achromatic, and the signature of lensing is multiple images with identical spectra. There are three complications, however, that in practice differentially modify the spectra. First, the ray paths for the various images may have different lengths, and the images we observe simultaneously were actually emitted at different times. If the source varies, the images will not be identical. (Although a complication in identifying lenses, time delays are central in the determination of cosmological parameters from lensing.) Second, quasars and other types of active galactic nuclei may have complicated radio structure on an angular scale comparable to the angular scale of the image separations. It is possible for lensed images to show different regions of the original structure. Third, intervening matter, possibly including the lensing mass itself, may produce differential absorption along the different ray paths. The strategy for identifying lensing, then, is to look for multiple images with approximately the same spectra, and then to demonstrate that any observed differences are due to variability or details of the image formation.

It is possible to calculate the number of lens systems that should be observed in a given sample of quasars, based on the spatial distribution and masses of galaxies and the redshift distribution of the quasars in the sample. Such calculations have been made by Turner *et al.* (*17*), who conclude that between 2.3 and 5.1 out of every thousand quasars will be lensed, depending on the number density and dynamical properties of galaxies and the value of q_0. The peak in the distribution of angular separations is near 1 arc second. Since at optical wavelengths the blurring effect of the earth's atmosphere is usually of this order, optical searches for lensing are inefficient. At radio wavelengths, however, interferometers such as the VLA routinely observe with resolutions of tenths of arc seconds. In addition, although most quasars found in optical surveys are too weak as radio sources to be detected with present-day instruments, most of the constraints on models of particular lensing systems come from high-resolution radio observations. (Of the three previously reported lens systems, only 0957+561 is a detectable radio source.) Therefore, not only is a VLA search for gravitational lensing likely to be more productive than optical searches, but any lens systems found are likely to be more useful as cosmological probes than radio-weak systems.

There are four steps in a VLA search for gravitational lenses: (i) observe a source at the VLA at 6 cm. If the structure suggests lensing, (ii) observe at the VLA at a second frequency. If the two-point radio spectra of the multiple images are the same, (iii) observe the source optically. If optical images are also consistent with lensing, (iv) obtain optical spectra. 2016+112 is the first lens system found by this method, and it is evidently an extraordinary system. Its discovery did not depend on its unusual features, however, and the above procedure should provide a sample of lens systems large enough to show both the common and the anomalous characteristics of gravitational lenses.

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Late Miocene Vegetational and Climatic Variations Inferred from a Pollen Record in Northwest Wyoming

Abstract. *A pollen stratigraphy from late Miocene lacustrine strata (Teewinot Formation) in Jackson Hole, Wyoming, permits analysis of vegetation and climate history over a time interval of less than 300,000 years with better temporal resolution of data than has been reported from terrestrial Tertiary deposits. The flora was essentially modern, and six successive pollen assemblages indicate alternating dry and wet conditions. The frequency of climatic change in this record is similar to that inferred from marine isotope records for both late Tertiary and Quaternary time.*

Major climatic fluctuations are well documented as a series of glaciations and interglaciations during the Quaternary Period, and the isotope record from marine sediments suggests that climatic cycles have occurred throughout the Cenozoic Era (*1*). Recognition of such events in nonmarine Tertiary strata has been difficult, however, since there are few long continuous records. An exception is the late Miocene Teewinot Formation (9-million-year-old lake sediments) of Jackson Hole, Wyoming. The pollen record shows that during the late Cenozoic a series of short-term vegetation changes took place as the overall aspect of climate and vegetation shifted from temperate to continental in the Rocky Mountains.

The Teewinot Formation is a sequence 2000 m thick of lacustrine sediments that outcrop in a 60-km^2 area in Jackson Hole (Fig. 1). The upper 68 m consist predominantly of interbedded calcareous claystone, siltstone, and coarse vitric tuff, which are exposed along the lower Gros Ventre River. Fossil vertebrates, mollusks, and ostracods indicate deposition in a large freshwater lake (*2*). The lake apparently occupied much of the present area of Jackson Hole and was fed primarily by streams from the north and east. A potassium-argon age of 9.2 million years and early Hemphillian vertebrates establish the late Miocene age (*3*). This formation predates the modern Teton Range, but the Snake River, Hoback, and Gros Ventre ranges and the Mount Leidy and Pinyon Peak highlands were present to the east, south, and north (*4*).

Estimated sedimentation rates suggest that the upper 68 m of the Teewinot Formation took 30,000 to 300,000 years to accumulate. Calcareous claystone probably had the slowest sedimentation rate: 1 m per 500 to 5000 years is estimated from dated, compacted sediments in reasonably analogous modern lakes and from varves in the Teewinot Formation (*5*). The time required for the accumulation of vitric tuffs and siltstones was probably relatively short and, for the purpose of this discussion, of negligible duration.

