geomagnetic pole and the geographic pole did not match, scientists conceptually moved the continents on the globe until the poles coincided and the previous geographic positions were established.

Paleomagnetic studies of layered sequences of lava flows on land revealed that the geomagnetic field has reversed itself every few hundred thousand years, taking a few thousand years or so to change its direction (Press and Siever, 1982). The history of magnetic reversals over the past 7 m.y. has been constructed by piecing together the ages and polarities of lava beds around the world. Based on this restoration of geomagnetic history, scientists compiled a time scale of magnetic reversals consisting of normal and reverse magnetic epochs (Figure 4). Each epoch lasted a few hundred thousand years or more, but included short-lived reversals, called **magnetic events**, that lasted from several thousand to 200,000 years (Press and Siever, 1982). The cause of geomagnetic reversals, however, is unclear.

Highly sensitive magnetometers developed during World War II to detect enemy submarines were later adapted by oceanographers to study the sea floor. These scientists discovered bands of magnetic anomalies that parallel the mid-oceanic ridges. The bands are almost perfectly symmetrical with respect to the ridge axes. In other words, bands of normal and reversed magnetism (known as positive and negative magnetic anomalies, respectively) in the rocks on one side of a ridge are mirrored in the rocks on the opposite side (Figure 5). In the 1960's, scientists suggested that these duplicate patterns were evidence for the theory of sea-floor spreading. This theory proposes that new oceanic crust solidifies from magma forced upward into the mid-oceanic ridges and spreads outward as it is pushed aside by new upwellings of magma. By comparing the magnetic anomalies on the sea floor with the magnetic reversals in lava flows on land, scientists were able to determine sea-floor spreading rates. Because the geomagnetic record is longer and more complete on the ocean floor than on land, scientists used these spreading rates. Because the geomagnetic record is longer and more complete on the ocean floor than on land, scientists

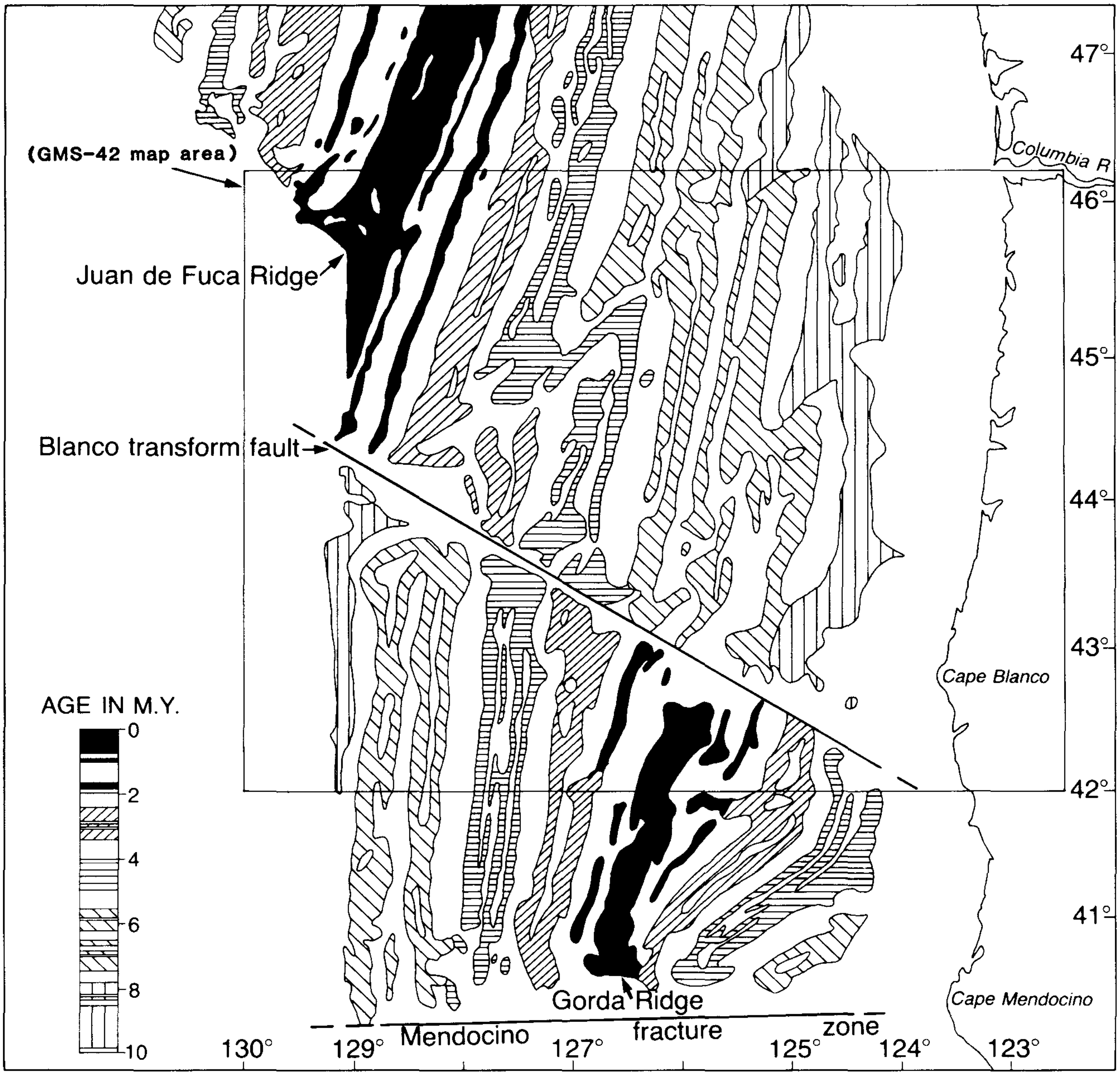

Figure 4. Magnetic anomaly map of the Pacific Ocean floor off the coast of Washington, Oregon, and California, showing zones of rocks with normal (black and patterned bands) and reversed polarity and their ages on the geologic time scale. Note the symmetry of rock ages on both sides of the ocean ridges. Modified from Peterson and others (1986).

used these spreading rates to extend the time scale of geomagnetic reversals back to the Jurassic Period, 162 m.y. ago (Press and Siever, 1982).

Paleomagnetism has provided not only a method to correlate rock formations but also evidence of continental drift and sea-floor spreading, two aspects of the unifying geologic theory of plate tectonics. One drawback of this method, however, is that magnetism in rocks is destroyed if they are heated above a certain temperature, called the Curie point. For most magnetic rocks and minerals, the Curie point is about 500 °C (Press and Siever, 1982). If a rock has been reheated, its paleomagnetic properties reflect the Earth's magnetic field at the time the rock cooled below its Curie point, not necessarily the geomagnetic field at the time the rock was formed.

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Correspondence

The following presents excerpts from letters to the editor or to the author, in response to the article "The case of the inverted auriferous paleotorrent—exotic quartzite gravels on Wallowa Mountain peaks," by J.E. Allen, published in the last issue of Oregon Geology *(p. 104-107).*

Dear editor:

This has little (nothing?) to do with agriculture. I get *Oregon Geology* at home and just want to let you know how much I enjoy some issues.

The September issue is a prize to me. I learned a lot from the article on beach placers.

What really caught my eye and admiration was the wonderful headline on John Eliot Allen's article—"auriferous paleotorrent." What a great way to say the magic words that excite any gold buff—"ancient river of gold"!

I hope it was all on purpose. Even if it wasn't, the excitement arose.

—Sincerely,
Virgil Rupp, Editor
Agri-Times Northwest

Dear John:

I read with interest your writeup in *Oregon Geology* about the quartzite gravels. I congratulate you for publishing the article, and I hope you'll motivate someone to take a closer look at the problem.

I've been intrigued by the gravels since I first saw them in Hells Canyon in the early 60's. I even mentioned them in my dissertation after I found them on top of the limestone near McGraw and Spring Creeks. Last summer I spent three days in that area, digging down into pockets or holes in the karst-eroded limestone, carrying the soil from the bottoms of the holes to a stream, and panning for color. I found only black sand and no gold. *However, John, I **know** it's there!*

The thickest deposit (10 meters) is on top of the Martin Bridge Limestone south of the confluence of the Grande Ronde and Snake Rivers in Washington. There, the boulders and gravels are a mixture of greenstone, quartz diorite (Jurassic-Cretaceous), and quartzite.

I have found quartzite gravels in many places along the contact between the Permian-Triassic and Columbia River Basalt Group in the canyon. Even last summer, I found new deposits at Pittsburg Landing and in the Seven Devils Mountains. I also recall an extensive surface covered by the boulders and cobbles, on Joseph Mountain, I believe, in the Wallowas. Interestingly, there are well-rounded boulders and cobbles in other places within the Blue Mountains: south of Sparta and toward Baker City they have a mixture of rock types, including quartzite and chert (from the Baker terrane).

