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GEOMORPHIC PROCESSES OF THE TEXAS PANHANDLE

by

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3.3.2.4 Jointing History

Joints are fractures in a rock that exhibit no detectable displacement between one face of the fracture and the other. Previous work on the origin of joints has determined different mechanisms to explain fracturing. Some researchers have explained joints in terms of their relationship to tectonic deformation and major structural elements (Harris and others, 1960; Price, 1966; Stearns and Friedman, 1972). Others have shown that joints may develop independently from tectonic deformation and that joints may form in sedimentary rocks early in their history (Parker, 1942; Hodgson, 1961; Price, 1966; Cook and Johnson, 1970). Price (1974) investigated the development of joints and stress systems in undeformed sediments during the accumulation of a sedimentary series, its downwarping and subsequent uplift, and accompanying de-watering of the sediments. Joints can also result from unloading due to erosion (Chapman, 1958). The formation of joints in sedimentary rocks is dependent on three factors (Hobbs, 1967): (1) physical properties of both the fractured rock bed and the surrounding rock beds; (2) thickness of the rock bed; and (3) degree of tectonic deformation of the beds.

Joints in the Palo Duro Basin were formed by tectonic processes associated with the development of the basin and by nontectonic processes associated with collapse or downwarping of strata related to evaporite dissolution (Collins, 1983; Goldstein, 1982). Regional fracture trends of the Palo Duro Basin area are shown in figure 1. Fracture patterns in Permian and Triassic rocks were determined by measuring joint orientations in outcrops and fracture orientations from fracture identification logs (FIL).

Figure 1, which shows varying fracture patterns throughout the region, indicates that jointing is more complex than simple regional development of several orthogonal joint systems. At Caprock Canyons State Park in Briscoe County, the dominant orientations of joints are 355° - 005° (north), 020° - 050° (northeast), and 075° - 085° (east). Westward near Tulia, and to the northwest along State Highway 207 in Palo Duro Canyon, the major fracture trend is 280° - 300° (west-northwest). This fracture trend (280° - 300°) apparently becomes less significant toward the west in Deaf Smith County where the dominant trends are 030° - 060° (northeast) and 070° - 090° (east). The age relationships of the regional fracture trends have not been determined yet.

Joint and fracture orientations at various locations in the Panhandle coincide with trends of basement faults mapped by Budnik (see section 3.3.2.), although in some areas basement data are sparse. A similarity between joint orientations and lineament trends also exists in parts of the Texas Panhandle (Finley and Gustavson, 1981). The correlation between basement structural trends, joints, and surface lineaments is exhibited in Randall County in the vicinity of Palo Duro Canyon (Fig. 2). Figure 2 shows basement faults in eastern Randall County trending in northwest and northeast directions. The basement faults in this area have been determined from seismic and borehole data. Fracture orientations from the Rex White #1 borehole show dominant northwest and northeast trends and a less significant easterly trend. Surface lineaments in the area also trend northwest and northeast (Finley and Gustavson, 1981). Joint measurements from Permian and Triassic rocks at Palo Duro Canyon State Park show a dominant trend to the northwest and less significant trends in northeasterly and westerly directions. This area coincides with a northwest trending basement fault.

Orientations of vertical gypsum-filled joints in Permian rocks cropping out along a section of the northwest trending canyon indicate that the joints have at least partially controlled stream incision and canyon development (fig. 3). The gypsum filling these joints is associated with evaporite dissolution, indicating that these joints predate features associated with more recent geomorphic unloading processes. The gypsum needles in these vertical veins are horizontal indicating maximum extension was horizontal at the time of mineralization. These vertical vein-filled joints predated dissolution-collapse (Goldstein, 1982) and are discussed in more detail further in this section.

Detailed field studies of joints and veins have been done at Caprock Canyons State Park in Briscoe County (Collins, 1983; Goldstein, 1982; Collins, in press). This area was studied because few outcrops occur in the interior of the High Plains. Caprock Canyons State Park is located along the Caprock Escarpment at the eastern part of the Palo Duro Basin, within a regional salt dissolution zone recognized by Gustavson and others (1980). Rocks exposed include Upper Permian, Triassic, and Tertiary units. Tectonic folding and faulting apparently have not affected these rocks, although regional systematic joints that predate dissolution-collapse are well developed. A variety of brittle and nonbrittle deformational structures have developed in the Permian strata because of collapse associated with salt dissolution.

Two styles of joints are present in the Permian and Triassic rocks. Systematic joints are vertical, evenly-spaced, regularly oriented fractures. The predominant systematic joint sets trend to the north, northeast, and east. A less significant set trends northwest suggesting two orthogonal joint sets exist. Within different subdomains in the study area, one or more of these four joint sets are predominant. Hackle-fringes on joint faces are evidence of horizontal propagation under the influence of horizontal extension. This fringe forms because a horizontally propagating fracture attempts to be perpendicular to both the stresses in the bed being fractured and the local stresses at the base and the top of the bed.

Zones of closely-spaced systematic joints occur throughout the area. The closely-spaced joint clusters extend vertically through Permian and Triassic beds, are as wide as 40 m (fig. 4), extend for horizontal distances up to 1 km and possibly farther, and occur for all of the systematic joint set trends. Within the closely-spaced joint clusters, joint densities average 5 joints per meter for sandstone beds 3 m thick. Away from these closely-spaced zones, densities average 0 to 1.5 joints per meter for 3 m thick sandstone beds. Bed thickness affects the spacing of the joints occurring within and beyond zones of closely spaced joints. In general, the number of joints per meter (joint density) for sandstone and siltstone beds less than 1 m thick increase as the bed thickness decreases (fig. 5). Joint densities are almost constant for beds greater than 1 m thick.

