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NRC Staff Other
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SECTION VI

GEOLOGY REPORT

AUGUST 2004

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4.0 ACTIVE AND INACTIVE GEOLOGIC PROCESSES

This section addresses active geologic processes in the vicinity of the facility. In discussing the "active" geologic processes, the "inactive" processes are discussed as well. Active geologic processes include flooding and submergence, faulting, seismicity, land surface subsidence, and the potential for surface erosion. Flooding is addressed by locating the facility out of a 100-year floodplain and submergence applies only to coastal zones. Faults, seismicity, land surface subsidence, and surface erosion are discussed in the following sections.

4.1 FAULTS

This section provides an analysis of faults in the vicinity of the facility at the regional and local scales. Various regulatory requirements for land disposal activities, as well as storage and processing of wastes, require delineation of all faults within the area of the facility, together with demonstrations for any such faults that:

(i) fault displacement has not occurred within Holocene time, or if fault displacement has occurred within Holocene time, that no such faults pass within 200 feet of the portion of the surface facility where treatment, storage, or disposal of wastes will be conducted;

(ii) it will not result in structural instability of the surface facility or provide for groundwater movement to the extent that there is endangerment to human health or the environment; and

(iii) disposal units will not be located near a capable fault that could cause a maximum credible earthquake larger than that which the unit could reasonably be expected to withstand.

The WCS site is situated over the north central portion of a prominent Paleozoic structural feature known as the Central Basin Platform. Significant faults are known in the deep subsurface as interpreted from petroleum exploration activities. The faults are expressed in Paleozoic rocks at depths of thousands of feet. The deep faults lose their expression as significant stratigraphic offsets after early Permian (Wolfcampian) time. All of the major faulting in the vicinity of the Central Basin Platform occurred in response to tectonic forces active before the global plate tectonic reorganization that created the North American continent. (Bally et al., 1989). The Paleozoic faults exhibit low natural microseismicity as a result of passive response to relatively low levels of tectonic stress in the trailing edge of the westward-drifting North American plate. The closest area of active regional tectonic stress and active faulting offsetting Quaternary or younger geologic deposits is the Rio Grande Rift that forms the eastern boundary of the Basin and Range Province. The Rio Grande Rift is over 200 miles west of the WCS area. There is no surface evidence of faulting within 3000 feet the WCS permitted area.

4.1.1 Regional Tectonic Setting and Faults

The WCS facility is located within the Permian Basin region of west Texas. The Permian Basin derives its name from the fact that it is underlain by extensive deposits of Permian sediments.

4.1.1.1 *Tectonic Setting*

The WCS site is situated over the north-central portion of a prominent structural feature known as the Central Basin Platform (Figure 6.4-1). The Central Basin Platform is a deep-seated horst-like structure that extends northwest to southeast from southeastern New Mexico to eastern Pecos County, Texas. The Central Basin Platform is flanked by two prominent structural depressions known as the Delaware Basin to the southwest and the Midland Basin to the northeast, and by the Val Verde Basin to the south.

From the Cambrian to late Mississippian, west Texas and southeast New Mexico experienced only mild structural deformation that produced broad regional arches and shallow depressions (Wright, 1979). The Central Basin Platform served intermittently as a slightly positive feature during the early Paleozoic (Galley, 1958). During the Mississippian and Pennsylvanian, the Central Basin Platform uplifted using ancient lines of weakness (Hills, 1985), and the Delaware, Midland, and Val Verde Basins began to form as separate basins.

Late Mississippian tectonic events uplifted and folded the platform and were followed by more intense late Pennsylvanian and early Permian deformation that compressed and faulted the area (Hills, 1963). Highly deformed local structures formed ranges of mountains oriented generally parallel to the main axis of the platform (Wright, 1979).

This period of intense, late Paleozoic deformation was followed by a long period of gradual subsidence and erosion that stripped the Central Basin Platform and other structures to near base-level (Wright, 1979). The expanding sea gradually encroached over broad eroded surfaces and truncated edges of previously deposited sedimentary strata. New layers of arkose, sand, chert pebble conglomerate and shale deposits accumulated as erosional products along the edges and on the flanks of both regional and local structures. Throughout the remainder of the Permian, the Permian Basin slowly filled with several thousand feet of evaporites, carbonates, and shales (Figure 6.4-2).

From the end of the Permian until late Cretaceous, there was relatively little tectonic activity except for periods of slight regional uplifting and downwarping. During the early Triassic, the region was slowly uplifted and slightly eroded. These conditions continued until the late Triassic, when gentle downwarping formed a large land-locked basin in which terrigenous deposits of the Dockum Group accumulated in alluvial flood plains and as deltaic and lacustrine deposits (McGowen, et al., 1979). In Jurassic time, the area was again subject to erosion.

During Cretaceous time, a large part of the western interior of North America was submerged, and the west Texas/southeastern New Mexico region was part of a large continental shelf sea in which a thick sequence of Cretaceous rocks was deposited. The Cretaceous sequence of sediments comprised a basal clastic unit (the Trinity, Antlers or Paluxy sands) and overlying shallow marine carbonates.

Uplift and southward– and eastward-retreating Cretaceous seas were coincident with the Laramide Orogeny, which formed the Cordilleran Range west of the Permian Basin. The Laramide Orogeny uplifted the region to essentially its present position, supplying sediments for the late Tertiary Ogallala Formation. The major episode of Laramide folding and faulting occurred in the late Paleocene. There have been no major tectonic events in North America since the Laramide Orogeny, except for a period of minor volcanism during the late Tertiary in northeastern New Mexico and in the Trans-Pecos area. Hills (1985) suggests that slight Tertiary movement along Precambrian lines of weakness may have opened joint channels which allowed the circulation of groundwater into Permian evaporite layers. The near-surface regional structural controls may be locally modified by differential subsidence related to groundwater dissolution of Permian salt deposits (Gustavson, 1980).

4.1.1.2 *Faults*

Two types of faulting were associated with early Permian deformation. Most of the faults were long, high-angle reverse faults with several hundred feet of vertical displacement that often involved the Precambrian basement rocks (Hills, 1985). The traces of these faults are shown on the Precambrian structure map provided in Figure 6.4-3. The second type of faulting is found along the western margin of the Central Basin Platform where long strike-slip faults, with displacements of tens of miles, are found (Hills, 1985; Bebout and Meador, 1985) (Figure 6.4-4).

The large structural features of the Permian Basin are reflected only indirectly in the Mesozoic and Cenozoic rocks, as there has been virtually no tectonic movement within the basin since the Permian (Nicholson and Clebsch, 1961). The east-west and north-south regional cross-sections provided in Figures 6.4-5 and 6.4-6 illustrate this relationship. Figure 6.4-5 shows the draping of the Permian and Triassic sediments over the Central Basin Platform structure, located approximately 7000 feet beneath the present land surface. The faults that uplifted the platform do not appear to displace the younger Permian sediments. The northernmost fault on Figure 6.4-6, located at the Matador Uplift, terminates in lower Wolfcampian sediments.

A further comparison of the structure of the Devonian Woodford Formation to the structure of the younger Upper Guadalupe Whitehorse Group (Permian) (Figures 6.4-7 and 6.4-8) indicates that the faults in the Devonian section do not continue upward into the overlying Permian Guadalupe Whitehorse Group. The regional geologic and tectonic information does not indicate the presence of significant post-Permian faulting within the regional study area, although minor post-Permian faulting in the WCS area is discussed below. In addition, the local information does not indicate Holocene displacement of faults within 3000 feet of the proposed WCS landfill site. The site-specific structural setting is discussed below.

Two regional stratigraphic cross sections constructed in the vicinity of the WCS site using oil and gas well logs are shown as Plates 6.2-2 and 6.2-3. The locations of the cross sections are shown in Figure 6.2-1. These cross sections depict the major stratigraphic units that occur within about 2000 feet below ground surface in the vicinity of the site. The stratigraphic units depicted on Plates 6.2-2 and 6.2-3 include the upper OAG unit of a few tens of feet in thickness, the underlying Triassic red beds of the Dockum Group with a thickness of 1,000 to 1,500 feet, the underlying Permian Dewey Lake Formation red beds, and the Permian evaporites of the Rustler and Salado Formations. These cross sections do not indicate the presence of significant faulting in the upper 2,000 feet of sediments within 3 to 4 miles of the WCS site. The base of the underground source of drinking water (USDW) is the bottom of the Santa Rosa Formation at about 1,400 feet below ground surface in the vicinity of the WCS facility. The Santa Rosa Formation is the lowermost formation of the Triassic Dockum Group.

4.1.1.3 *Post-Permian/Pre-Cretaceous Fault Investigation*

Faulting in a sandstone in the upper portion of the Triassic red beds of the RCRA landfill was anecdotally identified at a WCS project meeting February 11, 2004. Subsequently, photos taken in 1996 of an apparent southward-dipping reverse fault were located (Figure 6.4-9). Since regulatory criteria address the age of faults and the age of any geologic units affected or displaced by faulting, a geologic investigation of the fault was undertaken. The southeast wall of the RCRA landfill was extended about 200 feet to the southeast in May and June 2004, yielding about 60 feet of vertical geologic exposure along a length of about 400 feet. Two benches with subvertical walls were exposed.

The upper wall was approximately 25 feet high, extending about 6 feet into the Triassic red beds of the Dockum Group. The upper wall exposed caprock caliche developed on Cretaceous Antlers Formation sand and gravel, underlain by non-calichified Antlers sands and gravels, in turn underlain by the red bed clays of the Triassic Dockum Group. The upper 3 to 4 feet of the red beds have been altered from red to gray. Along the relatively sharp contact between the altered gray clay and unaltered red clay were numerous small faults with offsets ranging from a few inches to a few feet.

The lower wall was excavated an additional 30 to 35 feet into the red beds exposing a 10- to 15-foot thick sandstone layer in the upper part of the wall. The sandstone exhibited two opposing reverse faults with offsets of about 20 feet on the southward-dipping southern fault and about 3 feet on the northward-dipping northern fault (Figure 6.4-10). The southern reverse fault in the Triassic sandstone bed is the southeastern extension of the southward-dipping reverse fault in the 1996 photographs.

Geologic mapping

Geologic mapping of the upper and lower walls was completed by two field mapping teams, supervised by a senior coordinating geologist. Elevation baselines were surveyed onto both the upper and lower walls, and the walls were subdivided into five-foot square townships and ranges. Detailed geologic mapping was conducted on parts of the upper and lower walls using moveable five-foot square grids, subdivided into 25 one-foot square sections. The mapping focused on geologic contacts and distinguishable geologic features, including faults, joints, slickensides, bedding planes, partings, channels, alteration and weathering zones. The mapped geologic sections are provided in Figure 6.4-11.

The upper wall was mapped in considerably more detail than the lower wall in order to determine the youngest geologic units affected by faulting. The southern end of the upper wall, where the largest faults and offsets were observed, was mapped in the greatest detail. Parts of the upper wall were mapped by field sketching and photographic interpretation. The two faults in the lower wall were mapped in detail using the 5-foot grids, while the remainder of the lower wall was documented using photo mosaics.

Observations - Lower wall

The geologic materials exposed on the lower wall are part of the Triassic Dockum Group, specifically the Cooper Canyon Formation (Lehman, 1994b). The red beds are characteristically red and purple claystones, with interbedded discontinuous siltstone and sandstone units. As indicated above, a fine grained sandstone layer about 10 to 15 feet thick occurred in the upper third of the lower wall. The claystones were relatively plastic on excavation, drying within a week to a stiff, blocky structure.

The red beds exhibited nominally orthogonal, subvertical jointing with well-developed joints at about 0.5 to 1 foot spacing. Lower hemisphere stereonet projections of the poles to the subvertical joints show a maximum concentration at about 320° (north 40° west) with a secondary concentration at about 40° (north 40° east) (Figure 6.4-12). The subvertical joints are an expression of the orthogonal regional jointing system.

The concentration of subvertical joint directions at about 320° is partially due to bias induced by the orientation of the northeast-striking wall. If a similar length northwest-striking wall were available for measurement of subvertical joints, it is likely that the secondary concentration at about 40° would be more pronounced and the orthogonal pattern of the regional jointing system would be more obvious on the stereonet plot. There was only about 50 feet of northwest-striking wall exposed beneath the sandstone at the north end of the excavation, yielding a limited opportunity to eliminate the bias of the longer northeast-striking exposure of about 400 feet. The subvertical joints were often coated or partially coated with dark brown to purplish-black weathering products, likely manganese oxide. Slickensides on the subvertical joints were not observed.

Relatively large, continuous and 'wavy' lower-angle joints at about 30° to 60° from horizontal were also present, without an apparent well-developed spacing or repetition, as in the subvertical joints. The lower angle joints exhibited continuity over 10 to 15 feet of exposure on the lower wall, and slickensides were numerous and well developed on the wavy joints. The strike of the irregular, wavy joint planes show a maximum at about 300° (Figure 6.4-13), however the strikes of the irregular joint planes appear to be quite well distributed about the stereonet.

The sandstone exposed in the upper third of the lower wall was 10 to 15 feet in thickness. The sandstone exhibited two opposing reverse faults about 200 feet apart with apparent dips of the order of 30° to 40°. The southern reverse fault is the southeastern extension of the southward-dipping reverse fault in the 1996 photographs. The reverse fault in the southern end of the wall was south-dipping with a south-hanging-wall-up offset of about 20 feet. The reverse fault in the northern part of the wall was north-dipping with a north-hanging-wall-up offset of about 3 feet. The poles of the measured fault planes show a strike of the fault planes of about 277° to 280° (north 83° west to north 80° west) (Figure 6.4-14). Slickensides were measured on both the south and north fault planes, indicating dip slip with a compressional stress azimuth of about 15°

(north 15° east) (Figure 6.4-15). The sandstone was lower in the section on the northern third of the wall. The change in altitude may be related to possible fold development in the red beds in the vicinity of the reverse faults, or it may be depositionally-related in that the poorly developed bedding appeared to remain subhorizontal for much of the exposure.

Observations - Upper Wall

The geologic materials exposed on the upper wall include the upper 3 to 10 feet of Triassic red beds, overlain by Cretaceous Antlers Formation sands and gravels. The upper 10 to 15 feet of the Antlers Formation has been highly calichified and has developed into the characteristic caprock caliche of the Southern High Plains. The joint system in the red beds in the upper wall provided fewer subvertical joints to measure due to the limited exposure of only the upper few feet of the red beds over most of the upper wall. Of the comparatively limited number of measured subvertical joints, the strike maximum occurred at about 290° to 295° (Figure 6.4-16). The upper wall irregular, lower-angle, wavy joints with well-developed slickensides plotted similar to the lower wall irregular, low-angle, wavy joints, with a strike maximum at about 330° but also with a well distributed pole pattern throughout the stereonet (Figure 6.4-17).

There are numerous fault planes in the red beds on the upper wall. The faults in the red beds on the upper wall are very apparent, since the offsets occurred after the development of a grayish-colored altered layer approximately 3 to 4 feet thick at the top of the red beds. The sharp lower contact of the altered layer shows the offsets very well.

The faults in the red bed on the upper wall are virtually all reverse faults, with both south and north apparent dips on the fault planes. The offsets on the reverse faults range from inches to as much as several feet. The largest fault in the red beds on the upper wall, with an offset of about 4 feet, is in the southern third of the exposed wall. This fault is an upward continuation of the southern hanging-wall-up reverse fault in the sandstone on the lower wall, which shows an offset of about 20 feet. The fault appears to die out quickly in the vertical direction. The stress which caused the brittle failure and 20 feet of offset of the sandstone on the lower wall appears to be accommodated throughout the remainder of the red bed claystone/clay in the upper wall by a number of smaller faults and perhaps plastic deformation in the clays.

The faults in the red beds on the upper wall show a pattern of anastamozing slip surfaces, with many of the south- and north-dipping slip planes appearing to pair up and join into a primary slip plane with smaller dendritic slip surfaces splaying off the primary plane. The fault planes on the upper wall dip at about 30° to 40° to the northeast and southwest. Strikes of the fault planes on the upper wall show a maximum at about 284° (north 76° west) (Figure 6.4-18). Slickensides on the fault planes show dip-slip movement, with slickenside azimuths between about 340° and 30° (north 20° west and north 30° east) (Figure 6.4-19), consistent with the 15° apparent compressional stress azimuth of the faults on the lower wall.

During late Jurassic or early Cretaceous time, it appears that the upper part of the red beds was subjected to geochemically reducing conditions that altered the red bed clays from red to gray. The thickness of the altered layer is very uniform along the upper wall, which suggests that the alteration occurred while the top of the red beds were at some relatively uniform elevation, prior to faulting or folding. The reducing conditions and vertical downward advance of the alteration front suggest that the area may have been a submerged bog or shoreline with relatively stagnant, marshy conditions.

The alteration occurs to a very uniform depth marked by a sharp vertically delimited alteration front of about ¼ to ½ inch where the color of the red beds changes from gray to red. The sharp alteration front is most likely a diffusion front within the relatively impermeable clays. The uniform depth of penetration suggests matrix-dominated transport of a diffusion front, since the alteration front does not extend significantly further downward adjacent to the joints or fractures. The joints, though preferred fluid paths and perhaps marginally more transmissive than the unfractured matrix, apparently did not allow any significant additional downward penetration of alteration fluids. The joints were essentially non-transmissive to alteration fluids, likely due to the presence of swelling montmorillonite clays (Glass et al., 1973) and joint closure.

Liesegang banding between joints is very well developed within the altered layer. The liesegang banding parallels and mimics the joint surfaces in three dimensions. Alteration clearly occurred post-jointing, most likely as successive diffusion fronts moved inward from the joints from all directions under saturated conditions. The altered layer may have developed under successive, perhaps seasonal, wetting and drying conditions, with liesegang banding developing between joints as the joints swelled closed on passage of the wetting fronts.

At the top of the gray altered layer was a readily apparent parting that was present over approximately 80 to 90% of the exposed wall. The parting appears to be an erosional/depositional surface of either late Jurassic or early Cretaceous age based on the presence of some Cretaceous-aged gravels mixed into the upper portion of the zone above the parting. Above the parting are both reworked altered red beds (reworked and redeposited clays of the altered layer) as well as a second zone of alteration in the southern part of the wall where the reworked clays of the gray altered layer have apparently been further altered to a mixture of silt- to sand-sized crystalline carbonates and sulfates.

Above the reworked or reworked and altered clays are the Cretaceous-aged Antlers Formation sands and gravels. The lower part of the Antlers Formation contains numerous clasts and angular blocks of altered upper red beds or reworked altered red beds. The Antlers Formation exhibits a depositional pattern characteristic of braided streams, with a sequence of younger channels cross-cutting older channels and smaller channels a few tens of feet in width embedded within larger channel deposits. The Antlers Formation sands and gravels range from well-sorted fine to medium grained sands to poorly sorted sands and gravels with occasional cobble-sized particles. The lower few feet of the Antlers Formation is poorly to partially cemented sands and gravels apparently unaffected by the calichification process which is readily apparent in the upper parts of the section. Some of the finer sands higher in the section exposed on the upper wall appear well cemented, although the cementing may be due in part to the development of the caprock caliche.

