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U.S. GEOLOGICAL SURVEY

A Landowner's Guide to U.S.G.S. Investigations in Merced and Stanislaus Counties

by

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Introduction

For the past 15 years, the region surrounding the Merced River has been the focus of a number of investigations by the U.S. Geological Survey. The relationships between landform age, soil, and regional geology are understood and well documented, making this area an ideal location for further in-depth study. Instruments at these sites sample river deposits that span a wide range of geologic time. The youngest bottom land soil, the Hanford near Cox Ferry, has been forming for 10,000 years. The oldest deposit currently instrumented is the 600,000 year old Montpelier soil located on a hilltop overlooking Turlock Lake (see figure 1).

This report is the first in a series of informational publications detailing USGS investigations in Merced and Stanislaus Counties and will provide a general overview of project methods and goals. Subsequent publications will more closely describe the results and interpretations of these studies.

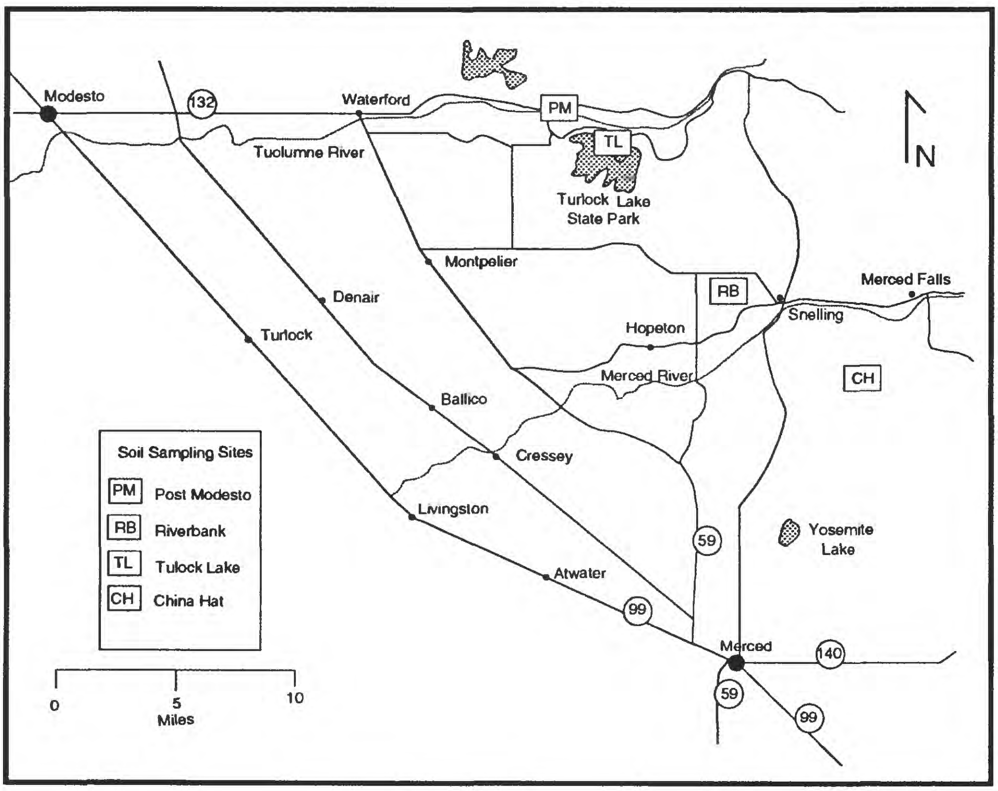


Figure 1: Location Map for USGS sites in Merced and Stanislaus Counties

Geologic Setting

Soils in the study area are developed on river terraces and alluvial fans which were deposited by the ancestral Merced and Tuolumne Rivers as the Sierra Nevada uplifted and the eroded material was carried to the San Joaquin Valley. These terrace and fan deposits can be divided into nine principal geologic units ranging in age from 200 to 3,000,000 years. The terraces are shown schematically in figure 2. Deposition of each unit was relatively rapid and was probably associated with climatic events such as melting of the sierran glaciers. The major depositional events were separated by longer periods of time, during which the Sierra Nevada continued to rise. The rising land surface caused downcutting of the river channel through the underlying sediment and produced alluvial surfaces that have been isolated from stream activity. As a result, the isolated surfaces (terraces) retain a soil that has been developing since uplift.