In this area, nonsystematic joints are curved, irregularly spaced, show no preferred orientation and truncate against systematic joints, thus postdating them. Many nonsystematic joints have surface markings which indicate vertical propagation directions. Wallner lines on the surfaces of nonsystematic joints indicate that some fractures propagated from the base of the bed upward; other fractures show the reverse. Nonsystematic fractures never exhibit horizontal propagation directions. It is proposed that they have formed as a result of collapse and related vertical extension.

A suite of brittle deformational structures has been observed at Caprock Canyons State Park which is believed to be a result of dissolution and collapse. The mechanical and geometric analysis of these normal and reverse faults, veins, and fractures gives some insight into the kinds of processes that occur in and adjacent to zones of salt dissolution.

In the area, thinly-layered sandstones contain numerous veins of satin spar , a form of fibrous gypsum. The veins are bisected by a medial scar that marks the site of earliest mineralization. Mineral material was added at the vein-wall rock contact, and the mineral fibers indicate the direction of maximum principal extension at the time they were added to the vein.

Three types of veins are present, including vertical veins, veins which are parallel to bedding, and veins which cut the bedding at angles from thirty to sixty degrees. The gypsum fibers in the vertical veins are horizontal indicating that these veins formed by horizontal extension. Small-scale normal and reverse faults with displacements usually less than 0.5 m are also gypsum-filled. Nearly all veins within fault planes display undeformed crystals adjacent to the vein-wall rock contact, indicating that fault movement predated mineralization. Also the mineral fibers of these veins are vertical, indicating that mineralization occurred during vertical extension.

The geometry of vein intersections also indicates that faulting predated mineralization. The mineral fibers of adjacent horizontal and inclined veins merge without a break. Some veins have fibers which have a sinusoidal or "S" shape indicating that some motion occurred during vein growth. For the most part, however, vein fibers are straight and do not deviate from vertical by more than approximately 10 degrees. The vertical long axis of the mineral fibers in the horizontal and inclined veins indicate these veins have formed through vertical extension. Where the veins intersect, vertical veins are always cut by inclined veins and nearly always cut by the horizontal veins. The most likely cause for the vertical extension recorded by these veins is dissolution of salt and collapse or gentle lowering under the influence of gravity.

Field relationships of the joints and veins at Caprock Canyons State Park indicate that vertical systematic joints predate collapse caused by evaporite dissolution and could have served as pathways for fluid migration (fig. 6). These systematic joints developed regionally during the initial burial of the rocks (Stage 1, fig. 6). As dissolution was initiated, small-scale faulting (displacements less than 1 m) occurred (Stage 2, fig. 6). A stress regime characterized by vertical extension occurred as dissolution-collapse processes continued (Stage 3, fig. 6). Gentle folding and non-systematic fracturing continued due to the removal of support from below. Gypsum mineralization continued to occur during vertical extension as indicated by the vertical fiber growth of the inclined veins.

Clastic dikes are among the deformational features observed in outcrop in Randall, Potter, Moore, Oldham, Briscoe, Hartley, and Hall Counties of the Texas Panhandle, as well as at localities in the Oklahoma Panhandle, and eastern and northeastern New Mexico. These clastic dikes usually range in thickness from about 15 cm to 3 mm although dikes in northeastern New Mexico and western Oklahoma are as thick as 1.5 m. In the Texas Panhandle, poor exposures prevent tracing the vertical and lateral extent of most of the dikes. Almost all of the dikes cut upper Triassic strata, although clastic dikes have also been observed in the Pliocene Rita Blanca Formation in Hartley County , in Pleistocene deposits in Hall County, and in Permian strata in Potter County.

The mechanics of dike emplacement are difficult to determine unless the dikes can be traced in outcrop to source beds. The composition of a dike usually cannot indicate a definite source bed because Triassic, Tertiary, and Quaternary sediments have similar lithologies.

The dikes appear to have been formed from the filling of fractures or fissures from above. At Buffalo Lake in western Randall County, dikes from overlying Ogallala source beds cut Triassic Dockum sediments. Where a dike termination can be observed with depth, the dike thins and pinches out. The trends of these dikes are very similar to fracture orientations measured at this location (fig. 7). Dikes in Hartley, Randall, and Oldham Counties, Texas, and dikes in southeastern Quay County, New Mexico, also appear to be due to fracture filling (fig. 7). Subsidence is the likely mechanism by which horizontal strain and extension have opened the fractures or fissures. In the Texas Panhandle geomorphic features such as recent fissures, sinkholes, collapse basins, and breccia-filled chimneys have been attributed to subsidence processes caused by evaporite dissolution (Gustavson and others, 1982). Subsidence created by differential compaction is another mechanism that can develop fissures (Jachens and Holzer, 1982), although in the Texas Panhandle evaporite dissolution is the most likely cause for subsidence.

Although most of the clastic dikes in the Texas Panhandle appear to be emplaced during the Cenozoic, dikes cutting Triassic sediments at one locality in Palo Duro Canyon State Park appear to have originated from a sand unit within the Triassic. The predominant dike trend at this locality is the same as one of the joint trends, although dikes strike in other directions (fig. 7).

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FIGURE CAPTIONS

Figure 1. Regional fracture patterns in the Palo Duro Basin area, Texas Panhandle. Joint measurements are from outcrops and borehole fracture identification logs.

Figure 2. Map showing relationship between basement faults and joint and fracture measurements in eastern Randall County, Texas Panhandle.

