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TECTONIC LINEAMENTS IN THE CENOZOIC VOLCANICS OF SOUTHERN GUATEMALA: EVIDENCE FOR A BROAD CONTINENTAL PLATE BOUNDARY ZONE

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ABSTRACT

The northern Caribbean plate boundary has been undergoing left-lateral strike slip motion since middle Tertiary time. Current rates are estimated between 2 and 3.7 cm/yr. The western part of the boundary occurs in a complex tectonic zone in the continental crust of Guatemala and southernmost Mexico, along the Chixoy-Polochic, Motogua and possibly Jocotan-Chamelecon faults. Previously mapped offsets along these faults do not appear to be capable of accommodating the required cumulative displacement.

We have mapped prominent lineaments visible in radar imagery in the Neogene volcanic belt of southern Guatemala and western El Salvador and interpret them to suggest southwest extensions of this already broad plate boundary zone. Because these extensions can be traced beneath Quaternary volcanic cover, we suggest that this newly mapped fault zone is active and is accommodating some of the strain related to motion between the North American and Caribbean plates. Onshore exposures of the Motoqua-Polochic fault systems are characterized by abundant, tectonically emplaced ultramafic rocks. Because several Leg 84 sites that recovered ultramafic rocks occur within our postulated fault zone, we suggest a similar mode of emplacement for these off-shore ultramafics.

INTRODUCTION

Geological studies of the northern Caribbean plate boundary can reveal the history of interaction between the North American and Caribbean plates. Such studies may also yield insight into broader tectonic questions, such as the opening history of the Atlantic Ocean (e.g., Anderson & Schmidt, 1983). The Northern Caribbean plate boundary has undergone left-lateral strike-slip motion since at least middle Tertiary time. Current rates of strike-slip motion are estimated between about 2 cm/yr (MacDonald and Holcombe, 1978) to nearly 4 cm/yr (Sykes et al, 1982). The western part of the boundary occurs in a complex tectonic zone in the continental crust of Guatemala, southernmost Mexico, and western Honduras along the Chixoy-Polochic, Motogua and possibly Jocotan-Chamelecon faults (figure 1). The Chixoy-Polochic fault system may currently be the most active fault (Muehlberger and Ritchie, 1975) but the actual amount of offset along this and the other related faults is contentious.

Previous interpretations of regional structure in Northern Central America have emphasized the influence of the subducting Cocos plate and associated compressional tectonism on the overlying lithosphere. For example, Carr (1976) related transverse breaks in the subducted Cocos plate to northeasterly lineaments in the overlying Caribbean plate. Associated northerly and northwesterly lineaments were interpreted as normal and right-lateral faults respectively.

Recent results from site surveys and drilling during Leg 84 of the Deep Sea Drilling Project (DSDP) strongly suggest a lack of mechanical coupling between the subducted and overriding plate along the Middle America trench, because there is no evidence for an an accretionary wedge (e.g. Aubouin et al, 1982; Von Huene et al, In Press; Aubouin and Von Huene, In Press).

If coupling between the Cocos and Caribbean plates is not a major factor in deformation of the overriding Caribbean plate, then regional Neogene and Quaternary structures may be largely controlled by the strike-slip boundary between the Caribbean and North American plates.

In this paper, we interpret lineaments visible in radar imagery of Southern Guatemala to suggest southwest extensions of this already broad fault zone. Because these lineaments can be traced beneath Quaternary volcanic cover, we suggest that this remapped plate boundary zone is active and is accommodating some of the strain related to motion between the North American and Caribbean plates. The existence of this fault zone also suggests another interpretation of the affinity of ultramafic rocks recovered offshore during DSDP Leg 84. These rocks are currently thought to be related to ultramafic material exposed to the southeast in the Nicoya complex of Costa Rica. To reach their present location from a position near the Nicoya complex would necessitate large amounts ($\sim$500 km) of right-lateral strike-slip motion along major faults parallel to the middle America Trench, for which there is little physical evidence.

GEOLOGIC SETTING OF NORTHERN CENTRAL AMERICA

The geology and physiography of Guatemala (fig. 1) are dominated by the left-lateral strike-slip boundary between the North American and Caribbean Plates, and the Middle America Trench off the Pacific Guatemala coast where the Cocos Plate is subducted beneath Central America. The former feature is expressed in the Central Cordillera (Dengo, 1973), a geologically complex region exposed along the Motagua River valley and mountains to the north and south. Several large serpentinized ultramafic bodies occur in this fault zone and were emplaced during the Cretaceous (Dengo, 1972). The serpentinites of the Central Cordillera are associated with metavolvanic and metasedimentary rocks of the El Tambor Formation

(McBirney and Bass, 1967) including phyllites and recrystallized limestone. Near Sansare south of the Motagua fault, limestone occurs with pillow basalts and radiolarian chert (Wilson, 1974). The entire sequence is considered Mesozoic and possibly as young as Campanian, deformed and emplaced during or after Campanian time. Structural features indicate thrusting to the north over the Maya Block and to the south over the Chortis Block, the main crustal block in the western part of the Caribbean Plate (Dengo, 1973). Thus, the ultramafics rocks were tectonically emplaced, probably as a result of convergence between the North American and Caribbean plates (Malfait and Dinkelman, 1972).

South of the Motagua Fault several stratigraphic assemblages have been described. Between the Motagua and Jocotan-Chamelecon Faults are high-grade (garnet-staurolite) metamorphic sediments and igneous rocks, as well as silica-rich schists, gneisses, amphibolite, and marble. In the area of Sierra de Omoa in Western Honduras, Horne et al (1976) describe a northern low-grade metavolcanic assemblage, a central medium-grade metamorphic assemblage and a southern assemblage of low-grade metasediments intruded by granitic rocks of various ages, but mainly Jurassic or older.