Origin? I doubt if we can ascribe it to a single stream. Rather, I think of an extensive area of coalescing alluvial fans (Bajadas) that formed in the Late Cretaceous-Miocene (probably -Eocene) interval at the foot of a spectacular mountain range caused by uplift of central Idaho. The mountain range may have formed as a consequence of the Blue Mountain island arc/North America collision and/or intrusion and uplift of the Idaho Batholith. The quartzites themselves are a problem, but I have noted that they may have been eroded from the quartzite beds in the Revelle Group of central and northern Idaho.

Anyway, John, if someone bites, let me know, and I'll help them find significant outcrops of boulders in the canyon.

Once again, congratulations! You have been a fantastic salesman on the geology of Oregon. Keep it up!

—Best regards,
Tracy Vallier
U.S. Geological Survey
Menlo Park, California

Mineral information on Oregon now available as computer database

The Oregon Department of Geology and Mineral Industries (DOGAMI) has placed on open file a database containing a variety of information on minerals in Oregon.

Mineral Information Layer for Oregon by County (MILOC),
compiled by Jerry J. Gray.
DOGAMI Open-File Report O-91-4, 2 diskettes, $25.

MILOC is a database in dBase III+ format that can be imported into computerized geographic information systems or used with a personal computer as a stand-alone, county-by-county database. It provides information on approximately 7,650 mineral occurrences, prospects, and mines in Oregon. Records on individual sites include a great variety of data on location, commodity, geology, descriptions of mine workings, and many other subjects.

The database was developed in cooperation with several federal and state natural-resource agencies and will serve as a mineral-data layer to fit with other portions of a variety of geographic information systems. For that purpose, each site is located by latitude/longitude and Universal Transverse Mercator (UTM) coordinates.

MILOC is a useful information source for universal applications in industrial, county, state, and federal planning, exploration, and management.

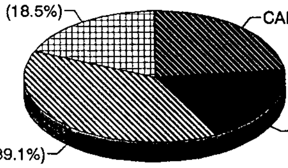
The new release, DOGAMI Open-File Report O-91-4, consists of two 1.2-megabyte (5¼-inch) high-density diskettes in MS-DOS format. It is now available at the DOGAMI Portland Office (address on p. 122 of this issue). Orders may be charged to credit cards by mail, FAX, or phone. FAX number is (503) 229-5639. Orders under $50 require prepayment except for credit-card orders. □

Exploration spending for nonferrous metals reported

From a survey of current and recent exploration programs of 167 companies (representing at least 80 percent of worldwide exploration spending on nonferrous metals), the Metals Economics Group reports the following totals for 1991:

The 1991 exploration budgets of 153 companies worldwide, including expenditures for precious, base, and other nonferrous hard-rock metals, as well as diamonds and any industrial minerals sought by the mining companies surveyed, amount to a total of $1.846 billion.

Of this amount, 60.9 percent was directed to projects in Canada (23.3 percent, $430 million), Australia (19.1 percent, $353 million), and the United States (18.5 percent, $341 million). Canada's share, though still largest, has declined considerably since 1987 and 1988, when Canadian expenditures totaled more than $1 billion per year. U.S. expenditures have remained relatively stable during the past few years, while Australian expenditures have declined steadily since 1987.



Worldwide 1991 exploration spending by location in 153 company budgets totaling $1.846 billion.

Rough estimates of spending in other countries indicate that about $245 million is being spent in South Africa this year (13 percent of the surveyed total), $200 million in Latin America (11 percent), $125 million in the South Pacific area (7 percent), $80 million in Europe (4 percent), and $70 million (4 percent) in Africa outside South Africa. Small amounts of the surveyed budgets are being spent elsewhere, including Japan, China, India, and southeast Asia.

The ten largest spenders on exploration in 1991, with budgets ranging from $102 million to $44.2 million, include Anglo American, RTZ, CRA, Falconbridge, DeBeers, BHP, Noranda, Anglovaal, Placer Dome, and Western Mining. Together, these companies account for 35 percent of the surveyed exploration spending.

By the way, the complete study can be purchased for only $9,500 from Metals Economics Group, 200 Barrington Street, P.O. Box 2206, Halifax, Nova Scotia B3J 3C4, Canada, phone (902) 429-2880, FAX (902) 429-6593.

—Metals Economic Group news release

DOGAMI has openings for volunteers

The Department of Geology and Mineral Industries (DOGAMI) has volunteers currently helping in the library and sales office, doing work that could not be done otherwise. These valued helpers have added much to DOGAMI, and their help is greatly appreciated.

We could use other volunteers, both in the new store/information center that will be opening next year (see page 136) and now in the library and the existing map and publications sales office. If you want to help where your contribution of time really makes a difference, contact Beverly Vogt, DOGAMI, 910 State Office Building, Portland, OR 97201, phone (503) 229-5580. □

AGI publishes curriculum guide for earth-science content

Earth Science Content Guidelines K-12 is an 80-page guide for incorporating earth-science content into the precollege curriculum. Published recently by the National Center for Earth Science Education of the American Geological Institute (AGI), the guide consists of a set of questions organized according to the interacting systems that characterize Earth and its relationship to the solar system. In each of the six content areas—solid Earth, air, water, ice, life, and Earth in space—the questions are divided into these grade levels: K-3, 3-6, 6-9, and 9-12.

The content-guide report also has a large section of notes outlining ideas that teachers might want students to understand while investigating the questions. The notes include suggestions for what teachers can do to help students acquire that understanding. They are arranged in a three-column format with the following column headings: Essential questions, Key ideas, and Seeking answers.

Earth Science Content Guidelines K-12 is based on the set of goals, concepts, and recommendations for improving earth-science education in the nation's schools that was published by AGI earlier this year in a 40-page report, *Earth Science Education for the 21st Century: A Planning Guide.* This report discusses goals to guide earth-science education, essential concepts in earth science, recommendations for teaching earth science in grades K-12, and recommendations for implementing new precollege earth-science programs.

Both guides were developed by earth scientists, teachers, and other science educators with support from the National Science Foundation and other contributors. Copies are available from the AGI Publications Center, Box 2010, Annapolis Junction, MD 20701, phone (301) 953-1744. Volume discounts are available for each publication.

For more information about the content of the guides or AGI's education program, contact Andrew J. Verdon, Jr., National Center for Earth Science Education, AGI headquarters, 4220 King Street, Alexandria, VA 22302-1507, phone (703) 379-2480.

—AGI news release

Washington geologic map adds second quadrant

The second quadrant of the geologic map of Washington has been completed and published. The first (southwest) quadrant was published in 1987 as Geologic Map GM-34.

Geologic Map of Washington—Northeast Quadrant, by K.L. Stoffel, N.L. Joseph, S.Z. Waggoner, C.W. Gulick, M.A. Korosec, and B.B. Bunning. Washington Division of Geology and Earth Resources Geologic Map GM-39, 1991, 36 p., 3 sheets, geologic map scale 1:250,000.

Price for folded sheets in thumb-notched envelope is $7.42 (plus $.48 tax for Washington residents only); flat sheets (limited supply, mailed in tubes) are $9.28 (plus $.72 Washington tax). The topographic base map is available separately as Map TM-2, folded or flat, for $1.86+$0.14=$2.00 or $3.25+$.35=$3.50, respectively.

Orders should be addressed to Department of Natural Resources, Division of Geology and Earth Resources, Mail Stop PY-12, Olympia, WA 98504. To each order, $1 should be added for postage and handling. □

Early Oligocene paleoenvironment of a paleosol from the lower part of the John Day Formation near Clarno, Oregon

by Aberra Getahun and Gregory J. Retallack, Department of Geological Sciences, University of Oregon, Eugene, Oregon 97403

ABSTRACT

The red basal part of the lower Oligocene John Day Formation consists of numerous, superimposed fossil soils. One of these, reported here and named Luca clay paleosol[1], is a well-developed red clayey profile similar to modern Udalfs[2]. It represents a well-drained land surface that was stable for at least a few tens of thousands of years. It probably formed under forest vegetation, as can be judged from abundance of root traces and a well-developed subsurface clayey horizon. Its smectitic-kaolinitic clays and base-poor chemical composition are compatible with a sub-humid to humid paleoclimate.

INTRODUCTION

The colorful badlands of mid-Tertiary nonmarine rocks in the high desert of the John Day country of central Oregon are a delight to the eye, well known from scenic landmarks such as the Painted Hills and Sheep Rock now protected within the John Day Fossil Beds National Monument. Only recently has it been realized that these striking color bands are ancient soils within tuffaceous deposits (Retallack, 1981, 1985).

This study of a fossil soil in the Oligocene part of the John Day Formation in north-central Oregon aims to provide a brief description of the paleosol and to interpret its significance for paleoenvironment and paleoecology of the area. The lower member of the John Day Formation, which rests unconformably on older rocks of the Clarno Formation, is composed mainly of brilliant red claystones and siltstones. The red color of the lower John Day Formation has been ascribed to mixing of volcanic ash with lateritic soil derived from the Clarno Formation (Waters and others, 1951; Fisher and Wilcox, 1960; Hay, 1962). In a later study Fisher (1964) explained the red clay as a continuation, into John Day time, of deep and prolonged weathering that was responsible for the post-Clarno "lateritic" paleosol. No exceptionally iron-rich rocks with evidence of irreversible hardening (plinthites or "laterites" formed in place) were found with the present work.