Figure 3. Map displaying trends of vein-filled systematic joints in Permian rocks cropping out in Palo Duro Canyon, Randall County. Representative vein and joint orientations were measured along each traverse.

Figure 4. Cross-section view of a joint zone extending through Permian and Triassic rocks at Caprock Canyons State Park in Briscoe County. Overlying Tertiary Ogallala sediments are also fractured, although it is uncertain if the Ogallala fractures are actually systematic joints that are part of the joint zone.

Figure 5. Graph showing weighted joint density vs. log of bed thickness for data from Caprock Canyons State Park, Palo Duro Canyon State Park, and joint zones at both parks. Joint densities were weighted using the following expression (Jackson, personal communication):

$$\text{double weighted mean joint density} = \bar{X}_m + \sum_{i=1}^{n} (x_i - x_m) \cdot \frac{y_i}{y_m} \cdot \frac{N_i}{N_m}$$

$n = 5$ in 5 point weighting

$n = 3$ in 3 point weighting

subscript $_m$ refers to value for midpoint

Figure 6. Conceptual model of brittle deformation above dissolution zones. Stage 1 represents normal burial; Stage 2 represents horizontal extension as a precursor to dissolution collapse; and Stage 3 represents collapse (from Goldstein, 1982).

Figure 7. Comparison of clastic dikes and joint orientations in the Texas Panhandle and eastern New Mexico. Data were collected from the follwoing localities: (a) near Buffalo Lake dam, western Randall County, Texas; (b) U.S. Highway 385 at the southern edge of the Canadian River Valley, eastern Oldham County, Texas; (c) New Mexico State Highway 93 at the western caprock escarpment, Quay County, eastern New Mexico; and (d) 1.8 km north of Lighthouse Peak at Palo Duro Canyon State Park, eastern Randall County, Texas.

The clastic dikes cut Triassic Dockum sediments and the joints were measured in Triassic Dockum (Trd) and Tertiary Ogallala (To) rocks. The joint data from the Buffalo Lake locality (a) are from Finley and Gustavson (1981, p. 25).