Overlying the tectonized metabasalts of the Chortis block is a thick sequence of Mesozoic sediments. Late Triassic to Early Jurassic sandstones and shales are overlain by a continental sandstone of probable Late Jurassic to Early Cretaceous age. Above this a thick early Cretaceous limestone extends from southern Guatemala to northern Nicaragua. Post-Albian rocks are predominantly continental redbeds with intercalations of limestone and gypsum. These beds are locally disrupted by mid-Cretaceous to early Tertiary intrusive rocks. The Tertiary section contains Eocene or older red beds, restricted marine sedimentary deposits on the Caribbean side of the Chortis Block and Tertiary basalts and andesites which form the basal part of the Volcanic Highlands of Guatemala.

The Volcanic Highlands are the product of subduction of the Cocos Plate under Central America at the Middle America Trench. The oldest volcanics are thick, extensive flow basalts and andesites of probable Oligocene age. These are overlain by Miocene to Pliocene rhyodacitic ignimbrites and a discontinuous chain of high relief Quaternary volcanos parallelling the Pacific coast. Smaller Quaternary cones are associated with north-south trending faults and grabens in western El Salvador, southeastern Guatemala and Central Honduras (Williams and McBirney, 1969).

METHODS

In order to investigate possible tectonic movement south of the presently defined strike-slip fault zone between the North American and Caribbean plates, synthetic aperture radar (SAR) imagery was examined to map lineaments in the Tertiary and Quaternary Volcanic Highlands. The image data were obtained in November 1981 during the second flight of the Space Shuttle, which carried the Shuttle Imaging Radar Experiment (SIR-A). A description of the SIR-A experiment is given in Elachi et al (1982). Image resolution of the SIR-A imagery is about 40 m. The incidence angle (off nadir) is 50°, $\pm 3^{\circ}$.

Imaging radar has been used extensively in geological reconnaisance of tropical regions (e.g. Wing, 1971). The sensitivity of radar backscatter to surface slope means that it is an excellent tool for investigating tectonic problems where individual structural elements are likely to have topographic expression. Structural interpretations from radar imaging must take into account the direction of radar illumination, since scarps perpendicular to this direction are more strongly enhanced than those parallel to it (MacDonald, 1969; Ford, 1980). The available SIR-A imagery has only one illumination direction (from the northwest); consequently structural elements trending northeast-southwest will be enhanced, while those trending northwest-southeast will be less apparent.

Analysis of radar imagery in high relief terrain must also take into account "fold-over" distortion, or apparent fore-shortening of slopes facing the radar illumination vector. The effect is large for steep incidence angle systems (e.g. NASA's Seasat Satellite) but is much less apparent for the SIR-A system with its more shallow incidence angle.

For convenient comparison of radar features to geological features the imagery was printed at the same scale (1:500,000) as the geologic map. Lineaments of probable tectonic origin 5 km or more in length were considered for SIR-A. The lineaments were recorded on an overlay and compared to trends of faults mapped on the Geologic Map of Guatemala (Bonis et al., 1970). Linear features with no obvious tectonic association such as short drainages were not considered. The following discussion refers only to the trends of lineations in the Volcanic Highlands in order to separate younger tectonism from pre-Tertiary deformation.

RESULTS & DISCUSSION

Figure 2 shows the image data and interpreted lineaments. Figure 3 shows the Rose Diagram indicating trends of lineaments in the Volcanic Highlands. Two major groups of lineament orientations stand out: a north-northwest trend and an east-northeast trend. The stippled wedges in the figure indicate the trends of faults in the Central Cordillera compiled from the Geologic Map of Guatemala. The larger stipple (north-northwest trend) corresponds to extensional faulting while the smaller stipple (east-northeast) indicates the range of left-lateral strike-slip fault trends. Quaternary volcanic cover is cut by both groups of lineations, suggesting tectonic activity in this area since Pleistocene time.

The Rose diagram illustrates a strong correspondence of lineaments in young Tertiary and Quaternary volcanics to older but still active structural features of the Central Cordillera, i.e. to the exposed fault zone that marks the plate boundary between North America and the Caribbean. The lineaments most probably reflect accommodation in the volcanic cover of movement along underlying faults. A similar accommodation was suggested by Erdlac and Anderson (1982) in the cental Cordillera of Western Guatemala. The simplest explanation for the correspondence between lineaments in the volcanic cover and the exposed plate boundary fault zone is that the lineaments mapped in the volcanic cover mark southward extensions of the active Motogua-Polochic fault system . Thus, the plate boundary fault zone may be considerably wider and more complex than previously recognized.

Comparison of on-land structural cross sections with those developed offshore reveals a structural similarity which implies that the offshore margin is a continuation of a broad plate boundary. Dengo (1973) presented a generalized north-south cross-section through Central America showing a series of high angle strike slip faults in the Central Cordillera trending east-west which continues through the Volcanic Highlands. Dip-slip motion also occurs on these faults, and the mapped or estimated vertical offset along them may be as much as 500m with the down-dropped block generally to the south (Sanchez-Barreda, 1981). Seismic profiles of the Guatemalan margin (Ladd et al., 1982) reveal a series of landward-dipping reflectors. Based on DSDP Leg 84 results (Aubouin et al., 1982) these have been interpreted as the tops of normally faulted and tilted blocks of continental margin material, with the faults striking nearly east-west and dipping south. We therefore suggest that the plate boundary fault zone exposed in Guatemala may extend to the south and west to include the continental margin of Guatemala (Figure 4a) similar to the plate boundary originally proposed by Molnar & Sykes (1969).

The possibility that the zone of deformation associated with the present boundary between the North American and Caribbean plate in Central America is much broader than previously suggested has a number of important implications. We will address two: (1) the origin of ultramafic rocks discovered offshore near the Middle America Trench during Deep Sea Drilling Project (DSDP) Leg 84, and (2) the controversy surrounding mappable offsets along the Motogua and Chixoy-Polochic fault zones.

