The Chixoy-Polochic fault and its associated fractures in western Guatemala

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ABSTRACT

In western Guatemala, post-Cretaceous volcanic and sedimentary rocks locally cover the trace of the Chixoy-Polochic fault. No single throughgoing fault cuts these units. However, a complicated series of en echelon lineations identified from aerial photographs and field mapping represent the accommodations of displacements along the underlying fault.

Comparison of fracture trends in the Chixoy-Polochic fault zone with models from experimental studies and field examples of strike-slip faults suggest that left-lateral displacement along the Chixoy-Polochic fault in this area is probably no more than a few kilometres, since the accumulation of the overlying beds of probable post mid-Tertiary age. Earlier lateral displacements of large magnitude are not precluded, although none have been documented by field study.

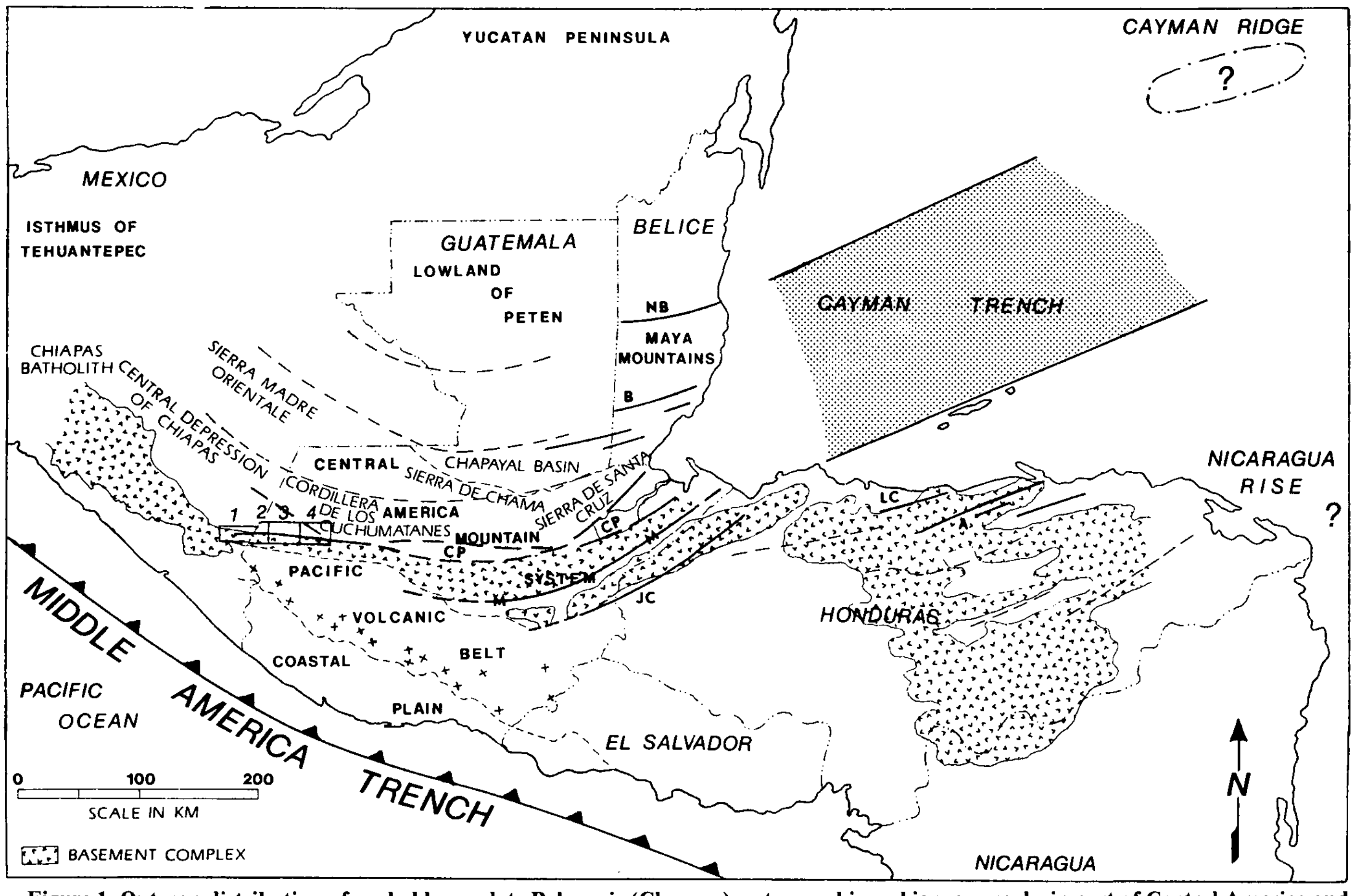

Figure 1. Outcrop distribution of probable pre-late Paleozoic (Chuacus) metamorphic and igneous rocks in part of Central America and southern Mexico showing their relation to major tectonic and geologic features. Also shown are the physiographic-tectonic provinces of Guatemala and the quadrangles along the Chixoy-Polochic fault zone discussed in the text. 1 = Motozintla; 2 = Canibal, 3 = Cuilco, 4 = San Sebastian Huehuetenango; NB = Northern Boundary Fault; B = Bladen Fault; CP = Choxoy-Polochic Fault; M = Motagua Fault; JC = Jocotan-Chamelecon Fault; LC = La Ceiba Fault; A = Aguan Fault. Adapted from Horne and others (1976), Muehlburger and Ritchie (1975), and Kesler (1971).

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INTRODUCTION

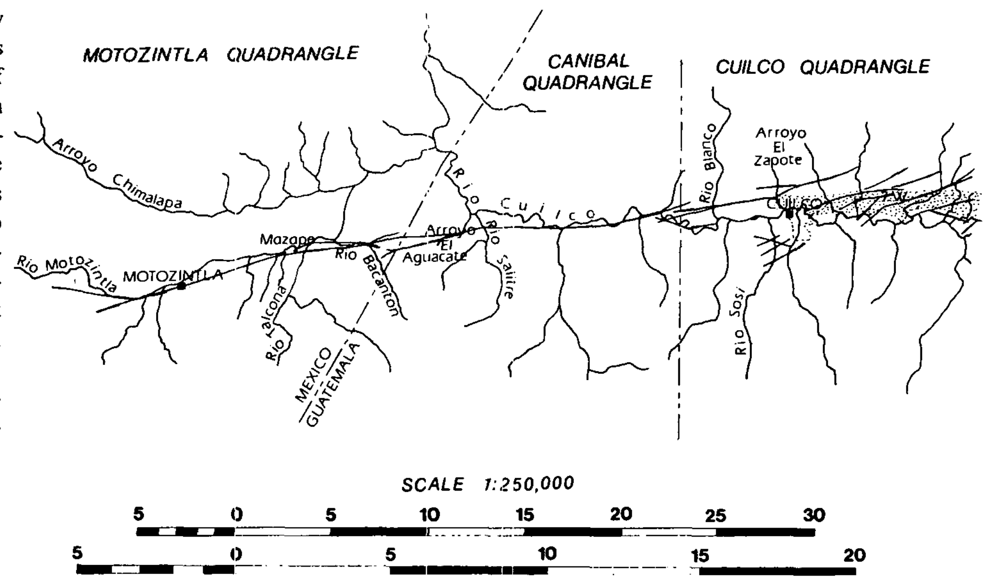