Figure 1

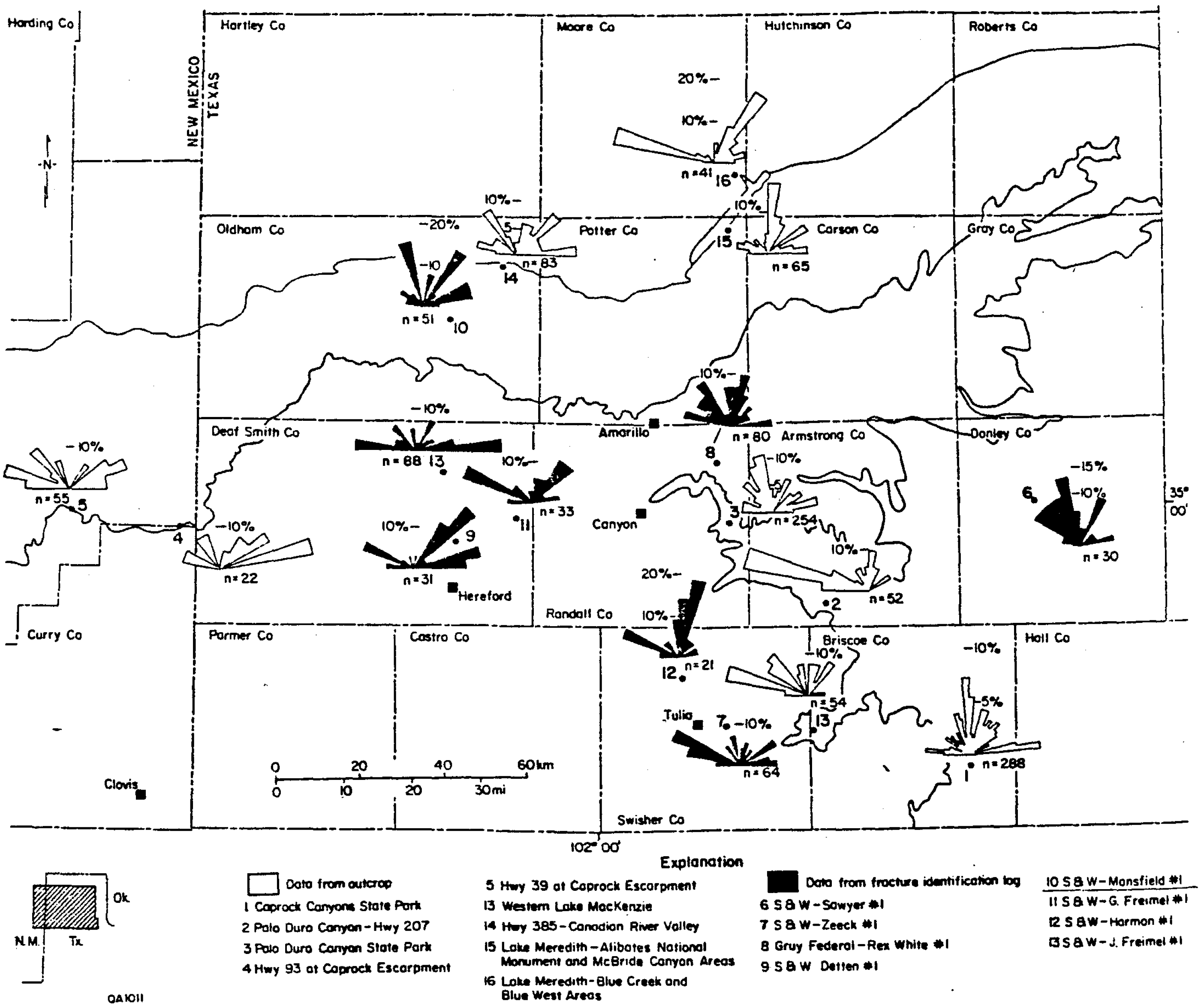
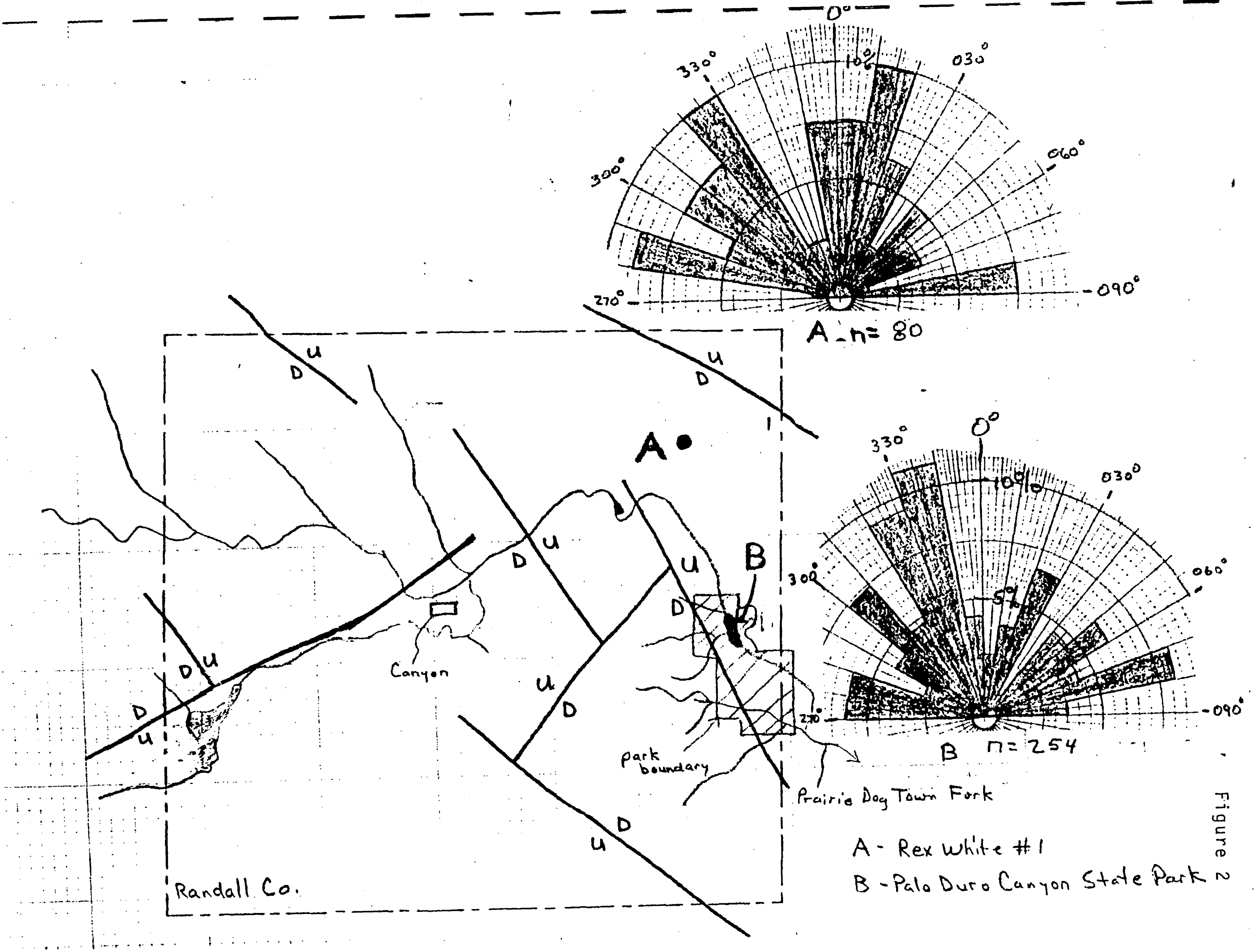
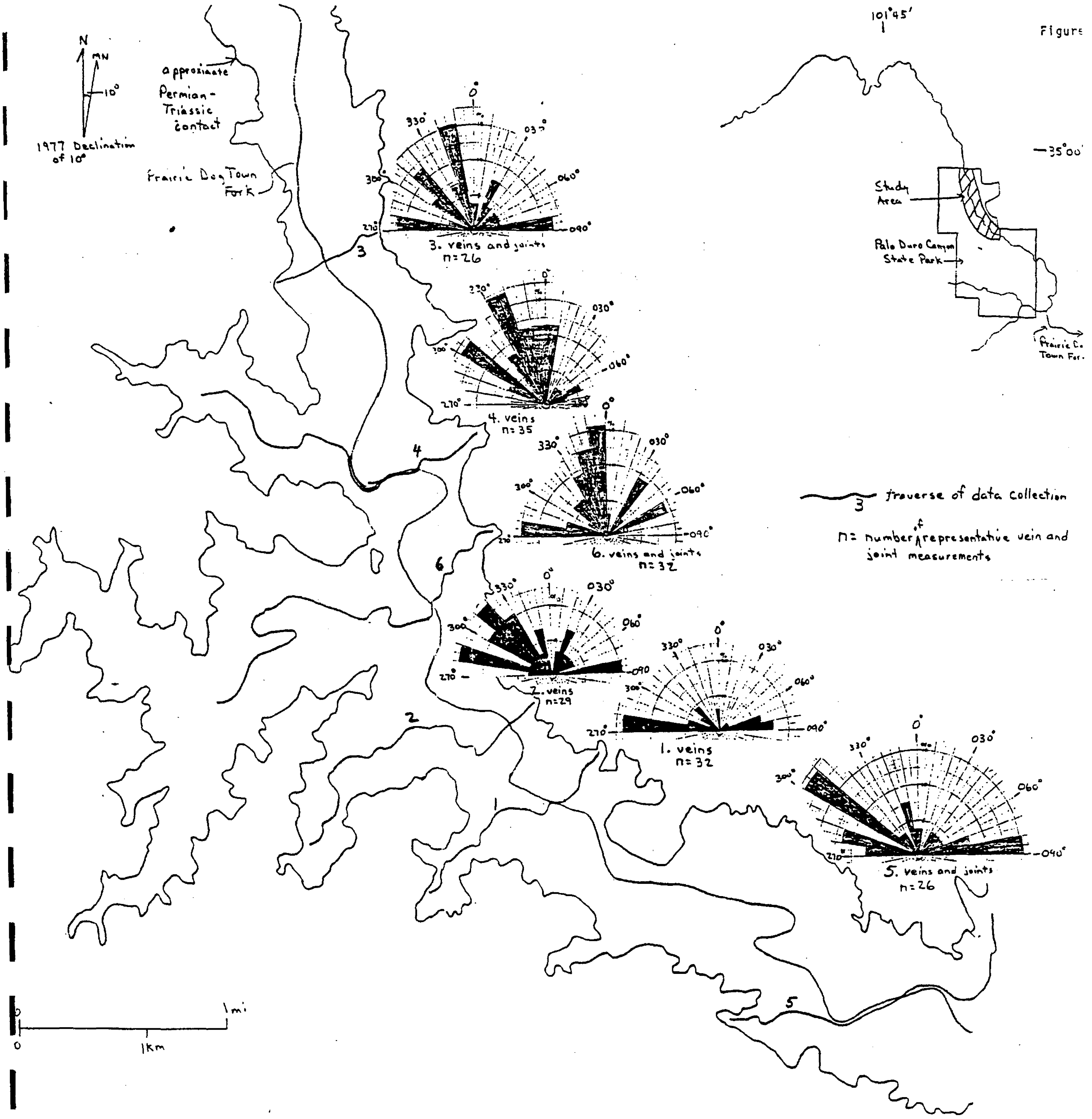