1. The recovery of ultramafic rocks during drilling of DSDP Leg 84 off the coast of Guatemala gave rise to the controversial problem of their provenance. In all of the sites on Leg 84 where basement was reached (566, 567, 569, 570; fig. 1) mafic and/or ultramafic rocks were recovered. Primarily consisting of serpentinite with minor vestiges of the original peridotite, metadiabase, metagabbro and metabasalt, the rocks were generally similar to the ophiolitic assemblages described on land in Costa Rica (the Nicoya Complex; Dengo, 1962) and in Guatemala (Williams, 1960; Rosenfeld, 1980).

The serpentinized ultramafic rocks of the El Tambor formation outcrop along the exposed length of the Motagua-Polochic-Chamelecon fault system (geologic map of Guatemala, 1970; fig. 1), the left-lateral strike-slip boundary between the North American and Caribbean plates. These rocks are related to a pre-Tertiary history of convergence along this plate boundary (e.g., Malfait and Dinkelman, 1972). The full extent of this plate boundary is obscured by a broad belt of Tertiary to Quaterary volcanoes, the product of offshore subduction along the Middle America Trench. Thus the southern and western edges of the plate boundary are unknown.

The shipboard scientific party (Aubouin et al, 1981) suggested that the ultramafics recovered on Leg 84 were related to the Santa Elena peridotites of the Nicoya Complex, requiring strike-slip displacements of about 500 km. While faults subparallel to the required trend exist (see Dengo 1973) these are mapped as normal faults with very limited lateral offset. To our knowledge there is no offshore or onshore expression of a major strike-slip fault subparalleling the middle America coast between Costa Rica and Guatemala. However, Von Huene et al (in press) suggest transcurrent faulting along an ancestial offshore Polochic-Motugua system as an explanation of bench topography and basement deformation in the Guatemalan continental slope.

We suggest that the ultramafics of the Guatemalan continental slope are related to those exposed on land in outcrops of the El Tambor Formation (McBirney and Bass, 1969). Figure 1 shows the known extent of ultramafics in Central America including those drilled on Leg 84. The Leg 84 material was recovered south of the exposed trend of the Guatemalan ultramafics along the Motogua-Polochic fault zone, but can be directly related to the broad tectonic zone we infer on the basis of the radar imagery.

2. MacDonald and Holcombe (1978) used magnetic lineations in the Cayman Trough to estimate the relative motion of the North American and Caribbean plates at 2 cm/yr from 0-2.4 Ma, and 4 cm/yr from 2.4-8.3 Ma. More recently, Sykes et al (1982) argued that a rate of 3.7 cm/yr must characterize the easterly motion of the Caribbean with respect to North America for at least the last 7 Ma and possibly since 38 Ma (late Eocene) implying displacements of 1400 km since the inception of spreading in the Cayman Trough (late Eocene) and more than 250 km of displacement since 7 Ma (Pliocene time).

The active faulting accommodating motion across this plate boundary is believed to be concentrated along the Chixoy-Polochic (CP) fault (e.g. Muehlberger and Ritchie, 1975). However, mapped offsets along this fault are much less than the total estimated motion across the plate boundary. Kesler (1971) suggested that the CP fault has accommodated less than

150 km of displacement during the entire Cenozoic. Burkhart (1978) suggested that 132± 5 km of motion on the CP fault has occurred since middle Pliocene (7 Ma) or possibly as early as middle Miocene (15 Ma). Erdlac and Anderson (1982) suggested that no more than a few kilometers of displacement has occurred along the CP fault since the emplacement of young volcanic rocks of probable Miocene to Pliocene age.

All of the above workers recognized the possibility that motion between the North American and Caribbean plates was likely accommodated on other faults besides the CP fault. The topographically distinct Motogua fault zone is a major candidate. The great earthquake of 1976 in Guatemala occurred along this fault and caused meter-scale left-lateral displacements over hundreds of kilometers (Plafker, 1976; Kanamori and Stewart, 1978). The Jocotan-Chamelocon fault (fig. 1) is another candidate to accommodate strain across the North American Caribbean plate boundary (e.g., Schwarz et al, 1979). Schwarz et al (1979) mapped Quaternary offsets along the Motogua fault zone to derive slip rates of .15 to .60 cm/yr. They assumed equivalent slip rates would characterize the CP and Jocotan-Chamelocon fault zones and estimated a cumulative displacement of 170 to 685 km between the North American and Caribbean plate since late Eocene time. This is still significantly less than displacements expected if present rates of motion (Sykes et al, 1982) are extrapolated to late Eocene time.

Based on our observations of recent tectonism within the Tertiary and Quaternary volcanic belt, we agree with the suggestion of Carr and Stoiber (1977) that subsididary faults south of the Motogua and Jocotan-Chamelecon fault zones also take up some of the strain related to motion between the Caribbean and North American plates. Thus, mappable offsets within the better exposed northern fault system (Chixoy-Polochic and Motogua) cannot be expected to equal cumulative displacements inferred from rates based on magnetic lineations in the Cayman Trough (MacDonald and Holcombe, (1978) or plate motion solutions derived from earthquake slip vectors and fracture cone azimuths (Sykes et al., 1982).

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FIGURE CAPTIONS

Figure 1: Geological sketch map of Central America with major plate boundaries. Location of ultramafic rocks exposed on the surface and discovered offshore during Deep Sea Drilling Project Leg 84 as well as the Nicoya ultramafic complex in Costa Rica, are also shown. Modified from Dengo (1973).