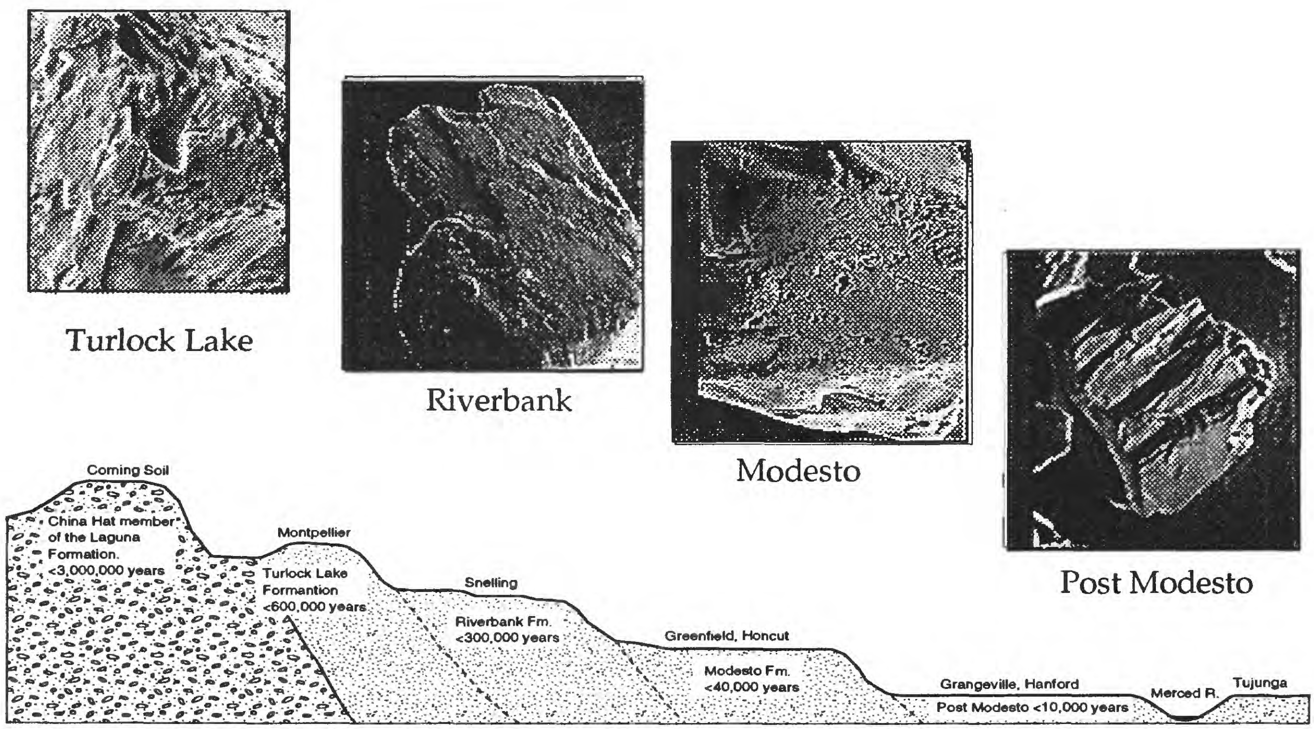
The development of soils of different ages on the same underlying parent material under the same soil-forming conditions provides a unique opportunity for the study of soil development over time. Because the Merced River soils have formed under similar environmental influences, with only their age as a variable, these soils may be viewed as the same soil at various stages of maturity. This approach, called a soil chronosequence, presents an excellent natural experiment for the study of soil formation and weathering rates.

Through close co-operation with land owners in Merced County and the state park system, the U.S. Geological Survey is examining the different aged soils of the Merced River chronosequence to learn more about the ways that minerals weather, soils develop, and carbon and nutrients accumulate over time.