The relationship between faulting in the Triassic red beds and the overlying Cretaceous Antlers Formation was carefully evaluated to determine if any displacement of the younger Cretaceous deposits had occurred. The Triassic red beds are separated from the overlying Cretaceous Antlers Formation sands and gravels by the distinct and mappable parting at the top of the gray altered layer of red beds. None of the observed fault planes or slip surfaces in the Triassic red beds in the extensively mapped section cross or offset the parting. In addition, the bedding in the Antlers Formation is continuous where observable and not calichified, and in particular, there are no Triassic/Cretaceous contact offsets or bedding offsets in the Cretaceous Antlers Formation above the area in the Triassic red beds where the largest displacements occur nor is there any apparent folding of the Antlers Formation in this area. Therefore, there are no indications that the Cretaceous-aged Antlers Formation was affected by the faulting in the Triassic red beds. There are clearly no geologic Formations present in the excavation younger than Triassic that are affected by faulting and there are no regulatory issues related to faulting at the WCS site. Additionally, there are no issues with respect to potential migration pathways resulting from the faulting at the WCS site. The uppermost faulting occurred completely within the Triassic red beds; which have great capacity for healing and closing fault planes and joints to fluid migration as indicated by the limited penetration of the alteration front in the red beds.

4.1.1.4 *Red Bed Ridge Development*

Faulting of any significance in the vicinity of the WCS site or the Central Basin Platform is generally considered to be Permian or earlier (Nicholson and Clebsch, 1961). Galley (1958, p.439-441) indicates that although "events associated with Laramide and several Tertiary orogenies have broken, destroyed, submerged, or obscured various segments of Paleozoic structures at the southwest edge of the Permian Basin", "Elsewhere the Paleozoic strata lie at almost the same attitudes they had attained at the end of Ochoa time, having been affected subsequently only by regional tilting and local folding or faulting of small vertical displacement." These statements indicate that the Central Basin Platform area has not been significantly disturbed by tectonic events since late Permian (Ochoa) time.

The post-Permian/pre-Cretaceous tilting, folding and faulting discussed in the previous section may have contributed to the development of the red bed ridge by creating a relatively local topographic high uplifted by the minor compressional faulting/folding of the red beds. The local geology discussed in Section 5.3 indicates that the first continuous red bed sandstone, which occurs at an approximate depth of about 225 feet below ground surface, has a south/southwestward dip of about 80 feet per mile. The south/southwestward dipping bedding may represent the southwestern limb of an anticline or monocline with the red bed ridge as the fold axis. The red bed ridge area may have been an inter-drainage topographic high since the compressional event.

The Cretaceous seas began to retreat at the start of the Laramide Orogeny which uplifted the area. From late Paleocene to the end of the Pliocene the area was subjected to erosion, removing most of the Cretaceous deposits. Late Tertiary Ogallala and Gatuna Formations were deposited in stream channels between inter-drainage highs. Apparently neither the Ogallala nor the Gatuna Formations were deposited over the ridge in the WCS vicinity, suggesting that relatively resistant Cretaceous limestones over the Antlers Formation may have effectively capped the red bed ridge, maintaining the ridge as a mesa or inter-drainage high. The red bed ridge remains a local topographic high today, between Monument Draw Texas which drains to the Colorado River, and Monument Draw New Mexico which drains to the Pecos River.

4.1.2 Seismicity

The WCS facility lies in a region with crustal properties that indicate minimum risk due to faulting and seismicity. Crustal thickness is the most reliable predictor of seismic activity and faulting in intracratonic regions (EPRI, 1993). Crustal thickness in the vicinity of the WCS facility is approximately 30 miles (50 km), one of the three thickest crustal regions in North America (Mooney and Braile, 1989). In comparison, the crustal thickness of the Rio Grand Rift is as little as 7.5 miles (12 km) in places. Further, the seismic velocity of the crust in the Southern Great Plains implies that the crust is unusually intact and continuous in this region (EPRI, 1989).

The Central Basin Platform is an area of moderate, low intensity seismic activity based on data obtained from the National Geophysical Data Center of the National Oceanic and Atmospheric Administration (NOAA, 1992 as reported in Terra Dynamics, 1993) and the U.S. Geological Survey (USGS) Earthquake Data Base available from the National Earthquake Information Center (http://neic.usgs.gov/). Table 6.4-1 provides the historical seismic activity within 250 kilometers of the WCS facility (32.433°N, 103.05°W). Table 6.4-1 includes the data through 1992 from the NOAA data base, which was submitted in the original RCRA permit application, updated with information through 2003 from the national seismic data base operated by the USGS. The computer search for all recorded seismic activity within a 250 km (155 mile) radius of the proposed WCS landfill site provided a list of 188 seismic events (188 total with 68 suspected duplicates by Terra Dynamics (1993)) during the period from 1931 to 2003. Seismic activity for New Mexico and bordering areas, which includes Andrews County, is shown on

Figure 6.4-20. With respect to seismicity in the WCS area, Sanford et al. (2002) indicate that a large fraction of activity in southeastern New Mexico and adjacent areas of west Texas is induced by oil and gas production, secondary recovery, or waste injection.

Figure 6.4-21 illustrates the largest earthquakes (moment magnitudes >3) from the same data set used to develop Figure 6.4-20. The largest earthquake in the vicinity of the WCS facility, referred to as the Rattlesnake Canyon earthquake with a magnitude of 5, occurred in 1992. The Rattlesnake Canyon earthquake was located by the seismograph stations monitored by the New Mexico Institute of Mining and Technology at latitude 32°17.80N and longitude 103°10.33W (Sanford et al., 1993), which is approximately 11 miles southwest of the facility. The USGS located the Rattlesnake Canyon earthquake at latitude 32°20.16N and longitude 103°06.06W, about 7 miles southwest of the WCS facility; however, Sanford et al. (1993) indicate that due to the uncertainty in the location reported by the USGS, the location reported by Sanford et al. (1993) is more accurate. The location of the Rattlesnake Canyon earthquake was approximately three miles east of the Paleozoic west platform fault (Figure 6.4-4). The Rattlesnake Canyon earthquake was interpreted by Sanford et al. (1993) as a reverse fault, with movement consistent with the approximately east–west maximum horizontal stress orientation reported by Zoback and Zoback (1991) and Zoback et al. (1991).

The seismic hazard at a particular geographic position is due to ground motion or shaking. Seismic hazard is based on historical seismic activity and frequently presented as Peak Ground Acceleration (PGA) maps. The maps present the probability of the PGA due to earthquakes exceeding a particular value of acceleration (expressed as a fraction or percent of gravitational acceleration) over a particular time period. A PGA of greater than about 0.2 g is considered the acceleration level at which considerable damage can begin to occur to weakly built structures (Sanford et al., 2002). Figure 6.4-22 is a seismic hazard map of the western United States prepared by the USGS (http://geohazards.cr.usgs.gov/eq/, October 2002 revision). The map indicates that at the 90% probability level over a 50-year time period, the PGA of the southeastern New Mexico/Andrews County area would not exceed approximately 0.03 to 0.04 g (site specific search yields 0.0322 g). Figure 6.4-23 is a similar seismic hazard map of the western United States, which indicates that at the 98% probability level over a 50-year time period, the PGA of the southeastern New Mexico/Andrews County area would not exceed approximately 0.14 to 0.16 g (site specific search yields 0.1535 g). Golder Associates (1998) calculated the PGA at the WCS site for the Rattlesnake Canyon earthquake in the range of 0.06 to 0.07 g, which is well below the PGA of 0.2 g where considerable damage can begin to occur to weakly built structures (Sanford et al., 2002). Golder Associates (1998) indicate that these low estimated accelerations are "generally considered to be insignificant to well designed and constructed engineered structures or facilities."

4.1.3 Lineaments

Lineaments are relatively straight physiographic features typically identified by a review of surficial geologic maps, surface topography maps, LANDSAT images, and aerial photographs, including high altitude aerial photographs. Based on Landsat imagery, Finley and Gustavson (1981) identified more than 4600 lineaments throughout the Texas Panhandle, ranging in length from 1.2 miles up to 25 miles (Figure 6.4-24). Finley and Gustavson (1981) noted that the Landsat-identified lineaments fell into six categories: 1) stream segments, or short stream reaches commonly connecting at sharp angular junctions, 2) drainage lines, or linear valley trends independent of the orientation of stream segments within the trend, 3) scarps, or prominent topographic breaks, 4) playa alignments, 5) geologic contacts, or contacts between surficial materials with different reflectivities, and 6) tonal anomalies, or linear features that are not clearly a member of any of the previous categories and may be composites of previous categories.

Finley and Gustavson (1981) conclude that the development of physiographically-expressed lineaments is controlled or at least influenced by geologic structure. They further interpret that since few surface faults are mapped in the study area (91,500 square miles of the Texas Panhandle, including the Southern High Plains and most of Andrews County), joints rather than widespread faults are the likely geologic structural control on lineament development. Joints are fractures or partings in rocks along which movement has been negligible or absent (Dennis, 1972). The development of joints is an indication of the brittle behavior of rock, and is most evident in the Triassic and Permian sandstones within the area of the Southern High Plains. The poorly consolidated sediments of the Ogallala Formation do not exhibit well-developed jointing patterns. The Caprock caliche often exhibits an irregular, nearly orthogonal jointing pattern (Finley and Gustavson, 1981).

Finley and Gustavson (1981) suggest that minor or poorly developed jointing in the Pleistocene and Holocene deposits overlying the Caprock caliche may have offered preferred infiltration focus that could foster playa development at the intersection of joint sets, and that an area of increased joint density may localize playa-lake depressions.

Several mechanisms can account for the relationship between physiographically-expressed surface lineaments and susbsurface jointing. Joints form preferential planes that can be exploited by surficial and subsurface weathering processes. Joints offer paths of weakness and less resistance to erosional processes, allowing the development of surface drainage systems and linear stream segments in preferred orientations. Consequently, drainage systems in the Southern High Plains are often classified as lineaments, since their linear orientation is controlled by the joint systems that they exploit (Finley and Gustavson, 1981). Joints can be propagated upward into geologically younger sediments by many processes, including residual tectonic stresses (Price, 1966), crustal extension due to post-glacial rebound (Grisak and Cherry, 1975), shrinkage and differential compaction related to wetting and drying of clay-rich sediments, and differential compaction and dissolution of underlying materials (Finley and Gustavson, 1981). In the Southern High Plains, the orientation of joints and their associated surface lineations is controlled primarily by historical tectonic and structural trends (Finley and Gustavson, 1981). As shown in Figure 6.4-24, the dominant orientation for surface lineations in the Southern High Plains is northwest to southeast, with a secondary orientation of northeast to southwest.

At the regional scale mapped by Finley and Gustavson (1981), Figure 6.4-24 shows a multicomponent northwest-southeast lineament approximately 3 to 4 miles in total length about 10 miles north of the WCS facility in Gaines County. The lineament is located in the approximate vicinity of Monument Draw, Texas (note: there are two Monument Draws in the WCS vicinity: one in Texas which starts between Hobbs and Eunice in New Mexico and heads eastward as a tributary to Mustang Creek in Texas; and one which starts west of Monument, New Mexico, continuing southeasterly and turning south around Eunice about 5 miles west of the Texas/New Mexico border). A second lineament at the regional scale identified by Finley and Gustavson (1981) lies in Andrews County, about 14 miles east of the WCS facility. This lineament appears to be the continuation of Monument Draw, Texas. The lineament map of Finley and Gustavson does not indicate the presence of Landsat-identified lineaments at the WCS facility.

Also at the regional scale, Bolden (1984) suggests that there are several regional-scale lineaments 200 to 330 miles in length in Trans-Pecos Texas and the Texas Panhandle oriented between 298° and 306°. The nearest of these to the WCS facility is a shorter offshoot line oriented approximately 345°, extending through Ward and Winkler counties in Texas into Lea County in New Mexico. The offshoot line appears to be defined by Monument Draw, New Mexico and its southern extension to the Pecos River through Winkler and Ward Counties, Texas.

At the local scale, lineaments were identified by Terra Dynamics in the vicinity of the WCS site based on an analysis of NASA color-infrared aerial photographs (Terra Dynamics, 1993). Terra Dynamics indicated the lineaments were related to linear drainage features and ground surface color tone anomalies. The lineaments were shown as straight lines on the color infrared imagery used by Terra Dynamics (Terra Dynamics, 1993, Figure VI.A.12). Terra Dynamics identified 5 northwest trending lineaments. The southernmost of these lineaments extended through the WCS facility. Terra Dynamics also identified two north trending lineaments between the WCS site and Eunice. The lineament through the WCS site was described as an anomaly in the ground surface color tone on the color-infrared

Figure 6.4-25 is a 1983 color infrared photograph of the WCS area from the National High Altitude Program (note: the 1982 photograph included in the Terra Dynamics Geology report is not available from the EROS data center) and Figure 6.4-26 is a 1986 color infrared photograph of the same area at a slightly different scale. Four of the five northwest and north trending lineaments near the WCS site identified by Terra Dynamics are shown on Figure 6.4-26. The northernmost northwest-trending lineament identified by Terra Dynamics is off the photograph approximately 8 miles to the north of the WCS site.

Golder Associates also conducted an analysis of the lineaments in the vicinity of the WCS facility and provided a summary of their evaluation in a draft document to WCS dated January 4, 1999. Lineaments identified by Terra Dynamics and Golder Associates are discussed below.

The southernmost northwest-trending lineament through the WCS facility, identified by Terra Dynamics, is represented by aligned zones of enhanced vegetation, shallow depressions and darker ground tones trending about 300° to 310°. The aligned depressions are most evident where the Caprock caliche is at or very near the surface. The tonal contrast in the center of the photo is where the Caprock caliche is either at ground surface or covered by only a thin veneer of windblown sand. The largest of the depressions, which may be considered a small playa about 15 acres in size, is located about one-half mile northeast of the existing landfill. The alignment of the playas at the WCS site likely results from their development at the intersection of joints, with the primary jointing direction trending 300° to 310°.

Part of the surface expression of the 300° to 310° lineament is a bench in the topography between Windmill Hill and the existing landfill. The bench alignment is coincident with the regional 300° to 320° alignment of lineaments in the Southern High Plains (Finley and Gustavson, 1981) that likely represents one of the primary jointing directions in the Southern High Plains. The bench overlies and is aligned with the red bed ridge and is topographically expressed for about 6000 feet with a relief of about 20 feet. The bench is on the southwest slope of the drainage divide between the Pecos River and the Colorado River. The bench has developed as an erosional feature along the preferred jointing direction in the Southern High Plains. The bench projects to Baker Spring, to a notch in the topography about one-half mile northwest of Baker Spring, and parallels Mescalero Ridge, part of the Caprock escarpment about 15 miles northwest of the WCS site.

Two smaller lineaments oriented about 45° were identified by Golder Associates to the west and east of the permitted area. The westernmost 45° lineament, which is about 4000 feet in length, is a surface draw that empties into a depression at Baker Spring, New Mexico. The 45° lineament east of the permitted area is less developed. It extends through the ranch house area for a total length of about 4,500 to 5,000 feet, developing into a shallow draw southwest of the ranch house area. The north-trending lineaments identified by Terra Dynamics about 3 miles west of the WCS site in Lea County, New Mexico, may be related to tonal contrasts in the vicinity of Monument Draw, New Mexico.

The lineaments in the vicinity of the WCS facility do not have any geologic or geomorphic characteristics typical of active faults. There are no topographic shifts along the lineament, or any apparent offsets in local drainage, or any interruptions in the gradient of erosional terraces above Baker Spring (assuming Baker Spring comprises part of the lineament). The lineament in the vicinity of the WCS facility is considered to be an erosional feature.

4.2 LAND SURFACE SUBSIDENCE

This section addresses the potential for land surface subsidence due to ongoing geologic processes and human activities in the vicinity of the WCS facility. Subsidence can be defined as the sudden sinking or gradual downward settling of the earth's surface with little or no horizontal movement. Subsidence may be caused by natural geologic processes such as solution or compaction or by human activities such as subsurface mining or pumping of oil or groundwater.

4.2.1 Land Surface Subsidence due to Geologic Processes

No subsidence features related to geologic processes have been identified within the permitted area or the immediate vicinity of the site. The nearest active subsidence features to the WCS facility are the San Simon Swale, the San Simon Sink, the Wink Sinks, and a sink northwest of Jal, New Mexico (Figure 6.4-27). The San Simon Swale and the San Simon Sink are located approximately 20 miles west-southwest of the WCS facility in Lea County, New Mexico. The San Simon Swale is a large (100 mi^2), northwest- to southeast-trending, elongate depression that overlies and is parallel to the inner margin of the Permian Capitan Reef (Figure 6.4-27). The San Simon Sink is located within the southern end of the San Simon Swale and covers an area of 0.5 mi^2. The sink is approximately 130 feet deep and is filled with 400 feet of alluvium deposited on top of Triassic red beds (Baumgardner et al., 1982). Subsidence was last recorded at the San Simon Sink approximately 50 years ago.

