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LINEAMENTS PERCEIVED ON LANDSAT IMAGERY OF CENTRAL TEXAS--APPLICATIONS TO GEOTHERMAL RESOURCE ASSESSMENT[1]

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Linear trends of various geologic, geochemical, and geophysical phenomena are commonly observed in conjunction with geothermal resources. Examples include the geographic control of warm springs in western Virginia by fracture zones that trend normal to prevailing Appalachian structures (Geiser, 1979). Similar cross-cutting relations occur in the Ouachita Mountains at Hot Springs, Arkansas (Bedinger and others, 1979). Lineaments have also been frequently employed as a tool to delineate hydrothermal manifestations (both as ore deposits and as thermal resources) in the Cordillera of western North America. Presumably the coincidence of hydrothermal phenomena and lineaments relates in a general way to structural/tectonic influences on heat flow and on the migration of fluids. Simply put, active tectonic zones are areas of crustal discontinuities (thin crust in rift zones, for example), locally high heat flow, and marked seismicity; some of the surface manifestations of active tectonism in these areas may be perceived as lineaments. Yet even for relict areas of tectonic disturbance (for example, "dormant" orogens), there commonly are thermal expressions that are thought to result from deep circulation of waters along fractures and steeply dipping beds. Such areas are also often denoted by lineaments. However, as observed by Steeples and others (1979), some of these presumed "dormant" areas may still be more active than is generally recognized; microseismicity, for example, may accompany local heat-flow anomalies, and if hydrologic conditions are favorable, a geothermal resource may occur.

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The work by Steeples and coworkers is an important point of departure for our discussion, because that study dealt with a buried orogen, the Nemaha Ridge of the Mid-Continent. Moreover, the buried structure is also denoted by a trend of lineaments at the earth surface (McCauley and others, undated). Buried structural trends, then, may have surface expression through lineaments, and such features may be favorable loci for geothermal resources because of either locally high heat flow or heat convection by upwelling waters.

As part of a statewide assessment of geothermal resources in Texas, we evaluated lineaments perceived on Landsat images. The logic behind this effort is that, except for the Trans-Pecos area, Texas largely comprises terrain that is underlain by flat-lying sedimentary rocks. Fundamentally, our guiding hypotheses have been: 1.) geothermal anomalies accompany structural discontinuities; and 2.) structural discontinuities--even buried (or dormant) features--may be subtly expressed at the ground surface. A synoptic overview afforded by Landsat images provides a means to perceive large-scale (albeit subtle) features that indirectly indicate structural, hydrologic, and thermal anomalies.

We present here a case study that shows the convergence of seemingly diverse phenomena. As in the aforementioned studies of the Nemaha Ridge, we focus on a buried orogen--the Ouachita structural trend in Central Texas, a foundered hinge zone between the Texas Craton and the downwarping Gulf Coast Basin (fig. 1). Our aim is to show that lineaments may provide evidence for buried structures, which, in turn, apparently control the location of geothermal anomalies.

We developed a method for perceiving lineaments statewide that entailed each of three observers[2] independently viewing 51 Band-5 Landsat images for

[2]For the study area, the third person was Gary E. Smith. Eric J. Thompson assisted in these efforts and worked subsequently on numerical evaluation of these lineaments.