Rates of Soil Formation

Soil is a product of a variety of chemical, physical, and biological processes that occur on the earth's surface. Over time, the minerals that make up the underlying rock or sediment (the parent rock) slowly dissolve, releasing elements such as the alkaline earths - sodium, potassium, and calcium. Each mineral in the parent rock, called a primary mineral, has a unique chemical composition and atomic structure and will dissolve at a rate different from other primary minerals. By looking at the primary

Figure 2: Cross-Section of the Merced River Chronosequence



Schematic cross section through the terraces of the Merced River near Snelling. Names above surface are the formation names of the alluvial deposits that make up the terraces, along with their maximum ages. The photos are high magnification enlargements of Horneblende minerals taken from the soil formed on the alluvial deposits. Soil and soil age from Harden, 1987, mineral photos courtesy of Schulz and Blum, unpublished minerals in soils of different ages we can determine the order in which the minerals dissolved. Soils developed on terraces ranging in age from 200 (Post-Modesto) to 3,000,000 years (China Hat) were sampled at five locations. The amounts of primary minerals were determined by looking at X-ray diffraction, a method that examines the atomic structure of minerals (Figure 3).

The mineral hornblende, a dark silicate commonly associated with igneous and metamorphic rocks, is the first to disappear from the Merced soils, leaving all but the youngest soils significantly depleted in hornblende. Plagioclase-feldspar and potassium-feldspar are the next to weather and are almost completely gone within 3,000,000 years of soil development.

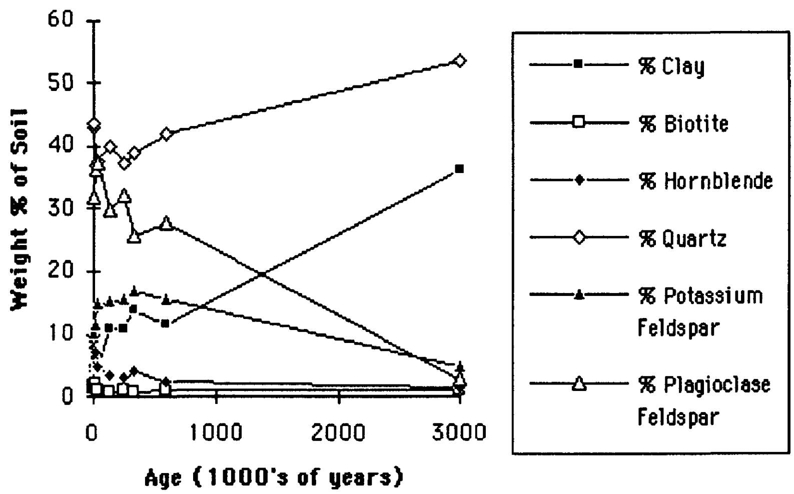


Figure3: Dissolution of Primary Minerals

This figure shows the loss of the minerals Hornblende, Potassium Feldspar, and Plagioclase Feldspar over time. Also note the development of clay minerals in the older soils.

In addition to releasing alkaline earths, dissolution of primary minerals also releases aluminum (Al) and silicon (Si) into the soil water. When the levels of Al and Si become high enough, they become the primary building blocks for clay minerals. The amount of clay present in soils of different ages, therefore, will also provide information about the rate of mineral weathering. As expected, clay content in the Merced soils increases with soil age.

Using the data in Figure 3 and laboratory studies, we can compare the rates at which each type of mineral weathers and determine how fast the soil forms. This information will allow us to estimate the age of other soils in similar environments by determining which primary minerals are present and how much clay has formed. In comparison, we are also examining the rates of soil formation in other soils with different climates, rock-types, vegetation and land-use. In this way, we hope to improve our understanding of soil formation in relation to issues such as nutrient availability, soil erosion, and water quality.

Hydrological Investigations

One of the primary goals of the research in the Merced area is to gain a better understanding of how soil formation affects water quality. Using our chronosequence approach, we have collected soil, water, and gas samples from each age surface present in the Merced area. These data will allow us to account for not only the minerals that exist in the soil today, but for the chemical constituents of the water and gas that are coming into the soil (rainfall and dust) and leaving the soil (gas and leaching water). This approach is somewhat different from the soil mineral analysis because we are trying to measure weathering and chemical changes right as they occur.