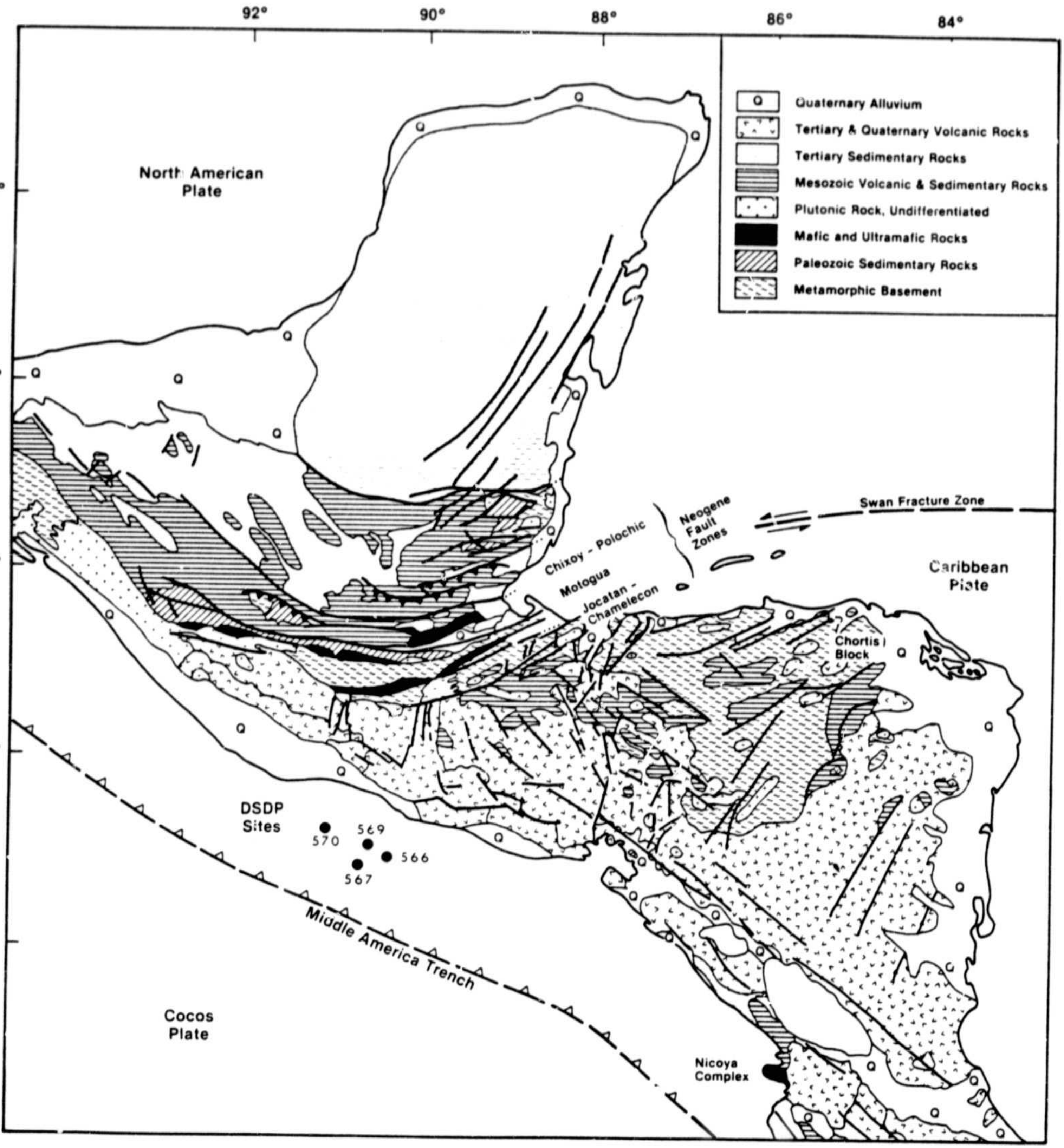
Figure 2a: Portion of the Geological Map of Guatemala covering the area of available SIR-A imagery (After Bonis et al, 1970, and

2b: Imagery from Shuttle Imaging Radar (SIR-A) data take 18

2c: Lineations over 5 km in length mapped from SIR-A data take 18

Figure 3: Rose diagram of lineament azimuth from Fig. 2c, scaled to lineament length.

Figure 4: Comparison of existing plate boundary interpretations: a) Molnar and Sykes, 1969; b) Bowin, 1976; c) Case and Holcombe, 1980. From Dengo (1984).



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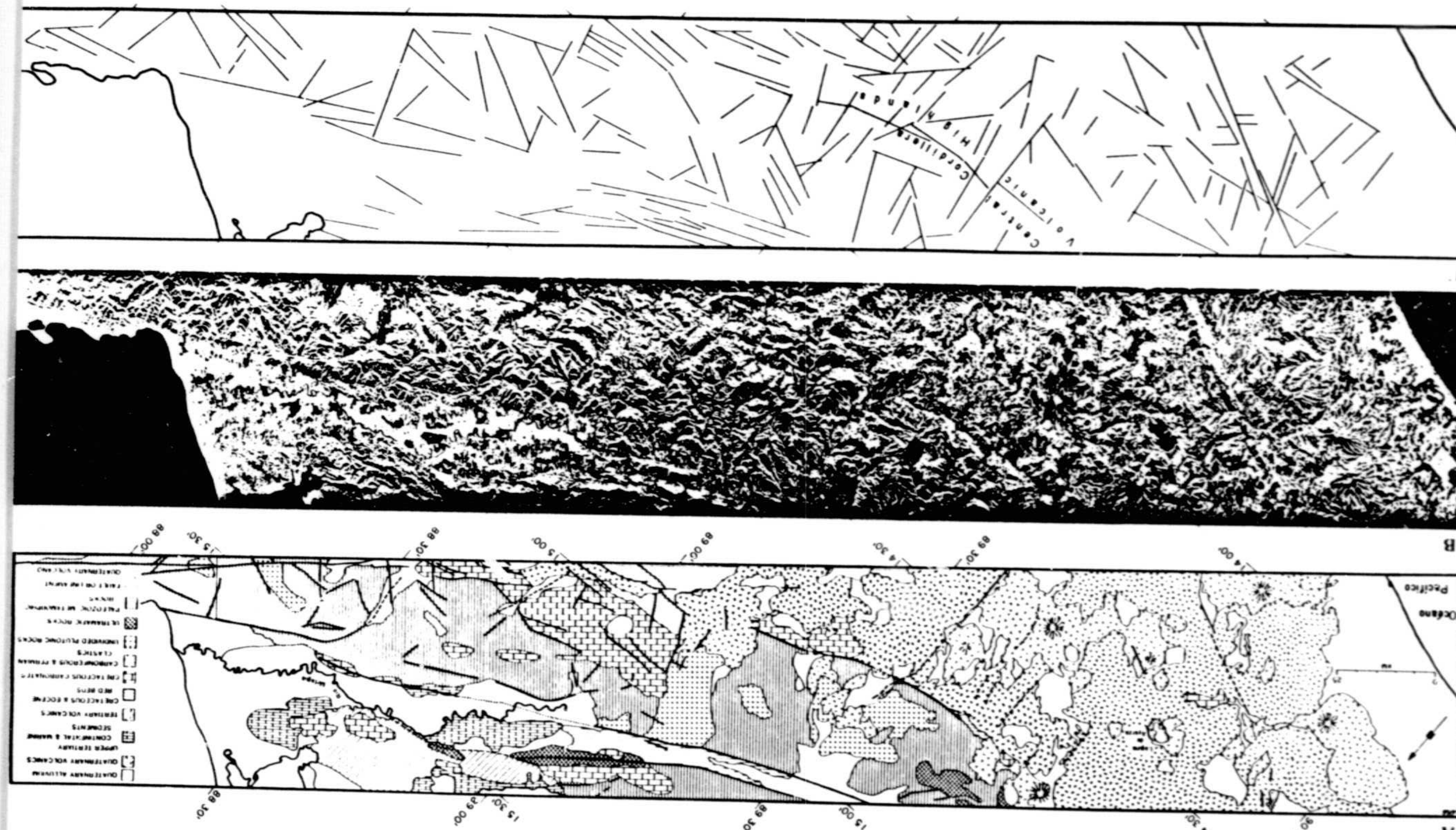