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TABLE 6.4-1
HISTORICAL SEISMIC ACTIVITY WITHIN 25 km (155 MILE) RADIUS
OF PROPOSED LANDFILL SITE (32.433N, 103.05W)

DATE	LOCATION		DISTANCE	DISTANCE	INTENSITY	MOMENT
	LATITUDE (N)	LONGITUDE (W)	(MILES)	(KM)		MAGNITUDE
08/16/31	30.6	104.1	140	225	VIII	
08/16/31	30.6	104.1	140	225		
08/16/31	30.6	104.1	140	225		
08/16/31	30.6	104.1	140	225		
08/16/31	30.6	104.1	140	225		
08/16/31	30.6	104.2	143	230	VIII	
08/16/31	30.7	104.6	150	241		
08/16/31	30.7	104.6	150	241		
08/18/31	30.6	104.1	140	225		
08/18/31	30.7	104.6	150	241	V	
08/18/31	30.7	104.6	150	241		
08/19/31	30.6	104.1	140	225	V	
08/19/31	30.6	104.1	140	225	VI	
08/19/31	30.7	104.6	150	241	III	
08/26/31	30.6	104.1	140	225	III	
08/26/31	30.7	104.6	150	241	III	
11/03/31	30.7	104.6	150	241	III	
12/20/35	34.4	103.2	136	219	V	
01/08/36	32.4	104.2	67	108	II	
01/08/36	32.4	104.2	67	108	II	
02/02/49	32.4	104.2	67	108	IV	
02/02/49	32.4	104.2	67	108		
05/22/52	33	105	120	193	IV	
01/27/55	30.6	104.5	152	245	IV	
01/27/55	30.6	104.5	152	245	IV	
01/27/55	30.6	104.5	152	245	IV	
12/10/61	32.24	103.86	49	79		
12/10/61	32.26	103.86	48	77		
12/10/61	32.263	103.865	48	77		
03/06/62	31.08	104.55	128	206		
02/11/64	34.35	103.73	138	222		
11/08/64	31.9	103	37	60		
11/08/64	31.93	102.98	35	56		
11/21/64	31.9	103	37	60		
11/21/64	31.92	102.98	35	56		
02/03/65	31.9	103	37	60		
02/03/65	31.92	102.96	35	56		
08/30/65	31.92	102.98	35	56		
08/30/65	32	102.3	53	85	IV	
08/30/65	32.08	102.42	44	71	IV	
08/30/65	32.1	102.3	49	79	IV	
08/30/65	32.1	102.3	49	79		
08/14/66	31.7	103.1	50	80	VI	
08/14/66	31.92	102.98	35	56		
08/14/66	32	102.6	40	64	VI	
08/14/66	32	102.6	40	64	VI	
08/14/66	32.12	102.34	47	76	VI	
05/02/68	33.02	105.27	135	217		

TABLE 6.4-1
HISTORICAL SEISMIC ACTIVITY WITHIN 25 km (155 MILE) RADIUS
OF PROPOSED LANDFILL SITE (32.433N, 103.05W)

DATE	LOCATION		DISTANCE	DISTANCE	INTENSITY	MOMENT MAGNITUDE
	LATITUDE (N)	LONGITUDE (W)	(MILES)	(KM)		
05/02/68	33.02	105.27	135	217		
07/30/71	31.64	103.17	55	89	III	
07/30/71	31.7	103	50	80	III	
07/30/71	31.7	103.1	50	80	III	
07/30/71	31.72	102.996	49	79		
07/30/71	31.74	103.09	48	77		
07/31/71	31.59	103.12	58	93		
07/31/71	31.65	103.12	54	87	IV	
07/31/71	31.7	103.1	50	80	IV	
07/31/71	31.7	103.1	50	80	IV	
07/31/71	31.703	103.061	50	80		
09/24/71	31.6	103.2	58	93		
09/24/71	31.63	103.18	56	90		
07/26/72	32.68	103.98	56	90		
07/26/72	32.68	103.98	56	90		
10/02/74	31.98	100.71	140	225		
11/12/74	32.06	100.98	123	198		
11/28/74	32.3	104.1	61	98	IV	
11/28/74	32.31	104.14	63	102		4
11/28/74	32.31	104.14	64	103		
11/28/74	32.311	104.143	64	103		
11/28/74	32.63	104.01	57	92		
11/28/74	33.765	104.99	144	232		
12/30/74	30.92	103.11	104	167		
12/30/74	30.92	103.11	104	167		
08/01/75	30.57	104.49	154	248	II	
08/01/75	30.65	104.57	152	245		
08/01/75	31.42	104.01	89	144		5
08/01/75	31.425	104.012	89	143		
01/19/76	30.9	103.1	37	60		
01/19/76	31.9	103.077	37	60		
01/19/76	31.9	103.08	37	60		4
01/19/76	31.9	103.09	37	60	IV	
01/22/76	31.9	103.07	37	60	III	
01/22/76	31.9	103.07	37	60		3
01/22/76	31.9	103.07	37	60		
01/22/76	31.9	103.071	37	60		
01/25/76	31.9	103.08	37	59		4
01/25/76	31.9	103.09	37	60	V	
01/25/76	31.902	103.08	37	60	V	
01/25/76	31.93	103.09	35	56		
04/03/76	31.3	103.17	78	126		
04/21/76	32.21	103.1	16	26		
04/21/76	32.21	103.1	16	26		
05/01/76	32.27	103.14	12	19		
05/01/76	32.4	103.1	3	5		
08/05/76	31.57	103.02	60	97		
08/05/76	31.57	103.02	60	97		

TABLE 6.4-1
HISTORICAL SEISMIC ACTIVITY WITHIN 25 km (155 MILE) RADIUS
OF PROPOSED LANDFILL SITE (32.433N, 103.05W)

DATE	LOCATION		DISTANCE	DISTANCE	INTENSITY	MOMENT MAGNITUDE
	LATITUDE (N)	LONGITUDE (W)	(MILES)	(KM)		
09/17/76	31.4	102.5	78	126		
09/17/76	32.21	103.1	16	26		
09/17/76	32.21	103.1	16	26		
09/19/76	30.69	104.43	144	232		
12/19/76	32.259	103.08	12	19		
12/19/76	32.26	103.08	12	19		
04/07/77	32.23	103.07	14	23	IV	
04/07/77	32.23	103.07	14	23		
04/26/77	31.9	103.08	37	59		3
04/26/77	31.9	103.08	37	60		
04/26/77	31.902	103.083	37	60		
04/26/77	32	103.1	30	48		
06/07/77	32.85	100.9	128	206		
06/07/77	32.858	100.77	135	217		
06/07/77	33.058	100.749	140	225		
06/07/77	33.06	100.75	141	227		4
06/07/77	33.13	100.94	131	211		
06/08/77	32.7	100.72	136	219		
06/08/77	32.8	100.9	127	204		
06/08/77	32.858	100.77	135	217		
06/08/77	32.89	100.95	126	203		
06/17/77	32.346	100.4	154	248		
06/17/77	32.35	100.4	154	248		
07/22/77	31.8	102.7	48	77		
11/27/77	32.862	100.68	140	225		
11/27/77	33.03	101.08	121	195		
11/28/77	32.95	100.84	134	216		4
11/28/77	32.954	100.837	133	214		
11/28/77	32.96	100.88	131	211		
11/28/77	33.022	100.84	134	216		
02/18/78	31.35	104.56	115	185		
03/02/78	31.52	102.41	73	117		
03/02/78	31.55	102.5	69	111	V	
03/02/78	31.56	102.51	68	110		4
03/02/78	31.562	102.512	68	109	III	
06/16/78	32.87	100.99	123	198		
06/16/78	32.961	100.79	136	219		
06/16/78	32.99	100.88	131	211		
06/16/78	33.03	100.766	138	222		
06/16/78	33.03	100.77	138	222	V	
06/16/78	33.03	100.77	139	224		5
06/16/78	33.067	101.19	116	187		
06/16/78	33.1	101.2	117	188		
06/29/78	31.05	101.94	115	185		
07/05/79	32.9	101.31	105	169		
07/05/79	32.949	100.895	130	209		
07/05/79	32.95	100.89	130	210		3
07/05/79	33	100.92	130	209		

TABLE 6.4-1
HISTORICAL SEISMIC ACTIVITY WITHIN 25 km (155 MILE) RADIUS
OF PROPOSED LANDFILL SITE (32.433N, 103.05W)

DATE	LOCATION		DISTANCE	DISTANCE	INTENSITY	MOMENT MAGNITUDE
	LATITUDE (N)	LONGITUDE (W)	(MILES)	(KM)		
08/03/79	32.85	100.94	125	201		
08/03/79	32.851	100.74	137	220		
05/08/81	32.212	101.51	91	146		
11/10/81	32	100.67	142	229	III	
01/04/82	31.18	102.49	93	149		4
01/04/82	31.18	102.49	92	148		
01/04/82	31.182	102.492	92	148		
04/26/82	33.02	100.84	135	217		3
04/26/82	33.02	100.84	134	216		
04/26/82	33.021	100.844	134	216		
11/09/82	31.99	100.7	142	228		3
11/28/82	33	100.8	136	219		
11/28/82	33	100.84	135	217		3
11/28/82	33.003	100.842	134	216	IV	
09/11/84	31.991	100.697	140	225		
09/11/84	32	100.7	140	225		
09/19/84	32.027	100.688	140	225		
09/19/84	32.027	100.688	140	225		
09/19/84	32.03	100.69	142	228		3
12/04/84	32.26	103.56	31	50		3
12/04/84	32.266	103.556	32	51		
12/04/84	32.266	103.556	32	51		
01/25/86	32.06	100.73	139	223		3
01/25/86	32.064	100.733	137	220		
01/30/86	32.066	100.693	140	225	IV	
01/30/86	32.07	100.69	140	226		3
01/02/92	32.33	103.1	7/11*	11/18		5
01/02/92	32.336	103.101	7/11*	11/18	V	
08/26/92	32.17	102.71	27	44		3
06/23/93	31.35	102.51	82	132		3
04/14/95	30.28	103.35	149	240		6
04/14/95	30.3	103.35	148	238		3
04/14/95	30.3	103.35	148	238		3
04/14/95	30.3	103.35	148	238		3
04/14/95	30.3	103.35	148	238		3
04/14/95	30.3	103.35	148	238		2
04/14/95	30.3	103.35	148	238		3
04/14/95	30.3	103.35	148	238		2
04/14/95	30.3	103.35	148	238		3
04/14/95	30.3	103.35	148	238		3
04/14/95	30.3	103.35	148	238		2
04/15/95	30.27	103.32	150	241		4
04/15/95	30.3	103.35	148	238		2
04/16/95	30.3	103.35	148	238		2
04/16/95	30.3	103.35	148	238		3
04/16/95	30.3	103.35	148	238		2
04/17/95	30.3	103.35	148	238		3
04/21/95	30.3	103.35	148	238		3

TABLE 6.4-1
HISTORICAL SEISMIC ACTIVITY WITHIN 25 km (155 MILE) RADIUS OF PROPOSED LANDFILL SITE (32.433N, 103.05W)

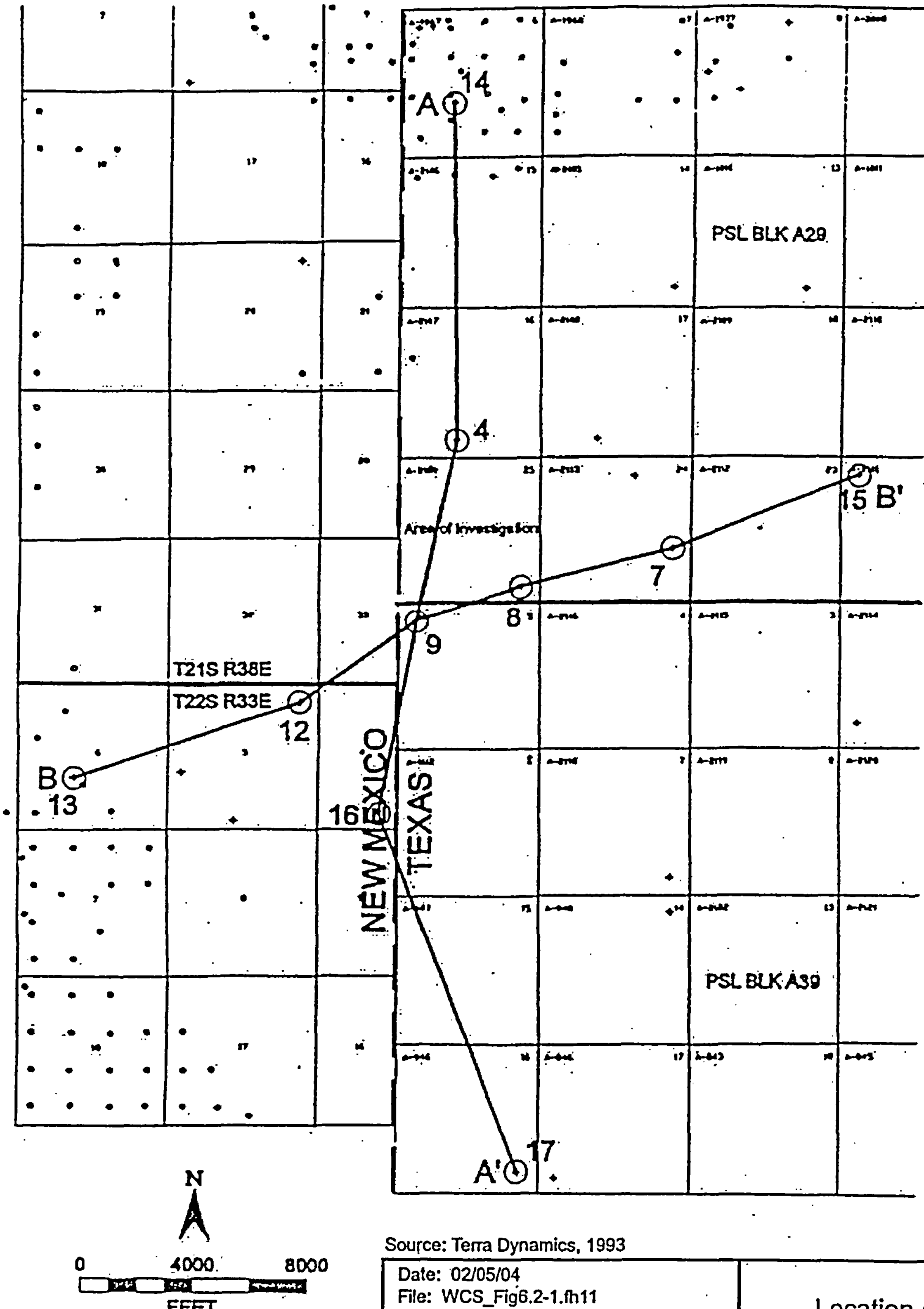
DATE	LOCATION		DISTANCE	DISTANCE	INTENSITY	MOMENT MAGNITUDE
	LATITUDE (N)	LONGITUDE (W)	(MILES)	(KM)		
06/01/95	30.3	103.35	148	238		4
07/06/95	30.3	103.35	148	238		3
07/06/95	30.3	103.35	148	238		3
11/12/95	30.3	103.35	148	238		4
04/15/98	30.19	103.3	Unknown	Unknown		4
03/01/99	32.57	104.66	93	150		3
03/14/99	32.59	104.63	92	148		4
03/17/99	32.58	104.67	94	151		4
05/30/99	32.58	104.66	94	151		4
08/09/99	32.57	104.59	89	144		3
02/02/00	32.58	104.63	91	147		3
02/26/00	30.24	103.61	155	249		3
06/02/01	32.33	103.14	9	14		3
11/22/01	31.79	102.63	52	83		3
09/17/02	32.58	104.63	92	148		4
09/17/02	32.58	104.63	92	148		3
06/21/03	32.67	104.5	85	137		4

Sources: National Oceanographic and Atmospheric Administration (1992)
United States Geological Survey (2004) http://neic.usgs.gov/

Definition of I Tremor not felt, or rarely felt only under especially favorable conditions
II Tremor felt indoors by few people; may cause slight movement of liquids and suspended or delicate objects
III Tremor felt indoors by several people; may cause swinging of suspended objects; movement may be appreciable on upper levels of tall buildings
IV Tremor felt indoors by many people; causing dishes and windows to rattle; noticeable movement of delicate objects
V Tremor felt by nearly all people; causes breakage of many delicate objects (dishes, glassware, etc); trees and bushes shaken slightly
VI Tremor felt by all people, both indoors and outdoors; causes considerable breakage of delicate objects, movement of furnishings, slight cracking of chimneys and plaster wall material.
VIII Fright, general alarm approaches panic; twisting fall of chimneys, columns, monuments and partial collapse of buildings, homes, etc.; moved, overturned very heavy furniture; sand and mud ejected in small amounts

Moment Magnitude: Moment Magnitude is the measure of total energy released by an earthquake, and is based on the area of the fault that ruptured in the earthquake.

* USGS location is at 7 miles: New Mexico Tech location is at 11 miles



Source: Terra Dynamics, 1993

Date: 02/05/04
File: WCS_Fig6.2-1.fh11

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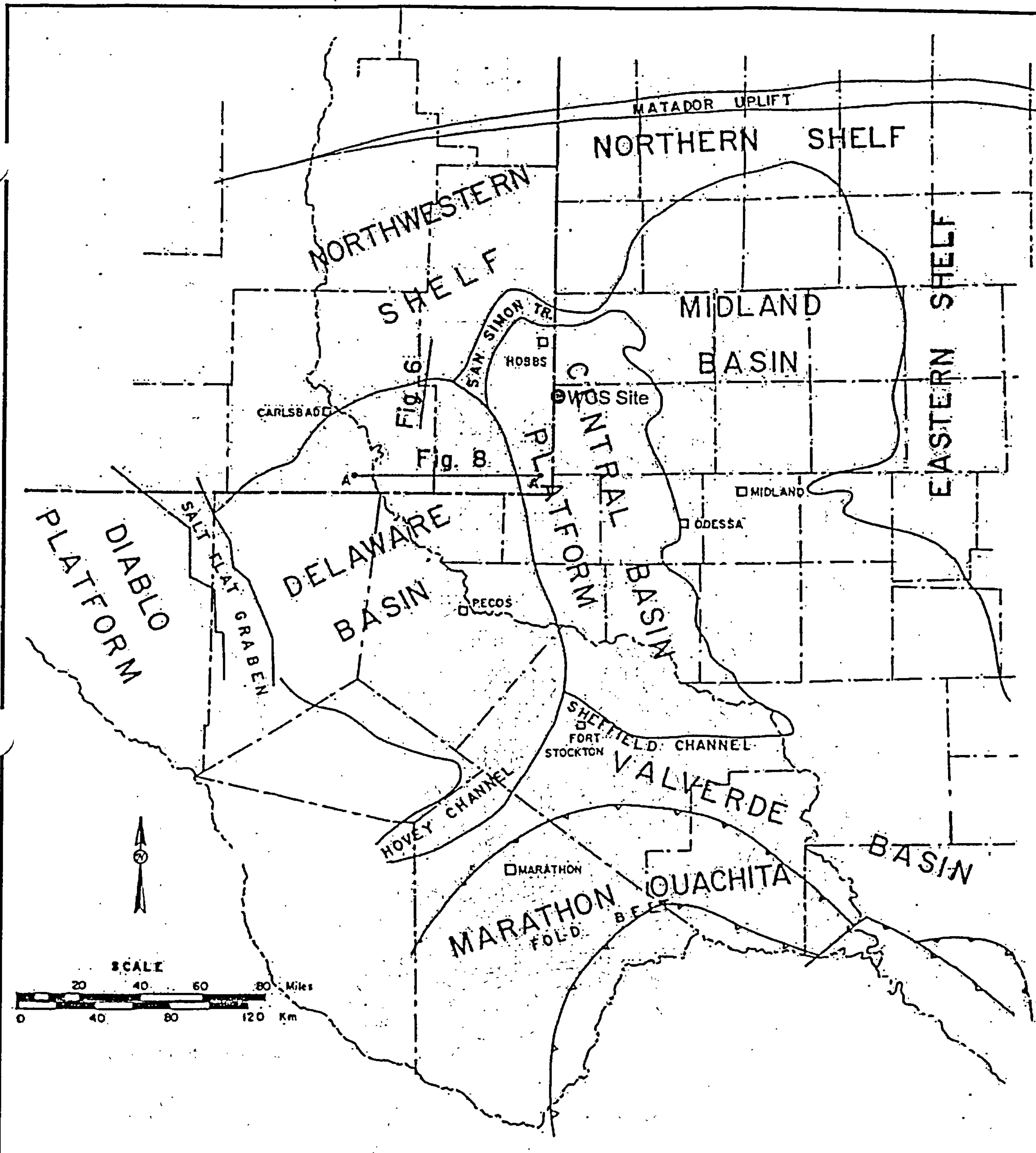
Location of Stratigraphic Cross Sections