We use instruments designed to capture water as it enters the soil, as it interacts with the minerals, and as it leaves the system (Figure 4). These sites are probably familiar to local residents and can be seen from the road near Cox Ferry, Snelling, and Turlock Lake State Park (See figure 1).

At the surface, rain gauges, rain-water collectors, and atmospheric samplers collect all the moisture and dry material (dust) which falls throughout the year. Soil water sampling devices known as lysimeters capture water as it moves thorough the soil. These are porous ceramic plates or cups that pull water from the soil into a collection chamber when a vacuum is applied to them. Shallow water moving through the A-Horizon is collected by a

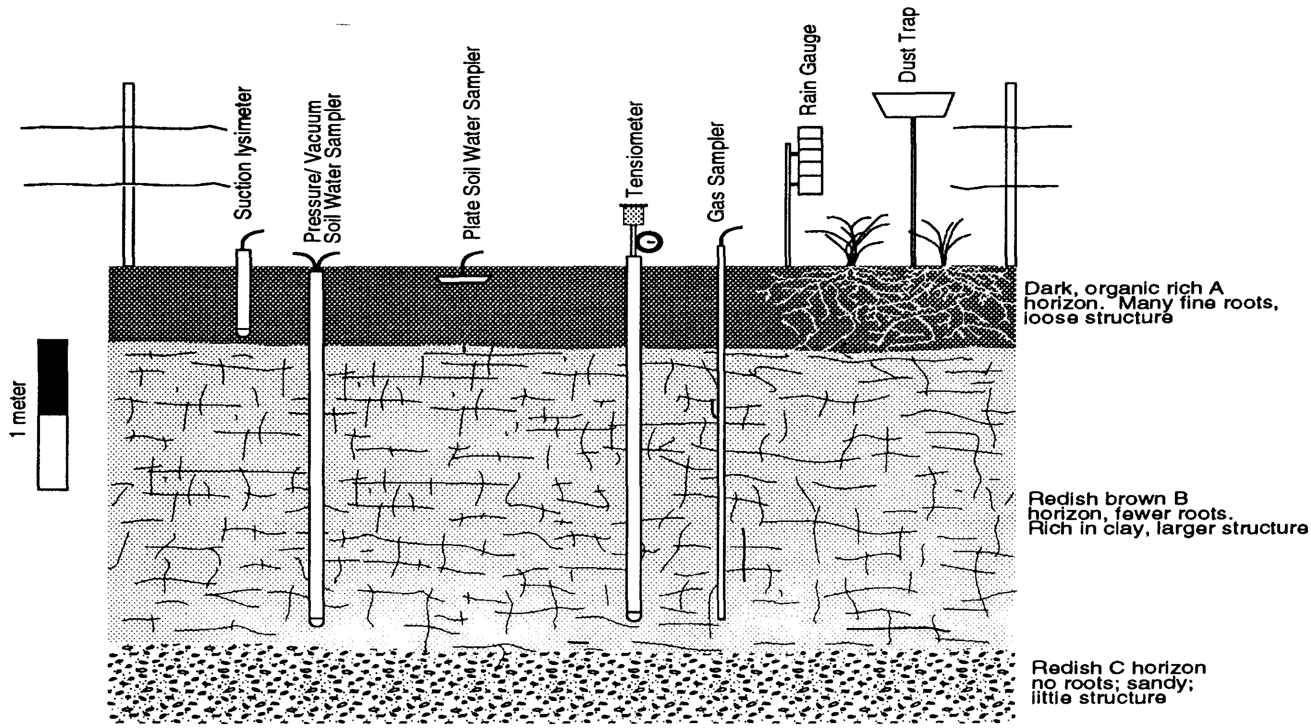


Figure 4: Typical instrument site in San Joaquin soil on 250,000 year old river terrace near Snelling, CA

ceramic plate-shaped sampler while deeper water (50 cm to 550 cm deep) is sampled with a ceramic cup attatched to the end of a PVC pipe. To measure the pressure of the soil water we use tensiometers, which are water-filled ceramic cups buried in the soil and connected to pressure gauges. The drier the soil, the more suction it will apply upon the water in the cup. Gas sampling tubes, extending to depths of 800 cm, measure gases in soil pore space. These gases are extracted and analyzed by a gas chromatograph to determine chemical constituents such as CO_2. The combined data from all of these instruments will ultimately allow us to quantify the inputs and outputs for the soils. By comparing the data between sites we will be able to better understand the weathering of minerals, the interaction of shallow and deeper water tables, and the way in which soils release nutrients for plant uptake.