Association of iron oxides, manganese oxides, kaolinite, montmorillonite, chalcedony, and calcite also has been reported within the same hardpan in the lower John Day Formation (Fisher, 1964). These kinds of hardpans are sometimes found in desert soils (Birkeland, 1984). The present study, however, did not identify calcareous hardpans, either through acid testing in the field or through chemical analysis.

This is not to imply that lateritic and calcareous paleosols are not present but rather to indicate the diversity of prior views on ancient weathering in these rocks and emphasize the need for detailed study of entire profiles. There are many different kinds of paleosols in these rocks (Smith, 1988; Pratt, 1988) as in other alluvial sequences (Retallack, 1983; Bown and Kraus, 1987). The paleosol profile described here is a start at unravelling their complex and changing paleoenvironment through paleosol study.

[1] The word "luca" is the term for the color red in the Umatilla dialect of the Sahaptin language spoken by early inhabitants of this area (Rigsby, 1965).

[2] For explanations of soil-science terminology, readers are referred to Soil Conservation Service (1975), Brewer (1976), and Birkeland (1984).

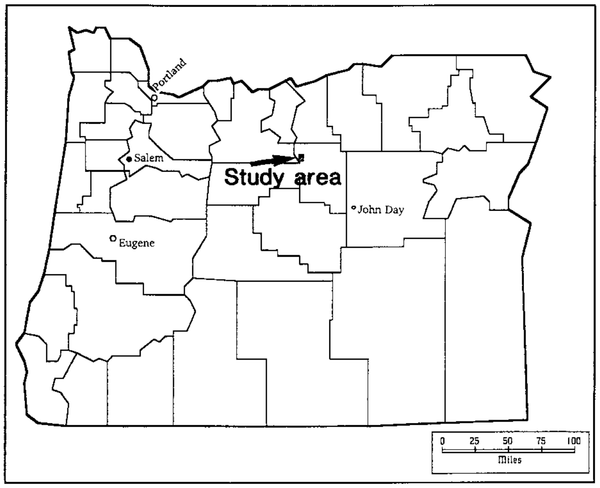


Figure 1. Location of Luca clay paleosol study area in Wheeler County, Oregon.

GEOLOGIC SETTING

The studied profile is located in the north-central part of Wheeler County, Oregon, in the S½SE¼ sec. 23, T. 7 S., R. 19 E., Clarno 7½-minute quadrangle (Figure 1). It is some 2.5 mi northeast of the bridge across the John Day River at the small village of Clarno. The outcrop studied is a prominent red knoll capped with white ash, in a grassy slope 1 mi northeast of Camp Hancock (Figure 2). This red outcrop is mapped within the lower John Day Formation, which overlies the basal ignimbrite of the formation, here dated at 37.3±11 million years (m.y.) (Robinson and others, 1984). The basal red part of the formation, which includes the paleosol described here, is poorly fossiliferous. Loose around the base of the outcrop studied were found a fragmentary large canine tooth like that of an entelodont (large piglike mammal) and some permineralized woody branches 12 cm in diameter showing a fracture pattern similar to that of charcoal. Some 50 m south of the outcrop and underlying the paleosol are brown paper shales and tuffs containing fish scales, cones, winged fruits, and leaves, including those of *Ulmus*, *Tetrapteris*, and *Metasequoia*. All of these remains are low in diversity and poorly preserved compared to those of the middle green and upper buff members of John Day Formation, which contain abundant fossil leaves (Manchester and Meyer, 1987), fish (Cavender, 1969), insects (Cockerell, 1927; Peterson, 1964), and mammals (Merriam and Sinclair, 1907; Woodburne and Robinson, 1977).

The John Day Formation of north-central Oregon is a widespread, largely pyroclastic sequence lying between the Clarno Formation of Eocene age and the Columbia River Basalt Group of Miocene age. The formation crops out in a belt along the southern margin of the Columbia River drainage basin, extending nearly 200 km eastward from the central Oregon Cascade Range. The formation provides a well-exposed and relatively continuous record of early Cascade Range volcanism. It consists largely of andesitic to dacitic tuffaceous claystone, air-fall tuff with numerous interlayered ash-flow sheets, and lava flows of rhyolite and trachyandesite (Woodburne and Robinson, 1977; Dingus, 1979).

Figure 2. General view of the lower John Day Formation, in Wheeler County, Oregon (arrow indicates position of Luca clay paleosol).

METHOD

A trench about 2.30 m deep and 80 cm wide was dug with hoe and shovel to create a better exposure of the various horizons of the paleosol. Dilute hydrochloric acid was used to check the presence of carbonate minerals. Color was identified using a Munsell color chart. Thin sections were made of samples from each horizon, and point counts were done. Chemical composition of each sample was assayed with atomic absorption by Christine McBirney at the University of Oregon. The clay minerals of the paleosol were identified by use of the Rigaku Miniflex X-ray diffraction machine. The detector was set to count over a range of 2θ from 70° to 5°. The X-ray wavelength was 1.54059 Å (CuK_{α}). The samples analyzed were not pretreated. Quartz and silicon metal standards were used for calibrating the machine.

DESCRIPTION OF THE LUCA CLAY PALEOSOL

The paleosols crop out in a red badlands slope (Figure 2). The top of the paleosol can be identified as a laterally abrupt contact between white ash and red mottled silty claystone. Below that, there is a thick gradational profile of claystone that becomes redder and darker in color as mottles of gray silty claystones become less abundant. The drab mottles are complexly interwined and tubular, like drab-haloed root traces (Retallack, 1983). The various horizons identified in the trench were a silty claystone surface (A), clayey subsurface (Bt), and a silty tuffaceous claystone parent material (C). Color varies from white (5YR8/1) in the A horizon to dusky red (10R3/4) and dark red (10R3/6) in the Bt and C horizons, respectively.

The A horizon (0-47 cm) is a noncalcareous silty claystone, containing slender, purple root traces surrounded by drab haloes. This horizon is sharply truncated by the overlying tuff unit that defines the top of the paleosol. The A horizon is dominantly clay with lesser silt. Slickensides also were observed. In thin section, it has porphyroskelic skelinsepic plasmic fabric (of Brewer, 1976); with plagioclase, volcanic rock fragments, glass shards, opaques, and a few sesquiargillans.

The Bt horizon (0.47-1.41 m) is a dusky red (10R3/4) claystone with less common drab-haloed root traces than the A horizon (Figure 3). This clayey horizon is riddled with slickensides, randomly arranged. Acid test indicates it is noncalcareous. There is a gradual decrease of the root traces downward into the C horizon. No fossil burrows or biological traces other than roots were found in this horizon. Microtexture is porphyroskelic skelmasepic, with plagioclase, volcanic rock fragments, opaques, and few quartz grains.

The C horizon (1.41-2.16 m) is dark red (10R3/6) and contains no root traces or burrows. The dominant grain size of this horizon is silt. This part of the paleosol gave no indication of a concentration of calcareous nodules or stringers. The lower portion of the horizon contains some recognizable feldspar grains and rock fragments (Figure 3). Microtexture is porphyroskelic skelmasepic in drab areas, isotic with sesquioxide stain elsewhere. Plagioclase, volcanic rock fragment, opaques, quartz, and a few sesquiargillans were also observed. The C horizon gradually passes into a clayey lower portion that also has been affected by weathering processes. It has the same color as the overlying horizon.

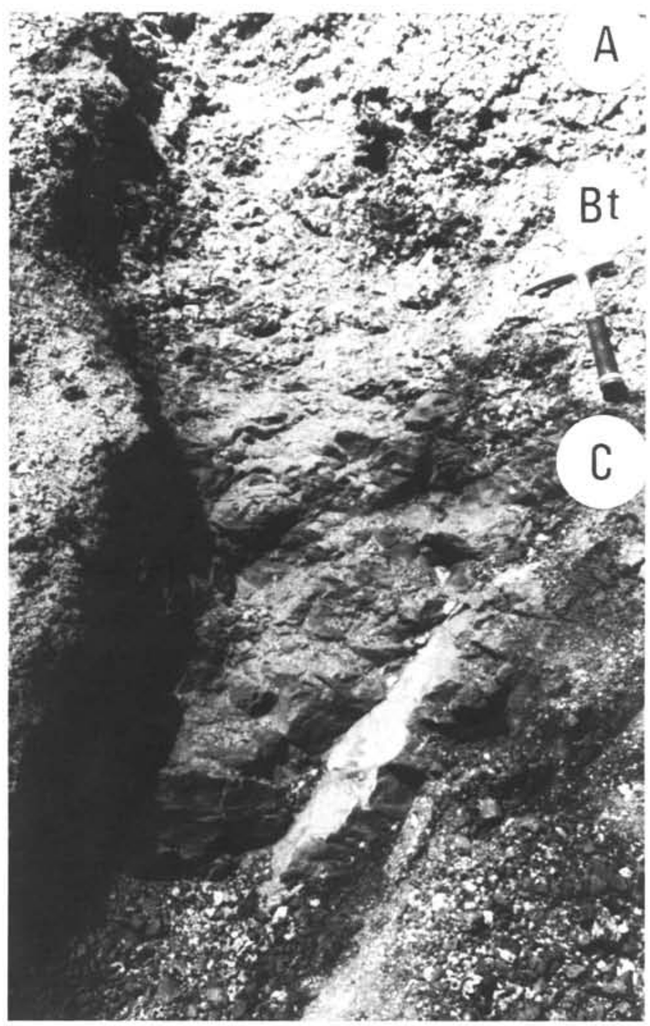


Figure 3. Paleosol horizons exposed after trenching of the Luca clay paleosol.