Figure 6.2-1



Source: Hills, 1985

Date: 02/04/04 File: WCS_Fig6.4-1.fh11	Major Structural Provinces of West Texas and Southeastern New Mexico
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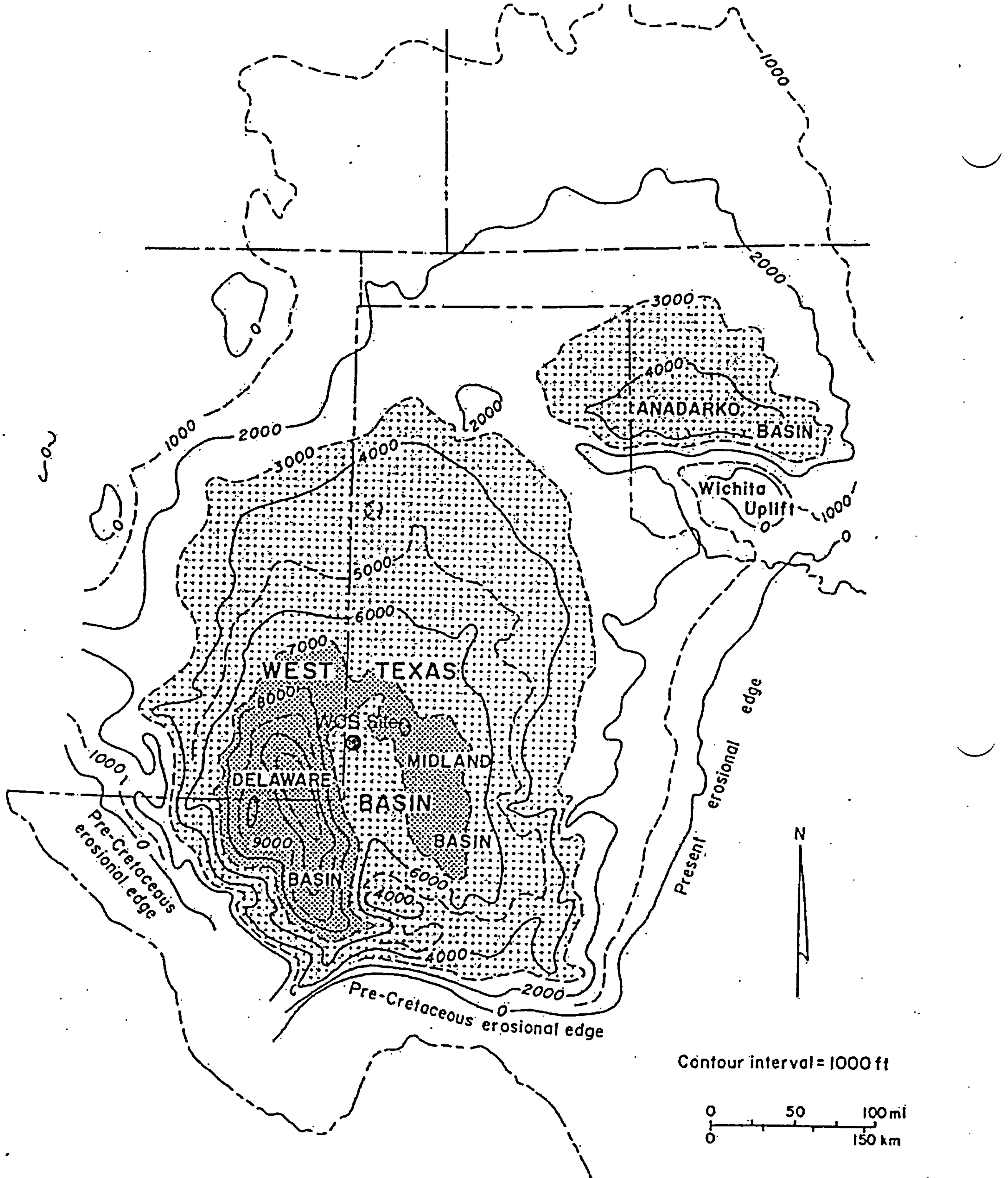

Source: Ewing, 1991

QA 15820

Date: 02/04/04
File: WCS_Fig6.4-2.fh11

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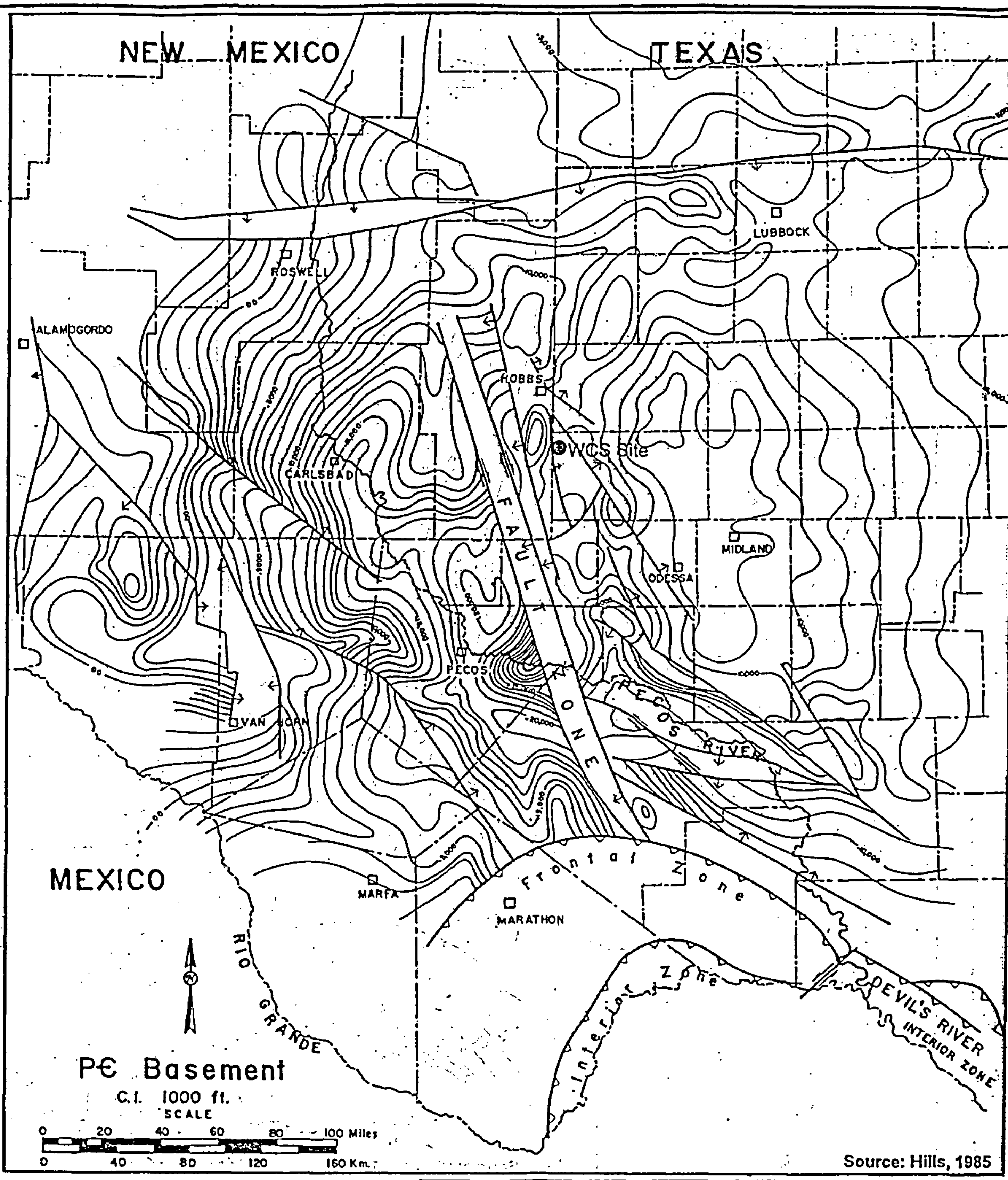
Isopach Map of post-Wolfcampian Permian Strata in the West Texas a Andarko Basins

Figure 6.4-2



Date: 02/04/04
File: WCS_Fig6.4-1.fh11

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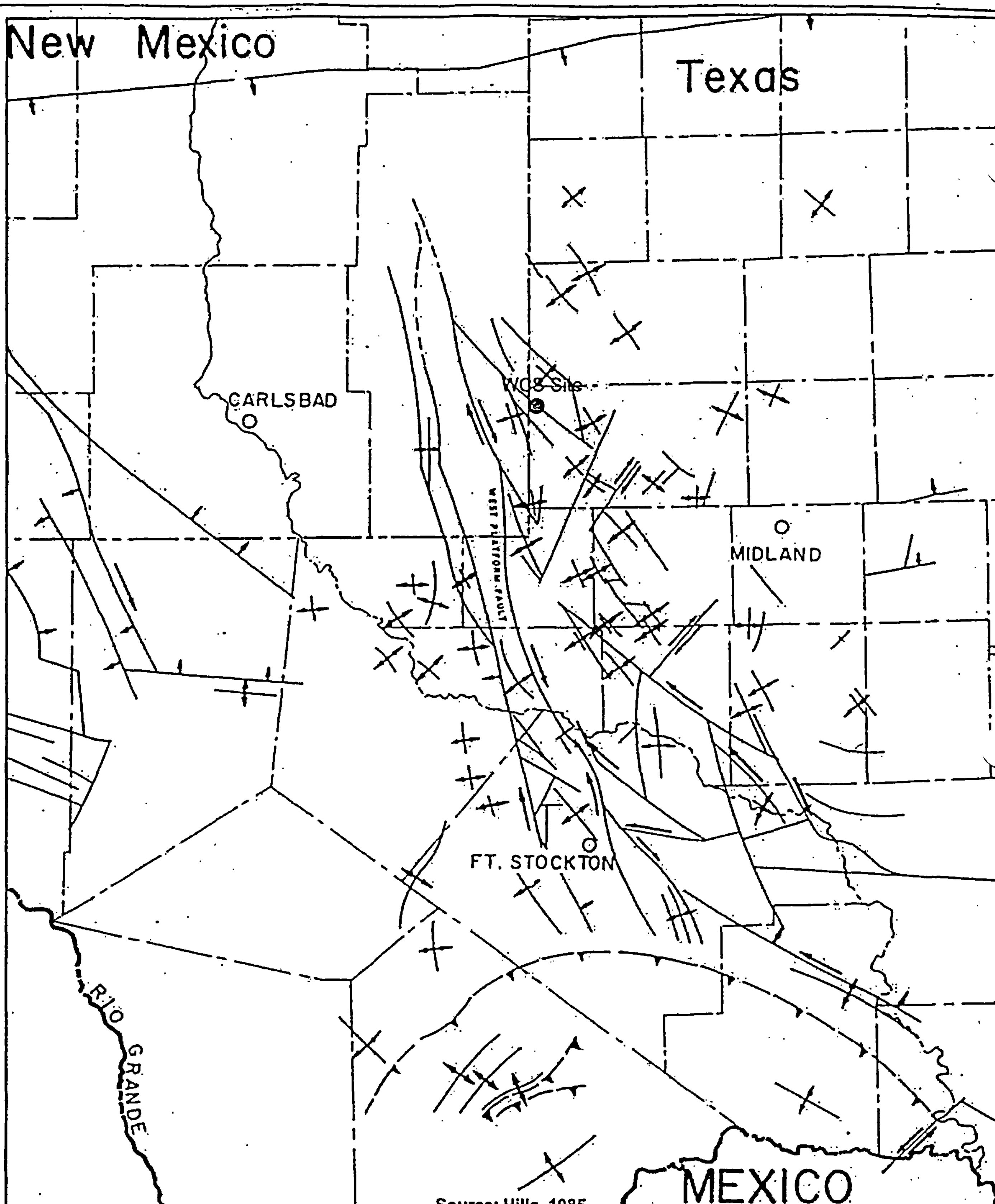
Regional Structure Contour Map of the Precambrian Basement

Figure 6.4-3



Date: 02/04/04
File: WCS_Fig6.4-4.fh11

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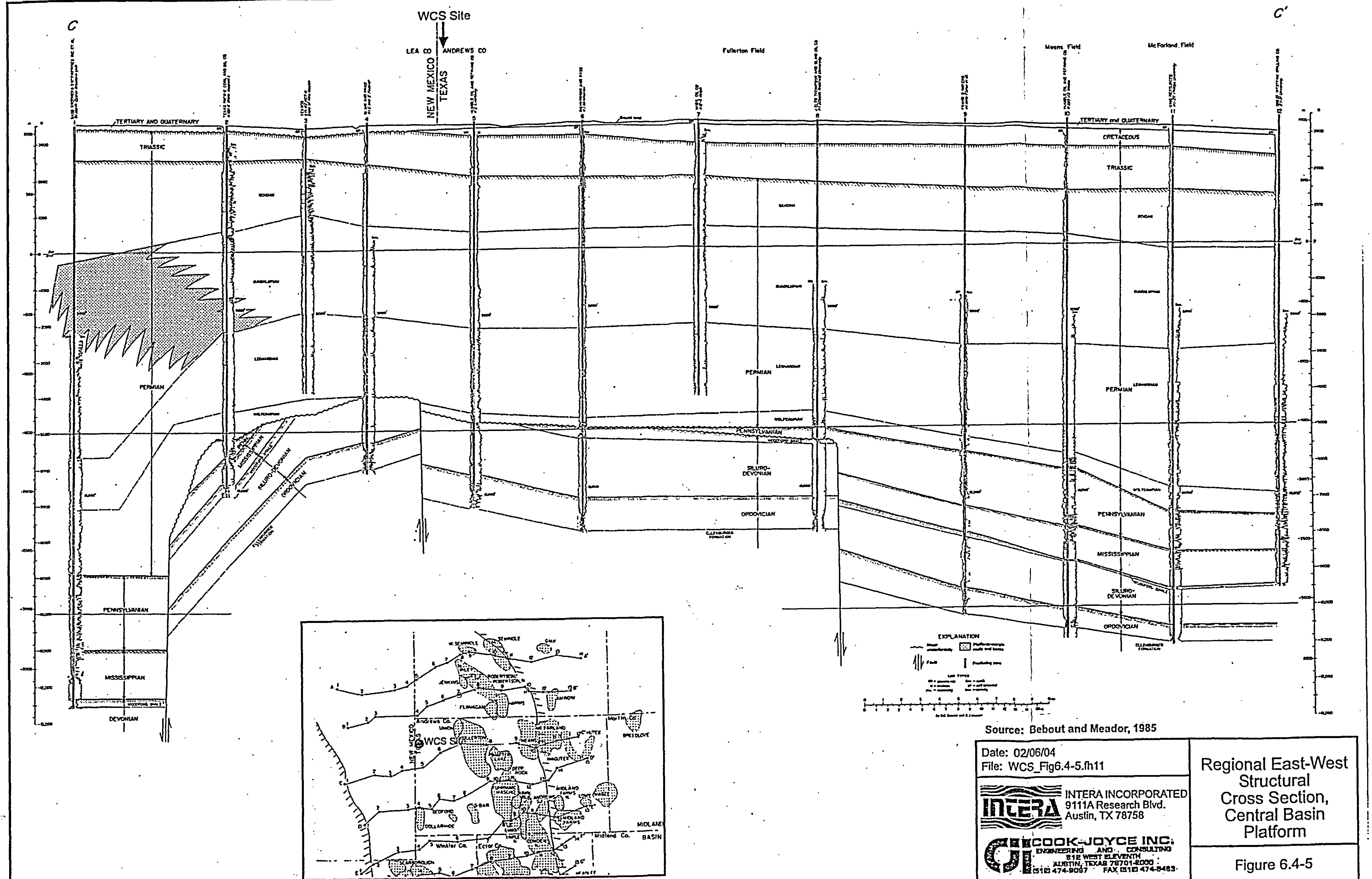
Major Tectonic Features of the Permian Basin - Late Mississippian Early Permain

Figure 6.4-4



Source: Bebout and Meador, 1985

Date: 02/06/04
File: WCS_Fig6.4-5.fh11

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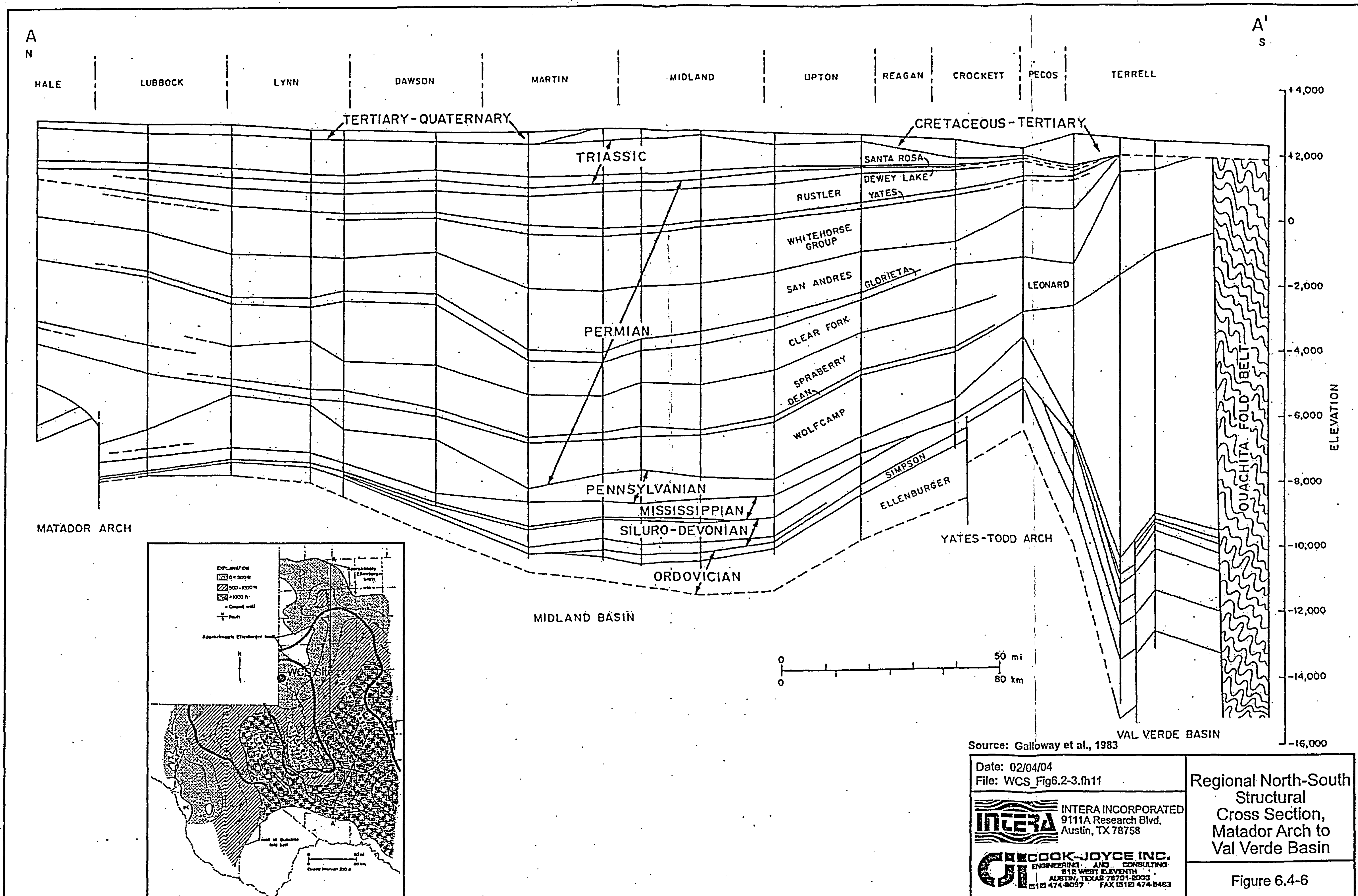
Regional East-West Structural Cross Section, Central Basin Platform