Carbon and Nutrient Dynamics

The different aged soils of the Merced River chronosequence also provide a valuable opportunity to examine the behavior of carbon and nutrients in soil. Data from these and other studies are being used to understand the role of soils in nutrient and carbon cycling on a global scale. As part of a large program in Global Change we hope to improve our understanding of how these elements might respond to future disturbances such as climate change, land use change, and acid rain.

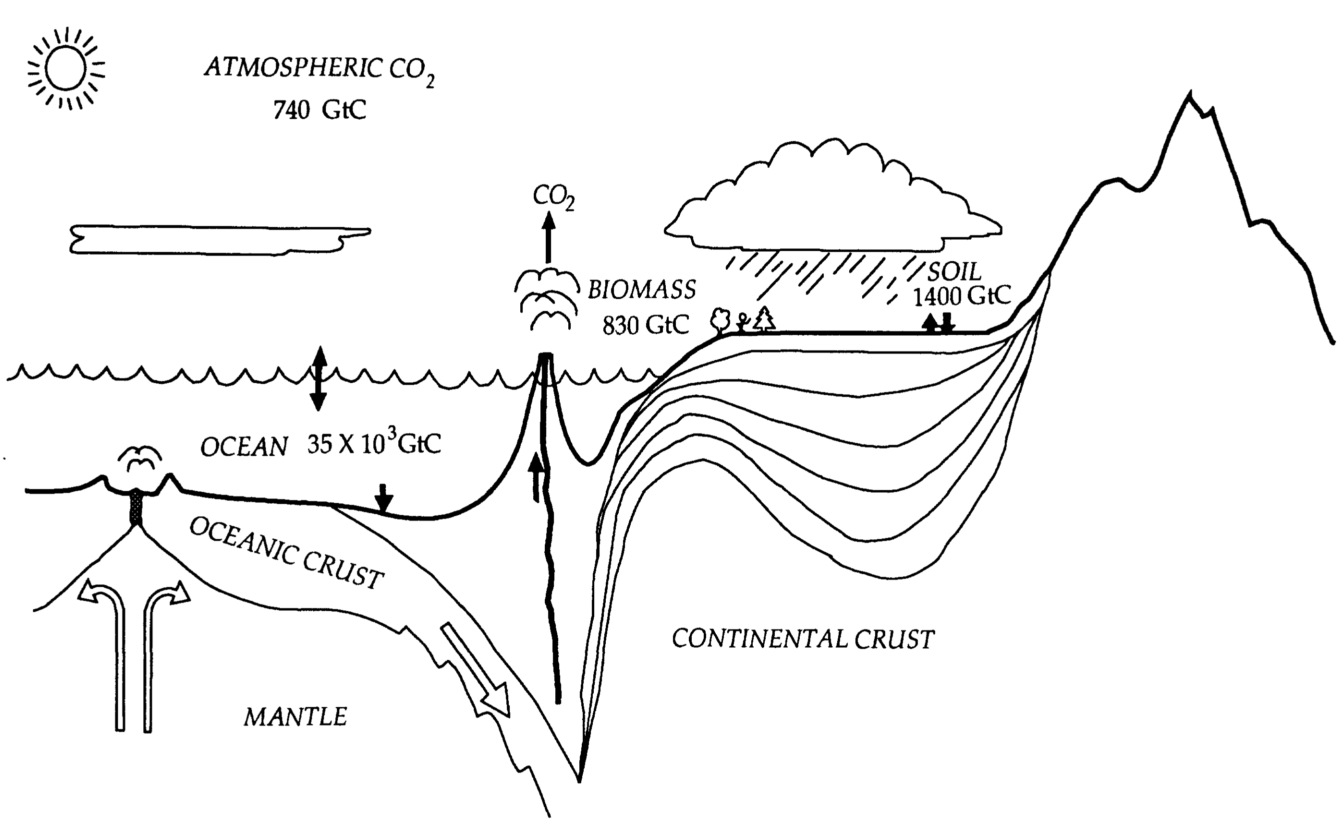
The "Greenhouse Effect" and Climate Change