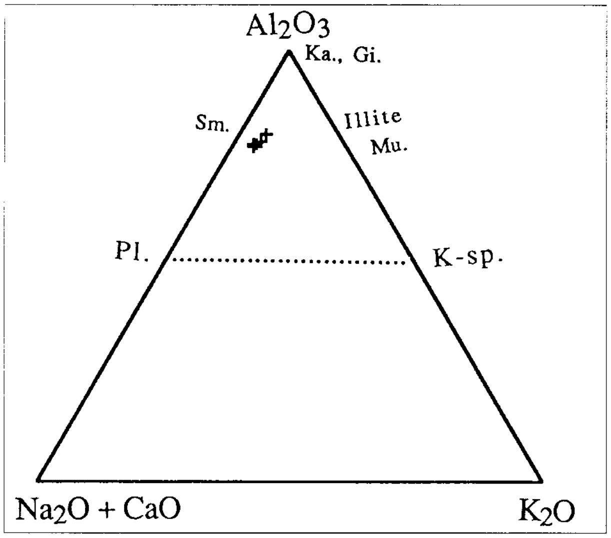


Figure 4. Triangular variation diagram constructed using molar proportions of Al_2O_3, Na_2O+CaO, and K_2O as end members for the weathering profile of Luca clay paleosol.

CLAY MINERAL COMPOSITION

Smectite is the dominant clay mineral followed by kaolinite, as revealed by X-ray diffraction studies. A triangular variation diagram plotted with Al_2O_3, K_2O, and Na_2O+CaO (following Nesbit and Young, 1989) as end members also indicates smectite to be the major clay component of the paleosol (Figure 4). Quartz and hematite also were detected in all the X-ray diffraction traces.

CHEMICAL COMPOSITION

Within the profile there is a general increase in the oxide values of SiO_2, CaO, MnO, Na_2O, and MgO and decrease of Fe_2O_3, K_2O, TiO_2, and Al_2O_3 from the lower horizon to the surface of the paleosol (Table 1). Three main patterns appear in the distribution of the trace elements in the paleosol. Co, Ni, and Sr are found in larger abundance in the surface and near-surface horizon; Cr, Rb, and Zn are found in greater abundance in the lower horizon, while Cu and Ba are enriched in the clay-rich Bt horizon.

The concentration of SiO_2 and some mobile elements (alkali and alkaline earth elements) in the A horizon compared to the lower part of the fossil soil may have been due to the addition of volcanic ash, dust, and thin increments of flood-borne silt (which are evident from the profile section; Figure 5). The depletion of potassium from the A horizon could be the result of plant uptake as found in surface soils by Mehlich and Drake (1955) and Tan (1984).

In general, Ba, Cr, and Zn tend to accumulate in clays of soils and other residual materials (Aubert and Pinta, 1977; Wedepohl, 1978). The abundance of these elements and Cu in the clay-rich Bt horizon may reflect the affinity of these trace elements for clay and hydroxides of iron and manganese. The surface enrichment of Sr, generally a mobile element during weathering, may be due to addition of new materials to the soil profile.

MOLECULAR WEATHERING RATIOS

Molecular ratios were employed to understand specific weathering processes in the development of the paleosol. The ratios are calculated by dividing the weight percent of each oxide or element involved by its molecular weight and then dividing the oxides or elements as specified by the particular ratio.

Table 1. *Major- and trace-element chemical data for the Luca Clay paleosol. Oxides in weight percent, trace elements in ppm; sample numbers indicate vertical position between surface (JD-1) and lower horizon (JD-5)*

Sample	JD-1	JD-2	JD-3	JD-4	JD-5
SiO_2	59.46	59.26	57.68	53.20	51.50
TiO_2	1.46	1.52	1.58	1.67	1.58
Al_2O_3	16.13	16.20	16.42	17.17	17.36
Fe_2O_3	5.31	5.59	6.75	8.85	10.20
FeO	0.00	0.00	0.00	0.00	0.00
MnO	0.06	0.05	0.06	0.08	0.08
MgO	0.66	0.63	0.62	0.61	0.57
CaO	2.26	2.12	2.11	2.08	1.84
Na_2O	1.57	1.54	1.51	1.37	1.21
K_2O	0.80	0.82	0.92	1.03	1.08
H_2O^+	3.65	3.60	4.50	4.28	4.36
H_2O^-	8.68	8.56	7.65	9.75	10.34
P_2O_5	0.09	0.10	0.08	0.13	0.07
TOTAL	100.13	99.70	99.88	100.18	100.19
Ba	135	135	145	116	126
Co	78	28	15	20	20
Cr	20	21	23	25	27
Cu	80	112	106	130	45
Li	16	16	16	15	17
Rb	42	41	59	57	70
Sr	134	128	124	100	94
Zn	82	82	86	89	86

The ratios of Al_2O_3/K_2O, SiO_2/Fe_2O_3, SiO_2/Al_2O_3, Base/Al_2O_3, and Ba/Sr all decrease down the profile indicating leaching of bases and iron-rich clay from surface to subsurface horizons (Figure 6). The ratio of FeO/Fe_2O_3 is extremely low in all the horizons, evidence of a highly oxidized paleosol that was probably well-drained throughout. The Ba/Sr ratio of the Luca clay paleosol is also low throughout, an indication of limited leaching.

DIAGENESIS

The drab-colored A horizon, which originally would have been the part of the paleosol richest in organic matter, may have been discolored during burial gleization of the paleosol. Drab-haloed root traces, abundant in both A and Bt horizons, may also have been discolored by anaerobic decay of organic matter soon after burial of the fossil soil (Retallack, 1983). These drab haloes and horizons have none of the features, such as ferruginous concretions or a tabular pattern of carbonaceous root traces, that are found in originally waterlogged soils. The paleosol is also too highly oxidized to have been a gleyed soil.

The red color of the soil matrix is due to the presence of hematite as revealed by X-ray diffraction. Well-drained soils may have hydroxides of ferric iron in the form of gels, or minerals such as goethite, which form a light-brown or yellow stain. These minerals may have been converted to hematite by dehydration during compaction of the fossil soil (Walker, 1967). Thus the paleosol may