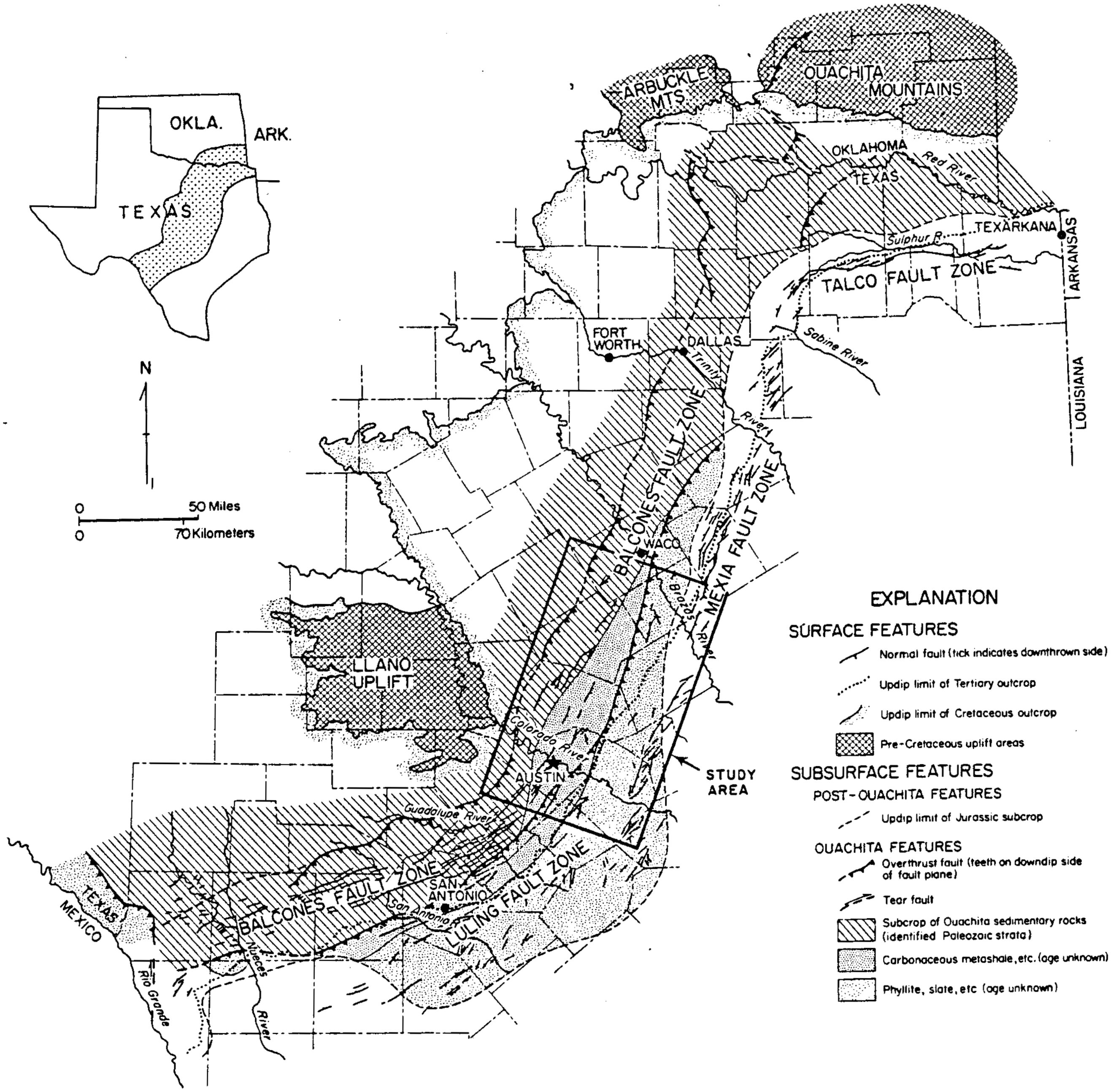

Figure 1. Balcones/Ouachita structural trend, Central Texas and location of lineament study area.