The planet earth is made habitable by the presence of certain gases in the atmosphere that trap long-wave radiation emitted from the surface of the earth and reflect it downward to warm the surface. Although water vapor is the most important of these "greenhouse" gases, significant contributions are made by carbon dioxide, methane, tropospheric ozone, and nitrous oxide. The concentrations of these naturally occurring gases are increasing annually, primarily because of human activities such as the burning of biomass and fossil fuels as well as large scale conversion of forested land to agriculture. If the current increases in greenhouse gases continue on their projected course, a mean global temperature increase of 1.5 to 4.5^{o}C is expected in just 40 years, a rate of change unparalleled in the history of the planet. Under these conditions, growing seasons in most regions of the earth would shift dramatically along with patterns of rainfall and ambient air temperatures. Perhaps more significantly, higher surface temperatures could result in thermal expansion of sea water and increased melting of polar ice caps. J.S. Levine (1990), an atmospheric scientist at the NASA-Langley Research Center, has suggested that a temperature increase of 4°C could raise mean global sea level by as much as 2 meters, flooding lands presently occupied by more than 40 million people. Although changes in the atmospheric concentrations of carbon dioxide (CO_2) appear to have the most direct effect upon climate change, the pool of atmospheric CO_2 (740 Gigatons or 10^{15} GtC) is very sensitive to changes in the larger pool of terrestrial carbon (2200 GtC), two-thirds of which is contained in soil organic matter (figure 5).

The Global Carbon Cycle

Carbon is the key element of life and is found in all of the earth's environments. The presence of carbon in the earth's crust results from the escape of carbon rich methane and carbon dioxide from the interior of the earth through volcanic activity. Some of this gaseous carbon is dissolved in sea water where it is taken up by plankton during photosynthesis and converted to carbonate ions. This carbon is either recycled within the ocean system or sinks to the bottom to form carbonate sediments which may

Global Carbon Cycle



This diagram illustrates the size and the interaction between the major resevoirs of carbon on the earth. The arrows show flows and linkages between carbon pools.

Figure adopted from DesMarais. Soil and biomass C data from Schlesinger (1977). Terrestrial sediment and oceanic carbon resevoir data from Bolin et al (1979). Atmospheric carbon data from Levine (1990) eventually turn into carbonate rock such as limestone or dolomite. In time, this carbonate rock may be returned to the atmosphere via weathering at the earth's surface or tectonic subduction, deep-crust melting, and re-release as carbon dioxide.

Atmospheric carbon is also taken up by land plants during photosynthesis where it accumulates in living plant and animal tissue. When these living organisms die, some of the fixed carbon is lost through oxidation to the atmosphere, but some becomes trapped in humus and is taken into the soil, where it is either re-absorbed into new plant and animal material or is integrated into the mineral soil. In cold climates or under saturated conditions, dead organic matter does not decompose rapidly but is covered by water or buried. Over long periods of time, this buried carbon may form organic deposits such as peat, coal, oil, and shale.

Theoretically, the carbon cycle is at equilibrium when the carbon flowing to the atmosphere is balanced by the carbon removed by organisms, soil, water, and rocks. At present, however, there is an incomplete understanding of the time frame over which the carbon pools interact, and the calculated carbon budget for the globe does not balance. Human activities, such as the burning of fossil fuels and the conversion of forested land to agriculture, release stored carbon to the atmosphere at a much faster rate then it can be taken up by plants. It is postulated that some of the discrepancy in the carbon budget can be accounted for by changes in carbon storage by the soil and plants.

