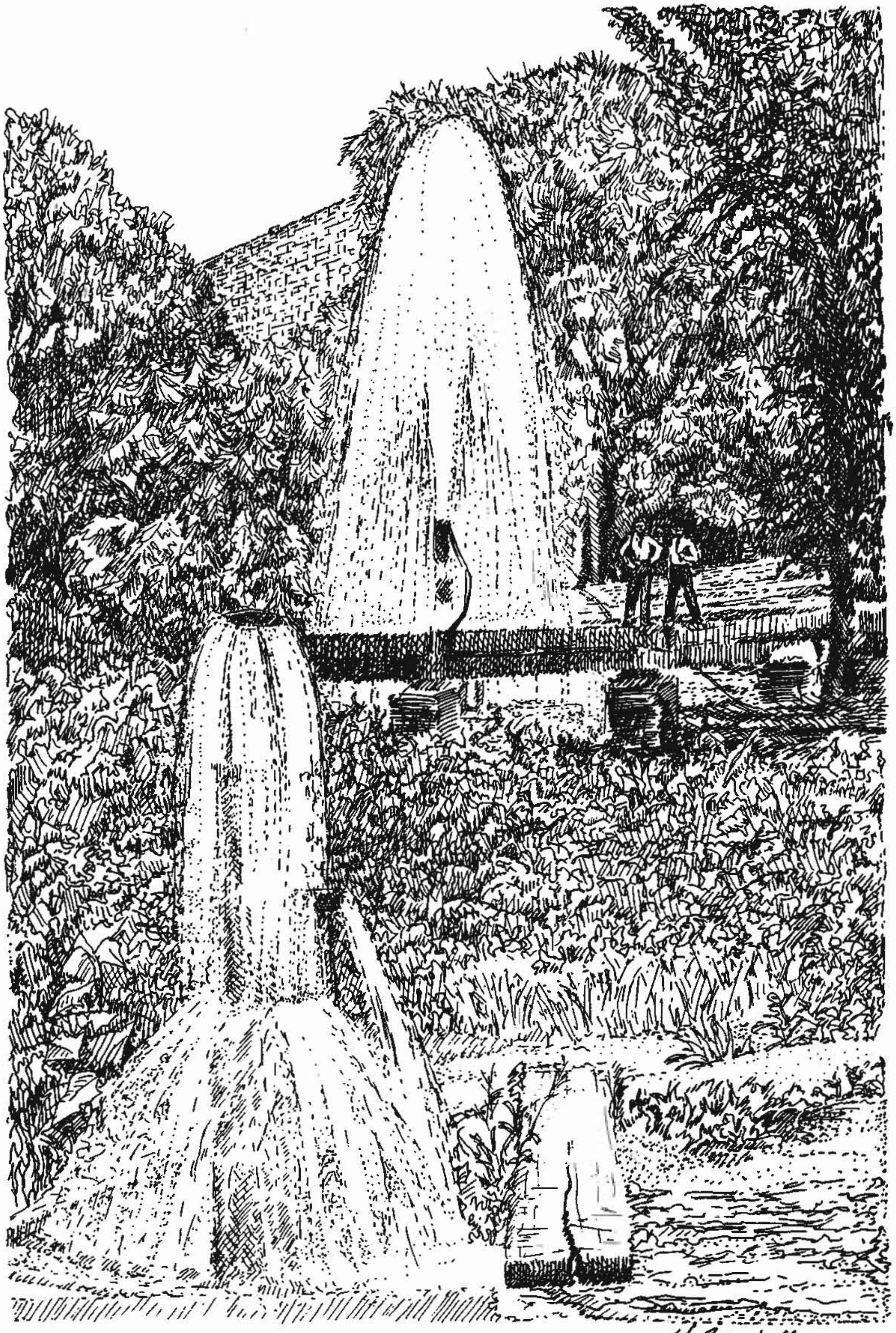
THE BALCONES ESCARPMENT



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STRUCTURAL STYLE IN AN EN ECHELON FAULT SYSTEM, BALCONES FAULT ZONE, CENTRAL TEXAS: GEOMORPHOLOGIC AND HYDROLOGIC IMPLICATIONS

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ABSTRACT

Detailed geologic mapping in the Balcones fault zone in the San Marcos area has revealed a structural style that may have had a profound effect on the geomorphologic and hydrologic evolution of the area. Two major en echelon step fault zones are present in the area, and a highly faulted ramp structure has formed in the zone between the en echelon fault zones.