Figure 6.4-5



Source: Galloway et al., 1983

Date: 02/04/04
File: WCS_Fig6.2-3.fh11

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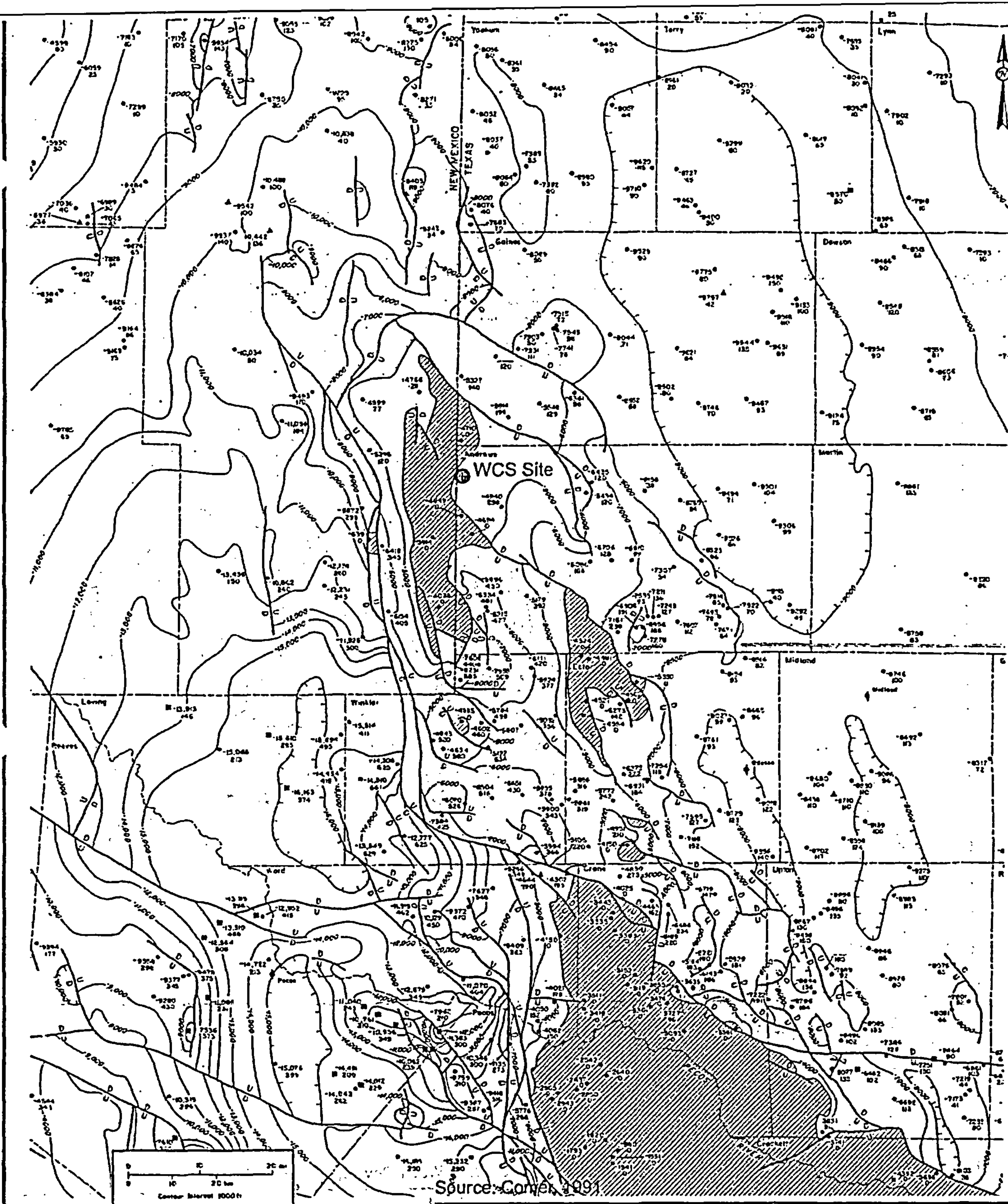
Regional North-South Structural Cross Section, Matador Arch to Val Verde Basin

Figure 6.4-6



EXPLANATION

- Wireline log — -4307 Subsea elevation, top of Woodford (ft)
- Scout ticket — 193 Thickness of Woodford (ft)
- Core — -7000 — Structure contour in feet below sea level, drawn on top of Woodford Formation; extrapolated where control is sparse on the basis of elevation of top of Ellenburger (SE) or top of Devonian (NW)
- Woodford absent

Date: 02/04/04
File: WCS_Fig6.4-7.fh11

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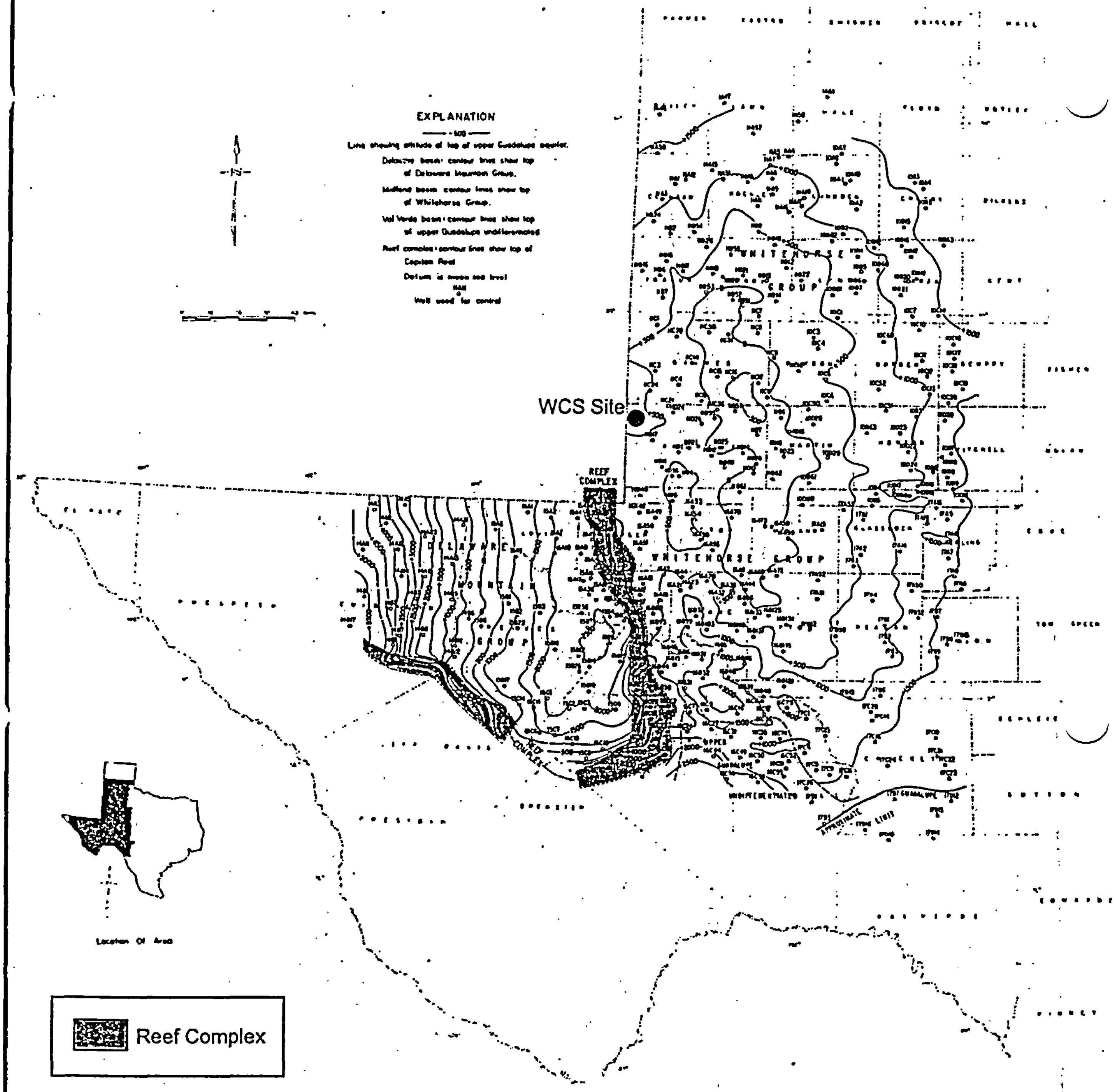
Regional Structure Contour Map of the Woodford Formation

Figure 6.4-7



Source: Texas Water Development Board, 1972

Date: 02/04/04 File: WCS_Fig6.4-8.fh11	Regional Structure Contour Map of the Upper Guadalupe (Whitehorse Group)
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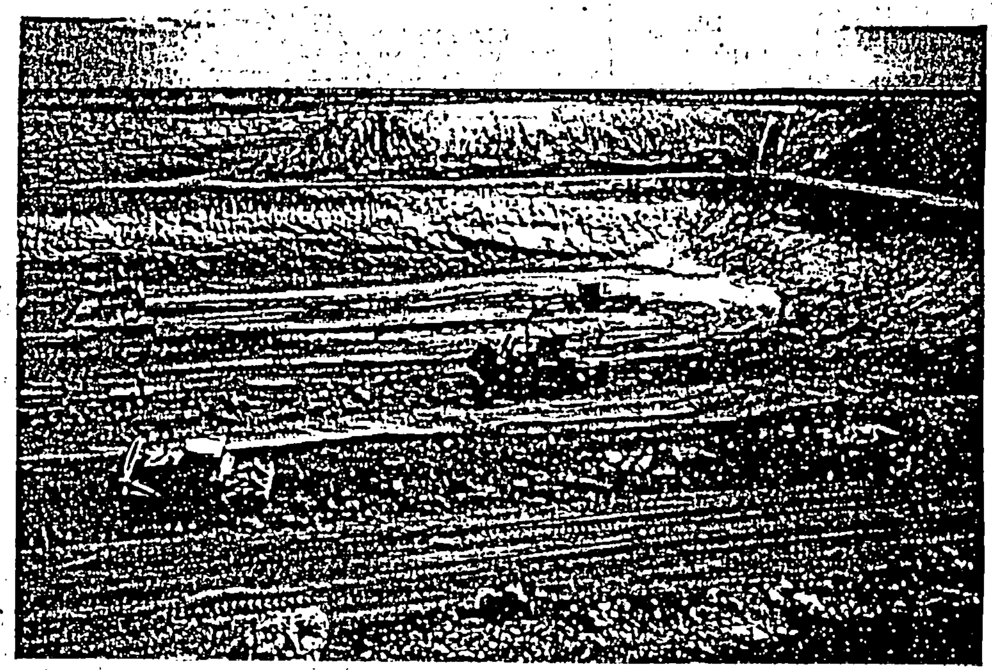

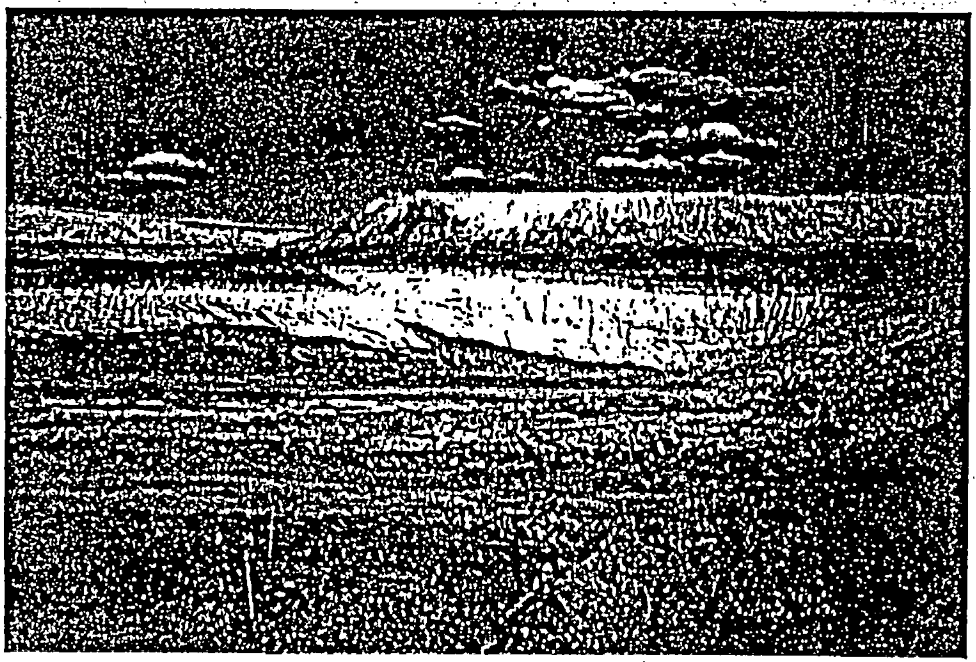

Date: 06/15/04 File: WCS_Fig6.4-9.fh11	1996 Photographs of Reverse Fault in Red Beds
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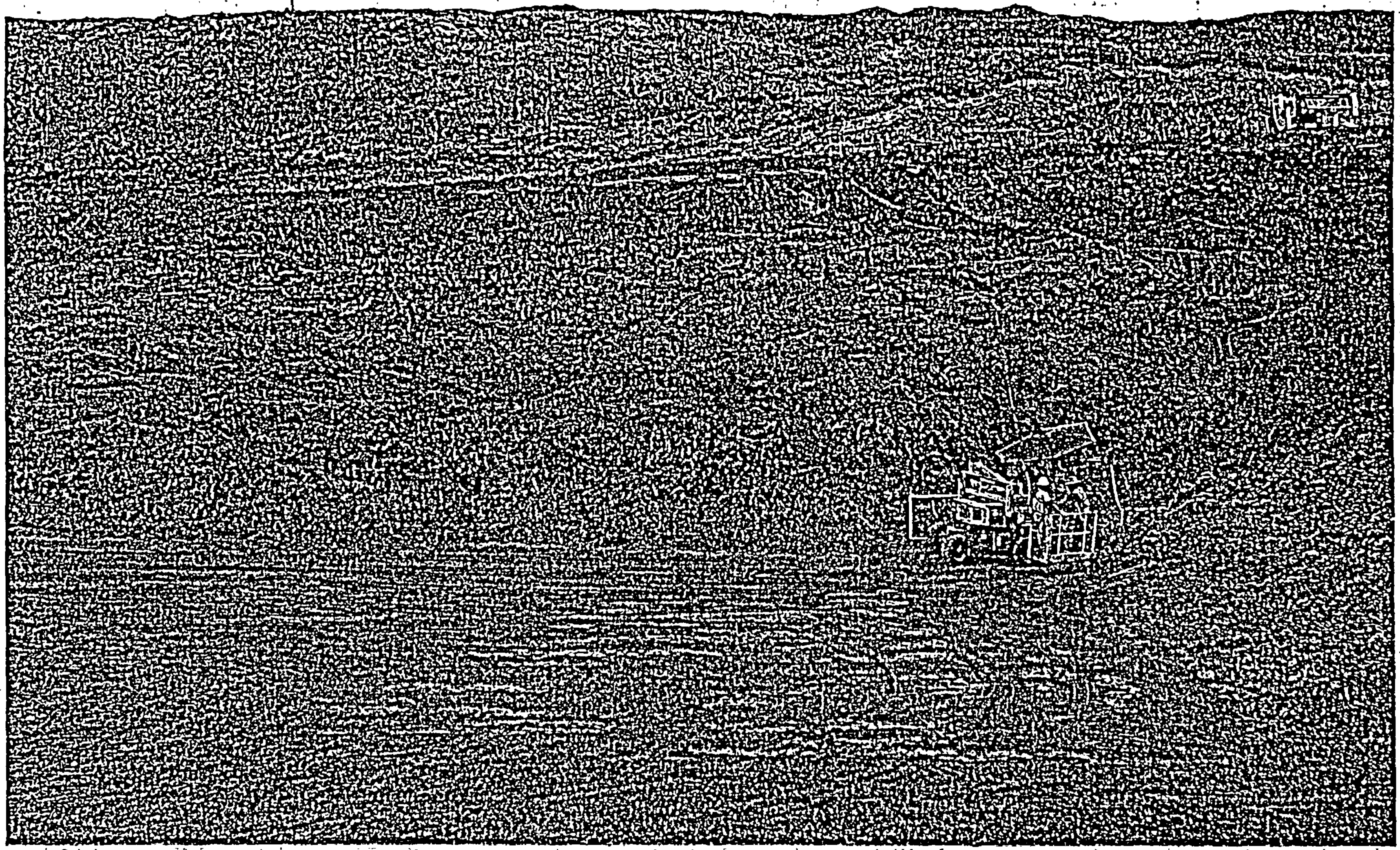
COOK-JOYCE INC. ENGINEERING AND CONSULTING 812 WEST ELEVENTH AUSTIN, TEXAS 78701-2000 (512) 474-9097 FAX (512) 474-8463	Figure 6.4-9