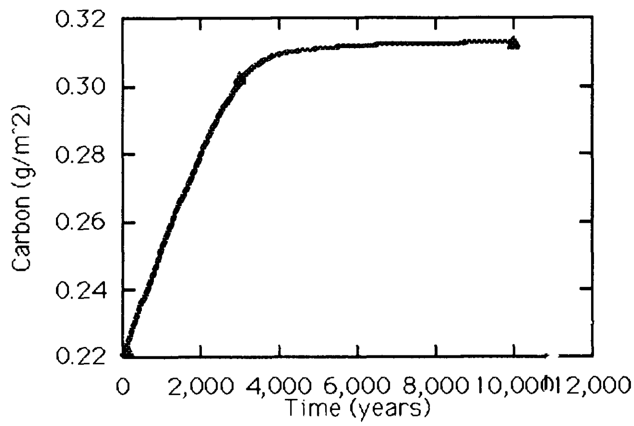


Figure 6: Average Carbon Accumulation, Merced Chronosequence

<u>Chronosequence Study</u>

In our study of soil carbon, we investigate the role of soil in the carbon cycle using the soil chronosequence. Total carbon content of different aged soils is plotted against soil age to determine the rate at which carbon accumulates in soils. Figure 6 illustrates this relationship. Uptake of carbon is greatest in young soils, but reaches an "equilibrium value" when decomposition "catches up" with the output from plants. The period of rapid uptake of carbon during the first 10,000 years suggests that young soils may serve as a net sink, or

Geology in the Schools

Fifth graders at Washington Elementary School in Winton will get down and dirty with USGS scientists later this spring. As a part of their annual Earth Day environmental awareness program, students in Joyce Cunningham's class have volunteered to help earth scientists learn more about the ways agricultural land use practices influence nutrient cycling in soils. Soil scientists from the USGS will visit with the class in May to discuss how different land use practices such as grazing and agriculture can alter nutrient cycling in soils, and, consequently, their ability to sustain plant growth. The students will then survey local land owners about their specific land use practices and create land use histories for various tracts of land. Information from the survey will be used to expand the current data base of historical land use practices in the Merced area as well as to identify potential sites for future study.

All the students who participate will receive a certificate of thanks from the USGS and any student whose site is selected will receive a Volunteer T-Shirt and an invitation to participate in the actual field data collection. In addition to increasing our knowledge of the impact of land use on soil dynamics, we hope that the participation of grade school students in current scientific research will increase understanding about the need for soil conservation and encourage student interest in the sciences.

resevoir, for carbon. As a test to this hypothesis, we are using ^{14}C dating to determine how fast carbon decomposes in different parts of the soil. ^{14}C dating determines when a sample of organic matter was last alive. ^{14}C is a naturally occuring isotope of the more abundant form of carbon, ^{12}C . When living organisms take in carbon dioxide from the air, they incorporate a small amount of ^{14}C. When these organisms die, the ^{14}C trapped in organic tissue is no longer replaced by atmospheric ^{14}C during respiration. Because the ^{14}C isotope decays at a known rate, the ratio of ^{14}C to ^{12}C in an organism represents the average time since the decomposed organic matter was last breathing the atmosphere. Dr. Susan Trumbore of the University of California, Irvine, has developed a method using ^{14}C to trace short term changes in soil carbon dynamics. With Dr. Trumbore's assistance we are applying this technique to the Merced chronosequence where we have old and new samples from the same sites. In 1949, four sites were sampled by R.J. Arkley when he originally mapped the area for the Soil Survey. In the early 1950's, ^{14}C from above-ground testing of nuclear bombs was added to the sites from CO_2 and rainwater. By sampling the sites in 1978 (J. Harden, USGS) and today, and analyzing soils from the three collection times, we can measure how much ^{14}C was incorporated into different parts of the soil. Analysis of chronosequence samples for ^{14}C will provide a good idea of how carbon enters the system, accumulates, decomposes, and eventually leaves the system.