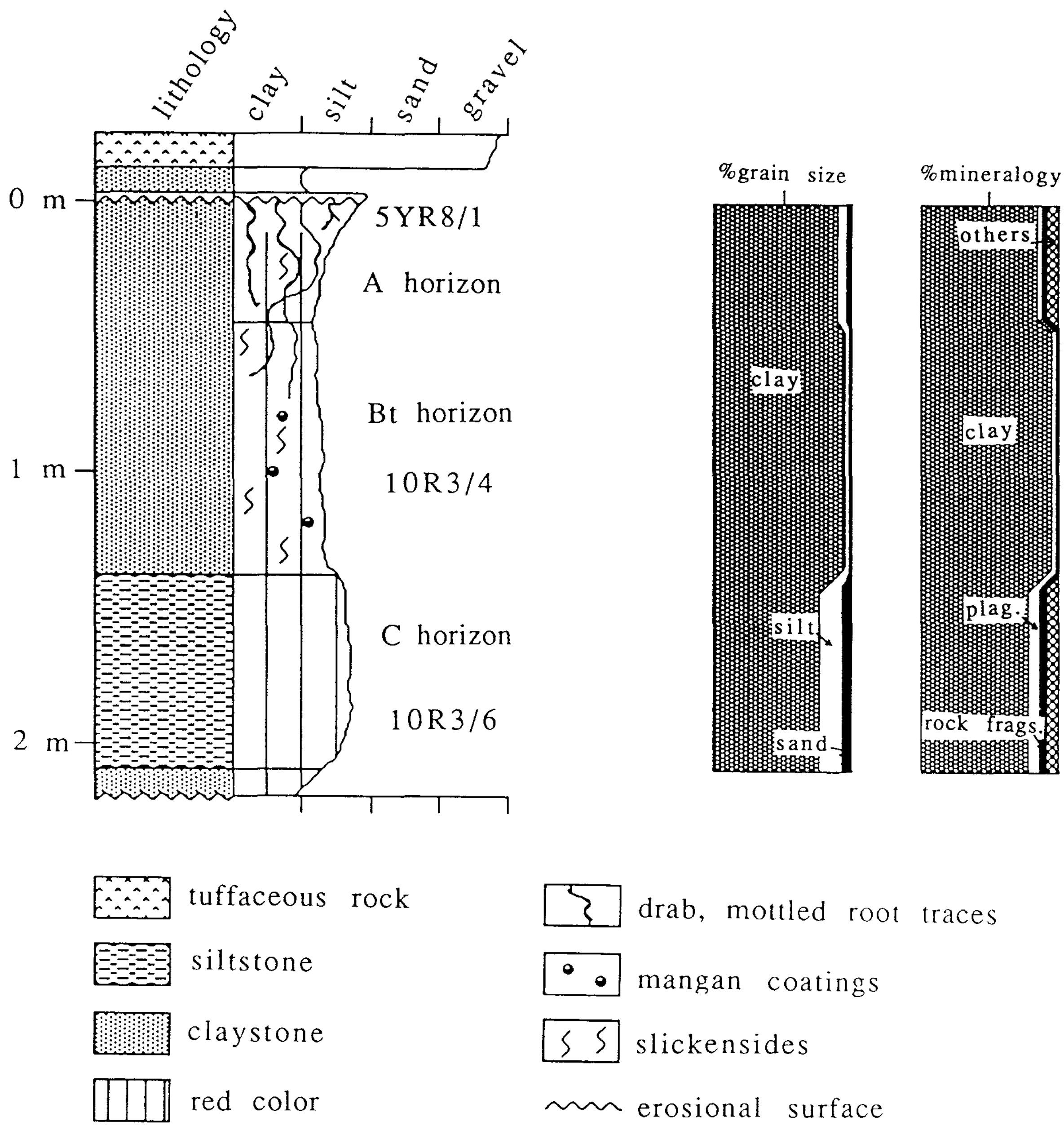


Figure 5. Columnar section (measured in field) and petrographic composition and grain size (from point-counting of thin sections) of the Luca clay paleosol within the lower John Day Formation in Wheeler County, Oregon.

be redder than the original soil by as much as three Munsell hue units, like some Quaternary paleosols compared to similar surface soils (Ruhe, 1969).

Compaction of paleosols by overburden is a common phenomenon that results in a reduction of their thickness. The deformed root traces of the Luca clay paleosol indicate a considerable reduction of thickness of the fossil soil by compaction. Slickensides form in clayey soils where peds are repeatedly heaved past one another or by crushing of peds one against another during compaction following burial (Retallack, 1990). Both of these mechanisms might have been the causes for the abundant slickensides observed in the paleosol. The smectitic nature of the clay (Figure 4) would have facilitated the swelling and shrinking of the soil upon wetting and drying.

IDENTIFICATION

Modern soils with clayey subsurface (argillic) horizons include Alfisols and Ultisols, which are distinguished and classified according to their base status. The greater abundance of smectite than kaolinite indicates a mildly alkaline to neutral pH. The former Eh of the paleosol can be constrained within broad limits from mineral assemblages. Unlike a reducing environment, where soil hue is usually bluish or greenish gray and where root traces are confined to shallow depths and horizontally oriented, the Luca clay paleosol has a red hue and numerous branching and deeply penetrating root traces. This indicates an oxidizing environment during the development of the fossil soil.

From these considerations the paleosol can be classified as an Alfisol of Soil Conservation Service (1975). Considering its non-calcareous composition and depth of weathering, it probably was a Udalf.

PALEOENVIRONMENT

Climate

The absence of calcium carbonate and degree of leaching and base depletion indicated by molecular weathering ratios (Figure 6) within the horizons indicate humid conditions. The abundance of smectite and slickensides is compatible with moderate seasonality of wet and dry conditions during formation of this fossil soil. There is no pronounced evidence of clay heave (mukkara structure of Paton, 1974) as in Vertisols of strongly seasonal climate.

Vegetation

The Luca clay paleosol is deeply weathered and has a full sequence of horizons (A—Bt—C). These features and abundant root traces that emanate from the surface down into the profile are evidence that it once supported a woodland or forest ecosystem. The drab-colored portions of the A and Bt horizons (Figures 2 and 3) may have formed during burial around areas once moderately rich in organic matter, as already outlined. This would probably have been an ochric epipedon of a well-drained soil rather than a histic one of a swampy soil. The charcoalified wood found near the paleosol may be taken as an indication of occasional forest fires. Fossil plants in a lacustrine deposit underlying the paleosol include *Ulmus*, *Tetrapteris*, and *Metasequoia*. This is similar to forest floras known from lake deposits higher in the John Day Formation (Manchester and Meyer, 1987), but such lakeside vegetation did not necessarily grow in the well-drained paleosol reported here.

Animals

No burrows were recognized in the paleosol. A stout canine tooth like that of an entelodont was found loose on the surface near the base of this paleosol. This fossil is similar to those found higher on the John Day Formation (Merriam and Sinclair, 1907). Such stout teeth are more readily preserved than shells or porous bones, and the noncalcareous Luca clay paleosol would not have been especially favorable for the preservation of bones or teeth. Thus the paleosol may have supported a diverse mammalian fauna that remains poorly known because of preservational biases.

Topographic setting

The Luca clay paleosol was formed on a stable land surface. The deeply penetrating and evenly spread root traces in the fossil soil are indications of high porosity, permeability and drainage. The red hue from hematite pigment of the Bt horizon probably formed by burial dehydration of iron oxyhydrates or gels (Walker, 1967). It is unlikely, however, that such a clayey soil interbedded with coarse-grained gray to white tuffs was oxidized during burial by ground water. Thus the very low molecular weathering ratio of FeO/Fe_2O_3 (Figure 6) can be taken as evidence of a strongly oxidized soil. The drab color of the A horizon was not caused by waterlogging but by anaerobic reduction of organic matter as the buried soil subsided below water table. The former water table was probably at least 3 m below the surface during soil formation.

Parent material

The Luca clay paleosol formed on a volcanogenic tuffaceous material that probably had been reworked from preexisting soils and redistributed by rivers. The ratios of SiO_2/Al_2O_3, SiO_2/Fe_2O_3, and FeO/Fe_2O_3 at the base of the profile are unlike those of fresh ash and may have been produced by desilication and ferruginization in the drainage basin. Such processes continued during the development of the fossil soil from its parent material as revealed by these same molecular ratios (Figure 6).

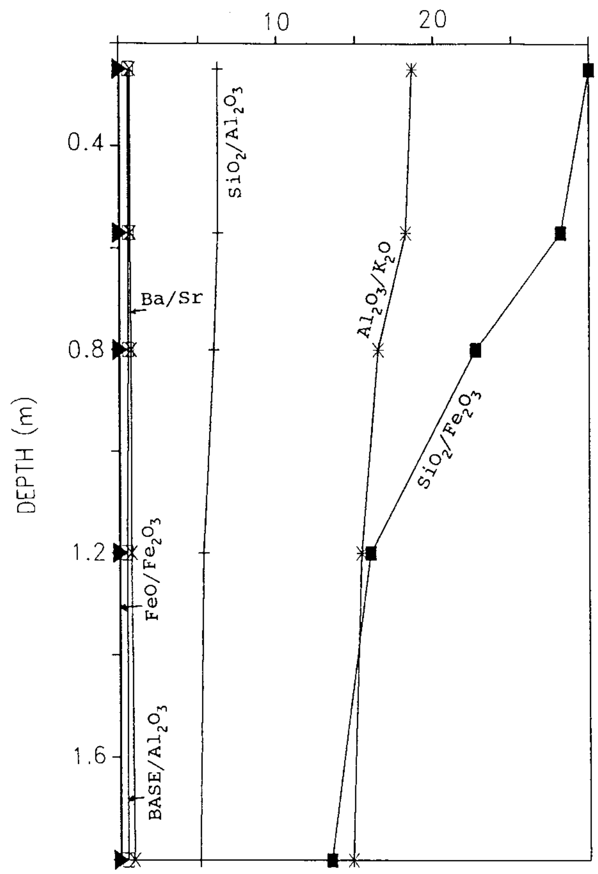


Figure 6. Selected molecular ratios chosen to demonstrate degree of weathering of the Luca clay paleosol.

Time for formation

The clayey subsurface (Bt) horizon of the Luca clay paleosol is moderately developed (in the sense of Retallack, 1988). In soils of alluvial terraces of the Merced River in the San Joaquin Valley of central California (Harden, 1982) such differentiated argillic horizons take some 10,000 to 40,000 years to form. Similar estimates are gained by comparison with Bt horizons in a variety of other chronosequences of surface soils, as summarized by Birkeland (1984). Thus the development of the Luca clay argillic (Bt) horizon of the paleosol may also represent a few tens of thousand years.

CONCLUSION

The Luca clay paleosol in the Oligocene lower John Day Formation is a well-preserved and differentiated paleosol with gray to white A horizon and dusky to dark-red clay-rich Bt and silty C horizon. Numerous drab-haloed root traces extend from the A into the Bt horizon. It was formed in a humid to subhumid climate on the well-drained and stable land surface of an extensive alluvial plain downwind of a major volcanic mountain range. These ancient soils were evidently vegetated by large trees, probably forest, similar to that in evidence from associated lacustrine leaf beds.