Differential erosion of rock units in the ramp structure may have determined the course of a stream which captured the Blanco River from an easterly flow direction into the Onion Creek basin to its current southeasterly flow direction. Subsequently, the Blanco may have "tapped" the Edwards aquifer by down-cutting or side-cutting action at or near the San Marcos Springs location. Thus, both the capture of the Blanco and the current location of San Marcos Springs hay have been indirectly caused by the local structural setting between the two major en echelon fault zones of the Balcones system.

Similar major ramp structures are apparent by map inspection in at least three other locations in the Balcones fault zone, one near Austin and two west of San Antonio. A fourth structure may also be present near New Braunfels.

INTRODUCTION

The Balcones fault zone is a tensional structural system consisting of numerous normal faults, cross faults, grabens, horsts, step faults, en echelon faults, and similar features in central and south Texas. The fault zone extends from Waco southward to Austin and San Antonio and then westward to Del Rio. Generally, the rocks exposed at the surface west of the fault zone are Lower Cretaceous stratigraphic units consisting of resistant limestones, dolomites, and marls; east of the zone, the rocks exposed are Upper Cretaceous nonresistant chalk and calcareous clay units. The difference in resistance to erosion has resulted in a fault-line scarp known as the Balcones Escarpment. Soils east of the scarp are deep and well developed, and the predominant historical agricultural land use has been for cropland. West of the scarp, the soils are thin and rocky, and ranchland is the the predominant agricultural land use.

The Balcones Escarpment and fault zone are especially well developed in the area around San Marcos, Texas about 35 miles south of Austin. The purpose of this paper is first to describe the structural style in a case study area between two major en echelon step fault systems and then to set forth hypotheses on geomorphologic and groundwater implications of the zone of adjustment between these en echelon fault systems. The discussion of structural style and resulting outcrop patterns is based upon detailed geologic mapping for environmental geologic purposes in two 7-1/2 minute topographic quadrangles in the rapidly growing San Marcos area (Grimshaw, 1976).

The principal features of the case study area, besides the city of San Marcos, are Interstate 35, the town of Kyle, the Blanco River, Purgatory Creek, Sink Creek, San Marcos Springs, and the San Marcos River (Figure 1).

