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A NORTHEAST TRENDING TRANS-PENINSULAR LINEAMENT ACROSS BAJA CALIFORNIA

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RESUMEN

En una fotografía de Apollo 9 se distingue un lineamiento, con rumbo N 75°E, que atraviesa la Sierra San Pedro Martir, en el norte de Baja California. Este lineamiento se observó en el terreno y se denominó como lineamiento Venado Blanco. Este rasgo se extiende hacia el poniente hacia la costa del Pacífico donde su rumbo es N 60°E, y también hacia el oriente a través de la Sierra de San Felipe con una trayectoria arqueada. No existe evidencia alguna de desplazamientos significativos de rasgos mayores a lo largo del lineamiento. Se le considera como una zona de debilidad erosionada, que se originó como una falla con ligero movimiento sinestral. Su cercanía a la falla de Agua Blanca, cuyo rumbo es hacia el norponiente, permite sugerir la posibilidad de que ambos rasgos se desarrollaron como consecuencia de una rotación amplia de la península de Baja California en el sentido de las manecillas de reloj, a medida de que ésta se estaba alejando de la parte continental de México.

ABSTRACT

A northeast trending (N 75°E) lineament across Sierra San Pedro Martir in northern Baja California, is apparent on an Apollo 9 photograph and was observed in a ground reconnaissance. Named the Venado Blanco lineament, the feature appears to extend westward toward the Pacific margin where it strikes N 60°E, and eastward in an arcuate path through Sierra San Felipe. No evidence for motion or significant displacements of large-scale features along the lineament exists, and it is interpreted as an eroded zone of weakness that originated as a fault with slight left-lateral motion. Its proximity to the northwest trending Agua Blanca fault suggests a possible relationship in which both features were developed as a result of a broad clockwise rotation of the Baja California peninsula as it moved away from the mailand.

INTRODUCTION

Numerous large-scale faults, including several with a trans-peninsular nature, have been reported or proposed for the Baja California peninsula. Beal (1948) mapped the trans-peninsular La Paz fault at the southern tip of the peninsula and suggested (p. 92) what is now called the Agua Blanca fault. Allen *et al.* (1960) described the northwest trending Agua Blanca fault (Figure 1) and presented evidence for 11 km of "modern" right-lateral slip; recent workers (*e. g.* Moore, 1969) have considered the Agua Blanca fault to be a southeasterly extension of the San Clemente fault of the California Continental Borderland. However, neither Allen *et al.* (1960) or Gastil *et al.* (1975) in a comprehensive geological reconnaissance of Baja California found evidence of the Agua Blanca fault east of the San Matias pass (Figure 1) where it intersects the axial peninsular batholiths.

Rusnak *et al.* (1964) pointed out the possibility of extensions across the peninsula of the Salsipuedes fault (at about 30° N. Lat.) and the Santa Rosalia fault (at about 28° N Lat.). Rusnak and Fisher (1964) also proposed a scheme of motion involving left-lateral movement along transpeninsular faults to account for the opening of the Gulf of California. Normark and Curray (1968), however, postulated a system of northwest trending transcurrent faults with initial left-lateral, then right-lateral movement to allow an opening of the gulf that began in the northern end of the basin.

The portion of the Baja California peninsular batholith extending southward from the San Matias pass and the southeasternmost tip of the Agua Blanca fault is known as the Sierra San Pedro Martir (Figure 1). This northwest trending massif is an uplifted fault block of largely tonalitic composition bounded on the east and west by normal faults (Woodford and Harriss, 1938). Presumably, the batholith was emplaced during the Cretaceous as a result of subduction off the west coast of North America (Hamilton, 1969). As a consequence of late Cenozoic behind-arc extension (Karig and Jensky, 1972) and opening of the Gulf, it was subjected to normal faulting with its eastern side subsequently down-dropped approximately 2.5 km (Slyker, 1969) and largely covered by alluvium in the Valle de San Felipe.

To accomodate right lateral motion between crustal blocks along the Agua Blanca fault, Hamilton (1971) outlined an area of crustal extension in the Valle de San Felipe. Relative westward motion of the crustal block south of the Agua Blanca fault would be compensated by extension from normal faulting along the east face of the Sierra San Pedro Martir and within the Valle de San Felipe. Hamilton proposed a west-northwest trending "hidden transform fault" east of the batholith (Figure 1), consistent with an eastward extension of the Sierra, although only faults essentially parallel to the batholith had been mapped.