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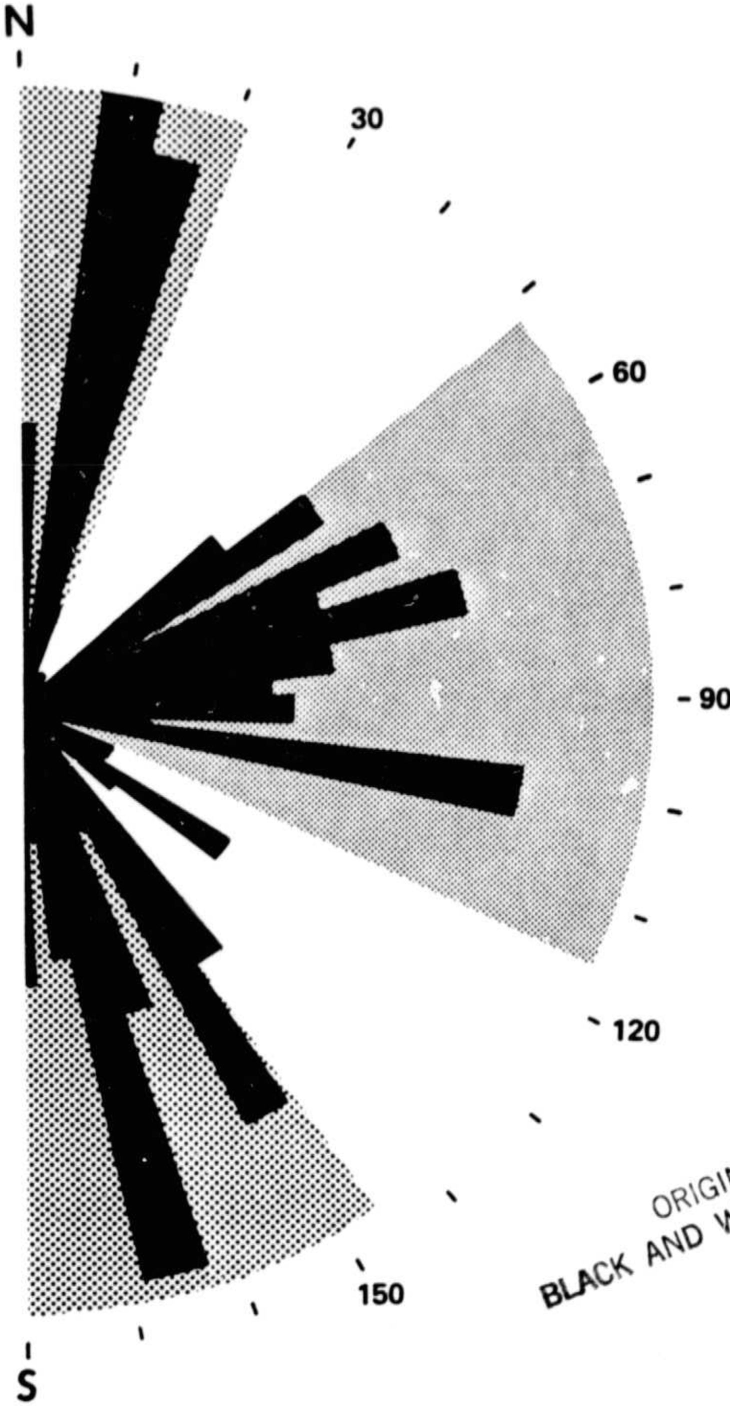
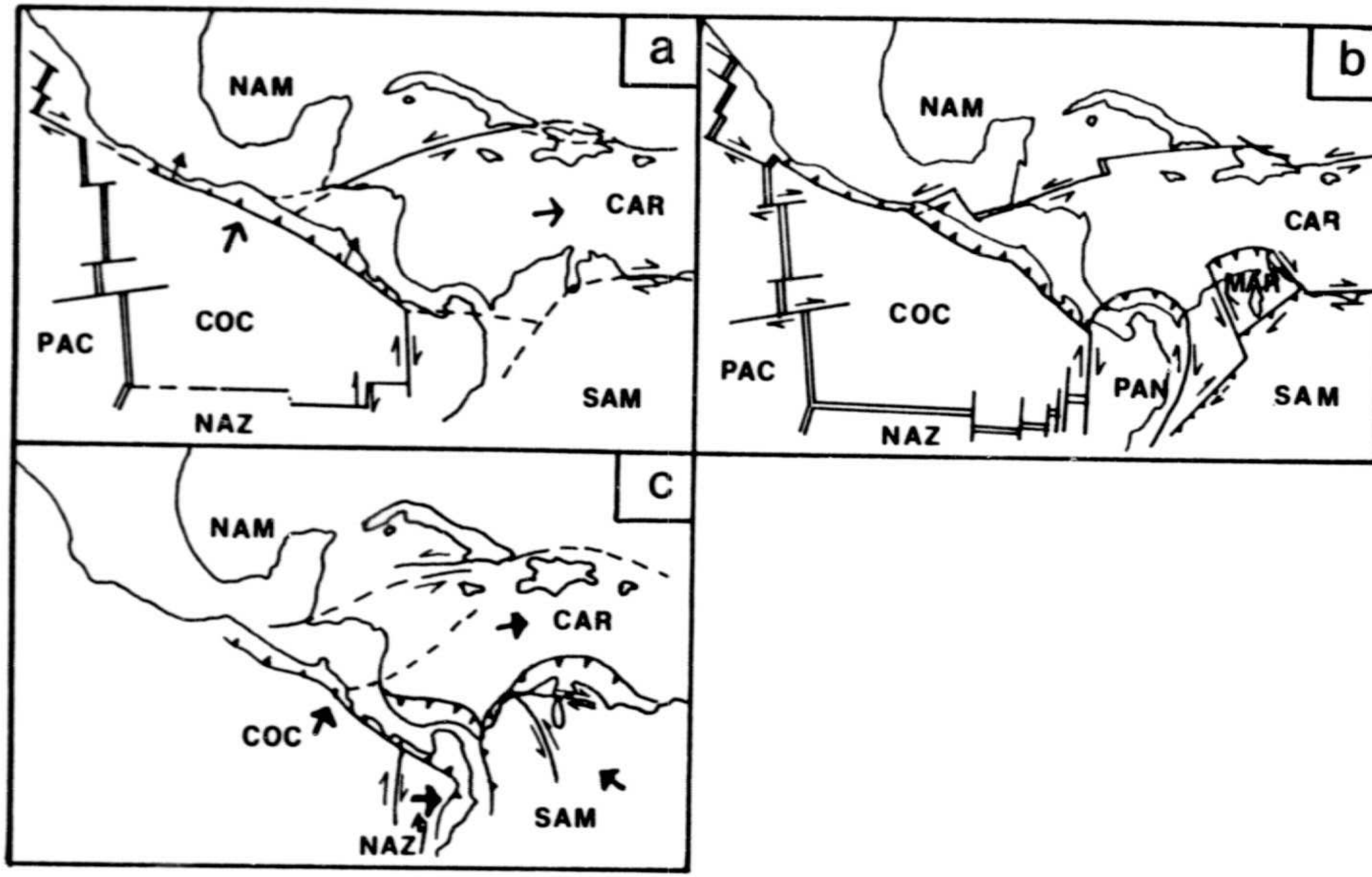
LINEATIONS IN THE TERTIARY AND QUATERNARY VOLCANIC HIGHLANDS, GUATEMALA