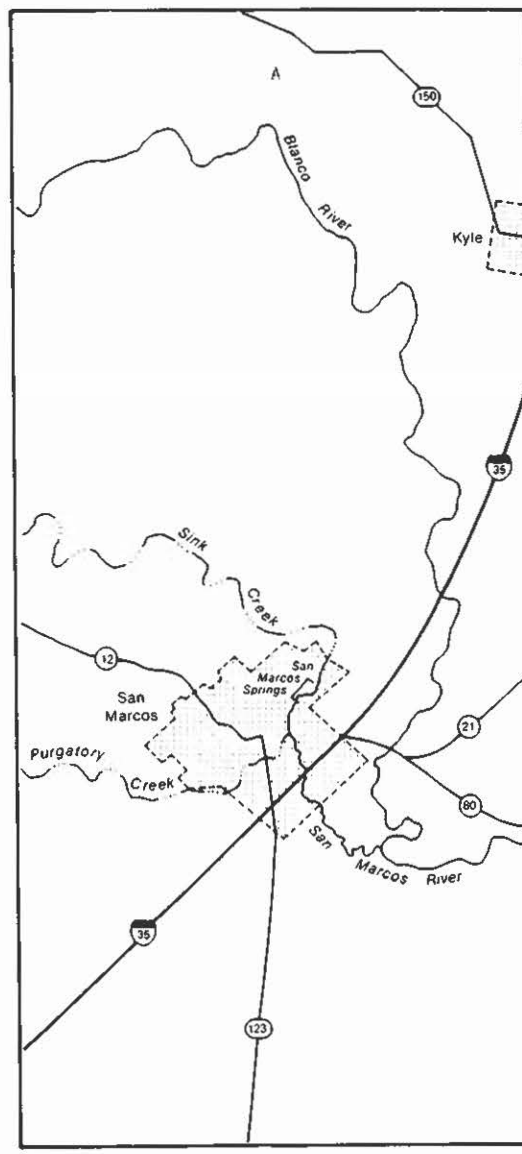

Figure 1. Principal Features Of The San Marcos Case Study Area.

in Abbott, Patrick L. and Woodruff, C. M., Jr., eds., 1986.
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GEOLOGIC OVERVIEW

A generalized geologic map of the San Marcos area is shown in Figure 2. The principal rock-stratigraphic units in the area, in descending stratigraphic order, are shown below. All are Cretaceous in age.

Unit	Approximate Thickness (ft)
Taylor Group (clay)	925
Austin Group (chalk)	170
Eagle Ford Formation (clay)	25
Buda Formation (limestone)	50
Del Rio Clay	50
Georgetown Formation (marl)	33
Edwards Group (limestone)	475

Major faults of the Balcones system traverse the study area from northeast to southwest. The net displacement in the case study area, as elsewhere in the Balcones fault zone, is downward to the southeast. The faults of major displacement strike about N30 E. The Edwards Limestone crops out over most of the area west and north of these faults, and the Austin chalk and Taylor clay compose the subsurface east and south of the faults. Outcrops of the thin intervening formations between the Edwards and Austin occur in numerous fault blocks within the fault zone.

The regionally important Edwards aquifer is especially significant in the San Marcos area, both as an essential source of copious fresh water and as a recreational resource associated with San Marcos Springs. These springs are a major discharge point of the Edwards aquifer; discharge averages about 161 million gallons per day. The extensive outcrop area of the Edwards limestone in the western and northern portions of the area is an important part of the aquifer recharge zone.

The Balcones fault zone enters the northeastern part of the case study area as two major step faults -- Mustang Branch fault and Mountain City fault (Figure 2). These faults are referred to hereafter as the "northeastern step fault zone". The Kyle fault, located farther to the southeast, is another step fault in this succession. Similarly, the Balcones fault zone is represented in the southwest part of the area by three major step faults -- Comal Springs fault, San Marcos Springs fault, and Bat Cave fault, referred to hereafter as the "southwestern step fault zone". The major northeastern and southwestern step fault zones are thus in en echelon relationship across the study area.

The fact that fault traces are not at all influenced by topography indicates that all faults are vertical or nearly so.

STRUCTURAL INTERPRETATION

The cumulative displacement across the northeastern step fault zone generally decreases to the southwest. Similarly, cumulative displacement across the southwestern step fault zone decreases to the northeast. Thus, the total displacement downward to the southeast remains relatively constant across the study area, but is "transferred" from the northeastern to the southwestern step fault zone as is typical for en echelon fault zones in a tensional fault system like the Balcones.