Date: 06/15/04
File: WCS_Fig6.4-10.fh11

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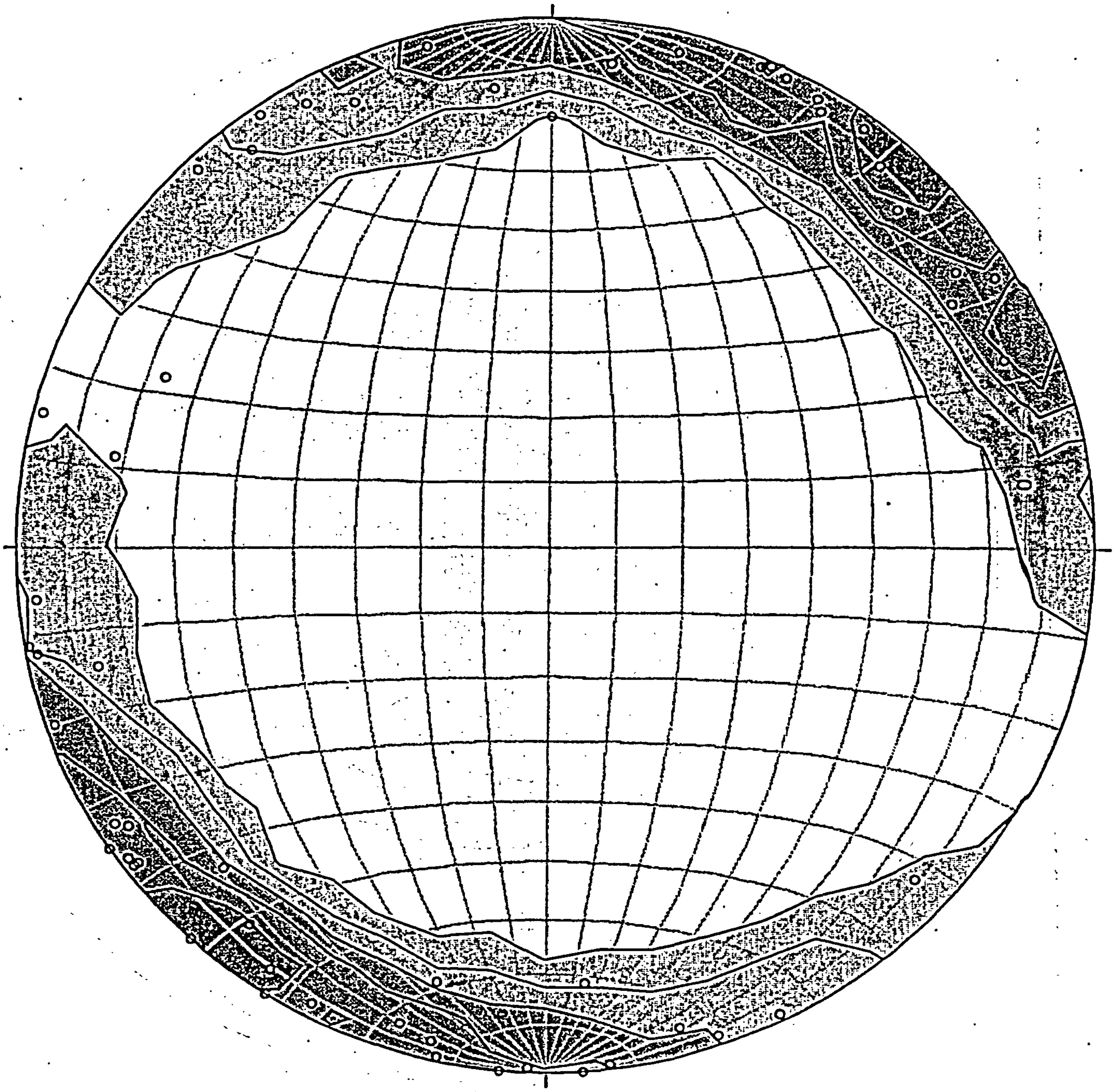
2004 Photograph of Excavation Showing Lower and Upper Walls and Offset Sandstone Layer in Lower Wall

Figu[illegible].4-10



o Plane Pole

— Kamb Contour

KAMB CONTOUR OF P-AXES (n = 0):

Contour Int = 2.0; Counting Circle Area = 0.067

Expected Number = 3.73;

Significance Level = 2.0 sigma

Date: 06/14/2004 File: WCS_Fig6.4-12.fh11	Poles of Subvertical Joint Planes and Kamb Contours, Lower Wall
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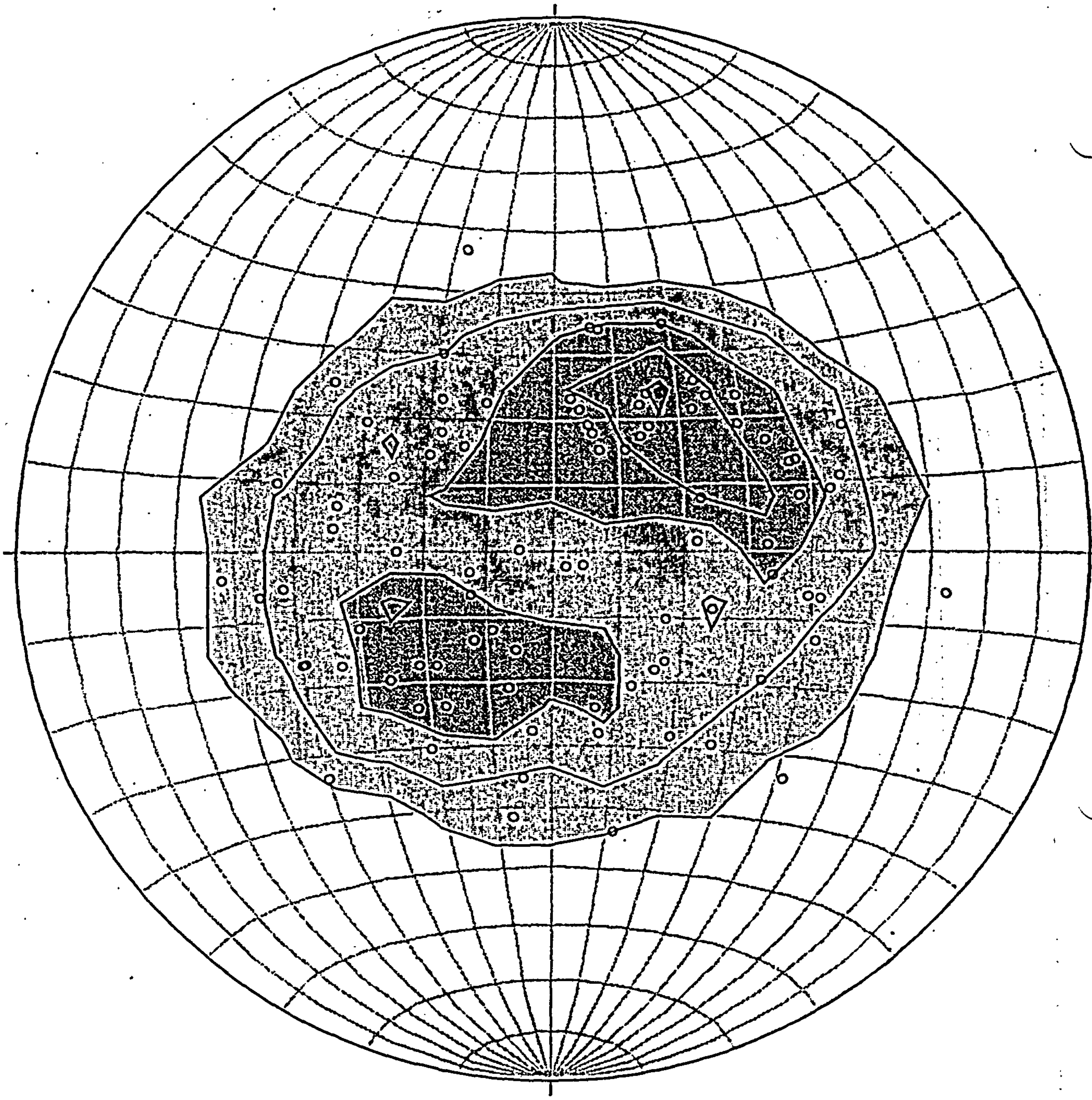

o Plane Pole

—— Kamb Contour

LINES SCATTER PLOT (n = 85):

Contour Int = 2.0; Counting Circle Area = 0.045

Expected Number = 3.82;

Significance Level = 2.0 sigma

Date: 06/14/2004 File: WCS_Fig6.4-13.fh11	Poles of Irregular Joint Planes and Kamb Contours, Lower Wall
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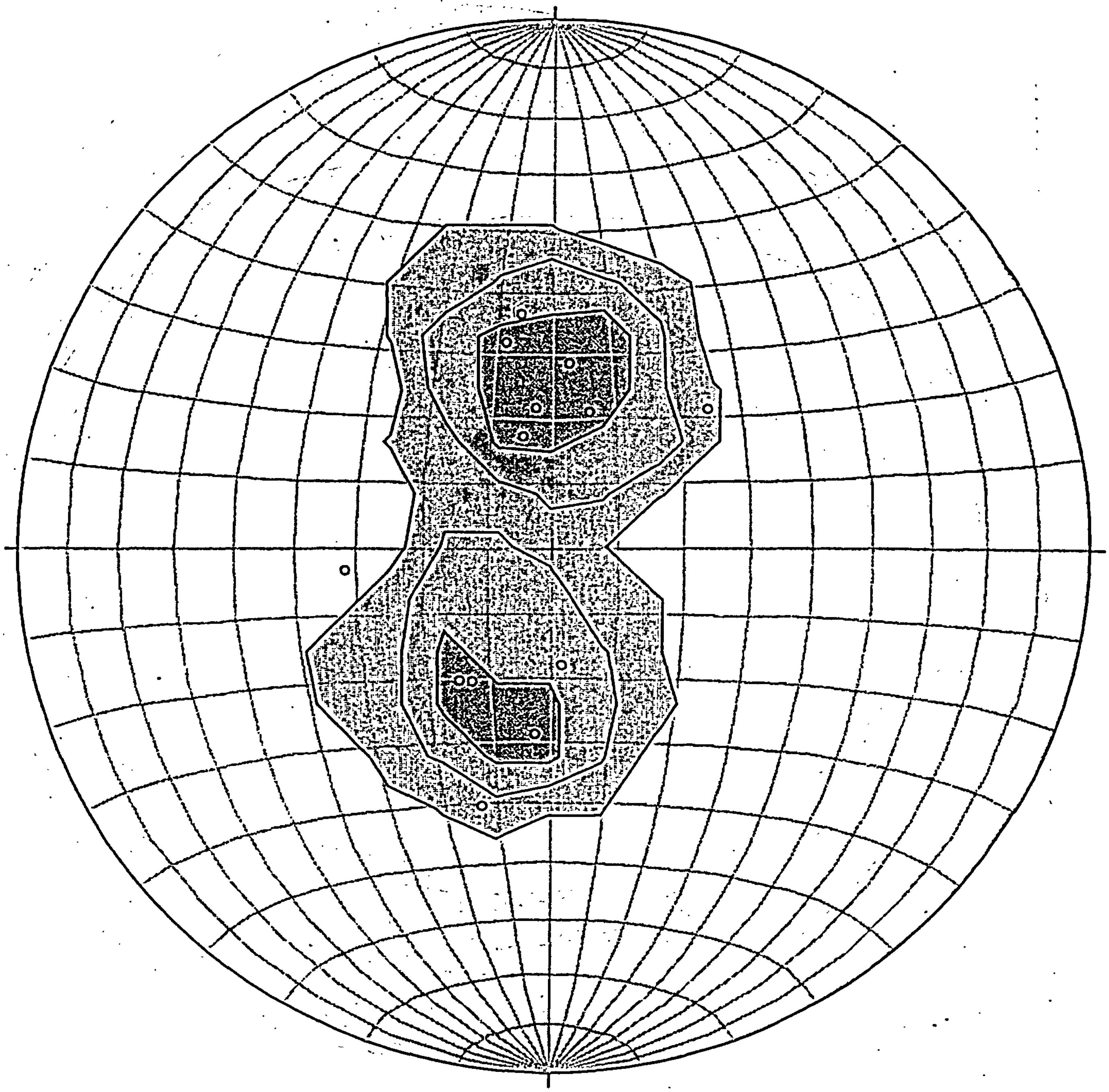

o Plane Pole

—— Kamb Contour

KAMB CONTOUR OF P-AXES (n = 14):

Contour Int = 2.0; Counting Circle Area = 0.067

Expected Number = 0.93;

Significance Level = 1.0 sigma

Date: 06/14/2004 File: WCS_Fig6.4-14.fh11	Poles of Fault Planes and Kamb Contours, Lower Wall
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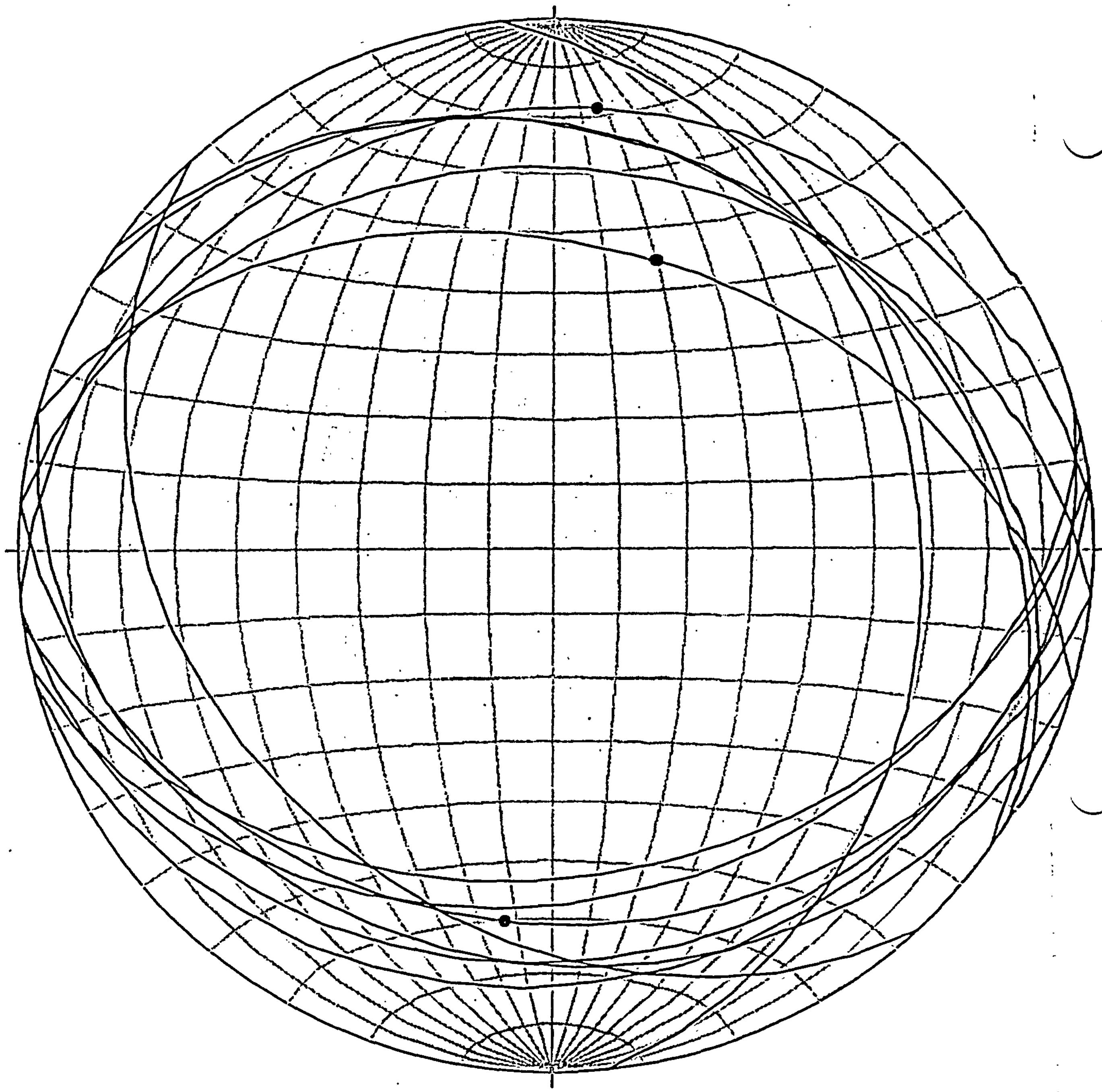

● Slickenside Direction

—— Great Circle

LINES SCATTER PLOT (n = 3):

Planes (n = 14):

Date: 06/14/2004 File: WCS_Fig6.4-15.fh11	Great Circles for Fault Planes with Slickenside Directic Lower Wall
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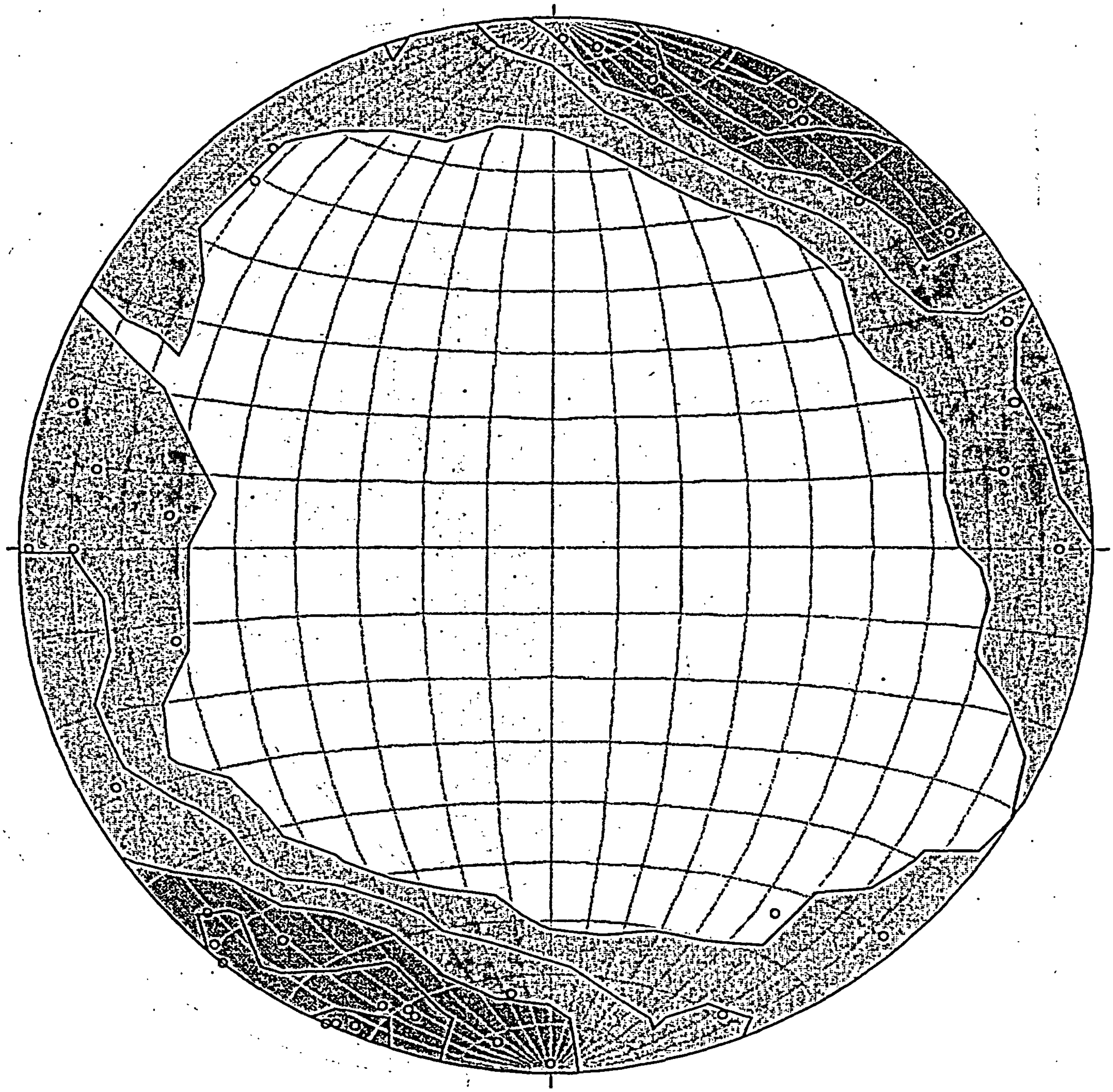
COOK-JOYCE INC. ENGINEERING AND CONSULTING 812 WEST ELEVENTH AUSTIN, TEXAS 78701-2000 (512) 474-9097 FAX (512) 474-8483	Figure 6.4-15



o Plane Pole

—— Kamb Contour

KAMB CONTOUR OF P-AXES (n = 36):
Contour Int = 2.0; Counting Circle Area = 0.100
Expected Number = 3.60;
Significance Level = 2.0 sigma