OBSERVATIONS

Figure 2 is a photograph (AS9-26A-3780A) of a portion of northern Baja California taken from

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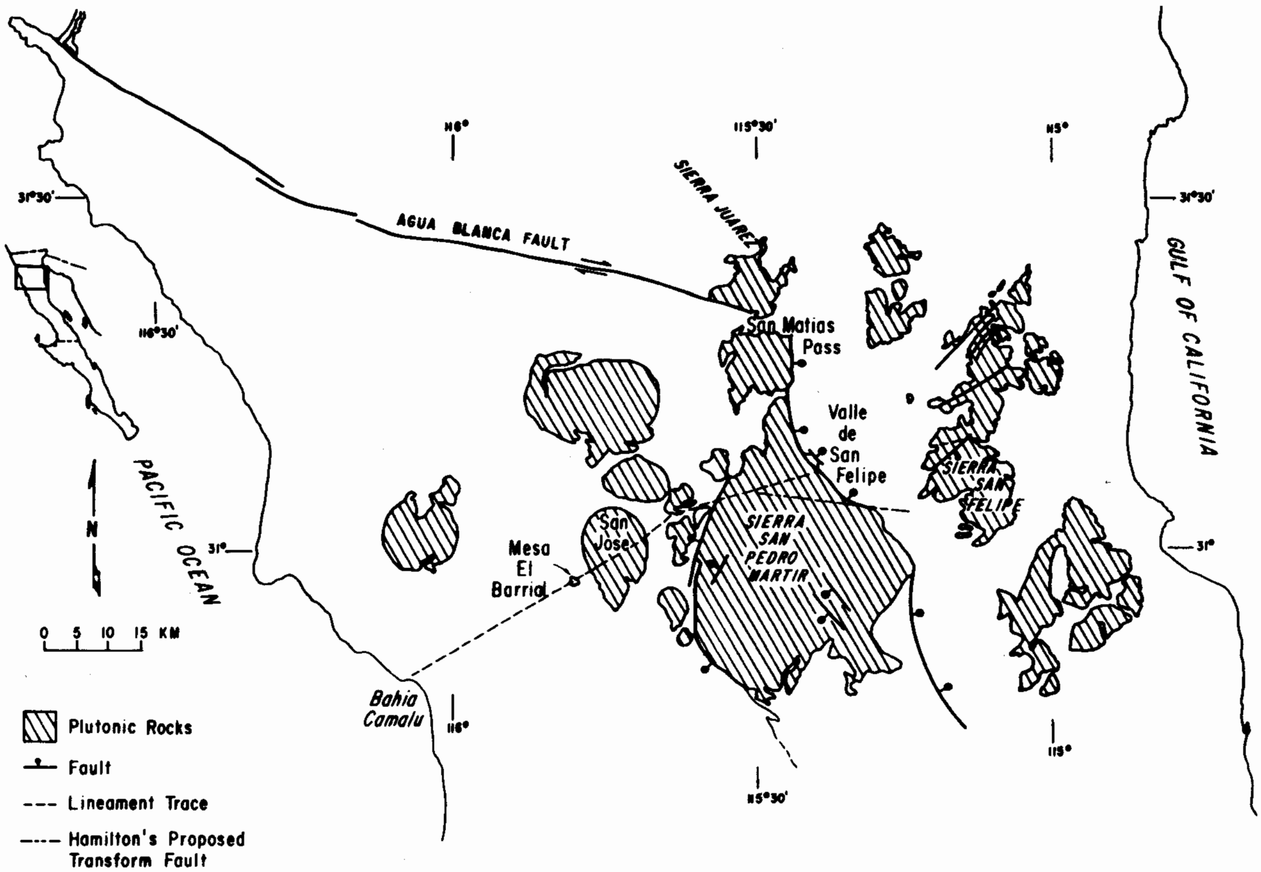

Figure 1.—Location map of the Venado Blanco lineament in northern Baja California. Distribution of plutonic rock and faults from Gastil *et al.*, (1975). Hamilton's proposed transform fault from Hamilton (1971).

Apollo 9 using color infrared film. The structural features appear enhanced and are more visible than in standard photographs (National Aeronautics and Space Administration, 1967; Hamilton, 1971). In addition to numerous faults and lineations trending parallel and subparallel to the Sierra San Pedro Martir, a northeast-trending lineament is apparent (arrows) in Figure 2.