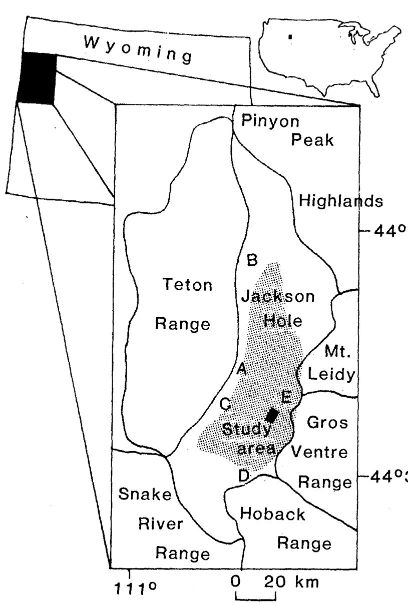
Claystone was sampled for pollen at intervals of 30 cm, the equivalent of 150 to 1500 years, according to the rates mentioned above. The fossil pollen from 73 levels was referable to modern types at the level of genus or family (*6*). Although the ecological ranges of some taxa may have been different 9 million years ago, a study of modern plant communities and their relationships to present-day vegetation, climate, and pollen rain was used to reconstruct the late Miocene vegetation around Jackson Hole (*7*).

The upper part of the Teewinot Formation has high percentages of *Pinus* (50 to 95 percent) (pine), *Abies* (fir), and *Picea* (spruce) pollen (Fig. 2), suggesting that these conifers were important in the montane vegetation. Relative abundances are similar to those in modern pollen spectra from Jackson Hole (Fig. 2). Percentages of *Picea* and *Abies* pollen change little, and the pollen was probably transported long distances from upper slopes. Percentages of *Pinus* pollen, on the other hand, fluctuate with Cupressaceae (*Juniperus*-type) (*8*) and the nonconifer component; pine and juniper probably grew on the lower slopes, and the changes in relative abundance of their pollen were the result of fluctuations in the position of the lower tree line.

Other Tertiary relicts, including *Carya* (hickory), *Pterocarya* (wing nut), *Ulmus* (elm) and *Zelkova* (keaki tree), and Sapindaceae (soapberry family), today are confined to hardwood and conifer-hardwood forests and floodplains of eastern, central, and southern North America, Central America, Asia, and Europe. Pollen and leaves of these deciduous hardwoods in pre-Hemphillian sediments in the western Cordillera suggest that they were once more widely distributed (*9*), and the pollen in the Teewinot Formation represents one of their last records in the Rocky Mountains. To survive in a dominantly conifer forest during the late Miocene, these temperate taxa probably grew in protected valleys and riparian environments.

The high percentages of *Sarcobatus* pollen may be attributed to *S. vermiculatus* (greasewood), a halophytic shrub found today throughout the American West. Most other nonarboreal taxa (Fig. 2) appear in modern communities around Jackson Hole and are represented by low percentages in modern pollen rain. Today surface spectra collected from sagebrush communities in Jackson Hole often contain more than 50 percent *Artemisia* pollen. The low percentages in the Teewinot record, however, are more typical of spectra from forested regions, where *Artemisia* sect. Tridentatae (sagebrush) is not of local importance.

The pollen record is characterized by six successive assemblages: T1, T3, and T5 are dominated almost exclusively by *Pinus* and *Abies*; T2, T4, and T6 register high percentages of *Juniperus*-type, *Sarcobatus, Ephedra*, deciduous hardwoods, and herbaceous taxa. The latter three assemblages may represent dry pe-



