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 However, many pull-apart basin deposits are deformed and their boundary faults are usually no longer active.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