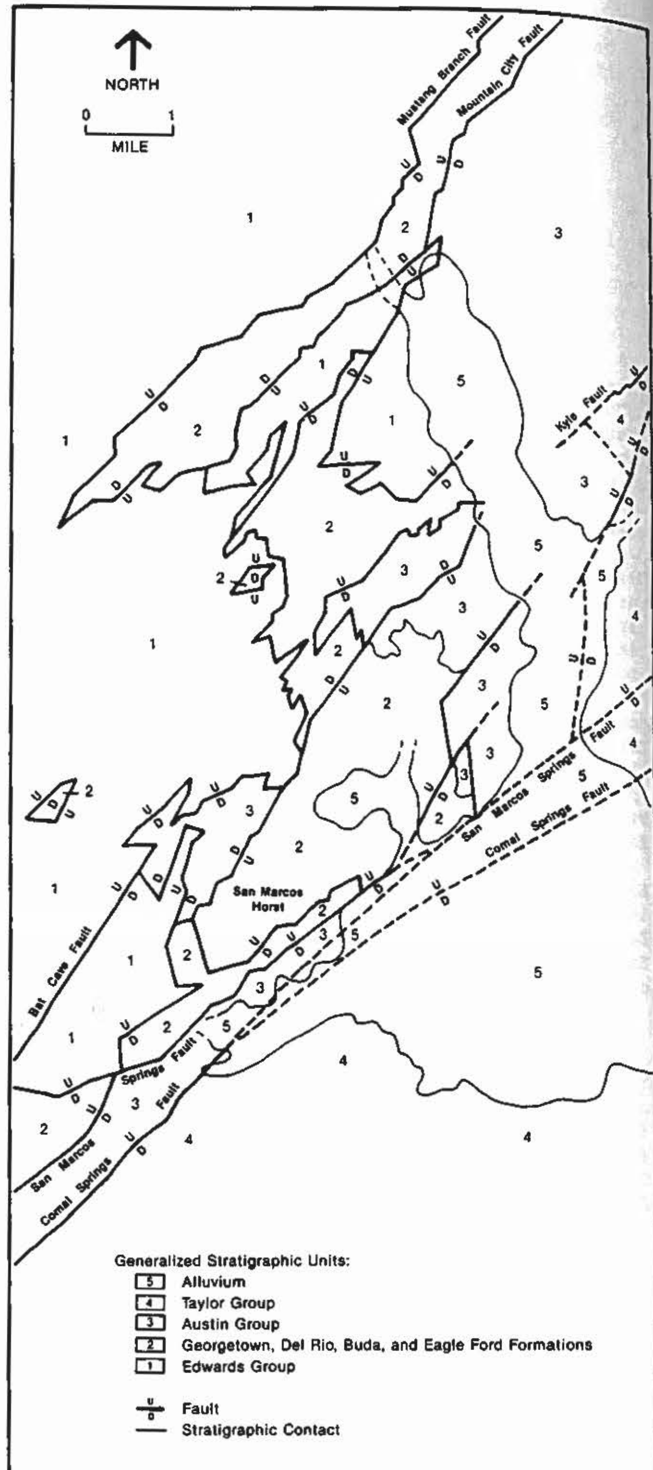

Figure 2. Simplified Geologic Map Of San Marcos Area, Showing Step Fault Zones and Associated Faulting In The Area Between.

The transfer of displacement between the step fault zones is shown in block diagram form in Figure 3. The area of adjustment between the step fault zones forms a ramp-like structure which bends downward to the northeast from the upthrown side of the southwestern step fault zone to the downthrown side of the northeastern step fault zone. If this ramp were eroded to a level surface parallel to the bottom of the block in the diagram, an outcrop pattern with older rock units exposed in the southwest and successively younger units exposed to the northeast would be displayed. Just such a pattern is exhibited in the case study area, where Edwards limestone exposures in the southwest part of the area, on the upthrown side of the southwestern fault zone, give way northeastward to Austin chalk and Taylor clay bedrock on the downthrown side of the northeastern step fault zone.

The ramp structure is broken up into several irregularly shaped grabens, horsts, and step fault blocks which are, in turn, broken up into numerous small, irregular fault blocks as small as 100 yards (or less) in dimension as shown in Figure 4. The overall structural grain of the faulting in the ramp is consistent with the regional Balcones fault zone, with the larger-displacement faults having a northeastward orientation, but with the smaller cross faults oriented in all directions.

The geometry of the larger grabens and horsts, as well as the much smaller individual fault blocks within them, suggests that the ramp was subjected to some torsional stresses, in addition to the dominant tensional stresses, as the southeastern part of the area "dropped away" from the northwestern part and the ramp area adjusted to the transfer of displacement from the northeastern to the southwestern step fault zone.

