would have been created by a process of uniform extension. Finally, we consider the forces of uplift on the flanks in the situation where the crust is treated as a thin elastic plate floating on a fluid upper mantle, the graben is bounded by two major normal faults, and there is subcrustal thinning under the flanks. We show that such normal faults produce uplift of the flanks and that this uplift can be significantly increased by the subcrustal thinning. Both kinds of forces give rise to uplift which can, in certain places, be misinterpreted as pre-rift doming. However, the uplift and erosion on the flanks of the graben associated with nonvertical faulting does not introduce significant error into the calculation of extensional parameters from subsidence analysis of a cross section of a basin.

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Sedimentation in Pull-Apart Basins—Modern Examples from Eastern Turkey

Well-exposed ancient pull-apart basin deposits have the following characteristics in common: (1) great stratigraphic thickness relative to basin size, (2) high rate of sedimentation, (3) asymmetry of sediment thickness and facies pattern, (4) organization of the facies into marginal fault-bounded fanglomerates and central flood-basin and lacustrine deposits, and (5) textural cycles that reflect tectonic activity and evolution. The relationship between basin deposits and boundary faults is usually well defined. However, many pull-apart basin deposits are deformed and their boundary faults are usually no longer active. Understanding of sedimentation in ancient pull-apart basins suffers from a limited knowledge about the original depositional and structural setting. In an attempt to develop a more comprehensive understanding of sedimentation in pull-apart basins, we examine the fault and depositional systems of two modern, active pull-apart basins in eastern Turkey.

The Erzincan pull-apart basin overlies the North Anatolian fault, a right-lateral, 1,200-km (745 mi) long intracontinental transform fault. It is 50 by 13 km (31 by 8 mi) and rhomboidal. Boundary strike-slip faults define sharp, steep, and relatively undissected mountain fronts. These active faults are characterized by an overlap of 32 km (20 mi) and a separation of 13 km (8 mi). Sedimentation within the basin is controlled by: (1) an axial fluvial system (the upper Euphrates River) associated with a broad flood plain/salt marsh, and (2) alluvial fans that prograde transversely from the boundary mountain fronts. Small calcalkaline volcanic cones intrude and overlie these sediments along subsidiary strike-slip faults within the basin. Aluvial fans are well-developed along the northern mountain front. They are steep, composed of fluvial and debris flow facies, and prograde over fluvial plain/salt marsh deposits. Along the southern mountain front alluvial fans have coalesced into a gently sloping alluvial apron composed of fluvial facies. These features suggest that the northern fault margin has probably been more recently active than the southern fault margin.

The Lake Hazar pull-apart basin overlies the East Anatolian fault, a left-lateral, 450-km (280 mi) long intracontinental transform fault. It is 25 by 7 km (16 by 4 mi), rhomboidal, and forms an asymmetric half-graben in cross section with its deepest part to the south. Boundary strike-slip faults form sharp, steep mountain fronts and are characterized by a separation of 3 km (1.9 mi) and an overlap of about 5 km (3.1 mi). Sedimentation within the basin is controlled by: (1) an axial fluvial system which enters the basin longitudinally and forms a large (5.1 km^2 [2 mi^2]), low-gradient (1.1°) fan delta which is composed of interbedded fluvial and lacustrine facies, and (2) lateral fluvial systems that enter the basin transversely and form small (0.03 to 0.23 km^2 [0.01 to 0.09 mi^2]), steep (2.5° to 8.5°) fan deltas composed of interbedded fluvial and debris flow facies.

The Erzincan and Lake Hazar pull-apart basins present an "instantaneous" structural and depositional picture of pull-apart basin evolution and provide a basis of comparison with ancient pull-apart basin deposits.

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Case History of Langley Deep Field in Lea County, New Mexico

In May 1978, ARCO Oil and Gas Co. completed the Langley Deep Unit 1 well in Lea County, New Mexico, discovering a deep gas field with production from 2 horizons. The discovery well produces gas from a northwest-southeast trending anticline that has a reverse fault at the Ellenburger formation on the northeast flank of the structure. This reverse fault generated an anticlinal feature in the upthrown block on the east flank of the Delaware basin that is the reservoir for the Langley Deep field Devonian strata, and the fault is the possible trap at the Ellenburger formation.