SCALED TO LINEATION LENGTH

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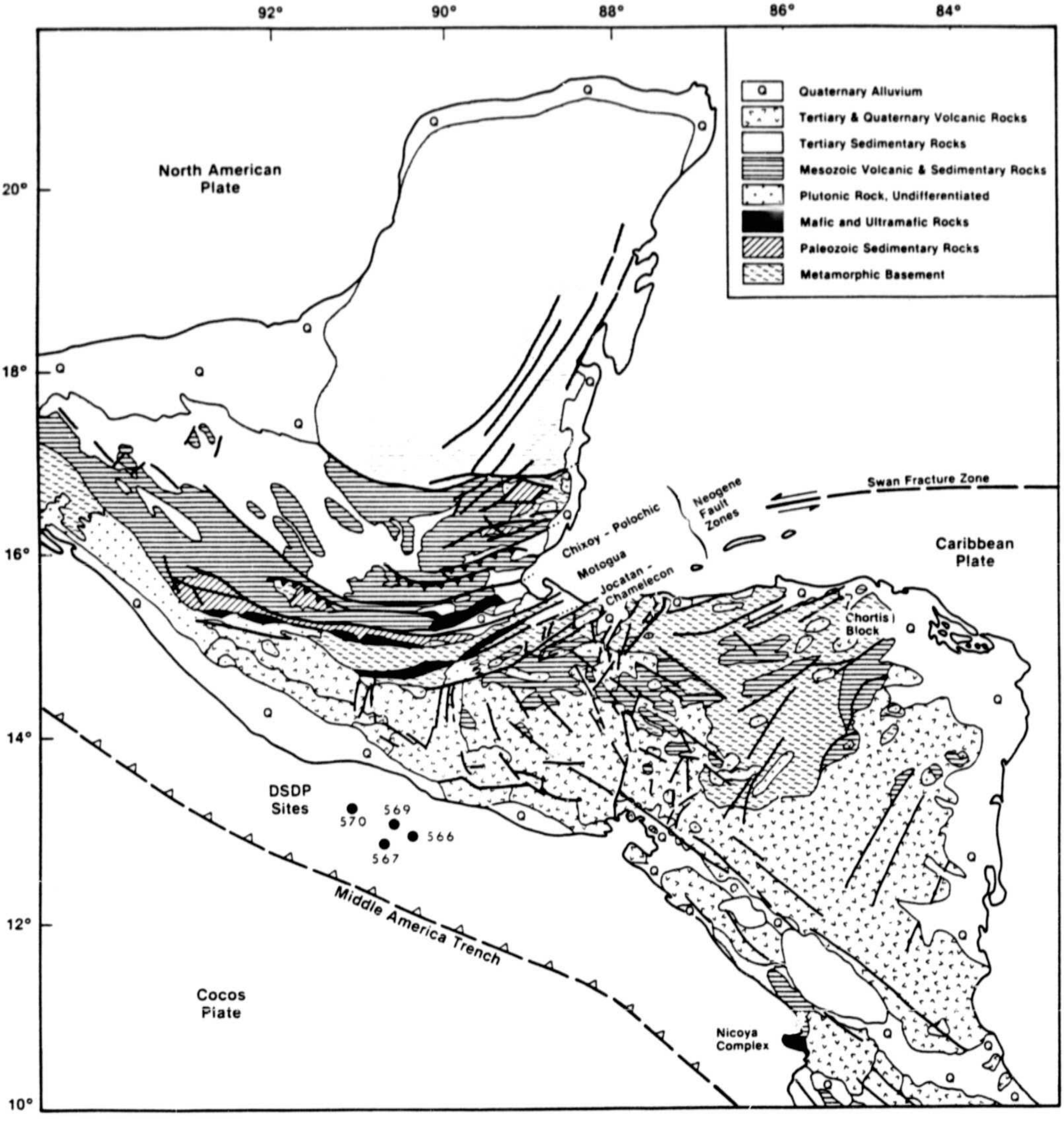