Harding Co
Hartley Co
Moore Co
Hutchinson Co
Roberts Co
NEW MEXICO
TEXAS
N
Oldham Co
Potter Co
Carson Co
Gray Co
Deaf Smith Co
Amarillo
Armstrong Co
Donley Co
Canyon
Hereford
Randall Co
Curry Co
Parmer Co
Castro Co
Briscoe Co
Hall Co
Tulia
Clovis
Swisher Co
35° 00'
102° 00'
20%
10%
n=41
16
15
n=65
5
n=83
14
-20%
-10
n=51
10
n=80
8
-10%
n=88
13
n=33
11
-10%
n=55
5
4
n=22
10%
9
n=31
3
n=254
10%
n=52
2
-15%
-10%
6
n=30
20%
10%
12
n=21
n=54
13
7
n=64
5%
1
n=288
0 20 40 60 km
0 10 20 30 mi
Explanation
Data from outcrop
1 Caprock Canyons State Park
2 Palo Duro Canyon-Hwy 207
3 Palo Duro Canyon State Park
4 Hwy 93 at Caprock Escarpment
5 Hwy 39 at Caprock Escarpment
13 Western Lake MacKenzie
14 Hwy 385-Canadian River Valley
15 Lake Meredith-Alibates National Monument and McBride Canyon Areas
16 Lake Meredith-Blue Creek and Blue West Areas
Data from fracture identification log
6 S & W-Sawyer #1
7 S & W-Zeeck #1
8 Gruy Federal-Rex White #1
9 S & W Detten #1
10 S & W-Mansfield #1
11 S & W-G. Freimel #1
12 S & W-Harmon #1
13 S & W-J. Freimel #1
Ok.
N.M.
Tx.
QA1011

Figure 2



A - Rex White #1

B - Palo Duro Canyon State Park



N
MN
10°
1977 Declination of 10°
approximate Permian-Triassic contact
Prairie Dog Town Fork
3
4
6
2
1
5
3. veins and joints n=26
4. veins n=35
6. veins and joints n=32
2. veins n=29
1. veins n=32
5. veins and joints n=26
0°
030°
060°
090°
270°
300°
330°
101°45'
35°00'
Study Area
Palo Duro Canyon State Park
Prairie Dog Town Fork
traverse of data collection
n= number of representative vein and joint measurements
0
1mi
1km