This discovery was the result of an ongoing seismic program that started with a regional group shoot in 1968 on the Central Basin platform and the Delaware basin in Lea County, New Mexico. This survey obtained data that has at best only short discontinuous reflectors in the present area of interest. It could be used only to obtain dips of unknown geologic horizons. ARCO Oil and Gas Co. has been in additional group shoots or has acquired seismic data in each year from 1973 through 1981 in the Delaware basin and Central Basin platform of New Mexico. Each vintage is an improvement in the quality of the section in terms of both the continuity of events and resolution of events. New acquisition and processing techniques contribute to the enhancement of the data. Even though better record sections are obtained with each succesive vintage, the improvement is limited in each case. The most improvement in record section quality is between the data acquired in 1968 and 1973.

The exploration play developed when data acquired in 1973 was reprocessed in 1975 including diffraction migration, which clearly demonstrated the presence of the critical east dip on Devonian and older formations. Subsequent seismic programs define the limits of the closure. The 1978 discovery well confirmed the existence of the seismic structure. Seven wells have been drilled to date on the Langley Deep seismic feature. Six wells have been completed and are producing gas from Devonian and Ellenburger formations. The seventh well had shows but is considered noncommercial. The only other deep well on the structure was drilled in 1962 to Conoco Inc. to the Ellenburger formation on the northern end of the Langley Deep feature, but was over 500 ft (150 m) lower at the Devonian formation when compared with the shallowest penetrations of these formations on the Langley Deep structure.

The success of finding the Langley Deep field is due to recognizing that the potential for finding reservoirs exists in the no-data zones on seismic. By continually investigating and searching for the causes of the no-data zones, new and improved acquisition and processing techniques revealed a gas field that would never have been found if exploration stopped after the initial efforts to define the subsurface. The continued efforts to specify the subsurface along the western edge of the Central Basin platform and eastern edge of the Delaware basin not only resulted in the discovery of the Langley Deep field, but also renewed interest of the majors and independents in this area. Conoco Inc., ARCO Oil and Gas Co., and Shell Oil Co. have drilled additional deep gas producing wells on similar features that are on trend with and to the south of the Langley Deep field. Thus, the effort of improving the quality of seismic reflections not only led to the discovery of the Langley Deep field but also generated the impetus that discovered additional reserves on other features along the same general trend.

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Coal-Bed Methane Development in Warrier Coalfield of Alabama

The University of Alabama School of Mines and Energy Development is conducting research on coal-bed methane development and utilization in the Warrior coalfield. Four test core holes, funded by the U.S. Department of Energy, have been drilled to depths of 2,800 to 3,400 ft (853 to 1,036 m). Gas quantities from coal samples were obtained by non-isothermal desorption and gas quality was determine by chromatographic analyses. Data from these tests were used to estimated total gas resources on targets of varying acreage around each core hole. Seams of the Pratt, Mary Lee, and Black Creek coal groups were found to have the greatest potential with gas contents ranging from 200 to 400 ft^3 per ton, typically consisting of about 95% methane. An evaluation of well completion options and stimulation techniques indicate that multiple stimulation open-hole completion provides the best return on investment. Utilization options considered include: (1) direct on-site use as a fuel for heating, (2) vehicular fuel, (3) sale to a gas transmission company, and (4) sale to other users (local only). The feasibility of various well completion and gas utilization options was assessed using Internal Rate of Return (IRR) techniques over a 10-year life with 50% to 75% recoverability. These analyses indicate an acceptable rate-of-return, but are tentative as the percentage of in-place gas that can be recovered and the optimum well spacing are still under investigation. A demonstration well completed on the University of Alabama campus is being observed to confirm estimates of production rate, capital cost, and operating expenses.