This northeast-trending feature, described herein as the Venado Blanco lineament, is most obvious where it crosses the northern part of Sierra San Pedro Martir with a strike of N 75°E. West of the batholith it appears to have a short deviation to the north, then follows a slightly curvi-linear path trending roughly S 60°W to the Pacific Coast. This extension occurs through Mesozoic metamorphic and Tertiary sedimentary rocks to a point near Bahia Camalu (*c. f.* Figure 1). Northeast of the batholith, no fault trace is visible across the alluvium-covered Valle de San Felipe, but numerous faults with various northeast strikes are present in the low-relief Sierra San Felipe east of the valley (Gastil *et al.*, 1975).

Two possible eastward extensions of the Venado Blanco lineament are indicated (A and B) on Figure 2. Lineation A is mapped by Gastil *et al.*, (1975) as an undifferentiated fault, but strikes N 60°E and would presuppose an offset of the lineament between Sierra San Pedro Martir and Sierra San Felipe. Consideration of possibility B (Cañón El Portezuelo) is predicated on the concept that the lineament may actually be arcuate in shape, curving to a general strike of N 80°E through Sierra San Felipe. Lineament B is not mapped as a fault by Gastil *et al.*, (1975), but is perceptible in Figure 2. Between the Sierra San Felipe and the Gulf of California, Quaternary alluvium and dunes prevent identification of lineaments at the surface.

Groud observations tend to substantiate the existence of the Venado Blanco lineament, but do not readily establish it as an active fault. Previous reconnaissance field mapping in the Sierra San Pedro Martir (Smith, 1972) had suggested a possible fault. An area of generally hummocky topography in the northern end of the Sierra San Pedro Martir is separated from the main plateau by a subdued scarp, implying a vertical offset along the lineament. Inspections of thin sections from rocks in this area (near Cerro Venado Blanco) reveal a cataclastic texture dissimilar to other samples from the batholith. The features observed include strong foliation in biotite and other ferromagnesium minerals, shattered crystals, zoned plagioclase, and garnet. Large tourmaline-rich pegmatites are present at the western end of this zone. Figure 3 shows the Venado Blanco lineament trending northeast from the step-faulted western face of the massif to the steep east-facing scarp bounding the Valle de San Felipe.