Figure

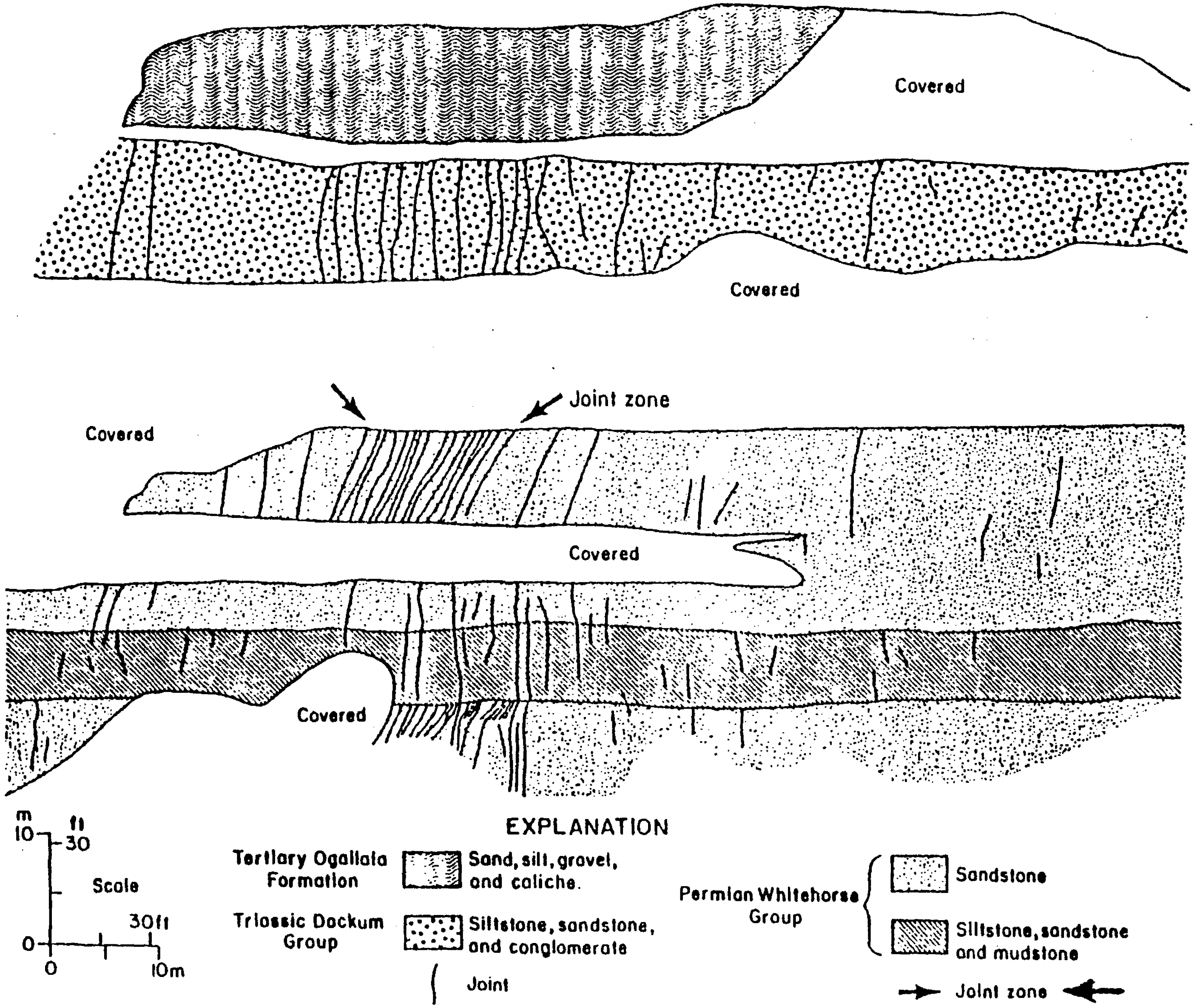

Covered
Covered
Joint zone
Covered
Covered
Covered
m
ft
10
30
Scale
0
0
30ft
10m
EXPLANATION
Tertiary Ogallala Formation
Sand, silt, gravel, and caliche.
Triassic Dockum Group
Siltstone, sandstone, and conglomerate
Joint
Permian Whitehorse Group
Sandstone
Siltstone, sandstone and mudstone
Joint zone