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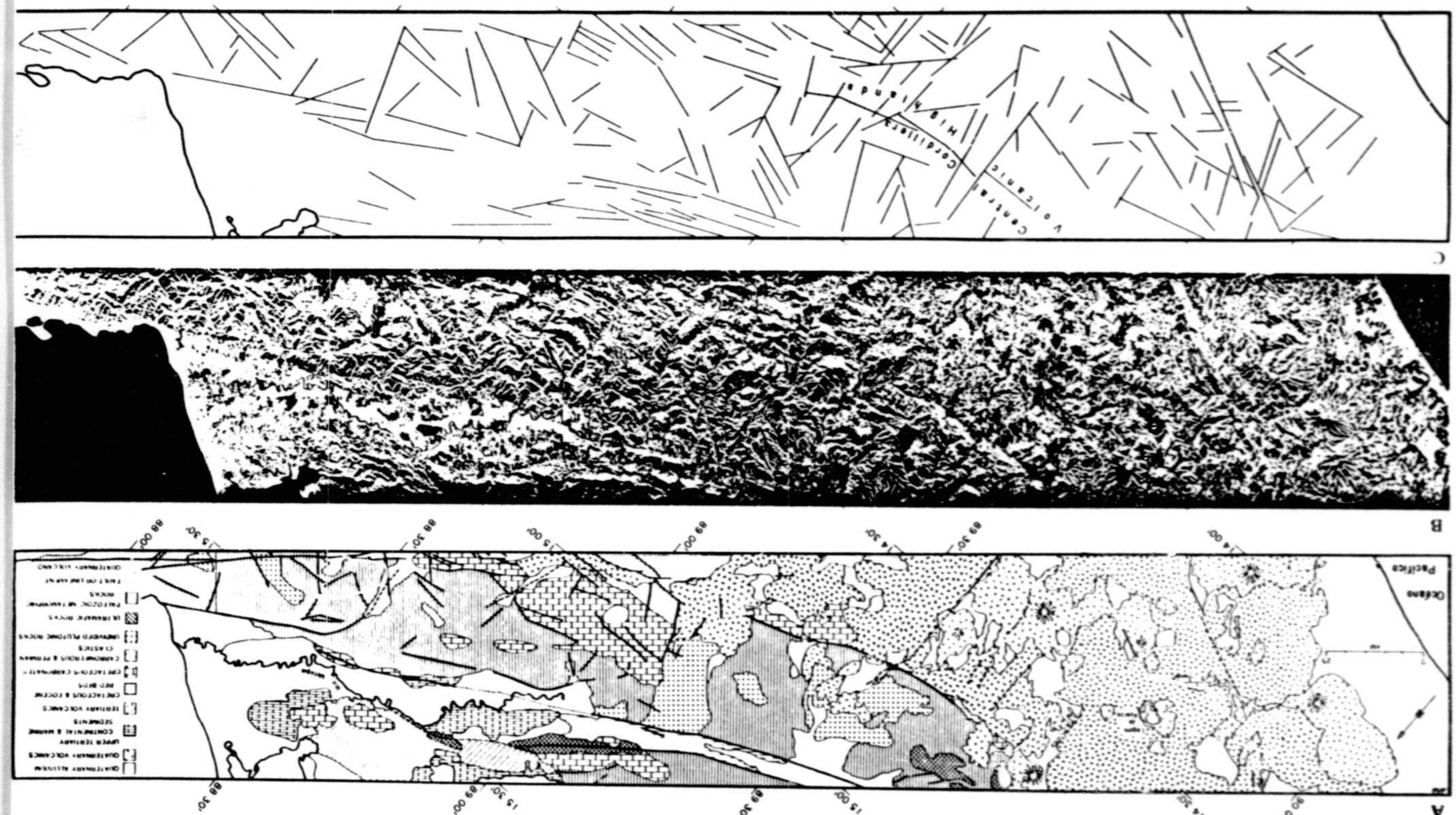