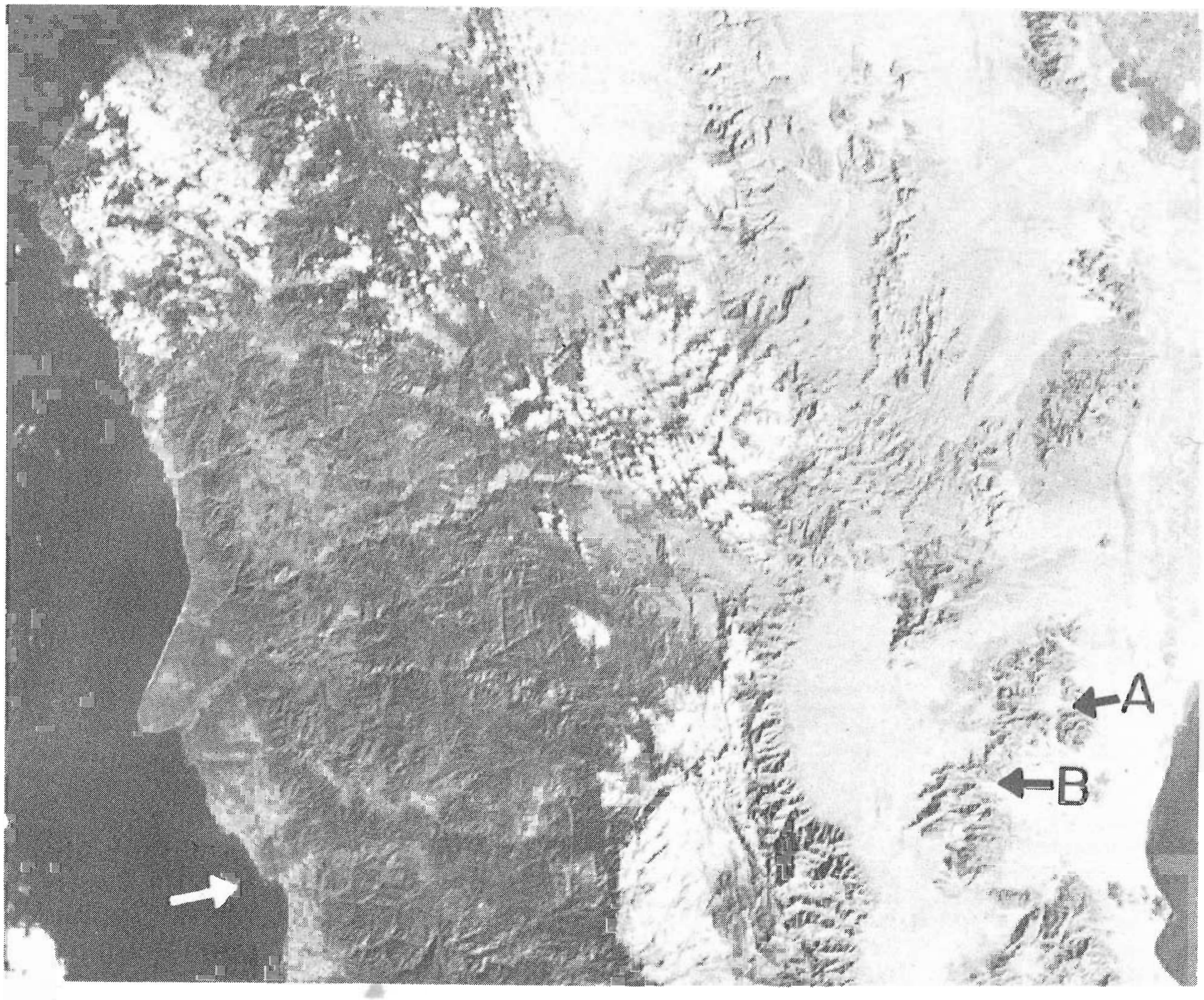

Figure 2.—Apollo infrared photograph of a portion of northern Baja California. Arrow shows the Venado Blanco lineament. Lines **A** and B indicate possible continuations of the lineament toward the east. See Figure 1 for identification of features.

West of the axial batholith, the lineament passes between outcrops of granodiorite and tonalite mapped as satellite plutons by Gastil *et al.* (1975). The strike of the lineament crosses the quartz diorite San José pluton farther west (Figure 1), but it is not easily discernible there (Figure 2). Murray (1972) mapped the San José pluton in detail, but reported no evidence for a major east-west trending fault.

A ground reconnaissance conducted during the summer of 1976 in the San José stream valley area north of the Rancho San José revealed topographic evidence for a lineament striking approximately N 60°E. A relatively narrow west-facing canyon carries La Concepción stream to a junction with the San José stream, which ultimately becomes the San Telmo stream. This canyon (Figure 4) reaches and crosses a divide, exposing fresh quartz diorite. The north wall of the canyon has a shallow slope while the south wall is much steeper. Fracture patterns and jointing in the canyon strike N 65°E with a dip of 65°S. No shear zones were evident, but some outcrops displayed surfaces suggestive of slickensides and small accumulations of accreted mylonite were visible (Figure 5).

West of the Concepción canyon, the Venado Blanco lineament crosses the north-south trending San José valley creating a minor ($\sim$ 1 km) offset consistent with left-lateral movement. Enhanced erosion channels are present on the west slopes of the valley, continuing as a marked, linear color change in vegetation. Northeast trending pegmatites with large masses of fibrous epidote were observed in this area.

West of the San José pluton, in the Cretaceous Alisitos Formation (Gastil *et al.*, 1975), the lineament is followed for a short way by an unpaved road (San Telmo to San José) and intersects a massive, one square kilometer pile of Tertiary conglomerate known locally as the Mesa El Barrial. The measured strike at this location is N 60°E.

No ground reconnaissance was conducted southwest of the conglomerate pile where the lineament crosses the San Telmo stream valley, which flows westerly at this point. There is, however, a topographic suggestion of a slight left-lateral offset. The lineament extends on to Bahía Camalu, passing between large accumulations of Tertiary conglomerates and disappearing into Quarternary alluvium near the Pacific coast.