Figure 4

Figure 5

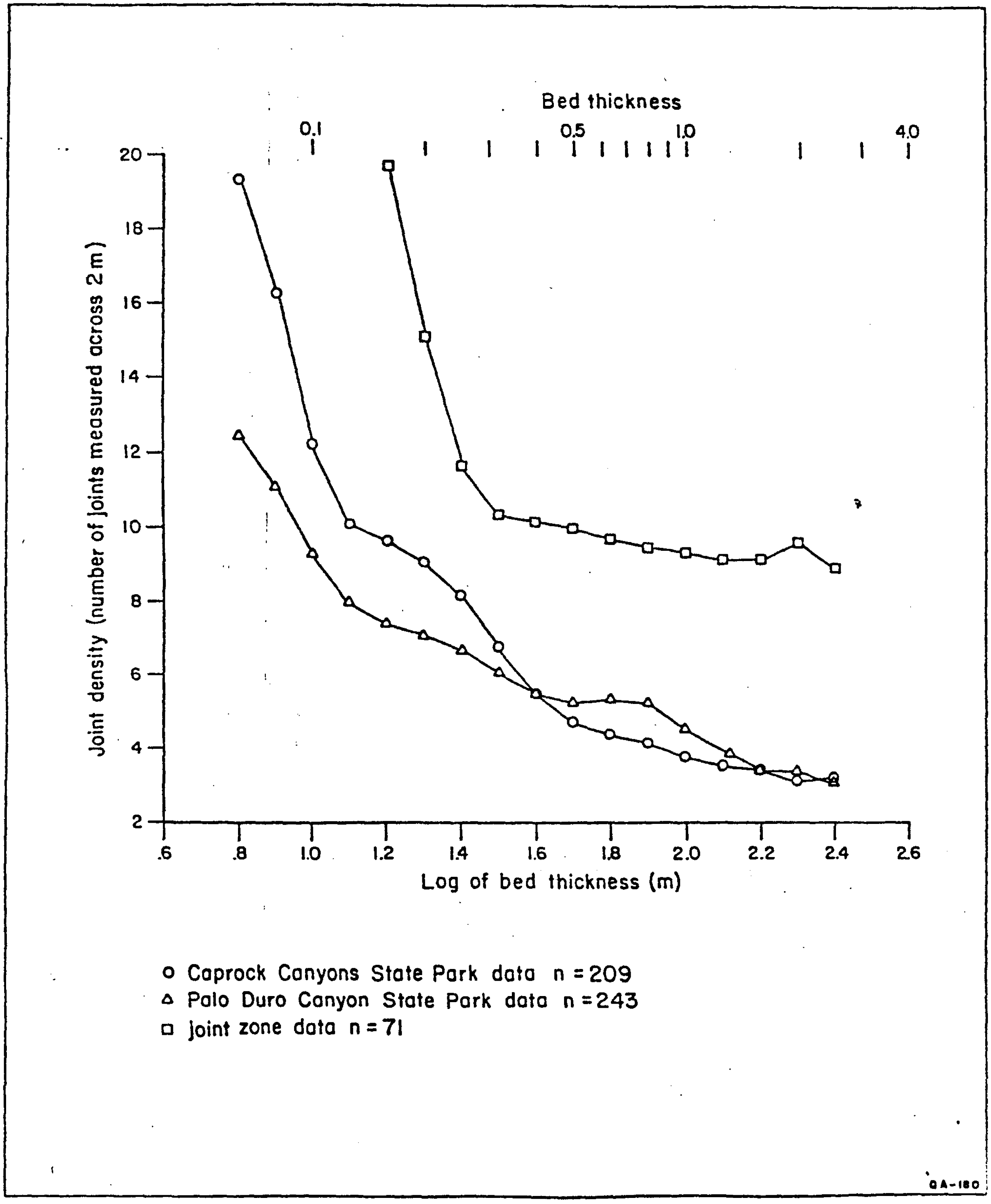
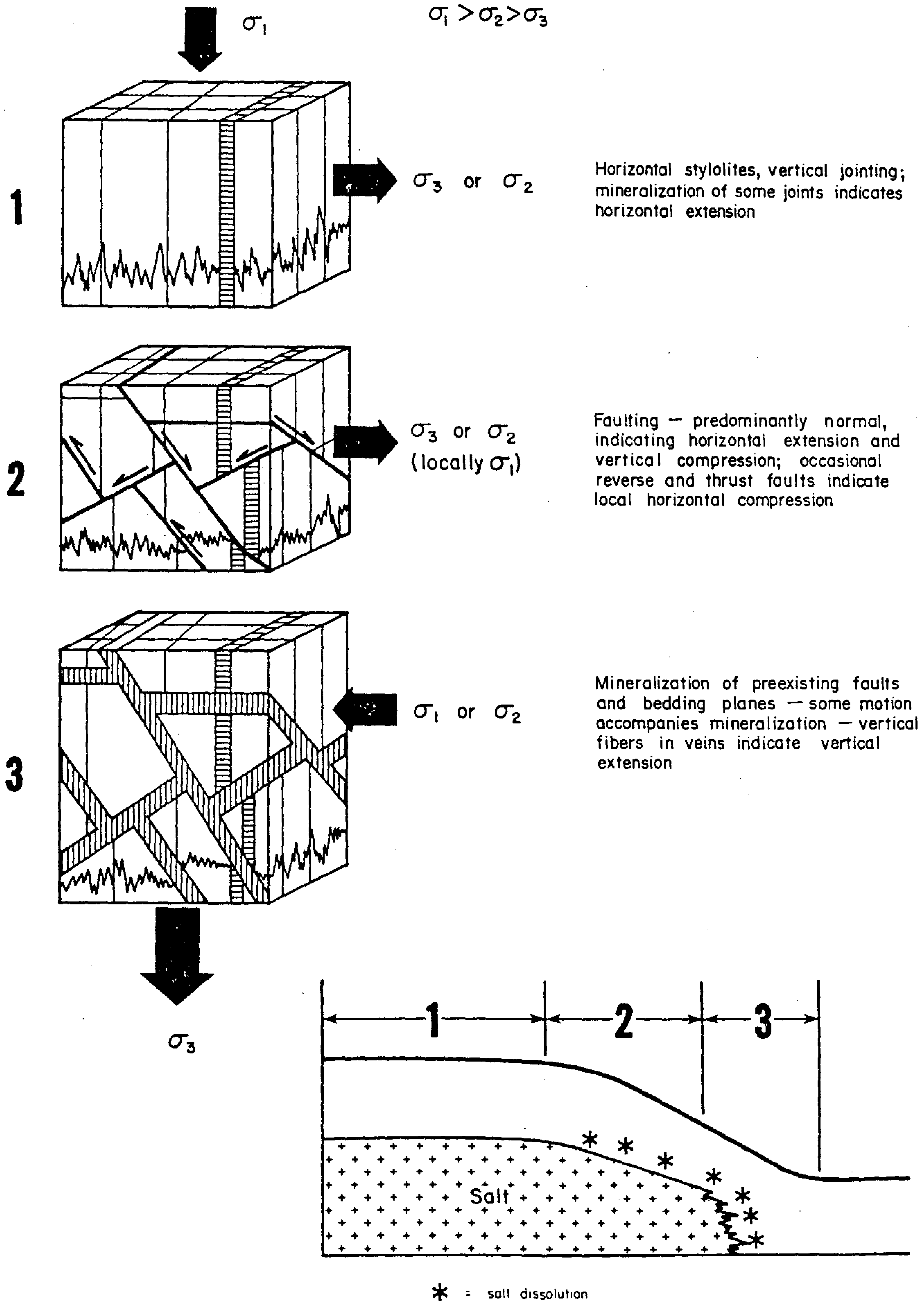