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DOGAMI to open natural-resource store/information center

The Oregon Department of Geology and Mineral Industries (DOGAMI) will open its new natural-resource information center/store when the new Portland State Office Building is completed in late February or early March of next year. Located on 800 Oregon Street NE near the Lloyd Center, the Convention Center, and MAX, Portland's light-rail system, the new building will house many state agencies, including DOGAMI.

DOGAMI's administrative offices, geologists, and library will be located on the ninth floor of the new structure. The 700-ft^2 store/information center, however, will be on the first floor, in the southeast portion of the building.

The purpose of the new store/information center is to make natural-resource and outdoor-recreation material readily available to Oregonians and visitors. It will continue to sell U.S. Geological Survey (USGS) maps and DOGAMI publications but will also handle material from other state and federal natural-resource agencies. The USGS has agreed to provide the facility with many of its educational and informational materials and has designated it as an Earth Science Information Center. A committee of representatives from several state agencies has developed the inventory policy for the store, and that policy is available from DOGAMI for anyone who wants to see it.

Several months ago, DOGAMI announced a store-naming contest. Numerous interesting and in some cases unusual names were submitted, and an outstanding winner was selected. The winning name, which we believe really summarizes our vision for the new facility, will be announced in connection with the opening of the store/information center, and the winner will receive the prize at that time.

DOGAMI is looking for volunteers to help in the new store/information center. If you like people, have interest or expertise in some aspect of Oregon's natural resources such as geology, plants, wildlife, birds, or forestry, want to learn more about any such subjects, or would like an opportunity to share your knowledge about Oregon with someone else, contact Beverly Vogt, DOGAMI, 910 State Office Building, Portland, OR 97201, phone (503) 229-5580. Training for the store/information center will start in January, but if you are not available then, we will have an ongoing training program, so our volunteers will be well prepared. If you want to help DOGAMI sooner than that, we have several volunteers working with us now and could use more to help us with the existing store and with planning and organizing the move to the new site.

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THESIS ABSTRACTS

The Department maintains a collection of theses and dissertations on Oregon geology. From time to time, we print abstracts of new acquisitions that in our opinion are of general interest to our readers.

I. Direction of maximum horizontal compression in western Oregon determined by borehole breakouts. II. Structure and tectonics of the northern Willamette Valley, Oregon, by Kenneth S. Werner (M.S., Oregon State University, 1991), 159 p.

Elliptical borehole enlargements or "breakouts" caused by systematic spalling of a borehole wall due to regional maximum horizontal stresses were identified in 18 wells drilled in the Coast Range and Willamette Valley of western Oregon. The breakouts generally indicate a north-northwest to north-northeast orientation of maximum horizontal compression (σH_{max}) that agrees with the predominant direction of σH_{max} determined from earthquake focal mechanisms, from post-middle Miocene structural features, and from alignments of Holocene volcanic centers in the Pacific Northwest. However, this orientation is inconsistent with the N. 50° E. convergence between the Juan de Fuca and North American plates determined by Riddihough (1984) from Juan de Fuca Plate magnetic lineations as young as 730 ka (the Brunhes-Matuyama boundary). The predominant north-northwest to north-northeast orientation of σH_{max} may be due to the complex interaction of a northwestward-moving Pacific plate driving into the Gorda and Juan de Fuca Plates and indirectly transmitting north-south compression across the strongly coupled Cascadia subduction zone into the overriding North American Plate. Alternatively, the predominant north-northwest to north-northeast orientation of σH_{max} may be due to a landward counterclockwise rotation of the direction of σH_{max} from N. 50° E. compression offshore to north-south compression in the Coast Range.

The northern Willamette Valley lies on the eastern flank of the broad north-northeast-trending Oregon Coast Range structural arch. Eocene to Oligocene marine sedimentary rocks crop out along the western side of the northern Willamette Valley and form a gently eastward dipping homocline. However, beneath the center of the Willamette Valley, Eocene to Oligocene strata are structurally warped up.

During the Eocene, several major volcanic centers subdivided the Coast Range forearc region into shallow to deep marine basins. Several such volcanic centers occur adjacent to the northern Willamette Valley and are associated with residual gravity anomaly highs and lineations.

The top of basalt in the northern Willamette Valley (middle Miocene Columbia River basalt except near the valley margins)

(continued on next page)

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(continued on next page)

is contoured based on petroleum exploration wells, water wells, and seismic-reflection data. It is structurally downwarped to an altitude of less than -500 m just north of Woodburn. The downwarp is bounded to the south by the northeast-trending Waldo Hills range-front fault and in part to the north by the northeast-trending Yamhill River-Sherwood fault zone.

The northwest-trending Mount Angel fault extends across the northern Willamette Valley between Mount Angel and Woodburn and deforms middle Miocene Columbia River basalt and overlying Pliocene and Miocene fluvial and lacustrine deposits. The top of Columbia River basalt is vertically separated, northeast side up, roughly 100 m based on seismic-reflection data near Woodburn, and 250+ m based on water-well data near Mount Angel. The Mount Angel fault is part of a northwest-trending structural zone that includes the Gales Creek fault west of the Tualatin basin; however, a connection between the Gales Creek and Mount Angel faults does not occur through Willamette River alluvial deposits.

A series of small earthquakes (6 events with m_c = 2.0, 2.5, 2.4, 2.2, 2.4, 1.4) occurred on August 14, 22, and 23, 1990, with epicenters near the northwest end of the Mount Angel fault. Routine locations indicate a depth of about 30 km. The preferred composite focal mechanism is a right-lateral strike-slip fault with a small normal component on a plane striking north and dipping steeply to the west.

Both recent mapping of the Mount Angel fault and the recent seismicity suggest that the Gales Creek-Mount Angel lineament is similar to the Portland Hills-Clackamas River lineament found to the north. Together, these two lineaments may take up right-lateral strike-slip motions imposed on the upper plate by oblique subduction.

Boring Lava appears to occur extensively in the subsurface of the northeastern portion of the northern Willamette Valley, as seismic data indicate. Many of the faults in the area are interpreted to be largely caused by doming from influx of Boring magma or subsidence associated with evacuation of Boring magma. Such faults occur at Petes Mountain, at Parrett Mountain, along the Molalla River, and possibly near Curtis. The fault along the Molalla River appears to offset the Pleistocene (?) Rowland Formation 1 m.

Systematic paleontology, stratigraphic occurrence, and paleoecology of halobiid bivalves from the Martin Bridge Formation (Upper Triassic), Wallowa terrane, Oregon, by Christopher A. McRoberts (M.S., University of Montana, 1990), 156 p.

The form-genus "*Halobia*" probably represents several different *Posidonia* and *Daonella* descendants. Species-level, systematic survey of Martin Bridge *Halobia* results in synonymy of previously described species from the same locality and discovery of halobiid species new to the Wallowa terrane. Reexamination of type material suggests that *Halobia ornatissima* is

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a junior synonym for *H. superba* and *H. dilatata* a junior synonym for *H. halorica* and that *H. dalliana* and *H. symetricia* are junior synonyms for *H. radiata*.

Geologic mapping revealed that the Martin Bridge stratotype is broken by thrust and high-angle faults. From the stratotype, five structurally isolated blocks were identified for stratigraphic analysis. The blocks consist of dark, finely laminated shale, finely bedded limestone, and limestone conglomerate.

Limited biostratigraphic resolution was possible. The presence of *Discotropites*, *Anatropites*, *Halobia oregonensis*, and *H. superba* low in the section indicates a late Carnian age, whereas, higher up, *H. halorica* indicates an early to middle Norian age. The occurrence of *H. beyrichi* and *H. austriaca* indicates proximity to the Carnian-Norian stage boundary, although faulting has obscured its exact stratigraphic position.

Halobiids from the section primarily occur in shell beds within a dark, finely laminated calcareous shale, probably deposited in an anaerobic or dysaerobic basin. The shell beds are interpreted to be the result of an increase in biogenic deposition rather than a decrease in background sedimentation or erosional lag deposit. Apart from *Chondrites*, the halobiid-bearing sediments are devoid of any benthos and evidence of bioturbation.

Previous arguments for the life habit of *Halobia* as endobyssate, reclining, or swimming are reconsidered. Morphologic evidence suggests a loosely nestling epibyssate habit. Evidence for halobiid attachment sites is lacking. Possible attachment to an algal substrate, either rooted or floating, is suggested. *Halobia* was probably opportunistic. A long-lived larval stage along with possible attachment to floating algae may explain its unusual facies and broad geographic distributions.

The carbonate petrology and paleoecology of Upper Triassic limestones of the Wallowa terrane, Oregon and Idaho, by Michael T. Whalen (M.S., University of Montana, 1985), 151 p.