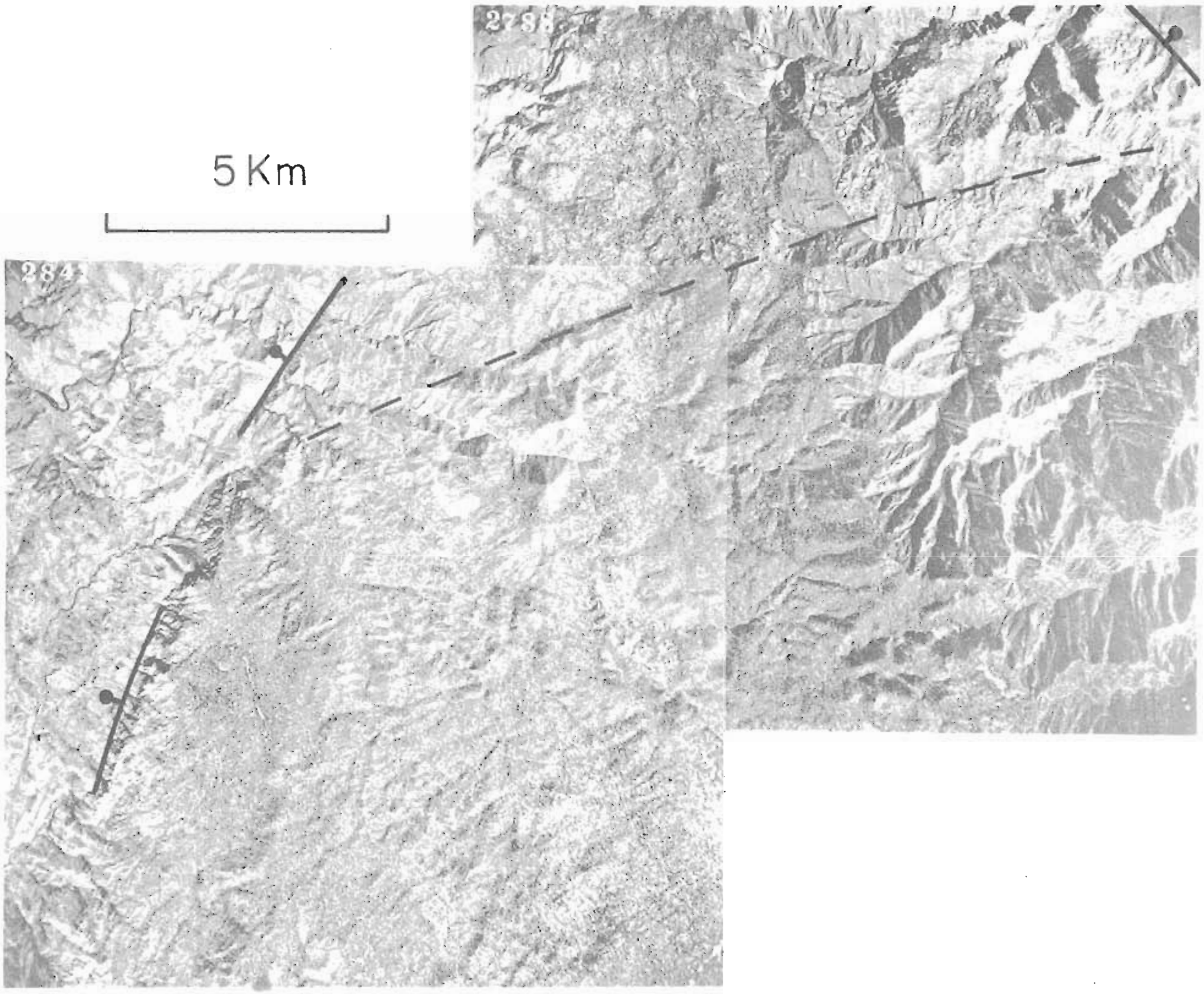

Figure 3.—Aerial photographs of the northern end of Sierra San Pedro Martir. Bounding faults on the west (left) and east (right) of the plateau are lined in. The northeast trending Venado Blanco lineament is traced with a dashed line.

DISCUSSION

Several possible explanations exist for the Venado Blanco lineament. Each is based on supposition and, indeed, provokes more uncertainties than it satisfies.