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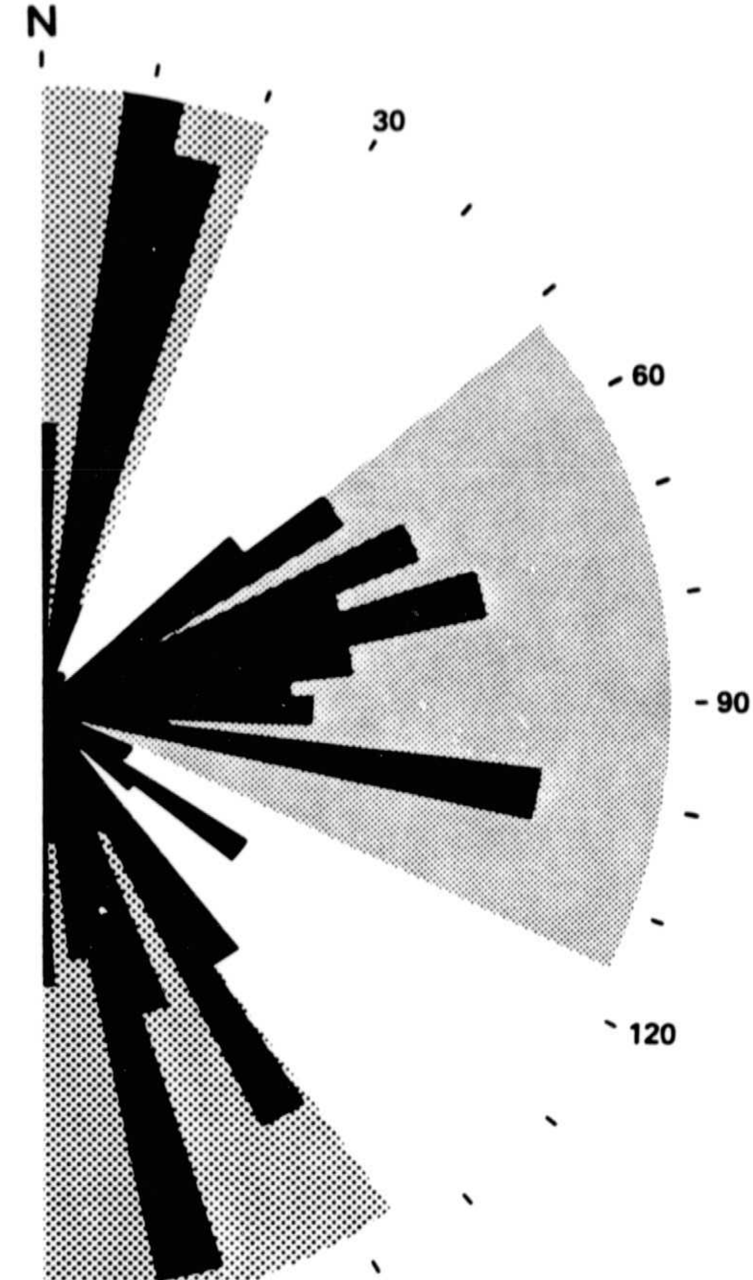

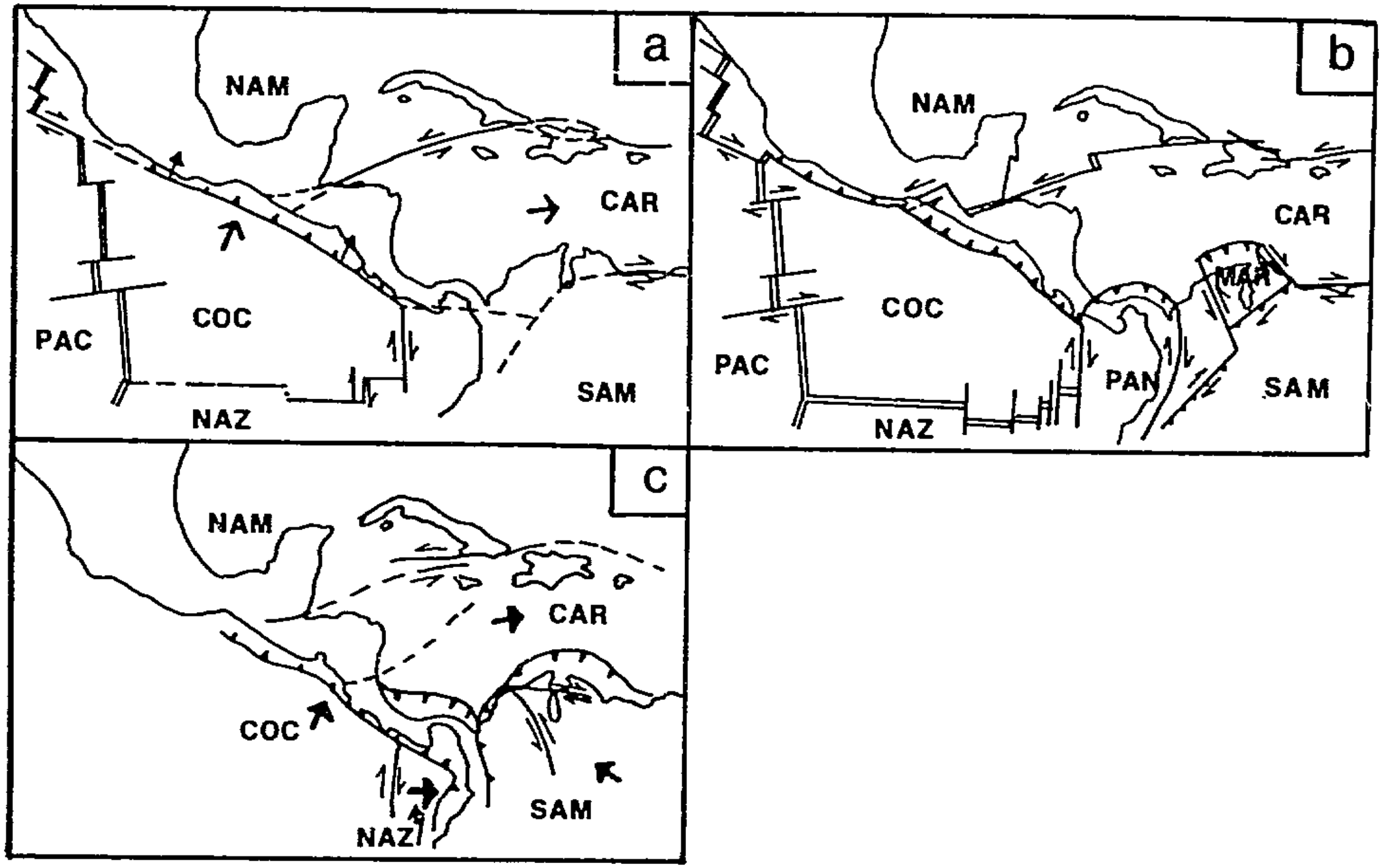
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