Bed thickness
0.1
0.5
1.0
4.0
Joint density (number of joints measured across 2 m)
20
18
16
14
12
10
8
6
4
2
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
Log of bed thickness (m)
○ Caprock Canyons State Park data n = 209
△ Palo Duro Canyon State Park data n = 243
□ joint zone data n = 71
QA-180

Figure 6



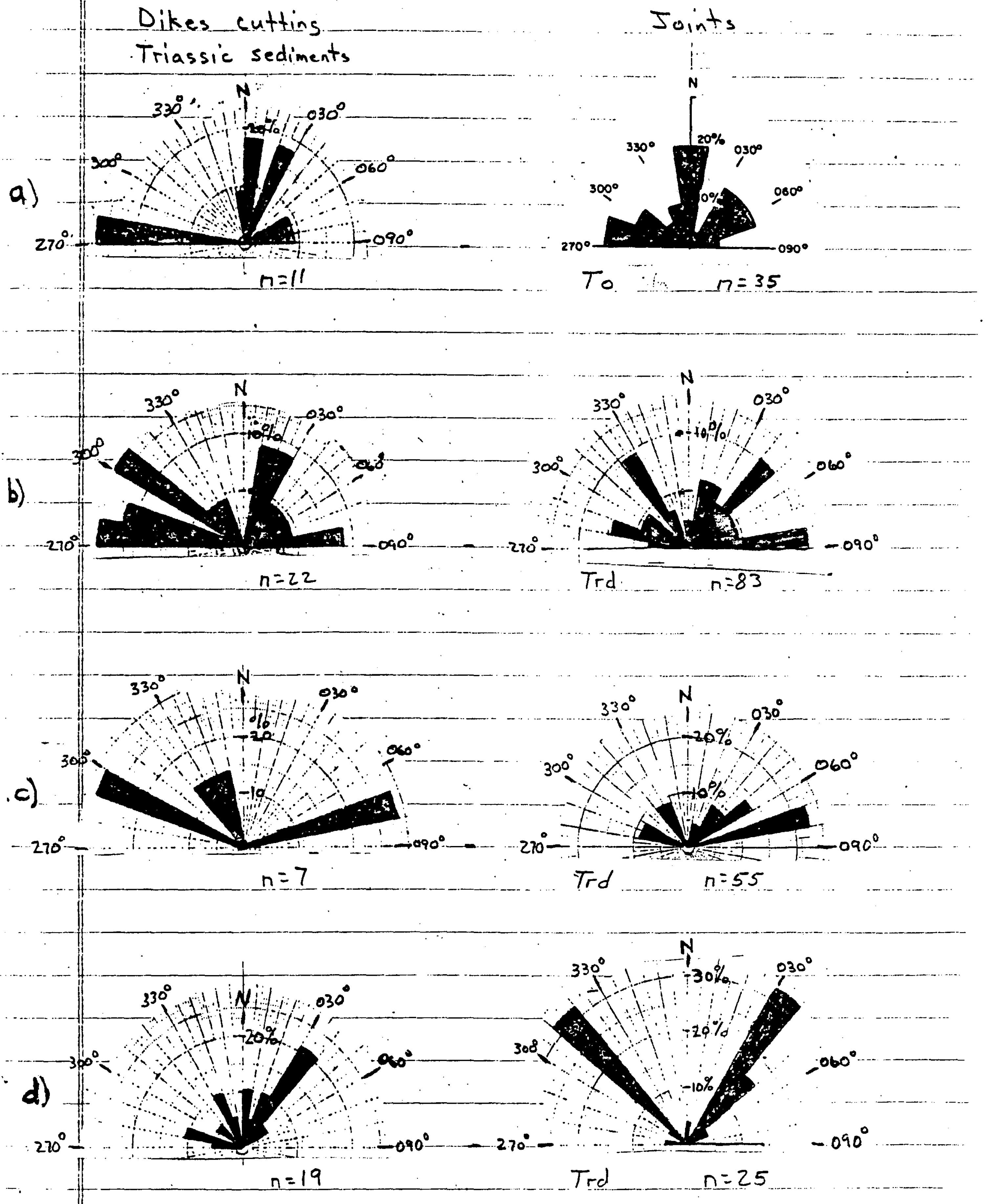
Horizontal stylolites, vertical jointing; mineralization of some joints indicates horizontal extension

Faulting — predominantly normal, indicating horizontal extension and vertical compression; occasional reverse and thrust faults indicate local horizontal compression

Mineralization of preexisting faults and bedding planes — some motion accompanies mineralization — vertical fibers in veins indicate vertical extension

Conceptual model of brittle deformation above dissolution zones. Stage 1 represents normal burial; Stage 2 represents horizontal extension as a precursor to dissolution collapse; and Stage 3 represents collapse.

Figure 7


Dikes cutting Triassic sediments
Joints
a)
N
330°
030°
20%
300°
060°
270°
090°
n=11
N
20%
330°
030°
300°
10%
060°
270°
090°
To
n=35
b)
N
330°
030°
10%
300°
060°
270°
090°
n=22
N
330°
030°
10%
300°
060°
270°
090°
Trd
n=83
c)
N
330°
030°
20
300°
060°
10
270°
090°
n=7
N
330°
030°
20%
300°
060°
10%
270°
090°
Trd
n=55
d)
N
330°
030°
20%
300°
060°
270°
090°
n=19
N
330°
030°
30%
20%
300°
060°
10%
270°
090°
Trd
n=25