Land Use

Land disturbances such as clearing, cropping, tilling, and grazing can dramatically alter the way in which carbon and nutrients behave in soils. Knowledge of how these practices impact the long term nutrient and carbon budgets is an important

Ask the Scientists

Tom Sawyer of Cox Ferry asks: Why is the Hanford soil on my land near the Tuolumne River less productive than on my other nearby fields?

Tom Bullen of the USGS: A study of the source area or "parent material" of local soils using the element Strontium indicates that young soils near the upper Tuolumne formed from reworked older soil and metamorphic rocks of the foothills, whereas other productive bottom land soils formed from fresh granitic material transported from higher in the Sierra Nevada. If Mr. Sawyer's pasture is on soil reworked by the river long ago, it may be less productive today due to the absence of essential nutrients lost as minerals have weathered away.

Don Robinson of Snelling asks: Water samples from a deep well on the bluff south of the Merced River near Snelling contained 210 parts per billion Strontium when they were recently tested. Is this a safe level and what is the source of this element?

Tom Black, USGS: Strontium is an alkaline-earth element that is often a minor constituent in the minerals Hornblende, Plagioclase, Biotite, and Apatite which occur in the granitic alluvium of the Merced River. Our chemical analysis of soil in the Snelling area shows a decreasing amount of Strontium in the fine fraction with age. Strontium is lost from the dissolving minerals and passes into ground water on its way to the ocean. The most abundant isotope of Strontium (^{88}Sr) is not considered dangerous to humans by the EPA at these concentrations. You may have heard of the radioactive isotope Strontium 90 (^{90}Sr) that entered into the atmosphere after the incident at the Chernobyl nuclear reactor in the former Soviet Union. This release spread appreciable amounts of ^{90}Sr over northern Europe and was found in cows' milk in much of the northern hemisphere. This unstable deacy product of nuclear fission is a known carcinogen and can build up in the bones of animals becasue of its chemical similarity to Calcium.

Ask the Landowners

Jennifer Harden asks: What is the history of the Hopeton cemetary? We could learn a lot about the rates of soil formation and recovery from disturbance if we knew how long the cemetary has been fenced from cows.

Tom Black asks: Do you know of any areas along the Merced River where the bottom land was not tilled for agriculture? An undisturbed plot of the rich Hanford soil could prove invaluable as a reference point for other heavily used fields and pastures.

If you have a question for the USGS scientists or an answer to one of our questions, please feel free to contact:

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step not only in understanding biogeochemical cycling, but also in evaluating the resiliancy of soils to massive disturbance. To help evaluate the effect that differences in land-use practices have on carbon and nutrient cycling, the USGS is working closely with land owners, long time resudents and school children in Merced County to gather information about historic land-use practices for specific sites. Sites whose history is well known are then sampled and evaluated for carbon and nutrient levels. By comparing carbon and nutrient levels in similar soils which have undergone different land use practices, we can quantify the impacts of these practices and gauge the ability of the soil to "recover" from disturbances.

Computer Modeling

Information gathered from the Merced sites is used to develop computer models of carbon and nutrient cycling in soil. Using site specific information such as soil texture, weather conditions, and land use practices, existing computer models "simulate" development of Merced soils from the initial river deposits to the present day. Theoretical data obtained from the computer models is then compared to the actual data from chronosequence studies to better understand how our approach might be improved. In addition, once models are tested and validated, these models can be expanded to simulate carbon and nutrient dynamics in similar areas of the world, providing an inexpensive and efficient means of understanding the importance of soil to the rest of the carbon cycle.

Conclusions

The soils of the Merced River drainage provide an excellent opportunity to study soil carbon and nutrient levels from a variety of perspectives. We are focusing our research on the effects of soil age, land use, and disturbance on the carbon budget and its dynamics. With a more complete understanding of the interaction between soil carbon and the environment we will be able to identify carbon sources and sinks in the soil system. We will apply our The other parts of the world to fill in gaps in the current knowledge of terrestrial carbon sources. Data derived from the ^{14}C study will provide insight into the stability and residence times of soil carbon reservoirs. We need this information to determine over what period young soils are actively removing carbon from the atmosphere and to what extent human use of the soil resource contributes to or alleviates the greenhouse effect.

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