Convincing field evidence for displacement along the lineament is lacking. No offsets of appreciable magnitude exist along the exposed boundaries of the Sierra San Pedro Martir where it is intersected by the lineament. Likewise, no offsets have been recognized along the boundary of the San José pluton (Figure 1), although some topographic relationships within the pluton suggest slight left-lateral displacement. This type of relative motion can also be inferred from the Pacific coastline at Bania Camalu (Figure 2), but the intact boundaries of the Tertiary Mesa El Barrial and the Late Cretaceous igneous intrusions preclude consideration of the Venado Blanco as an active fault.

It seems most likely, that the lineament represents the trace of an older, now largely inactive, fault or zone of weakness. Enhancement of the surface topography by erosion, particularly in the zones of cataclastic crystals and pegmatites, maintains the appearance of the feature. The original fault may have been associated with the emplacement of the axial batholith during the Cretaceous, or it may be related to more recent forces which eventually caused the opening of the Gulf of California in the late Tertiary.

The nonlinear strike of the Venado Blanco lineament may be a result of differential movement across the normal faults trending north-south in the Valle de San Felipe (Gastil *et al*., 1975) or perhaps of crustal decoupling and extension (Hamilton, 1971) in the same valley. If line B (Figure 2) represents the original fault and an extension of the current lineament, its curvi-linear pattern reflects either distortion within the peninsula since formation of the fault or relative displacement restricted to a rotational sense. Projeced eastward extensions of the Agua Blanca fault and the Venado Blanco lineament intersect at angles from 25° to 35° between Sierra San Felipe, where numerous tensional and undifferentiated faults trend northwest and northeast, and the Gulf of California coastline (Figure 6). Several speculations concerning the origin of forces may be advanced if an original motion along the Venado Blanco lineament is assumed.

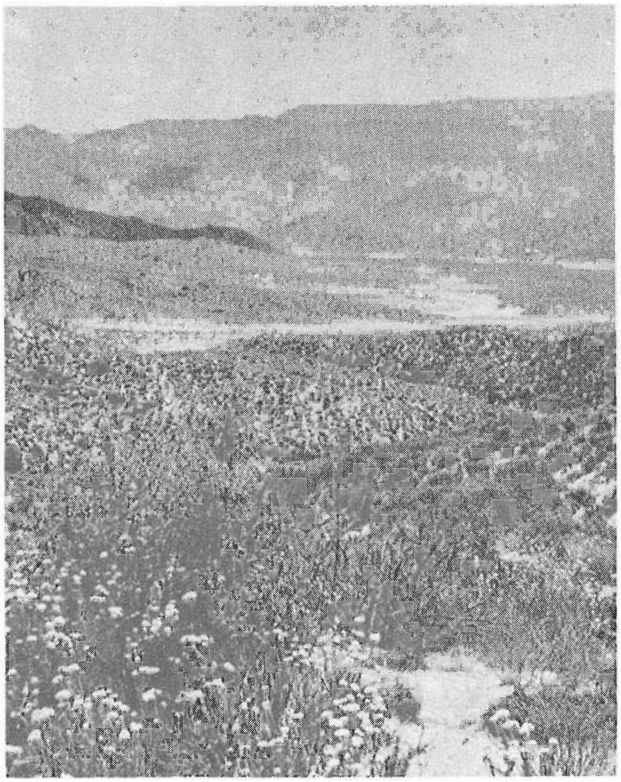

Figure 4.—View facing east from San José pluton of San José valley and Concepción canyon. Northern end of Sierra San Pedro Martir is on skyline. The Venado Blanco lineament follows the path from the photographer to the skyline break of the batholith in the background.

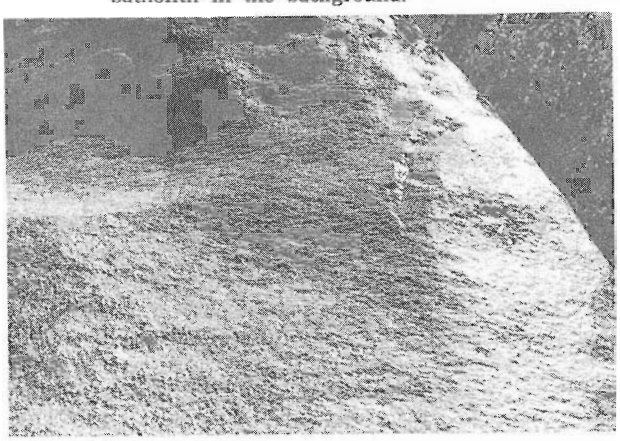

Figure 5.—Boulder with possible slickensides in Concepcion canyon. Tree at right suggests scale.