The Upper Triassic Martin Bridge Formation is exposed as a thick sequence of limestone in Hells Canyon along the Idaho-Oregon border. The allochthonous structural setting and low-latitude origin of the Martin Bridge Formation and underlying Seven Devils Group, which comprise the Wallowa terrane, are fairly well established. A slightly younger unit, the Mission Creek limestone, is exposed about 25 km southeast of Lewiston, Idaho, along Mission Creek. This unit is stratigraphically and structurally isolated, and its exact relationship with the Martin Bridge Formation is unclear.

Through stratigraphic and petrographic analysis of these limestones I have ascertained that the Martin Bridge Formation was deposited first under supratidal conditions and then as intertidal and shallow subtidal platform deposits. Isolation of these carbonates from a cratonic sediment source is indicated by the absence of terrigenous sediments. The Martin Bridge Formation in Hells Canyon has been subjected to at least eight diagenetic processes that obscured many of the original depositional textures. Well-preserved fossils occur in coarse grainstone tempestites in the Martin Bridge Formation in Hells Canyon. The fossils were preferentially silicified, and their external morphology is well preserved. Epifaunal, suspension-feeding bivalves and spongiomorphs dominate the assemblage and indicate a relatively shallow, warm-water depositional setting.

The Mission Creek limestone was also deposited in warm, shallow water as evidenced by the silicified fossil assemblage dominated by red algae, spongiomorphs, and corals that formed small framework buildups. The lithology and the fauna of the Mission Creek limestone differ form those of the Martin Bridge Formation, and the Mission Creek appears to be younger in age.

Post-Triassic plate-tectonic movement transported, rotated, and accreted the allochthonous Wallowa terrane to the continental margin of North America. This terrane may be correlative with the coeval Wrangellia Terrane of southeastern Alaska and Vancouver Island but the existing evidence does not establish that they once formed a contiguous fragment of the earth's crust.

Distribution of sand within selected littoral cells of the Pacific Northwest, by Don J. Pettit (M.S., Portland State University, 1990), 249 p.

Beach sand acts as a buffer to wave energy, protecting the shoreline from erosion. Estimates of the quantity and distribution of beach sand in littoral cells of the Pacific Northwest (PNW) are critical to the understanding and prediction of shoreline erosion or accretion. This study was initiated in order to (1) document the distribution of sand in littoral cells of the PNW, (2) determine the factors which have brought about these present distributions, and (3) address the relationship of beach sand distribution to shoreline stability.

Eight littoral cells were chosen to represent the variety of smaller cells present in the PNW. The eight littoral cells are the La Push and Kalaloch cells of Washington, the Cannon Beach, Otter Rock, Newport, and Gold Beach cells of Oregon, and the Crescent City and Eureka cells of northern California. Aerial photographs were analyzed for the eight cells: photo sets taken before and after the 1983-1987 El Nino-related erosion event. Data on beach width and orientation and on terrace location and height were collected from maps and aerial photographs for analysis. Forty-six beaches in the eight littoral cells were surface-profiled to mean low-low water using standard surveying techniques and were surveyed geophysically to determine the depth to the wave cut platform. The results of the surveys were used to estimate the area and volume of sand in each of the selected cells. Slopes of the beach face and beach widths were determined from the survey results. Sand samples were collected at mid-beach face from 48 beaches within the selected cells, as were representative samples from 22 terraces. Grain-size analyses were performed for the collected beach and terrace samples in order to develop information on possible sources and direction of transport for the beach sand.

Results of the study indicate that beach sand distribution within littoral cells of the PNW varies as a function of (1) proximity to sand sources such as rivers, terraces, and the presence of relict sands; (2) location of sand sinks such as dune fields and estuaries; (3) shoreline orientation; (4) shoreline configuration; (5) the direction of net sediment transport within the littoral zone; and (6) the location of barriers to sand transport. Based on sand distributions and grain-size trends, the net transport direction of sediment is to the north within the Cannon Beach, Otter Rock, Newport, Crescent City, and Eureka cells. The net transport direction is to the south for the northern third of the Kalaloch cell, while the southern two-thirds show net transport to the north. The Gold Beach cell shows both north and south transportation of sediments—-away from the abrupt change in shoreline orientation in the Redhouse Beach to High Tide Beach area. The net littoral drift of the La Push cell similarly shows a diversion of beach sand to the south and north from an area near the middle of the cell.

The potential for erosion of a given area is related to (1) the total quantity of source sands available on a given beach and, more importantly, (2) the quantity of sand above mean high-high water (MHHW) on each beach. The sand above MHHW is important because it is this sand that acts as the final buffer to storm-wave attack. There is a high correlation between areas experiencing erosion and those areas which have the least sand in storage above mean high-high water within a littoral cell. □

MINERAL EXPLORATION ACTIVITY

MAJOR MINERAL EXPLORATION ACTIVITY

County, date	Project name, company	Project location	Metal	Status
Baker 1990	Baboon Creek Chemstar Lime, Inc.	T. 19 S. R. 38 E.	Lime-stone	Expl
Baker 1990	Cracker Creek Mine Simplot	T. 8 S. R. 37 E.	Gold	Expl
Baker 1991*	Aurora Ridge Western Consolidated Mines	T. 10 S. Rs. 35.5, 36	Pre-cious Metals	Expl
Baker 1991	Cave Creek Nerco Exploration	Tps. 11, 12 S. R. 42 E.	Gold	App
Baker 1991*	Gold Hill Golconda Resources	T. 12 S. R. 43 E.	Gold	App
Baker 1991*	Gold Powder Kennecott Expl. Co.	Tps. 9, 10 S. Rs. 41, 42 E.	Gold	Expl
Baker 1991	Gold Ridge Mine Golconda Resources	T. 12 S. R. 43 E.	Gold	Expl
Baker 1991	Lower Granview Earth Search Sciences	T. 14 S. R. 37 E.	Gold	App
Baker 1992	Pole Creek Placer Dome U.S.	T. 13 S. R. 36 E.	Gold, silver	Expl
Coos 1991	Seven Devils Oreg. Resources Corp.	Tps. 2, 7 S. R. 4 W.	Gold	Expl com
Crook 1988	Bear Creek Independence Mining	Tps. 18, 19 S. R. 18 E.	Gold	Expl
Grant 1991	Buffalo Mine American Amex	T. 8 S. R. 35½ E.	Gold	App
Grant 1991	Canyon Mtn. Cammtex International	T. 13 S. R. 32 E.	Gold	Expl
Grant 1992	Standard Mine Bear Paw Mining	T. 12 S. R. 33 E.	Gold, copper	Expl
Harney 1990	Pine Creek Battle Mtn. Exploratn.	T. 20 S. R. 34 E.	Gold	Expl
Harney 1991*	Buck Mtn.-North Teck Resources, Inc.	T. 24 S. R. 36 E.	Gold	App
Harney 1991	Flagstaff Butte Noranda Exploration	Tps. 3, 9 S. R. 37 E.	Gold	App
Jefferson 1991	Red Jacket Bond Gold	Tps. 9, 10 S. R. 17 E.	Gold	App
Josephine 1990	Martha Property Cambiex USA	T. 33 S. R. 5 W.	Gold	Expl
Lake 1988	Quartz Mountain Wavecrest Resources.	T. 37 S. R. 16 E.	Gold	Expl
Lake 1990	Glass Butte Galactic Services	Tps. 23, 24 S. R. 23 E.	Gold	Expl
Lake 1991	8th Drilling Series Wavecrest Resources	T. 37 S. R. 17 E.	Gold	Expl
Lincoln 1991	Iron Mtn. Quarry Oreg. St. Highw. Div.	T. 10 S. R. 11 W.	Basalt	App
Linn 1991	Hogg Rock Oreg. St. Highw. Div.	T. 13 S. R. 7½ E.	Rock	App
Linn 1991	Quartzville Placer Dome U.S.	T. 11 S. R. 4 E.	Gold, silver	App
Malheur 1988	Grassy Mountain Atlas Precious Metals	T. 22 S. R. 44 E.	Gold	Expl, com
Malheur 1988	Harper Basin Project Amer. Copper & Nickel	T. 21 S. R. 42 E.	Gold	Expl
Malheur 1988	Jessie Page Chevron Resources	T. 25 S. R. 43 E.	Gold	Expl

MAJOR MINERAL EXPLORATION ACTIVITY (continued)