The regional tectonic grain of Guatemala is east-west. This trend is shown not only by faults and outcrop patterns but also by parallel orientation of physiographic axes of ridges and valleys of folded mountains of the Central America Mountain System (Fig. 1). Two extensive fault zones, Chixoy-Polochic and Motagua, which underlie major river valleys, traverse Guatemala as arcs gently convex to the south. These two fault zones, and possibly the Jocotan-Chamelecon (Fig. 1), appear to be the landward extension of the fault system that occupies the Bartlett or Cayman trough and extends from the Gulf of Honduras 1,600 km eastward to the Windward Passage between Cuba and Hispaniola (Meyerhoff, 1966; Holcombe and others, 1973; Perfit and Heezen, 1978).

The Chixoy-Polochic and Motagua faults divide the Central America Mountain System into three structural provinces. At most places the Chixoy-Polochic fault, which extends about 400 km through the Central America Mountain System to the Mexican border, juxtaposes sedimentary rocks of late Paleozoic and Mesozoic age to the north against pre-Permian igneous and metamorphic rocks to the south (Fig. 1). On the other hand, the Motagua fault breaks across igneous and metamorphic rocks for much of its length, locally separating rocks of different metamorphic grade. At its western extension, the fault cannot be traced in Cenozoic volcanic rocks.

PURPOSE OF INVESTIGATION

The area of study consisted of a section 86 km long along the Chixoy-Polochic fault in western Guatemala, extending west from the border of Chiantla quadrangle across the quadrangles of San Sebastian Huehuetanango, Cuilco, and Canibal in Guatemala, and continuing past the town of Motozintla into the surrounding regions of Mexico (Fig. 1). Emphasis was placed on characterizing the distinctive nature of the Chixoy-Polochic fault in Cuilco quadrangle, where its trace had been inferred on the basis of reconnaissance mapping. The purpose of investigation was three-fold: (1) to identify the previously unmapped Chixoy-Polochic fault by analyzing observed fracture patterns, (2) to determine the age of displacement by observing the youngest rocks cut by faulting, and (3) to estimate the amount of displacement by interpreting the fracture pattern using a method employed by Tchalenko (1970).