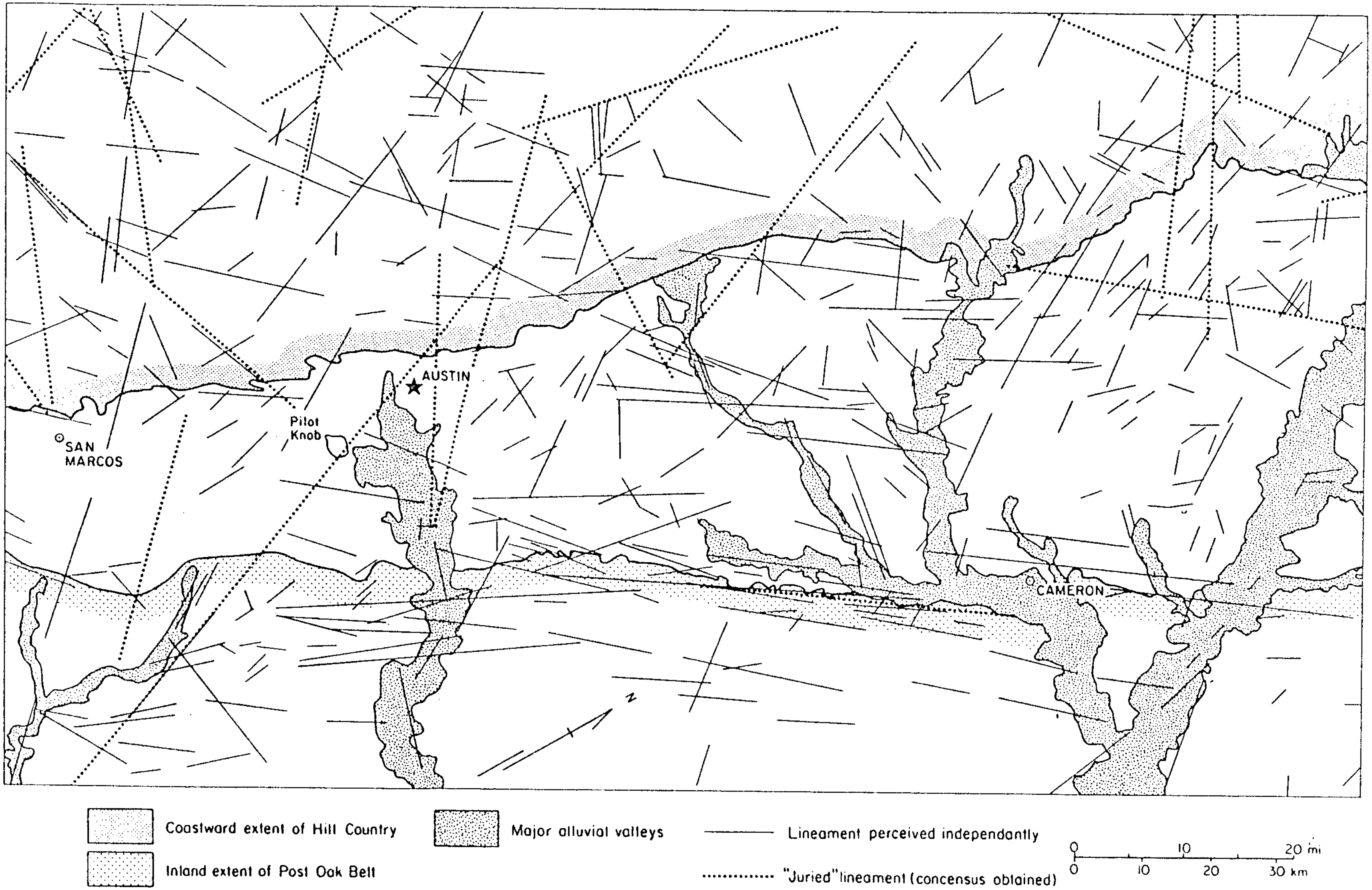

Figure 2. Lineaments perceived in study area; note, Blackland Prairie is the physiographic area between the Hill Country and the Post Oak Belt.

two periods of 30 minutes each (see Caran and others, 1981). For a pilot study in Central Texas we also conjointly viewed several mosaicked images and thus mapped large-scale, throughgoing figures as "juried" lineaments (fig. 2) along with the other linear features that we perceived independently. These two operations resulted in our perceiving more than 400 lineaments in an area of approximately 8680 km^2. We consider the lineaments, thus perceived, to be "raw data" without particular value until they are interpreted. In short, there is probably a high "noise to signal" ratio in a depiction of this kind. The interpretation of these data should allow a better discrimination of the salient information (signal) from the random background (noise).

Two sets of features stand out in this depiction of lineaments in Central Texas. One set trends oblique to the strike of stratigraphic units (that is, oblique to the boundaries of the Hill Country and the Post Oak Belt as depicted in figure 2). The other set aligns roughly parallel to the prevailing strike.

The oblique-trending lineaments compose mainly "juried" lineaments, although there are also families of the generally shorter features perceived by individual observers that, in the aggregate, produce orientations oblique to strike. We have no hypotheses on the implications of these features, except to note that Pilot Knob, a Cretaceous marine volcanic plug southeast of Austin, lies along the intersection of two of these large lineaments (fig. 2). Also, the northwest orientation exhibited by some of these features parallels a predominant trend of the Brazos River alluvial valley which, when depicted at a regional-scale, may be a giant lineament extending for over 120 miles oblique to the structural and depositional strike of the region.