Date: 06/14/2004 File: WCS_Fig6.4-16.fh11	Poles of Subvertical Joint Planes and Kamb Contours, Upper Wall
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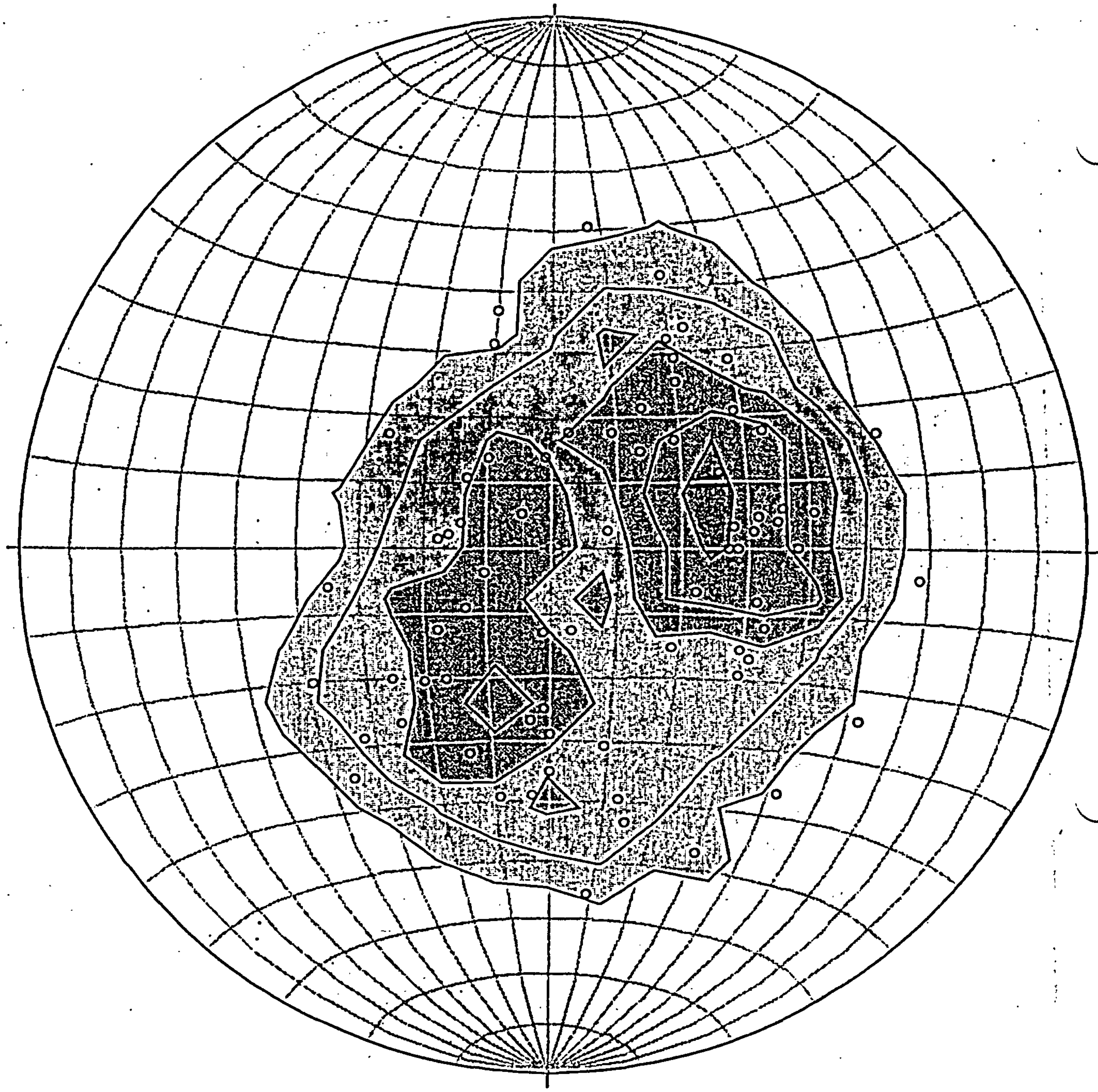

o Plane Pole

—— Kamb Contour

LINES SCATTER PLOT (n = 75):

Contour Int = 2.0; Counting Circle Area = 0.051

Expected Number = 3.80;

Significance Level = 2.0 sigma

Date: 06/14/2004

File: WCS_Fig6.4-17.fh11

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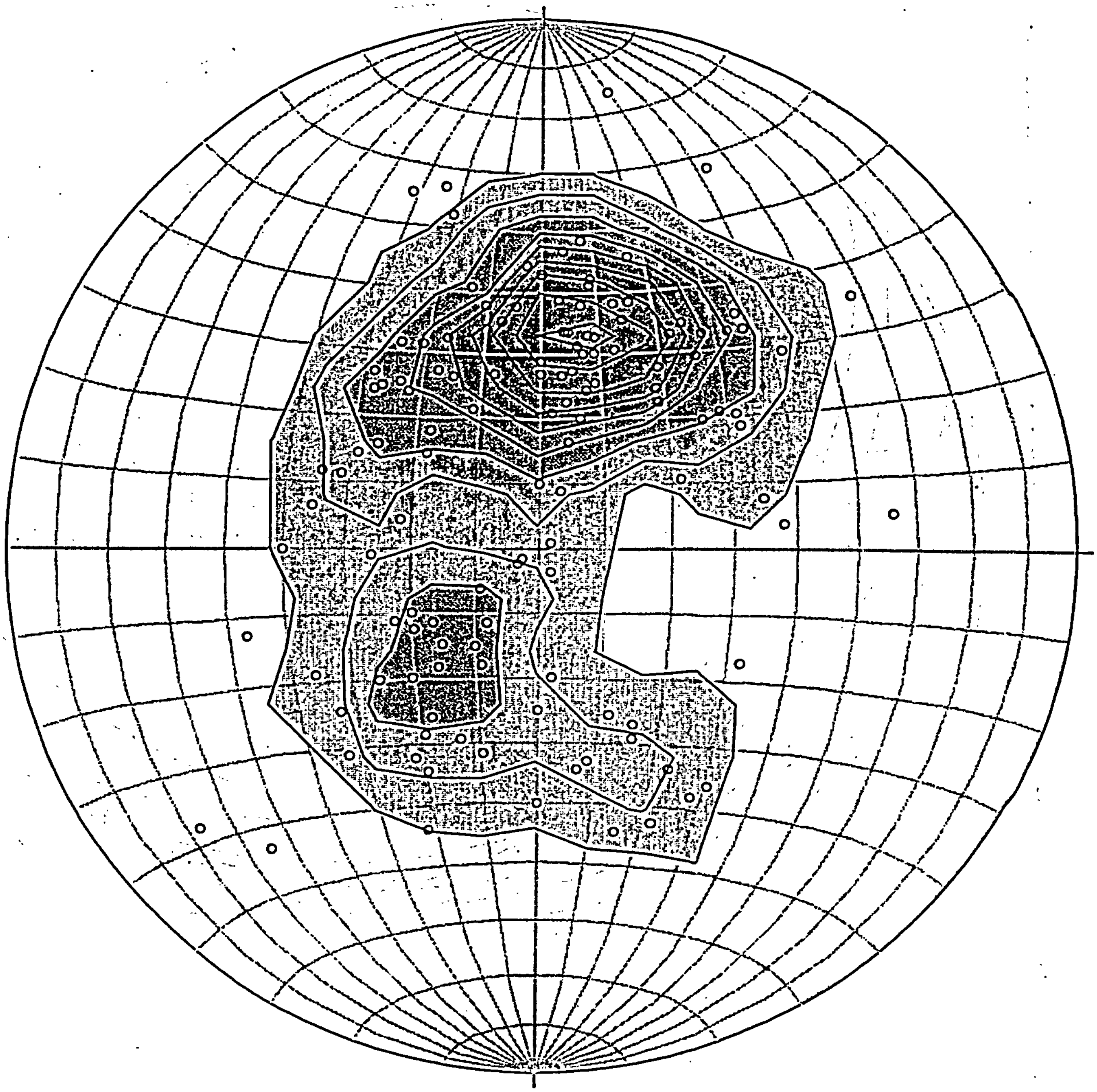
Poles of Irregular Joint Planes and Kamb Contours, Upper Wall

Figure 6.4-17



o Plane Pole

—— Kamb Contour

KAMB CONTOUR OF P-AXES (n = 138):
Contour Int = 2.0; Counting Circle Area = 0.028
Expected Number = 3.89;
Significance Level = 2.0 sigma

Date: 06/14/2004 File: WCS_Fig6.4-18.fh11	Poles of Fault Planes and Kamb Contours, Upper Wall
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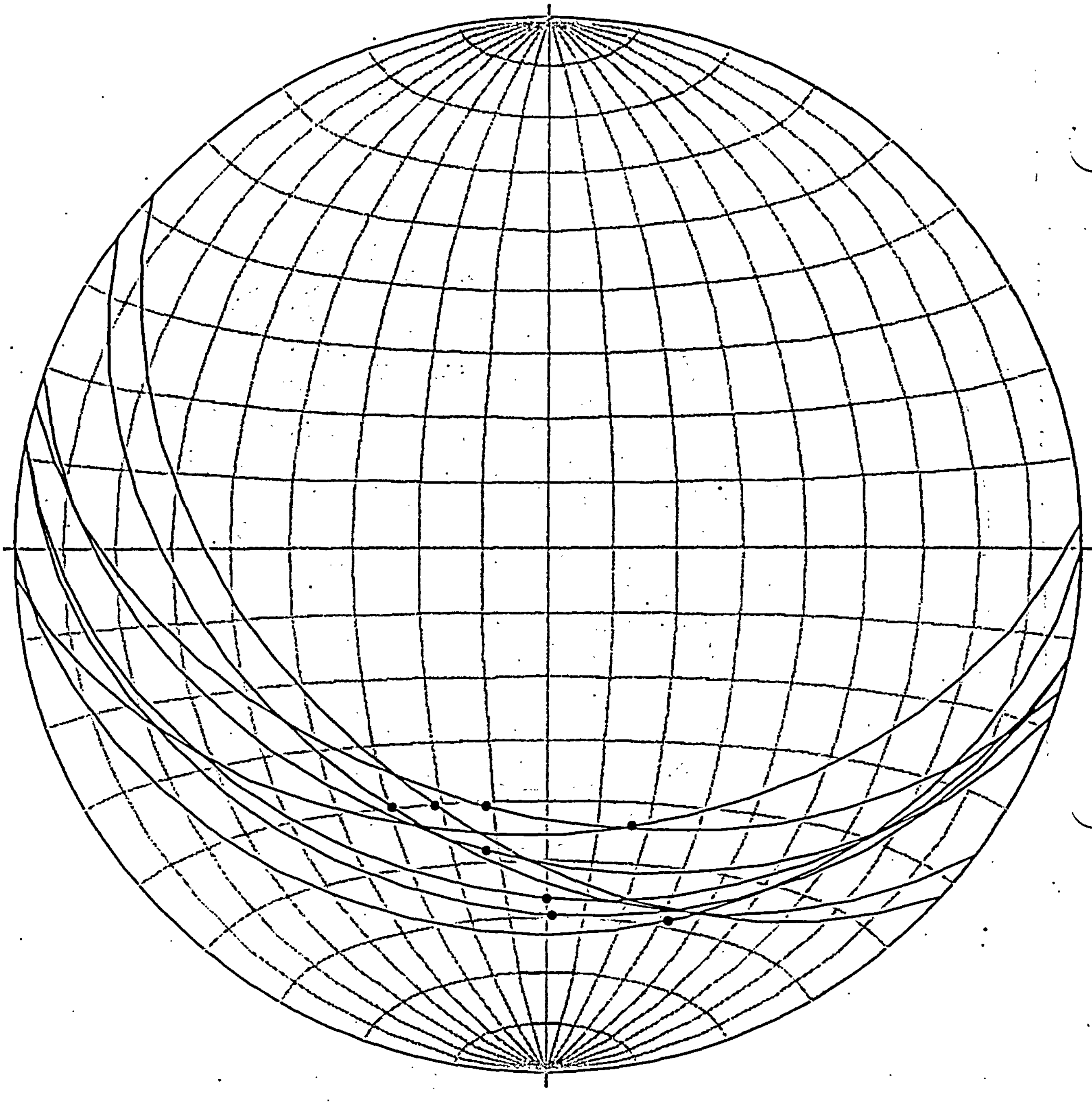

- ● Slickenside Direction
- —— Kamb Contour

LINES SCATTER PLOT (n = 8):

Planes (n = 8):

Date: 06/14/2004 File: WCS_Fig6.4-19.fh11	Great Circles for Fault Planes with Slickenside Directio' Upper Wall
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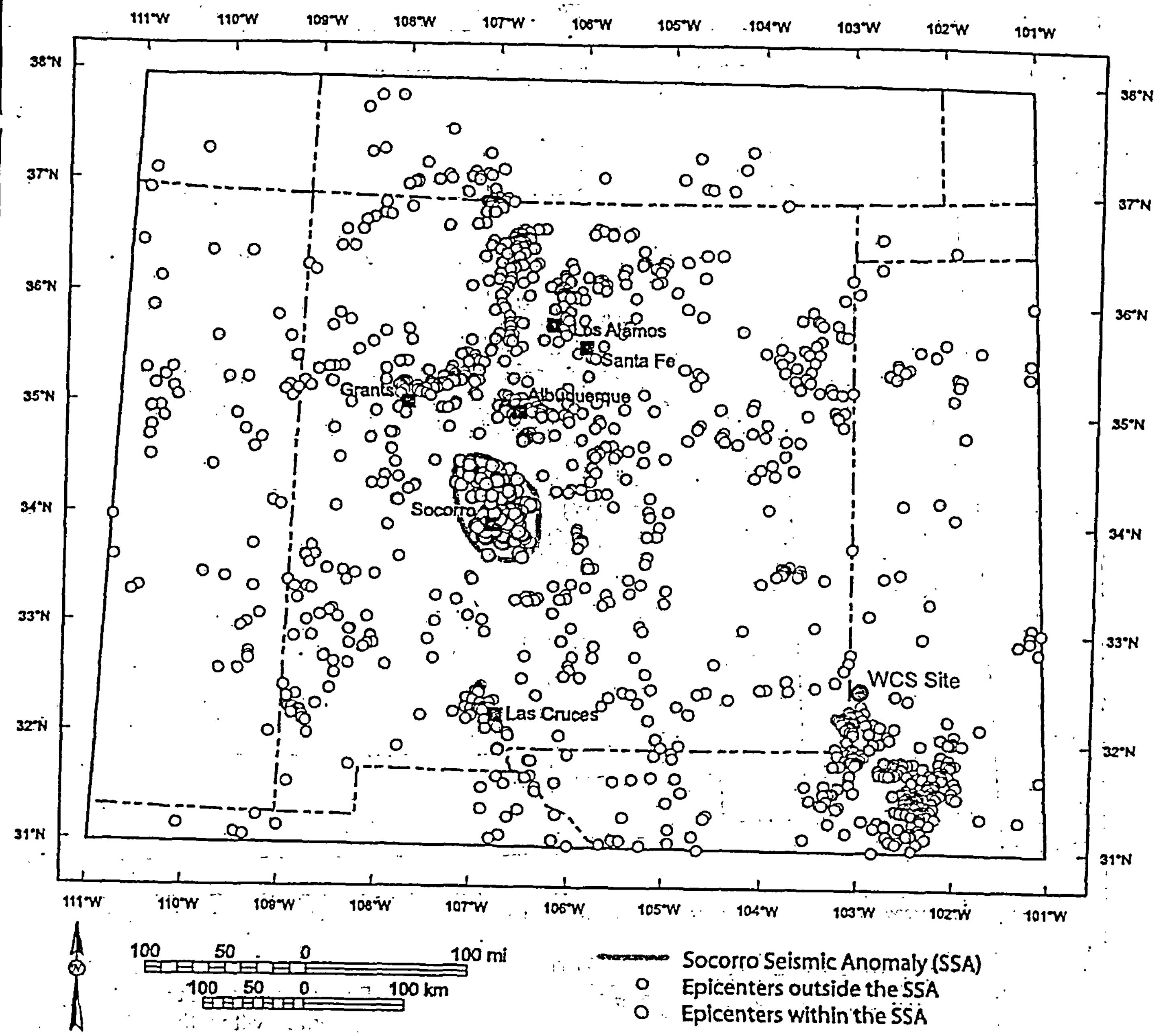