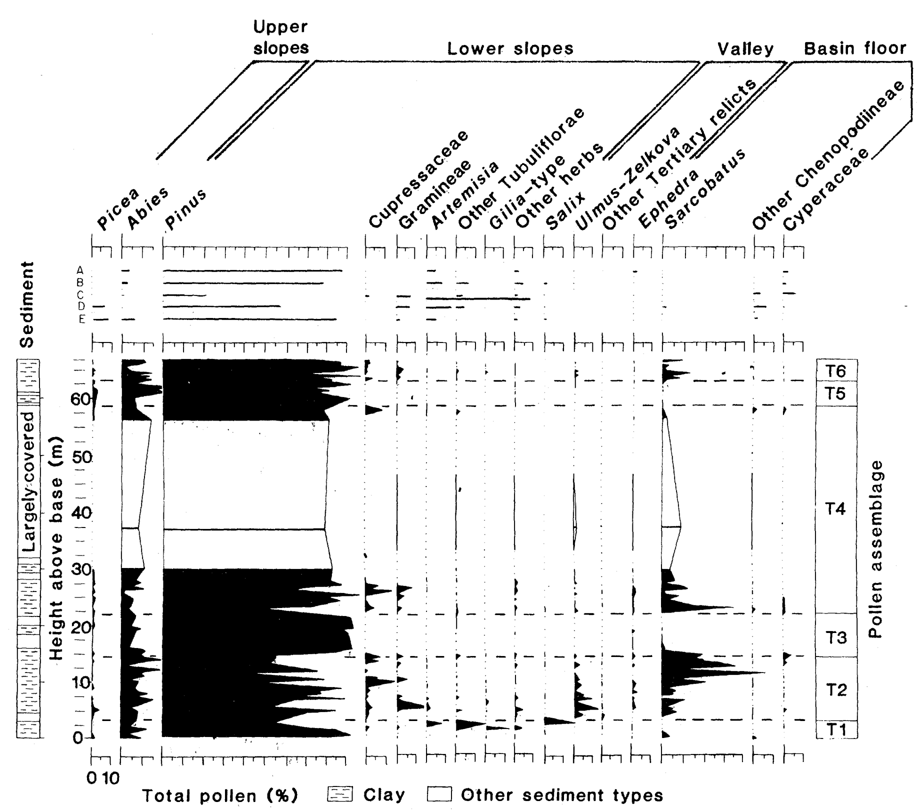


Fig. 1 (left). Map showing the area where Teewinot Formation is now present (stippled area) and location of study area and pollen surface samples (A–E). Samples A, D, and E were collected from *Pinus contorta* parkland and samples B and C from *Artemisia tridentata* communities. Fig. 2 (right). Pollen percentage diagram from the upper Teewinot Formation showing selected taxa and their inferred habitat. Also shown are the percentages of five modern pollen spectra (A–E) collected in Jackson Hole (see Fig. 1).

riods when the lake became shallow and vegetation on the lower slopes became more open. *Sarcobatus* and Cyperaceae spread over the exposed flats, and *Sparganium* expanded in the shallower water. Pine forests along the lower slope were replaced by a more open pine woodland that featured at different times *Artemisia*, Gramineae, and herbs in the understory and possibly *Juniperus* at its lower edge. At the same time the contribution from hardwoods growing in the valleys increased in the pollen record. The three arid periods are estimated to have lasted 5000 to 50,000 years (inferred from T2), 21,000 to 210,000 years (T4), and 2000 to 20,000 years (T6). The intervening wetter intervals lasted 1000 to 11,000 years (T3) and 1000 to 10,000 years (T5).

Pollen data from the Teewinot Formation help pinpoint the increase in continentality in the Rocky Mountains in the late Tertiary. Older Neogene floras in the western United States contain conifer assemblages with notable subtropical and temperate elements (*9, 10*), but the Teewinot record shows that the extirpation of these early Tertiary relicts was nearly complete in the Rocky Mountains by 9 million years ago (*11*). In northwestern Wyoming, post-Teewinot assemblages show an essentially modern flora by late Blancan (latest Pliocene) time (*12*). Epeirogeny, creation of orographic barriers to maritime air masses from the Pacific Ocean, and global climatic cooling all contributed to the development of drier conditions and greater seasonality in the West during the late Tertiary (*13*).

The vegetation reconstructions derived from the pollen data of this one interval of the Teewinot Formation suggest that climatic oscillations, each with a time span lasting between 1000 and 200,000 years, have occurred repeatedly during the late Miocene. These findings suggest that the Tertiary lake deposits such as the Teewinot Formation have the potential to reveal the nature of pre-Quaternary climatic variability.

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Turbulent Jets and Eddies in the California Current and Inferred Cross-Shore Transports

Abstract. *The instantaneous California Current is seen to consist of intense meandering current filaments (jets) intermingled with synoptic-mesoscale eddies. These quasi-geostrophic jets entrain cold, upwelled coastal waters and rapidly advect them far offshore; this behavior accounts for the elongated, cool surface features that are seen extending across the California Current region in satellite infrared imagery. The associated advective mechanism should provide significant cross-shore transports of heat, nutrients, biota, and pollutants. The dynamics of the current system should be crucially influenced by its highly variable structure.*

The California Current is the major eastern boundary current of the North Pacific. Its flow regime is important for fisheries and climate-related processes; for oil and gas recovery operations and waste disposal; for biological, chemical, and geological investigations; and for physical oceanographic studies. Nonetheless, the role of this current in the general circulation is not clear and its kinematics and internal dynamics have not been established. Such eastern boundary currents have generally been thought to be broad, shallow, and slow (*1, 2*), although some reports (*3*) of eddies, generally based on sparse information, do exist.

In a sequence of three quasi-synoptic studies conducted in March through August 1982, we mapped hydrographic fields with high spatial resolution within a domain 160 by 200 km in the California Current System (CCS). The flows that we observed did not consist of the previously conceived steady southward drift; instead, they were highly variable in space and time and were dominated by variously oriented jetlike strong current filaments and eddies. Preliminary results are presented here to provide new, relevant kinematic concepts and to aid in the interpretation of satellite infrared imagery from such regions. These studies initiated acquisition of a database in a "test block" of ocean established to provide the basis for a statistical-dynamical eddy-resolving model system for ocean prediction in general (*4*), and to provide for a dynamical analysis of the role of the eddies in the CCS (CCS is used here to connote an aggregate of flows: the California Current, the California Undercurrent, associated eddies, and transients, which coexist and intermingle along the West Coast). This effort was an early step in the Naval Postgraduate School–Harvard OPTOMA (Ocean Prediction Through Observations, Mod-