The lineament trend that is parallel to strike of strata is the expected set--especially along the Balcones Fault Zone. This is because of the abrupt discontinuity in bedrock, soils, vegetation, and land use that occurs along this structural trend. There are similar but more subdued surface expressions along the contacts of most formations along the Gulf Coastal Plain of Texas. The initial implication of this set of lineaments is that we have merely rediscovered the Balcones Fault Zone, or we have perceived the contacts of mapped stratigraphic units. If these findings account for the entire significance of the strike-parallel lineaments, then that family of lines is clearly trivial. We intend to demonstrate, however, that we have, instead, perceived a previously unrecognized zone of structural dislocation that has implications on the location of geothermal resources in Central Texas.

Of the lineaments parallel to strike, one set is especially prominent. These features compose a northeast-trending family of lines along the boundary between the Post Oak Belt and the Blackland Prairie. The lineaments lie mainly along the alluvial reaches of Brushy Creek near its confluence with the San Gabriel River and the Little River system. We have named the feature the Brushy Creek Lineament. Actually, several lineaments make up this zone. They include the coincidence of a major (juried) lineament and a high density of parallel, smaller features that align with relict and modern stream reaches, a straight drainage divide, a west-facing topographic escarpment, and the contact between the Midway and Wilcox Groups of Eocene age. This stratigraphic contact is also responsible for the major physiographic break between the Post Oak Belt and the Blackland Prairie and the attendant changes in soils, vegetation, and land use.

The intriguing thing about this particular part of the Post Oak Belt/Blacklands border is its remarkable linearity. In fact, this family of lines is much more strongly expressed in our lineament survey than is the Balcones fault-line escarpment, which is an area of similar physiographic importance but one clearly documented as a structural zone. Yet, no major structural discontinuity has been previously documented between the Post Oak Belt and the Blackland Prairie;

there, only a single short fault is mapped at the surface along this trend (Barnes, 1974). It is our thesis that this lineament zone is the surface expression of a deep-seated structural disturbance of a significance similar to the Balcones fault trend farther west.

To test this thesis we collected several types of independent evidence that bear on subsurface structures in the area (fig. 3). We have located subsurface faults displacing the basal Cretaceous Hosston Sand and the (shallower) Edwards Limestone (see Woodruff and McBride, 1979). We also obtained additional well data and constructed a new map showing faults displacing the Buda Limestone (a prominent subsurface datum on electric logs) along the trend of the Brushy Creek Lineament.

Several other structurally related phenomena also converge along this lineament trend. They include buried igneous plugs and associated oil fields, the updip subcrop limit of Jurassic rocks (the first indication of marine conditions along the western margin of the Gulf of Mexico during Mesozoic time), and the proximity of major basement discontinuities in the Ouachita rocks as mapped by Flawn and others (1961). In short, the convergence of these diverse structural data indicate that the Brushy Creek Lineament zone delimits the eastern part of the Ouachita hinge, just as surface faults of the Balcones system roughly delimit the western margin of that hinge.

The eastern margin of the Balcones/Ouachita structural trend is important in a geothermal context because this zone marks a major change in orientation of depositional systems--from dip-fed fluvial sand bodies on the west to strike-fed lagoonal and marine, sand, mud, and carbonate deposits on the east. This change in depositional systems (documented by Woodruff and McBride, 1979) marks the deepest part of a hydrologic system that allows ready access of meteoric recharging waters to depths sufficient for markedly increased water temperature