Employing the assumption of original trans-peninsular rigtht-lateral motion for the lineament, we can inquire about relationships of possible fault patterns with principal stress directions (Figure 6). The intriguing hypothesis of a compressive force, directed from near the spreading center, associated with the Wagner Basin in the Gulf of California and resulting in the Agua Blanca fault and a northeast trending Venado Blanco fault that intersected in the Valle de San Felipe, is obviated because motion on the Agua Blanca fault is right-lateral. A proper orientation of faults, however, does exist between the Venado Blanco lineament and Hamilton's proposed "hidden transform" for a principal east-west stress from within, or east of, the Valle de San Felipe. If Hamilton's fault does exist and the Venado Blanco lineament is related to it, then we must accept the supposition that, as been implied for the Agua Blanca fault (Gastil *et al.*, 1975; Halmilton, 1971), neither fault extends eastward beyond the Valle de San Felipe and their presence is related to extension between the crustal blocks described by Hamilton (1971).

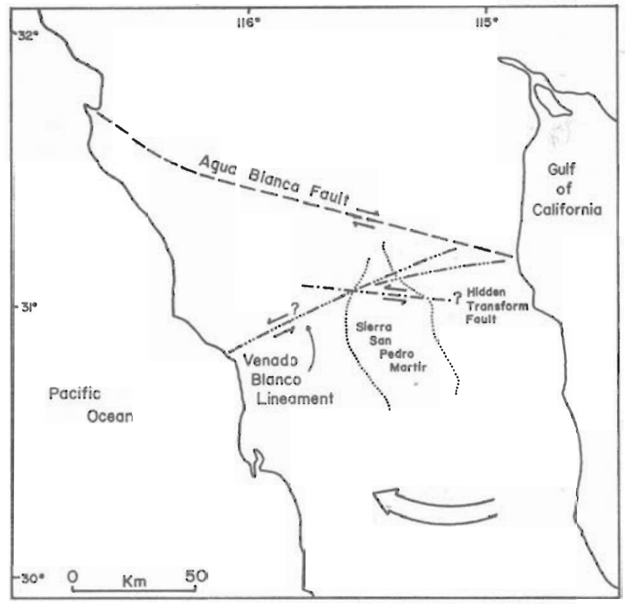

Figure 6.—Schematic of possible fault intersections showing the Sierra San Pedro Martir batholith, the Agua Blanca fault (and its eastward projection), Hamilton's (1971) theorized hidden transform fault, and the northeast trending Venado Blanco lineament with two possible eastward projections and a theoretical original left-lateral displacement. Broad arrow indicates a broad rotational motion for the peninsula as the wedge between the Agua Blanca and original Venado Blanco faults was forced westward.

The angle between the theoretical extensions of the Agua Blanca fault and the Venado Blanco lineament is such that the lineament could be considered a shear of the second order (McKinstry, 1953) or subsidiary of the Agua Blanca fault. This would require a right-lateral displacement on the northeast treinding Venado Blanco lineament, consistent with the Agua Blanca fault, and would not necessitate substantial movement.

If an original left-lateral displacement were the case for the lineament, a more rational theory evolves. We can dispense with the concept of principal stresses aligned along (north-south) the peninsular axis, because the angle between a left-lateral northeast trending Venado Blanco lineament and an eastwardly extended Agua Blanca fault is too large for the two to be a conjugate pair.

One can infer from the fault trends, however, a possible broad clockwise rotation about the point of intersection. This is consistent in a rudimentary sense with a "swinging out" pattern of motion for the peninsula that would be related to the origin of a proto Gulf of California in the north (Normark and Curray, 1968; Karig and Jensky, 1972). Later, the entire peninsula was involved in a rotation to accomodate some component of westward movement in the opening of the southern Gulf by compressing the wedge of peninsular crust between the Agua Blanca fault and the Venado Blanco lineament. This implies the presence of a more diffuse nature of tectonic activity, near the transition between a divergent plate margin in the northern Gulf and a transform fault plate boundary in southern California. Reyes *et al.* (1975) have attributed a major fault north of the Agua Blanca to strain resulting from the motion of the Pacific plate northwestward relative to the North America plate. A rotational origin of major faults (and lineaments) about the Valle de San Felipe is also suggestive of a decoupling point for a more independently moving Baja California peninsula with respect to that portion of California west of the San Andreas fault.