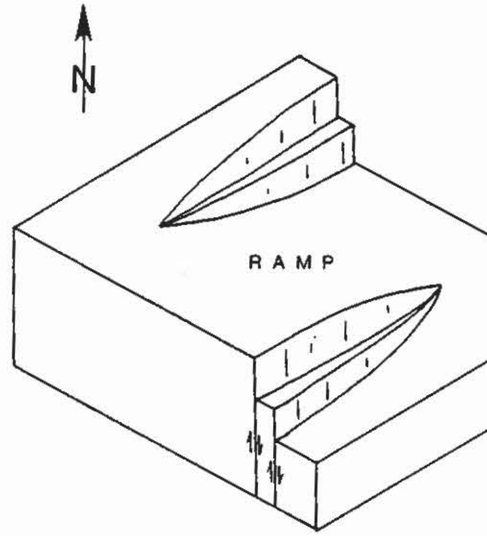

Figure 3. Block Diagram Of En Echelon Step Fault Zones Showing Intervening Ramp Structure.

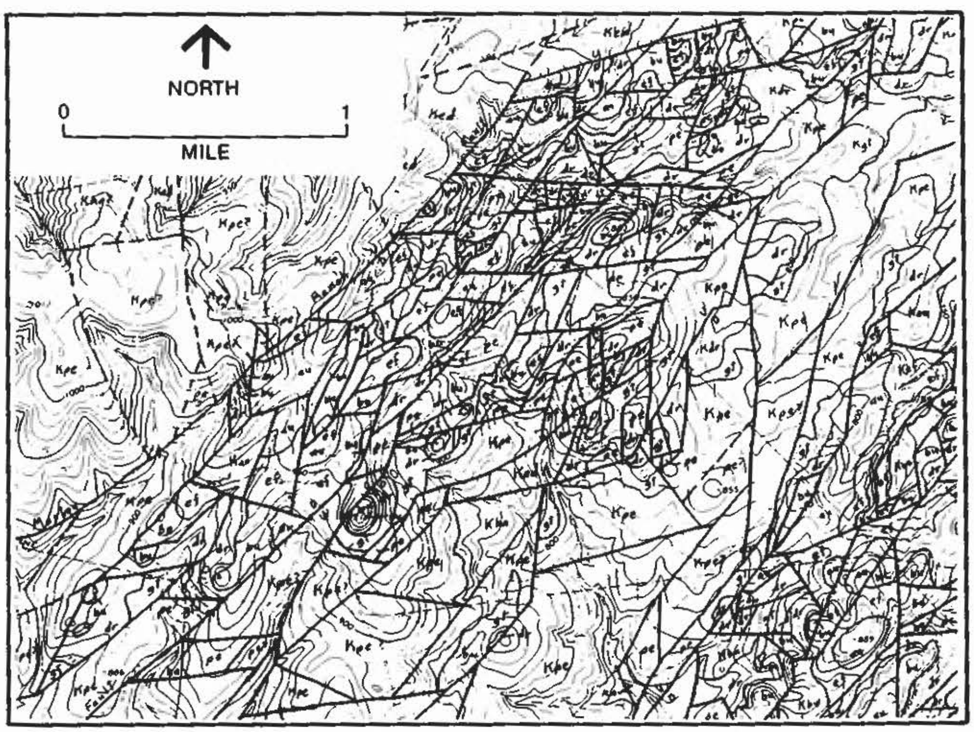

Figure 4. Detail From Geologic Map Of San Marcos Area, Showing Intensity Of Faulting In The Ramp Structure Area (from Grimshaw, 1976).