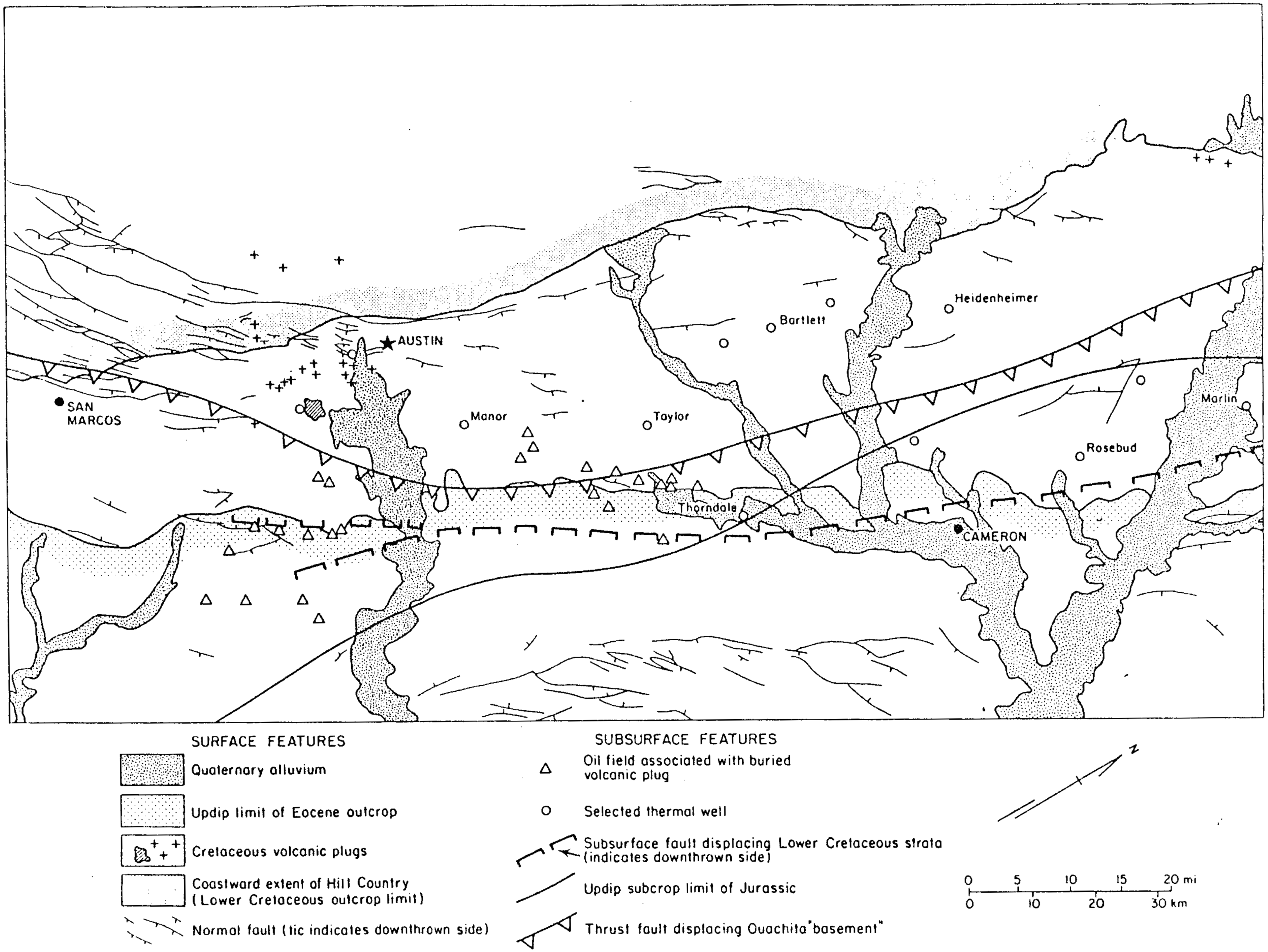

Figure 3. Surface and subsurface structural features in study area; note convergence of features near the Brushy Creek Lineament southwest of Cameron.

(given prevailing geothermal gradient) while maintaining low to moderate concentrations of dissolved solids.

A contour map of geothermal gradients across the study area shows gradient anomalies to generally align along the trend of the Brushy Creek Lineament (fig. 4). These anomalies may not indicate a zone of high heat flow (as would be expected in an area of active tectonism) but instead may indicate a locus of upwelling waters. The alignment of oil fields argues for this interpretation, in that the igneous plugs provide the preferred avenues for upward flow of waters and entrained hydrocarbons. As pointed out by Plummer and Sargent (1931), such areas of upwelling waters and hydrocarbons are part of expected basin-wide hydrologic interactions that also include geothermal gradient anomalies and the occurrence of warm (often saline) waters at a relatively shallow depth.

There are several thermal water wells in our study area. No discernible trend exists, however, because the locations of these wells are dictated by the prior siting of towns for which the wells supply water. On the basis of this lineament survey, we conclude that an exploration program for hydrothermal waters of potable quality should focus on the western side of the lineament zone in order to tap downward flowing recharge systems within the dip-oriented depositional facies. Hotter waters may occur on the eastern side of the lineament zone, but these would largely be upwelling waters from deep within the Gulf Coast Basin, and thus salinity would probably be quite high.