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An Integrative Gas Geochemical Technique for Surficial Petroleum Exploration

A new, innovative method of integrated gas geochemical exploration for petroleum has recently been developed and is being evaluated. The technique involves the shallow burial of Curie-point wire coated with a small amount of activated carbon in a cylindrical container in the topsoil where the carbon interacts with emanating soil gases. A collection period of several days to weeks is employed, depending on soil conditions. After removing the wires from the support apparatus, analysis is conducted using a Curie-point pyrolyzer directly coupled to a quadrapole mass spectrometer. The resulting mass spectra are analyzed by multivariate statistics using the program, ARTHUR. The results of the data analysis have been correlated to the presence of oil and gas along with the effects of gas emission on areal pattern variation.

The initial gas geochemical experiments have been conducted over known accumulations of petroleum in the Weld County section of the Denver-Julesburg basin, the southern overthrust belt in central Utah, and the Patrick Draw oil field in the eastern Green River basin of Wyoming. Initial testing of the technique has been over a period extending from June through September 1982. Effects on gas emission rates and pattern variations will be discussed with respect to geologic structure, hydrodynamic factors, soil conditions, and seasonal variations. The advantages and disadvantages of the integrative sampling techniques when compared to conventional gas geochemical methods used in petroleum exploration will also be discussed. Although the technique has been applied to a limited number of areas, the early results show great promise in reducing many of the problems associated with other gas geochemical methods.

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Bioturbation Patterns in a Channel-Levee-Overbank Sequence of Paleocene Submarine-Canyon Fill, Point Lobos, California

Bioturbation patterns in the Paleocene submarine canyon fill (Carmelo Formation) at Point Lobos, California, differ for channel, levee, and overbank deposits. Variation in (1) such ichnoassemblage characteristics as taxonomic composition, diversity, abundance, and behavioral/preservational types, and (2) the overall degree of biogenic reworking of the sediment are particularly significant. The ichnoassemblage of the channel-levee-overbank sequence includes *Arenicolites*, ?*Aulichnites*, *Chondrites*, ?*Helminthoida*, ?*Neonereites*, *Ophiomorpha*, *Scolicia*, *Thalassinoides*, escape structures, and two unidentified traces. All the trace fossils were produced by infaunal organisms burrowing at various depths below the sediment-water interface.

The channel deposits are characterized by relatively low diversity and density (in comparison with the overbank deposits), and mainly consist of traces of deep-burrowing animals (e.g., *Ophiomorpha*). The overbank deposits have a relatively diverse and dense ichnoassemblage produced by both deep- and shallow-burrowing animals. The levee deposits are similar to the overbank deposits in trace diversity, but are intermediate between the channel and overbank deposits with respect to their overall degree of bioturbation.

Bioturbation patterns in these three subenvironments differ as a consequence of the chance of preservation of biogenic sedimentary structures. Each bed type (e.g., mudstone) contains similar ichnoassemblages regardless of the depositional subenvironment in which the bed type occurs. This pattern indicates that the distribution of the infaunal organisms producing the traces was influenced more by factors associated with a particular lithology (e.g., texture or organic content) than by environmental factors peculiar to a specific subenvironment. Therefore, the relative abundance of the various bed types ultimately preserved within each subenvironment corresponds to the bioturbation patterns characteristic of the channel-levee-overbank sequence.

For example, physical sedimentary structures (e.g., Bouma a-b intervals in thick sandstone beds) and biogenic sedimentary structures (e.g., escape structures and truncation of traces) in the channel environment indicate frequent episodic events of extensive erosion, followed by rapid deposition of sand bed several tens of centimeters thick. Thus, traces produced by deep-burrowing organisms in thick sandstone beds are most frequently preserved. In the overbank deposits, an abundance of traces left by shallow-burrowing organisms (e.g., *Arenicolites*) in mudstone beds, the type of behavior (e.g., feeding burrows) represented by such traces, and the higher degree of bioturbation of all bed types indicate relatively slow, continuous deposition. Therefore, the change in conditions of sedimentation (e.g., frequency of significant erosional/depositional events, amount and/or type of sediment eroded/deposited, ratio of erosion to deposition) results in the preservation of a different bioturbation pattern within the more "tranquil" overbank subenvironment. The bioturbation pattern characteristic of the levee deposits repre-