The resulting overall outcrop pattern, with the Edwards giving way to the Austin and Pecan Gap northeastward along the ramp, and with the complex, irregular faulting between the en echelon step fault zones, is shown clearly in Figure 2. The intervening units between the Edwards Limestone and the Austin Chalk are exposed in the complexly faulted area extending generally southward from the northeastern step fault zone to the southwestern step fault zone. The outcrop pattern on a larger scale and in more detail is a mosiac of irregular fault block outcrops having an appearance not unlike a shattered pane of glass (Figure 2). The complex faulting of the ramp into irregular grabens and horsts at the smaller scale (Figure 3), and the small, irregular fault blocks at the larger scale (Figure 4), represent the adjustment of the ramp area to the tensional and lesser torsional stresses during the Balcones faulting.

The intensity of faulting depicted in Figure 4 is most clearly displayed in the band of outcrops of intervening stratgraphic units between the Edwards limestone and the Austin chalk in the graben and horst area between the en echelon step fault zones. It is likely that this intensity of faulting also exists in the areas of exposure where the Edwards, Austin, and Taylor Groups are exposed, but the lithologic homogeneity of these units does not allow the individual fault blocks to be mapped in such detail. It is only where the succession of thin, lithologically dissimilar units represented by the Georgetown (marl), Del Rio (clay), Buda (limestone), Eagle Ford (clay with thin siltstone layers) is affected by the intense faulting that sufficient stratigraphic control allows the very small individual fault blocks to be mapped.

Along the northeastern section of the southwestern step fault zone there is a major, high-standing fault block, herein named the San Marcos horst, which is undisturbed by the intricate faulting that characterizes most of rest of the area northwest of the step faults. The cause of this large, undisturbed, monolithic fault block remains problematical. The Balcones Escarpment is especially well developed along the eastern margin of this horst; the Old Main building of Southwest Texas State University is built on this prominent scarp and is a striking local landmark which is easily seen by travelers on nearby Interstate 35. Much of the western half of San Marcos is built on this large fault block, and San Marcos Springs discharges along its northeastern margin.

POTENTIAL GEOMORPHOLOGIC IMPLICATIONS: A HYPOTHESIS

Woodruff (1977), in a discussion of development of drainage patterns near the Balcones Escarpment, has shown that the Blanco River formerly discharged into what is now the Onion Creek drainage basin. The "elbow" in the course of the Blanco River in the northern part of the case study area is near the point at which a headward eroding smaller stream captured the Blanco and diverted its flow from generally eastward to a southeastward direction. The point designated "A" in Figure 1 is the location of a distinctive erosional feature which is interpreted to be a former channel of the pre-capture course of the Blanco. This feature is now located on the drainage divide between the Blanco River and Onion Creek drainage basins.

Not long after Balcones faulting occurred (currently believed to be during the Miocene), the stratigraphic units exposed in the vicinity of the en echelon faults and associated ramp structure in the study area were Upper Cretaceous or younger. It may reasonably be expected that as erosion occurred and the land surface lowered in the area, the more resistant Austin chalk was exposed in the southwestern part of the ramp structure while the less resistant Taylor clay was still present in the northeastern part of the structure. Further, because of marked difference in erodibility of these units, it may be expected that a small east-facing escarpment would have formed along the ramp.

The hypothesis or question then arises, "Could this small escarpment then have determined the course of the stream which ultimately captured the Blanco River?" If the answer is in the affirmative, then the physiographic development in the area was controlled by the presence of the en echelon faulting and associated ramp, and the present southeasterly course of the Blanco was ultimately determined by the presence of the ramp.

POTENTIAL HYDROLOGIC IMPLICATIONS: ANOTHER HYPOTHESIS

Woodruff and Abbott (1979) have hypothesized that the current principal discharge points of the Edwards aquifer, such as San Marcos Springs and Comal Springs, have developed at or near the locations where major streams and rivers traverse the Balcones Escarpment. In effect, these locations represent the lowest elevation points where the Edwards limestone is exposed. There, the actively downwardly eroding rivers have opened drains for the aquifer.

After the Blanco River was captured into its current southeastward course, its grade was increased and the currently visible deeply incised canyon where the river crosses the Edwards limestone was formed. This canyon opens to a wider valley containing alluvium at the point where the river crosses a fault and begins to flow on outcrops of younger strata, primarily the Austin chalk (Figure 2). The valley widens again, this time to a much greater extent, at the point farther downstream where the river begins to flow on the Taylor Clay.