CONCLUSIONS

The Venado Blanco lineament strikes roughly N 60°E across northern Baja California and is detectable on an Apollo photograph and in the field. No current relative displacement can be assigned to the lineament and it is interpreted as a zone of weakness with enhanced erosion that originated as a fault with slight left-lateral motion. The most likely path for the Venado Blanco lineament is trans-peninsular and curvi-linear, but its present trace may reflect disruptions created by normal faulting in the Valle de San Felipe or distortion within the peninsula (*i.e.* the crustal spreading proposed by Hamilton (1971)).

A possible relationship between the origin of a theoretical intersection with the right-lateral, northwest striking, Agua Blanca fault and the northeast trending Venado Blanco lineament may be consistent with stresses generated by a broad clockwise rotation of the lower peninsula about that point. This emphasizes the importance of this area as a possible focal point for tectonic stresses associated with migration of the peninsula away from the Mexican mainland.

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REFERENCES CITED

Allen, C. R., Silver, L. T., and Stehli, F. G., 1960, Agua Blanca fault a major transverse structure of northern Baja California, Mexico: Geol. Soc. America Bull., v. 71, p. 457-482.

Beal, C. H., 1948, Reconnaissance of the geology and oil posibilities of Baja California, Mexico: Geol. Soc. America, Mem. 31, 138 p.

Gastil, R. G., Phillips, R. P., and Allison, E. C., 1975, Reconnaissance geology of the State of Baja California: Geol. Soc. America, Mem. 140, 170 p.

Hamilton, Warren, 1969, Mesozoic California and the underflow of Pacific mantle: Geol. Soc. America Bull., v. 80, p. 2409-2430.

——— 1971, Recognition on space photographs of structural elements of Baja California: U. S. Geol. Survey, Prof. Paper 718, 26 p.

Karig, D. E., and Jensky, W., 1972, The proto-Gulf of California: Earth and Planet. Sci. Ltrs., v. 17, p. 169-174.

McKinstry, H. E., 1953, Shears of the second order: Am. Jour. Sci., v. 251, p. 401-414.

Murray, J. D., 1972, Emplacement history of the San José pluton, Peninsular Range batholith, northern Baja California, Mexico: Geol. Soc. America, Abs. with Progs., vol. 4, n. 3, p. 205, (abstract).

National Aeoronautics and Space Administration, 1967, Earth photographs from Gemini III, IV and V: National Aeronautics and Space Administration, Spec. Publ. 129, 266 p.

Normark, W. R., and Curray, J. R., 1968, Geology and structure of the tip of Baja California, Mexico: Geol. Soc. America Bull., v. 79, p. 1589-1600.

Reyes, A., Brune, J. N., Barker, T., Canales, L., Madrid, J., Rebollar, J., and Munguía, L., 1975, A microearthquake survey of the San Miguel fault zone, Baja California, Mexico: Geophys. Res. Ltrs., v. 2, p. 56-59.

Rusnak, G. A., and Fisher, R. L., 1964, Structural history and evolution of Gulf of California: *in* van Andel, Tj. H., and Shore, G. G., Jr., eds., Marine Geology of the Gulf of California. Am. Assoc. Petroleum Geologists, Mem. 3, p. 144-156.

Rusnak, G. A., Fisher, R. L., and Shepard, F. P., 1964, Bathymetry and faults of the Gulf of California: *in* van Andel, Tj, and Shor, G. G. eds., Marine Geology of the Gulf of California. Am. Assoc. Petroleum Geologists, Mem. 3, p. 59-75.

Slyker, R. G., Jr., 1969, Geological and geophysical reconnaissance of the Valle de San Felipe region, Baja California, Mexico: Geol. Soc. America, Spec. Paper 121, p. 560 (abstratc).

Smith, D. L., 1972, The vertical distribution of heat production and heat flow in northwestern Mexico: Minnesota Univ., Ph. D. thesis (unpublished), 174 p.

Woodford, A. O., and Harriss, T. F., 1938, Geological reconnaissance across Sierra San Pedro Martir, Baja California: Geol. Soc. America Bull., v. 49, p. 1297-1336.