In summary, lineaments may provide a tool for locating "blind" geothermal resources, because they are subtle indications of subjacent tectonic disturbances in areas covered by flat-lying rocks. Lineaments may be the surface expressions of fractures propagated upward through undisturbed strata. Such fractures may provide enhanced permeability avenues for downward flow of recharging

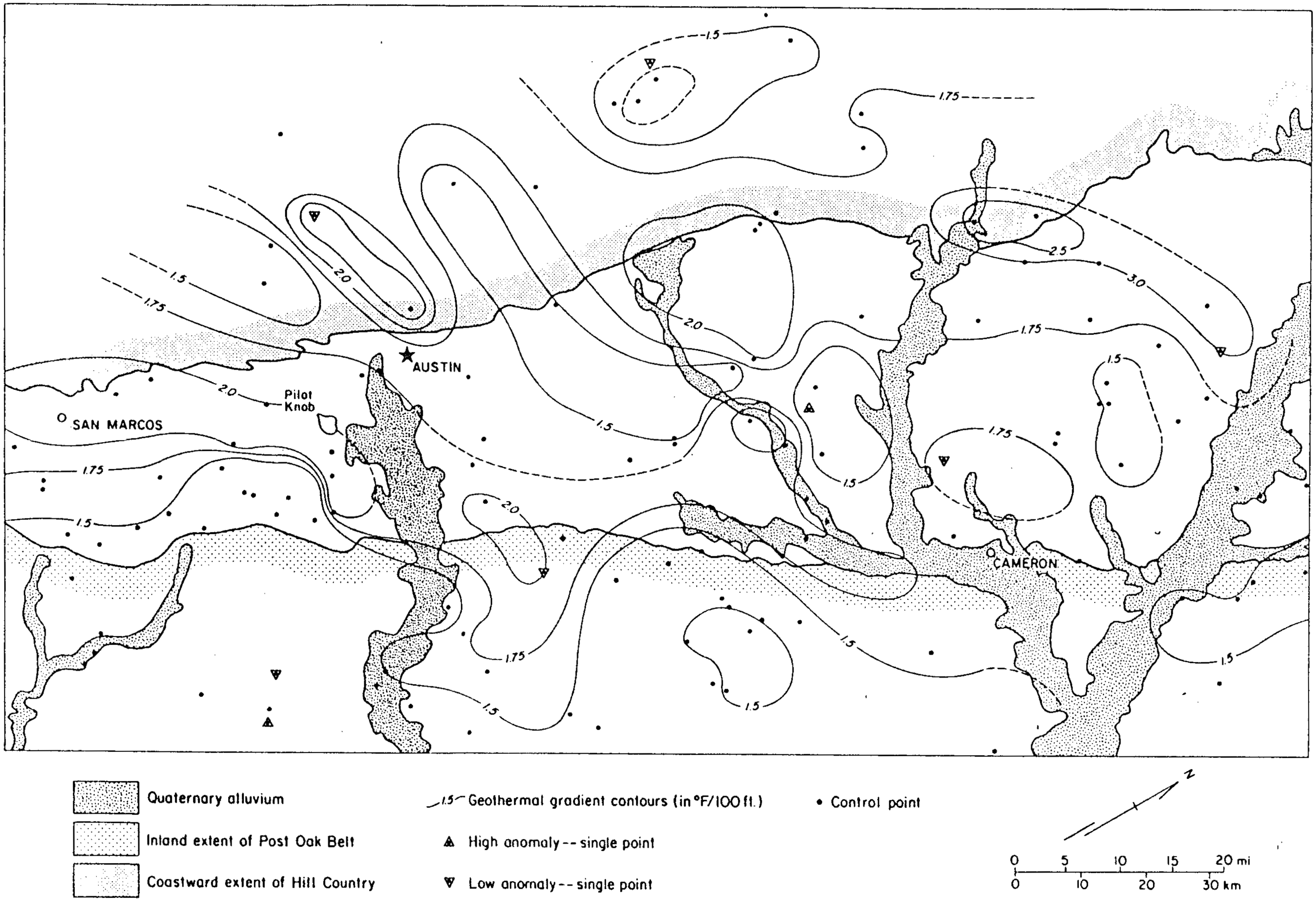

Figure 4. Geothermal gradient contours across lineament study area.

waters to a depth sufficient for thermal enhancement above mean annual air temperature. Also, such areas of high lineament concentrations may mark the loci of upwelling of hot (and often saline) waters from deep within a sedimentary basin.

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