Source: Sanford et al., 2002

Date: 06/14/04
File: WCS_Fig6.4-20.fh11

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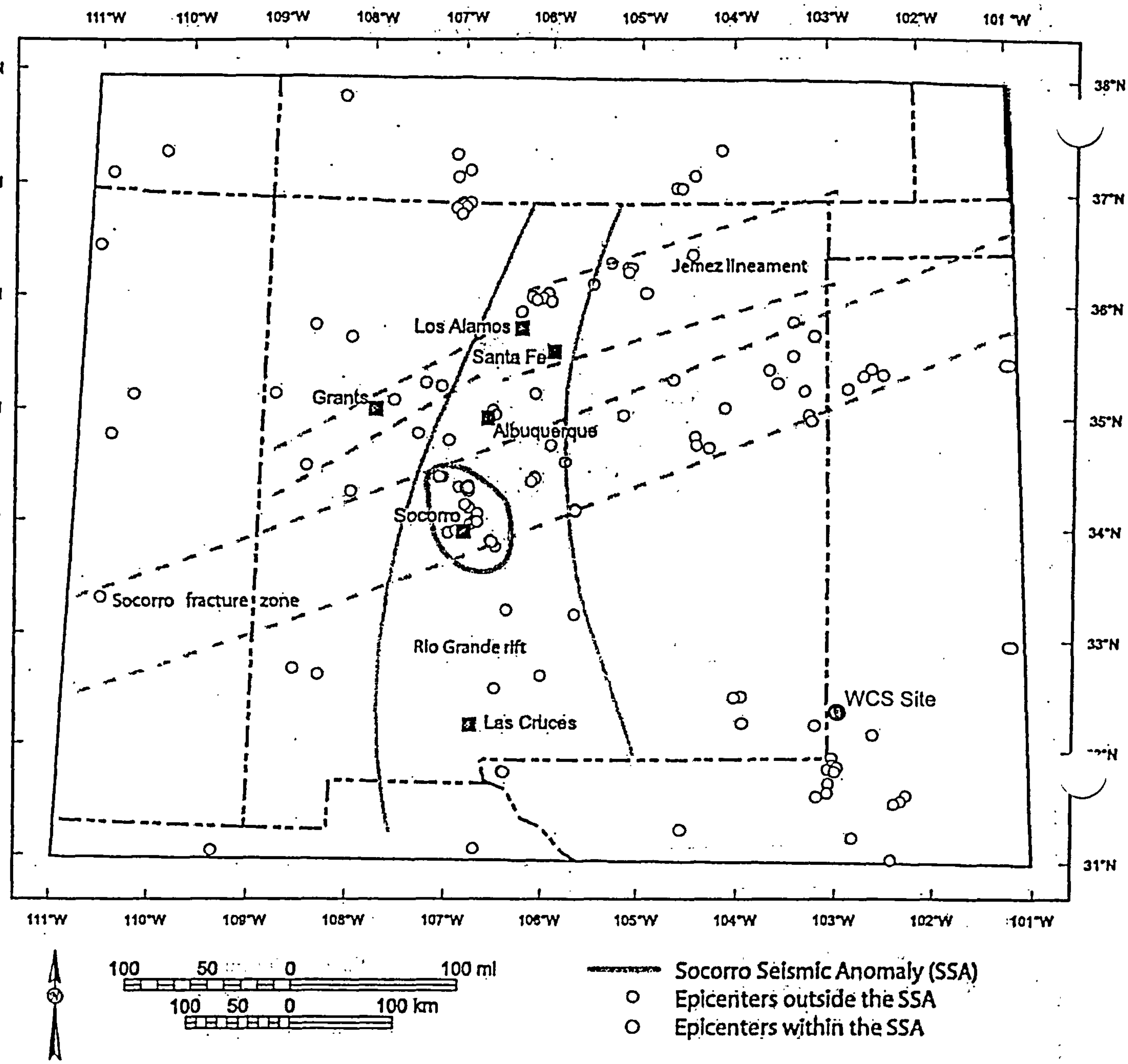
Seismicity of New Mexico and Bordering Areas (1962 - 1995; Moment Magnitudes > 1.3)

Figure 6.4-20



Source: Sanford et al., 2002

Date: 06/14/04
File: WCS_Fig6.4-21.fh11

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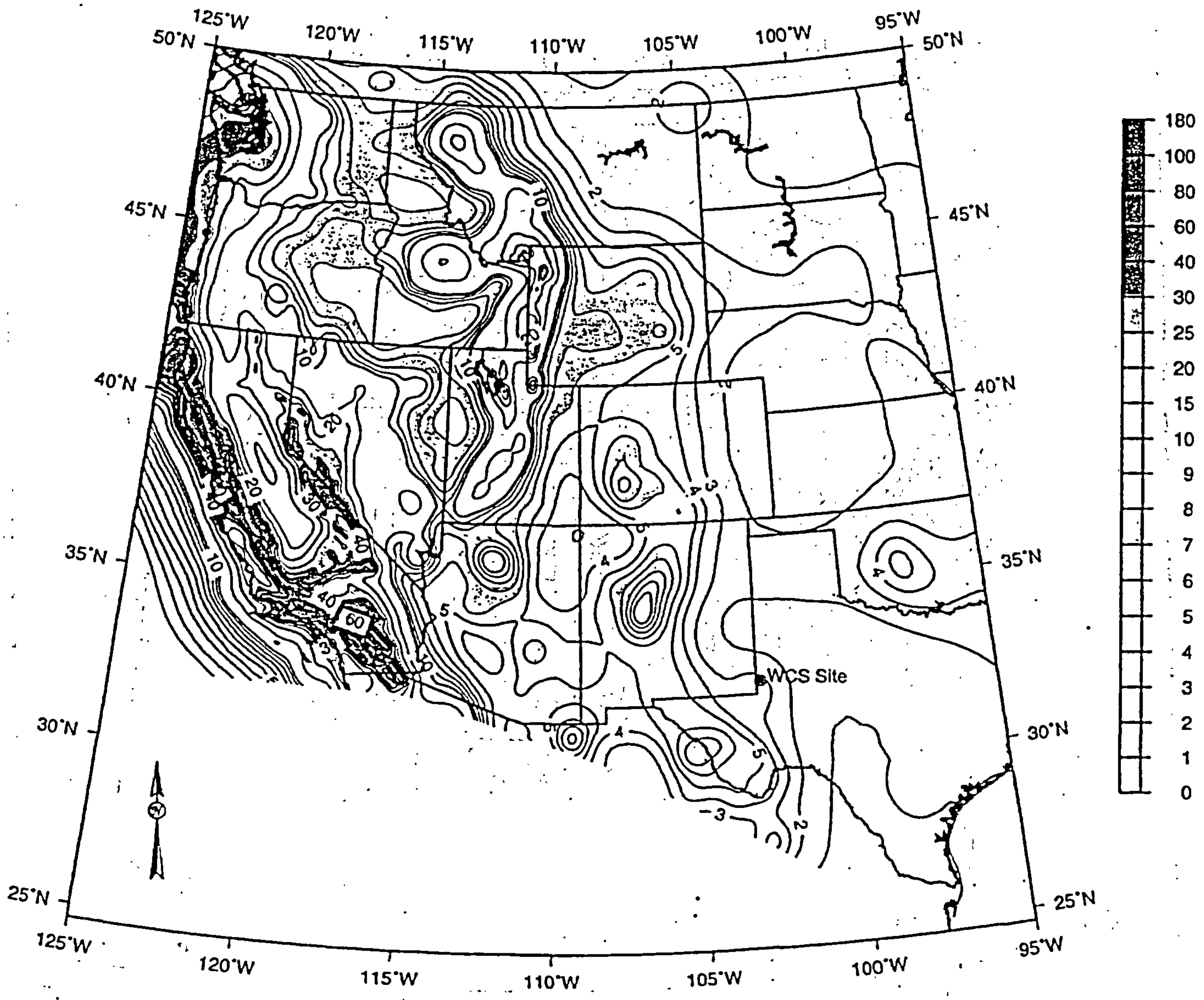
Seismicity of New Mexico and Bordering Areas
(1962 - 1995; Moment Magnitudes > 3)

Figure 6.4-21



Source: http://geohazards.cr.usgs.gov/eg

Date: 06/14/04 File: WCS_Fig6.4-22.fh11	Peak Ground Acceleration (%g) with 10% Probability of Exceedance in 50 Years
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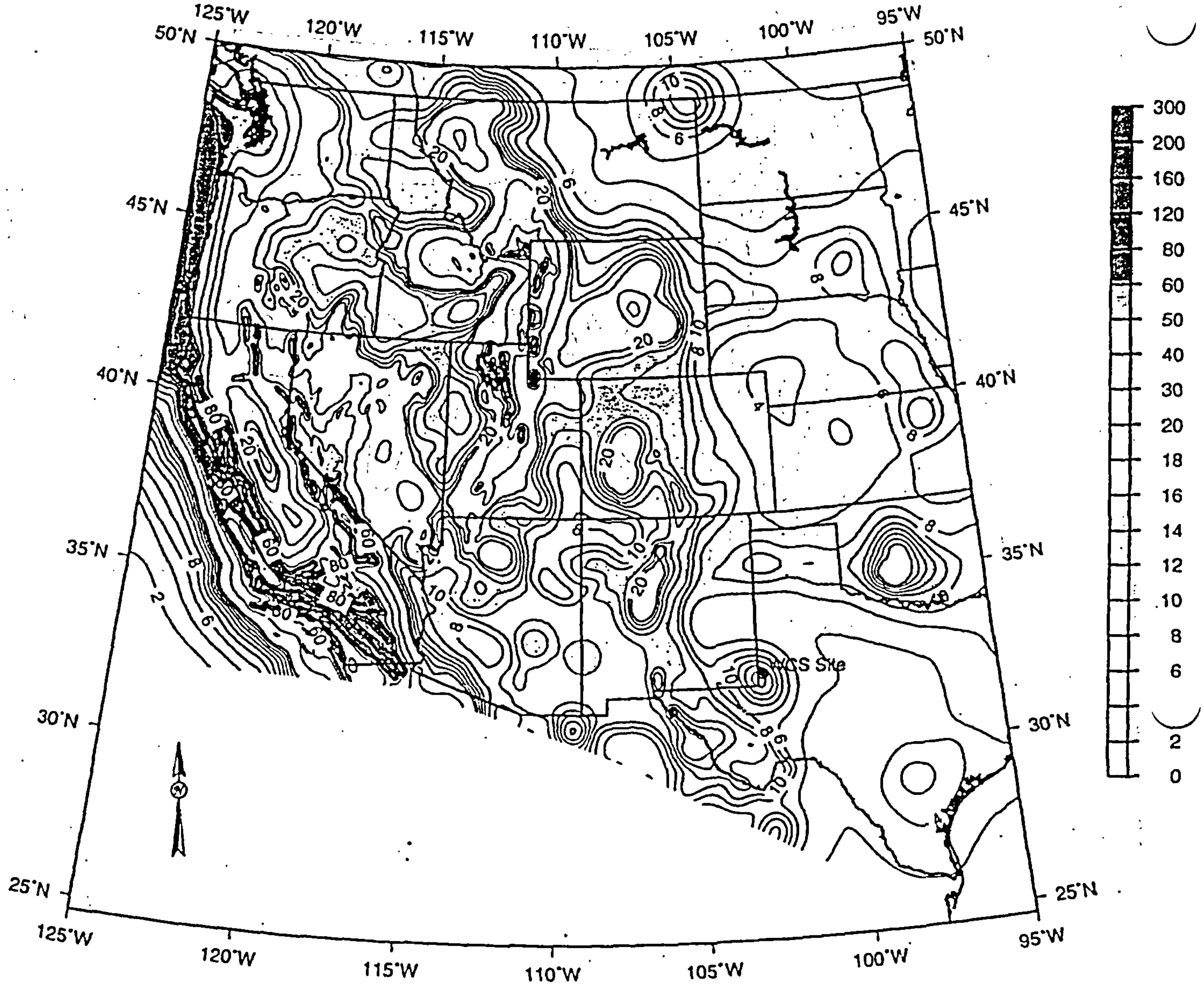

Source: http://geohazards.cr.usgs.gov/eg

Date: 06/14/04 File: WCS_Fig6.4-23.fh11	Peak Ground Acceleration (%g) with 2% Probability of Exceedance in 50 Years
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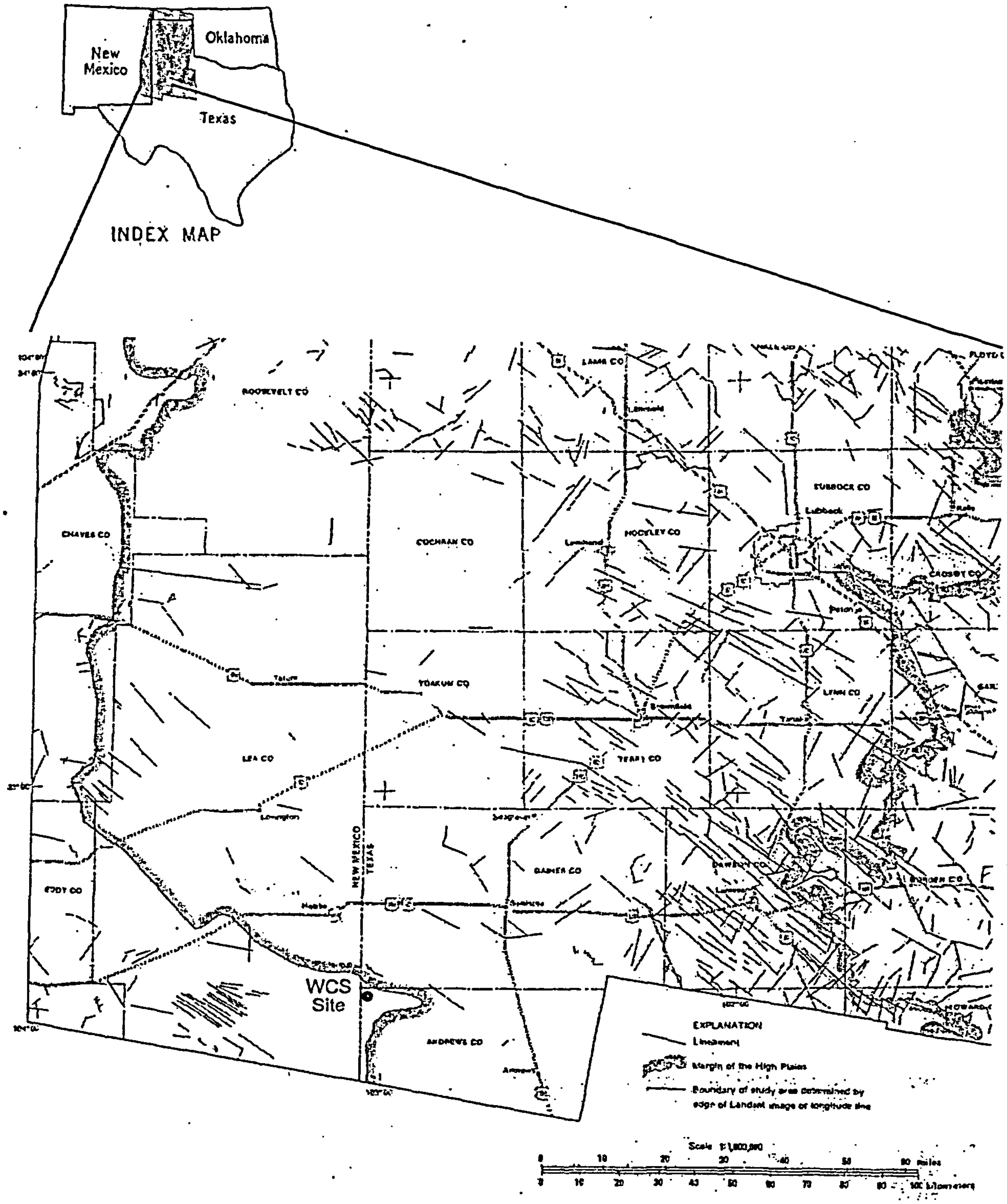

Source: Finley and Gustavson, 1981

Date: 06/14/04 File: WCS_Fig6.4-24.fh11	Lineament Map of the Texas Panhandle and Parts of Oklahoma and New Mexico
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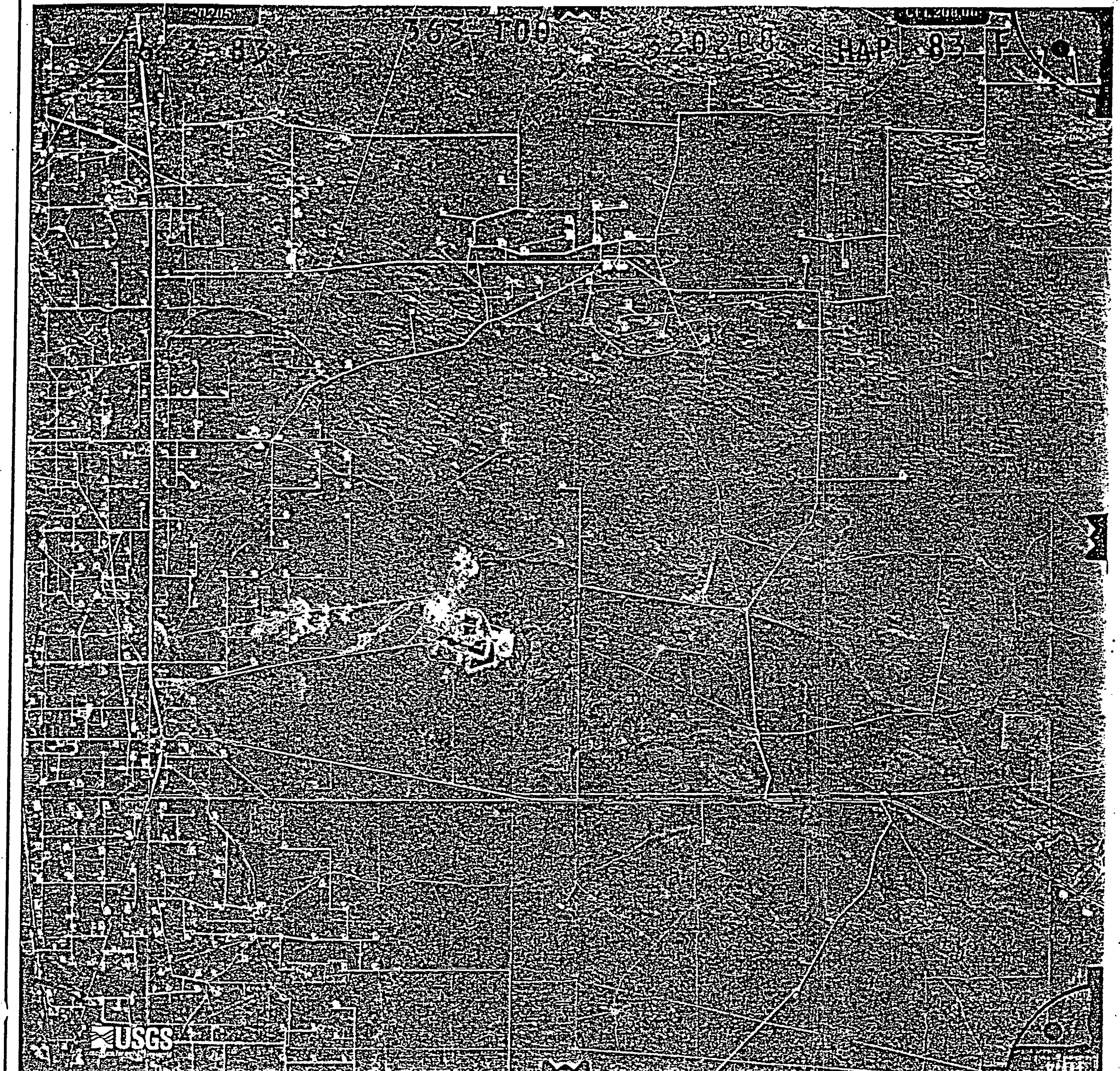

Date: 06/14/04
File: WCS_Fig6.4-25.fh11

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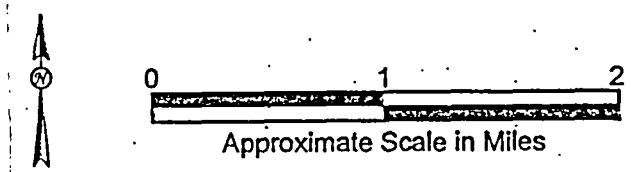
1983 Color Infrared Photograph - WCS Area

Figure 6.4-25



Lineaments

RCRA Permitted Area

Date: 06/14/04
File: WCS_Fig6.4-26.fh11

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1986 Color Infrared Photograph - WCS Area

Figure 6.4-26