is Mitchell's last dinosaur book (and we will hold him to the implied promise). Hopefully, however, this will not be the last analysis of dinosaurs, and their students and fans, as interesting intellectual phenomena. Perhaps the next book will be written not only with passionate insight but also with a scholar's patience and empathy, both for dinosaurs and for those who study them.

BOOKS: ARCHAEOLOGY

Confirming Antiquity in the Americas

Donald K. Grayson

The significance of this volume, and of the archeological site described within it, is grounded in the long-standing debates over the antiquity of human presence in the New World. In 1778, the French natural historian Georges Buffon argued that Earth had a long and dynamic history, but that people had not appeared until it had become modern in form. By the early 19th century, Georges Cuvier had demonstrated the relatively recent extinctions of huge mammals, such as ground sloths in the New World and mammoths in the Old. For Cuvier and those who followed, these extinctions became the great divide between pre-modern and modern worlds. "There are no fossil human bones" Cuvier observed in 1812, meaning people had not walked the earth with his now-extinct mammals.

Monte Verde
A Late Pleistocene Settlement in Chile, Vol. 2:
The Archaeological Context and Interpretation
by Tom D. Dillehay
Smithsonian Institution Press, Washington, DC, 1997. 1071 pp. $155.
ISBN 1-56098-680-8.

Of course, there were fossil human bones, and before long people were reporting their discovery. In Europe, cave after cave was argued to contain ancient human bones or artifacts. Under the lead of British geologist Charles Lyell, a set of criteria for evaluating these claims was soon developed. To be accepted, a site had to have undoubted human bones or artifacts, unequivocal evidence of great antiquity, and a geological context of unimpeachable integrity.

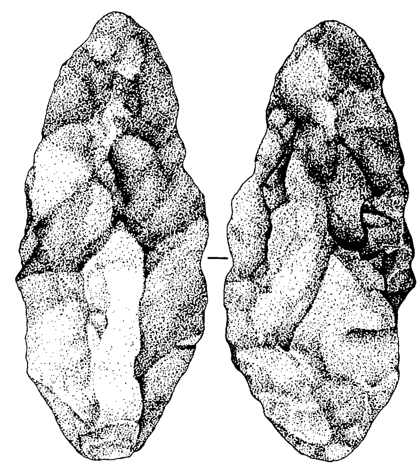
Until 1858, these criteria allowed the rejection of every potentially ancient cave site. That year, extraordinarily careful excavations at Brixham Cave, southwestern England, uncovered stone tools associated with the remains of extinct mammals. Even though cave deposits were not to be trusted, this particular cave had been excavated under the direction of some of Britain's finest geologists (including Lyell) and provided such strong evidence for unexpected human antiquity that it led scientists to a series of open-air sites in northern France's Somme River valley from which Jacques Boucher de Perthes had reported an identical association. There Lyell's criteria were satisfied, and all who visited the sites came away convinced that people and the now-extinct mammals had coexisted.

Once the critical time barrier had been broken, there was every expectation that even older human remains would be found. These expectations were shared by advocates and opponents of Darwin's views on the history of life on Earth. By the end of the century, artifacts of Tertiary age had been reported in both New World and Old (*1*).

In reaction, during the late 19th and early 20th centuries, criteria were again developed for evaluating such claims; in the Western Hemisphere, these were most forcefully advocated by William Henry Holmes and Aleš Hrdlička. To be accepted as documenting great human antiquity, a site had to have undoubted artifacts or human bones, clear and undisturbed stratigraphy, and compelling evidence of deep antiquity. One by one, all claims for Tertiary sites were rejected. Only after 1927 did a Pleistocene human presence in the New World become widely accepted, as the result of discoveries made at Folsom, New Mexico—a site that met all of the evaluative criteria that had been redeveloped during the preceding decades (*2*).

Remarkably enough, the process then began anew. By the mid-1960s, there were dozens of reports of New World sites from deep within the Pleistocene. During the 1960s and 1970s, explicit criteria for evaluating such claims—undoubted human remains, unimpeachable stratigraphy, unquestionable evidence of great antiquity (*3*)—were once again advanced, with geoarchaeologist C. Vance Haynes playing the critical role. By the late 1970s, it was almost universally acknowledged that the earliest archaeological sites in the New World, called Clovis and marked by a distinctive projectile point, dated to about 11,500 radiocarbon years ago.

It is this background that makes the Monte Verde site in south-central Chile so significant. Located in terrace deposits adjacent to a small creek between the Andes and the Pacific, Monte Verde was excavated from 1977 to 1985 by an international team led by Tom D. Dillehay of the University of Kentucky. The excavations recovered a remarkably diverse set of archaeological materials from what is called the MV-II occupation. These include stone tools, cut wood, quids (the chewed and expectorated fibrous



Chipped stone. A large (143 mm by 62 mm by 40 mm) lanceolate biface of quartzite, skillfully made with well-controlled flaking, one of 90 artificially shaped stones collected from MV-II.

remains of plants), bones of extinct mammal, plants that had been transported from afar, a human footprint, and a series of features that Dillehay interprets as the remains of huts. What makes the MV-II discoveries truly momentous, however, are the radiocarbon dates. They range from 11,790 ± 200 years before the present (years BP) to 13,565 ± 250 years BP, and average about 12,500 years BP.

Reactions to Dillehay's initial publications on Monte Verde varied from sheer disbelief through careful neutrality to full acceptance by those who had already accepted a pre-Clovis human presence in the New World on other grounds. The debates over the site picked up steam in 1989, when Dillehay published a major monograph presenting the stratigraphy of the site and the paleoenvironmental information it had provided (*4*).