County, date	Project name, company	Project location	Metal	Status
Malheur 1988	Kerby Malheur Mining	T. 15 S. R. 45 E.	Gold	Expl, com
Malheur 1989	Hope Butte Chevron Resources	T. 17 S. R. 43 E.	Gold	Expl, com
Malheur 1990	Ali/Alk Atlas Precious Metals	T. 17 S. R. 45 E.	Gold	Expl
Malheur 1990	Calavera NERCO Exploration	T. 21 S. R. 45 E.	Gold	Expl
Malheur 1990	Cow Valley Butte Cambiex USA, Inc.	T. 14 S. R. 40 E.	Gold	Expl
Malheur 1990	Freezeout Western Mining Corp.	T. 23 S. R. 42 E.	Gold	Expl
Malheur 1990	Goldfinger Site Noranda Exploration	T. 25 S. R. 45 E.	Gold	Expl
Malheur 1990	Grassy Mtn. Regional Atlas Precious Metals	T. 22 S. R. 44 E.	Gold	Expl
Malheur 1990	Katey Claims Atlas Precious Metals	Tps. 24, 25 S. Rs. 44, 46 E.	Gold	Expl
Malheur 1990	KRB Placer Dome U.S.	T. 25 S. R. 43 E.	Gold	App
Malheur 1990	Lava Project Battle Mtn. Exploratn.	T. 29 S. R. 45 E.	Gold	Expl
Malheur 1990	Mahogany Project Chevron Resources	T. 26 S. R. 46 E.	Gold	App
Malheur 1990	Racey Project Billiton Minerals USA	T. 13 S. R. 41 E.	Gold	Expl
Malheur 1990	Sand Hollow Noranda Exploration	T. 24 S. R. 43 E.	Gold	Expl
Malheur 1990	Stockade Mountain BHP-Utah Internatl.	T. 26 S. Rs. 38, 39 E.	Gold	Expl
Malheur 1990	Stockade Project Phelps Dodge Mining	Tps. 25, 26 S. R. 38 E.	Gold	Expl
Malheur 1991	Bannock Atlas Precious Metals	T. 25 S. R. 45 E.	Gold	App
Malheur 1991	Big Red Ron Johnson	T. 20 S. R. 44 E.	Gold	Expl
Malheur 1991	Birch Creek Ronald Willden	T. 15 S. R. 44 E.	Gold	App
Malheur 1991*	Buck Mtn.-South Teck Resources, Inc.	T. 24 S R. 37 E.	Gold	App
Malheur 1991	Deer Butte Atlas Precious Metals	T. 21 S. R. 45 E.	Gold	App
Malheur 1991	Harper Basin Atlas Precious Metals	T. 21 S. R. 42 E.	Gold	App
Malheur 1991*	Quartz Mtn. Basin BHP-Utah Intl., Inc.	T. 24 S. R. 43 E.	Gold	App
Malheur 1991	Rhinehardt Site Atlas Precious Metals	Tps. 18, 19 S. R. 45 E.	Gold	Expl
Malheur 1991	Sagebrush Gulch Kennecott Exploration	Tps. 21, 22 S. R. 44	Gold	App
Malheur 1991	White Mountain D.E. White Mtn. Mining	T. 18 S. R. 41 E.	Dia-toms	App
Marion 1990	Bornite Project Plexus Resources	T. 8 S. R. 3 E.	Copper	App com

Explanations: App=application being processed. Expl=Exploration permit issued. Veg=Vegetation permit. Com=Interagency coordinating committee formed, baseline data collection started. Date=Date application was received or permit issued. *=New site

Status changes

The exploration permit program has been in effect for one year. There are 55 active permits or applications. The Katey project in Malheur County was taken over by Atlas Precious Metals from ASARCO. The name change from Freeport McMoRan to Independence on the Bear Creek project in Crook County is due to a corporate name change.

Regulatory Issues

Major legislation affecting the permitting procedure for heap-leach mining required changes to the rules of the Departments of Geology and Mineral Industries (DOGAMI), Environmental Quality (DEQ), Fish and Wildlife (ODFW), and Water Resources (WRD), plus minor changes in the rules of a few additional agencies. The DOGAMI Governing Board has adopted most of the implementing rules; adoption may be completed at the Board's November meeting. DEQ has held hearings on proposed rules relative to water quality; the Environmental Quality Commission reviewed the issues involved at an October work session. Adoption of the final DEQ rules are expected later this year. ODFW and WRD are both in the process of revising their rules.

Questions or comments should be directed to Gary Lynch or Allen Throop in the Mined Land Reclamation Office of the Oregon Department of Geology and Mineral Industries, 1534 Queen Avenue SE, Albany, OR 97321, telephone (503) 967-2039. □

Salem club exhibits minerals

The Willamette Agate and Mineral Society of Salem has provided and installed the new exhibit in the display case of the Oregon Council of Rock and Mineral Clubs (OCRMC) at the State Capitol in Salem.

The current display represents the great variety of treasures from 15 Oregon counties: Pelecypod and gastropod fossils from the coast of Curry and Lincoln Counties; petrified wood, including a small piece of myrtle wood; nodules, including a Thistle Creek nodule that shows what appears to be a snow-covered scenery of tall trees; angel-wing and Maury Mountain moss agate; carnelian, including a large specimen, cabochons, and a pendant; "Chicken Track" jasper from Malheur County; realgar; spheres made from basalt and obsidian; nickel ore; and carvings made from soapstone and serpentine. Oregon's state rock, the Thunderegg, is represented by several polished halves; and Oregon's state gemstone, the Oregon Sunstone, is shown in rough and faceted specimens.

The display will remain in place until January 15, 1992.

—OCRMC news release

Mist Gas Field area study available

Northwest basin study (NBS-1) of the Nehalem-Astoria subbasins, Columbia and eastern Clatsop Counties, northwest Oregon (1991), has been produced by R.J. Deacon and C.J. Newhouse of Portland, Oregon. It covers the Mist Gas Field area and consists of the following:

- Four sheets of correlation stratigraphic cross sections (see illustration) showing the Mist Gas Field and other potential sand reservoirs. Vertical scale is 1 inch = 500 ft, horizontal scale is 1 inch = 4,000 ft. Sheet size ranges from 25 by 30 inches to 31 by 45 inches.
- One 30- by 42-inch exploration map showing topography, producing wells, dry holes, location of stratigraphic sections, and source-rock maturation diagrams on three wells.

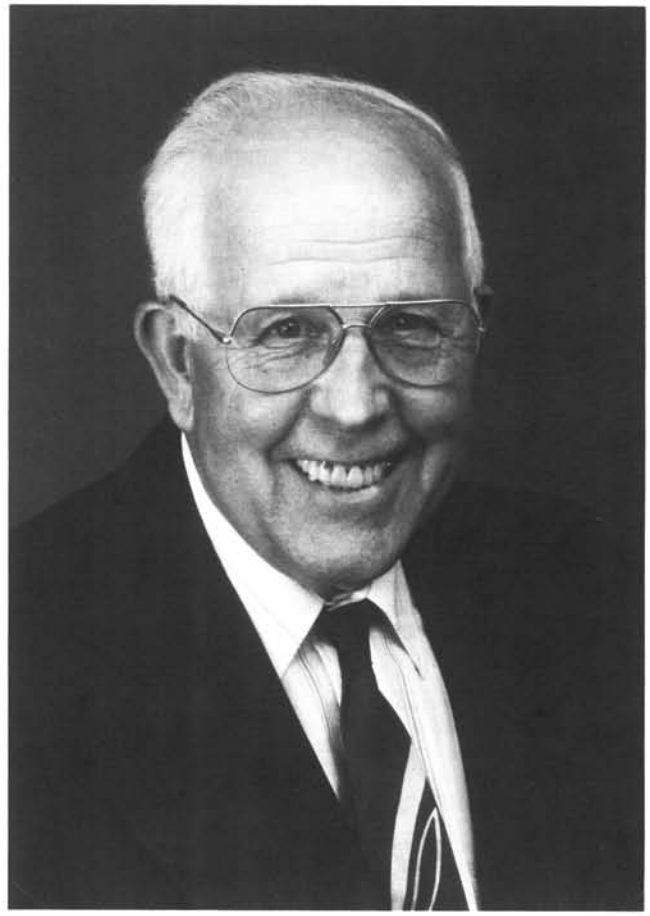
The full set is available from Newhouse/Deacon, 4204 SW Condor, Portland, OR 97201. The price is $245 plus postage.

—Northwest Basin Studies news release

Melvin Ashwill honored

Melvin S. Ashwill of Madras, Oregon, was selected by the Council of the Paleontological Society as the 1991 recipient of the Strimple Award. This highly prestigious national award recognizes the outstanding contributions of an amateur to the science of paleontology.

The award was presented at the annual banquet of the Paleontological Society during the 1991 national meeting of the Geological Society of America in San Diego in late October. Steven R. Manchester of the Florida Museum of Natural History was his citationist, and Ashwill's acceptance statement will be printed in the *Journal of Paleontology.*



Melvin S. Ashwill

Ashwill is well known to *Oregon Geology* readers for his contributions on a variety of geologic topics, especially paleobotany. Most recently he has summarized his knowledge of the discipline for us in papers on the history of paleontology in Oregon (December 1987) and on guidelines for collecting fossils in Oregon (July 1989).

Ashwill also maintains a private fossil museum next to his home in Madras. He will show his considerable collection to interested persons or groups by appointment. His phone number is (503) 475-2907.

We are very pleased to see such national recognition of Ashwill's work. We congratulate him most heartily and wish him many more years of fruitful work as a most accomplished paleontologist.

—The editors

Index to *OREGON GEOLOGY*, volume 53, 1991

Numbers refer to volume and beginning page of entry. Most subject entries include cross-references to author entries (in parentheses).

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