Although the river is still downcutting after it passes out of the Edwards, it is also effectively sidecutting as evidenced by the presence of alluvium in the valley in this stretch. The continued downcutting is indicated by the presence of bedrock exposures in the river channel. The thickness of the alluvium and the presence of a single sequence of fining upward grain size pattern in the alluvium indicate that the river is removing and redepositing its alluvial deposits as it shifts course in its valley.

The question naturally arises: "Was the Blanco River responsible for cutting a drain into the Edwards aquifer at the current location of San Marcos Springs?" The current locations of the river, the springs, and Sink Creek indicate that if the Blanco did open this discharge point of the aquifer by downcutting or sidecutting at the location of the springs, it occurred many years ago when the land surface and the river were at somewhat higher elevation than at present.

If the hypotheses outlined above and in the previous section are correct, then the current location of San Marcos Springs was determined by the presence of the Blanco River, whose location was in turn determined by the northeastern and southwestern en echelon step faults and the associated ramp structure. The role of the San Marcos horst in this sequence of events awaits further study.

POSSIBLE SIMILAR STRUCTURAL PATTERNS ELSEWHERE IN THE BALCONES FAULT ZONE

Inspection of maps of the Geologic Atlas of Texas published by the University of Texas Bureau of Economic Geology (Barnes, 1974a, 1974b, 1974c) suggests that similar structural patterns exist elsewhere in the Balcones fault zone. For example, a similar ramp structure is indicated in the Austin area, where outcrops of Edwards limestone in an en echelon step fault setting give way northeastward to Austin chalk outcrops. A band of outcrops of Georgetown, Del Rio, Buda, and Eagle Ford Formations extends southward from the Colorado River to the town of Buda. This band separates Edwards outcrops to the southwest from Austin chalk outcrops to the northeast, just as in the San Marcos area.

A smaller scale but similar pattern may also exist near New Braunfels, where outcrops of Edwards limestone gives way northeastward to Austin chalk outcrops in an apparent ramp structure, with a transition zone of Del Rio, Buda, and Eagle Ford Formation outcrops between.

Southwest of New Braunfels, the en echelon faulting in the Balcones fault zone reverses, with major displacement shifting from southeastward fault zones to northwestward fault zones. Ramp structures in this area are thus also reversed, with bending downward to the southwest rather than to the northeast as in the San Marcos area. One such "reversed" ramp structure, where Edwards outcrops give way southwestward to Austin chalk outcrops, and with intervening exposures of Georgetown through Eagle Ford fault blocks, is apparent immediately northwest of San Antonio. Another larger one appears to be present across most of Media County and far eastern Uvalde County.

SUMMARY

Detailed geologic mapping of intensely faulted Cretaceous strata in the Balcones fault zone in the San Marcos area has revealed a structural style and bedrock geometry which have potential implications for the geomorphologic and hydrologic development of the area.

The current location of the Blanco River and San Marcos Springs may have resulted from a sequence of events whose course was determined by this structural style and the relative resistance of the Cretaceous units to erosion. The presence of the two en echelon step fault zones and associated ramp structure may have been the ultimate cause of both the current, captured course of the Blanco River and subsequently the location of San Marcos Springs.

Similar en echelon structural patterns with ramps are indicated in at least three other locations in the Balcones fault zone.

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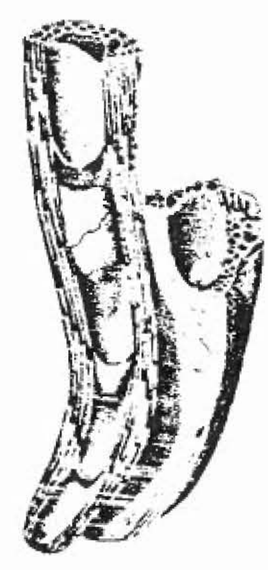

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