It is the current volume, however, that presents the critical archaeological information from Monte Verde. And what a volume it is—over 1000 pages of description and analysis by a team of 33 authors led by Dillehay. Among many other accomplishments, the contributors recount the site's setting and stratigraphy, present and analyze the radiocarbon data, describe and interpret the artifacts, and map and discuss the possible structures.

To those of us interested in the peopling of the New World, the work on Monte

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Verde had to answer two key questions: Is the MV-II occupation really archaeological and, if so, is it really that old? That is, does the site meet the modern version of the apparently eternal criteria first forged by Lyell? Reading this volume leaves no doubt that the answer is "yes." This was also the decision reached by an interdisciplinary team (of which I was a member) that examined the Monte Verde collections and visited the site in 1997 (*5*).

Intriguingly, there is more to the Monte Verde site than the MV-II findings. Dillehay has discovered other apparent archaeological material, called MV-I, at the base of glacial outwash deposits some 2.1 meters beneath the present ground surface and some 80 meters distant from the MV-II deposits. Associated radiocarbon dates fall at 33,370 ± 530 and >33,020 years BP; these are fully consistent with dates of ~25,000 years BP from higher in the stratigraphic sequence, and of >42,100 years BP from lower in that sequence. Dillehay is cautious about this material, but having seen some of the objects and the context from which they came, it is quite clear that at least some of it is artifactual (for example, the basalt core from which flakes were removed, illustrated in figure 14.70 in this volume).

It is hard to overemphasize the importance of the discoveries described in this book. We now have a New World archaeological site some 16,000 kilometers south of the Bering Land Bridge that predates Clovis by more than 1000 radiocarbon years (MV-II), and that might even contain a much earlier occupation (MV-I). As a result, archaeologists must rethink their ideas about the peopling of the New World, a process that has already begun (*6*). But in doing so, it would be good to remember what has happened in similar situations in the past after convincing breakthroughs. Criteria for evaluating potentially ancient archaeological sites have been relaxed and invalid sites interpreted as authentic, only to be rejected after virtually identical criteria were redeveloped to evaluate them. Then, one or more sites met the new criteria, and the process began again. That Monte Verde is quite clearly a pre-Clovis archaeological site does not mean that it is time to relax our skepticism about other sites—and there are many—that may or may not be archaeological and that may or may not be old.

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PERSPECTIVES: PALEOCLIMATE

The Sulfur Cycle and Atmospheric Oxygen

Robert A. Berner and Steven T. Petsch

The isotopic composition of carbon and sulfur in rocks and sediments provides an important record of global change over geologic time. Changes in the ratios of $^{13}C/^{12}C$ and $^{34}S/^{32}S$ of the oceans largely reflect changes in global biological processes that cause fractionation of these isotopes. The biological processes include photosynthesis, which brings about the depletion of ^{13}C (compared with its abundance in seawater) in sedimentary organic matter, and bacterial sulfate reduction, which brings about the depletion of ^{34}S in sedimentary pyrite (FeS_2). Because organic matter and pyrite burial in sediments, along with their weathering on the continents, constitute the four major processes affecting atmospheric oxygen, study of the rates of these processes is important, not only for the evolution of the carbon and sulfur cycles but also for the history of atmospheric oxygen (*1–3*) (see figure).

The record of $^{34}S/^{32}S$ of the oceans over geologic time (*4*, *5*) has heretofore been based on the analysis of calcium sulfate minerals precipitated from seawater through intense evaporation in restricted portions of the sea. However, there are problems with the use of evaporites for obtaining isotopic data because of their infrequent occurrence and their location at marine margins, which can lead to initial water compositions different from that of the open ocean (*6*). The alternate use of another sulfate mineral, formed from the open ocean at normal salinity, allows one to obtain a much more complete isotopic record and to avoid the pitfalls presented by marginal marine environments. As reported on page 1459 of this issue, this has now been done by Paytan *et al.* (*7*) for the Cenozoic era (the past 65 million years) by analyzing barite ($BaSO_4$), a common minor component of deep-sea sediments. The excellent correlation between different localities and the finding of the modern ocean $^{34}S/^{32}S$ ratio for barite in very young sediments show that this barite data set is reliable and provides the best record to date of the evolution of oceanic sulfur.

The processes that affect the evolution of oceanic sulfur over geologic time include (*8*) (i) river input from the weathering of pyrite and calcium sulfate minerals on the continents; (ii) removal of sulfur from seawater through bacterial sulfate reduction to hydrogen sulfide followed by the reaction of H_2S to form sedimentary pyrite plus minor organic sulfur compounds; (iii) removal from seawater through the precipitation of calcium sulfate in evaporite basins; and (iv) the exchange of sulfur through the interaction of basalt with seawater at midoceanic ridges.

Sedimentary pyrite formation and calcium sulfate precipitation constitute the two major processes of sulfur removal from seawater. By comparison, net removal of sulfur through thermally induced sulfate reduction at midocean ridges has been shown to be minor. This is based on both sulfur isotopic mass balance (*9*) and the inability to balance the oxygen cycle if this process were quantitatively important (*10*). Also, the permanent removal of sulfate as $CaSO_4$ at ridges can be shown to be minor from the study of sea-floor basalts (*9*). The addition of reduced sulfur to Earth's surface from the mantle may occur episodically; however, massive maintained sulfur fluxes have been shown to be quantitatively unimportant on the basis of both isotopic and oxygen mass balance considerations (*11*).

The sulfur that is removed from seawater as sedimentary pyrite involves considerable isotopic fractionation (*12*) and is highly depleted in heavy sulfur (low $^{34}S/^{32}S$), whereas calcium sulfate precipitation involves negligible isotopic fractionation. Input to the oceans from continental

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