Figure 2. Location map of rivers, towns, roads, and Colotenango beds (stipple pattern). Map also shows the location of major lineations which comprise the Chixoy-Polochic fault zone.



PREVIOUS WORK

Muehlberger and Ritchie (1975) state that the prominent fault zones that they observed on Skylab photographs of Guatemala have acted as the Caribbean–North American plate boundary at various times. They maintain that the present boundary is the Chixoy-Polochic fault zone. Although they gave no opinion as to the amount of motion that has occurred along the fault, they cited Kupfer and Godoy (1967), who suggested that Holocene left-lateral strike-slip offsets total 122 m, and Kesler (1971), who proposed that the Chixoy-Polochic fault is a Cenozoic plate boundary with less than 150 km of left-lateral offset.

Major displacement was also suggested by Burkart (1978), who argued that if the block north of the Chixoy-Polochic fault trace is moved eastward about 132 ± 5 km, a unique match of Cenozoic and older structures and pre-Cenozoic stratigraphy results. Burkart (1978) suggested that if a 2 cm/yr average strain rate exists along the Polochic fault, and the fault is still active, then its first movement would have occurred 6.5 m.y. B.P., or middle Pliocene. If this strain were shared along the Jocotan or Motagua faults or both, then an age of two or three times would apply, placing age of inception in middle Miocene.

Perfit and Heezen (1978) provided a somewhat different interpretation as to the amount of left-lateral offset along the Cayman trench and implied a similar amount of motion along each individual fault or distributed across the structures that may comprise the plate boundary in Guatemala (that is, Chixoy-Polochic, Motagua, and Jocotan faults). Their evidence points toward an average east-west full spreading rate of 0.4 cm/yr for the mid-Cayman spreading center for the past 5 m.y. By assuming that this average rate has prevailed from Eocene (~ 50 m.y. B.P.) to the present, then a total of about 200 km of left-lateral displacement has occurred across the plate boundary.

Schwartz and others (1979) have reported Quaternary faulting along the Motagua and the eastern portion of the Chixoy-Polochic. Evidence for this faulting included sag ponds, shutter ridges, scarps, springs, and offset streams and river terraces. These authors were able to determine a slip rate of between 0.45 and 1.8 cm/yr for Quaternary motion along the Motagua fault. They believed that the Chixoy-Polochic and possibly the Jocotan-Chamelecon faults, along with the Motagua, share portions of the total strain produced by the Cayman trough spreading center. According to Schwartz and others (1979) the cumulative slip for the Cayman trench would be between 170 and 685 km. The consistent up-to-the-north vertical movement found across all three faults

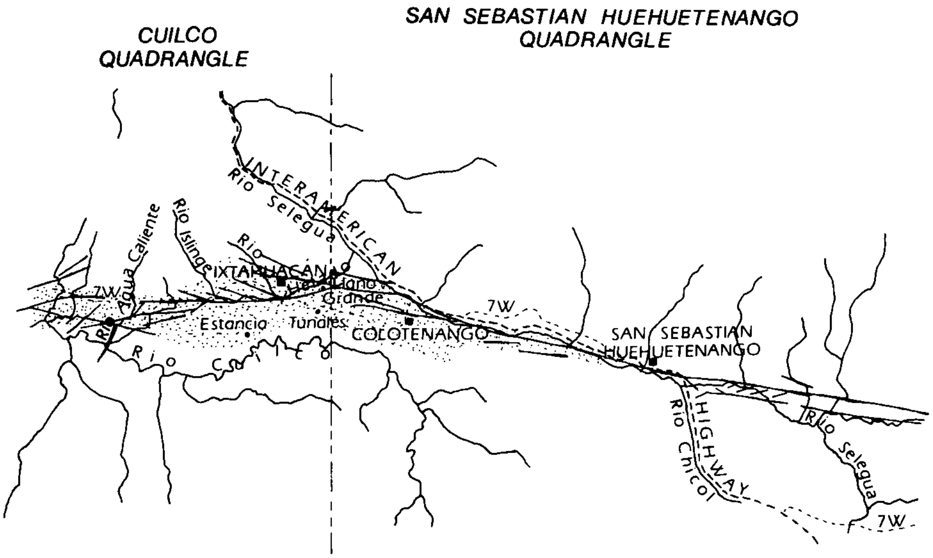


Figure 2. *(Continued).*

as described by Schwartz and others could possibly represent as much as 5% of the lateral component of slip along the plate boundary.

GEOLOGIC FRAMEWORK

Pre-Tertiary Stratigraphy of Cuilco Quadrangle

In western Guatemala, the Chixoy-Polochic fault generally separates sedimentary rocks to the north from crystalline rocks of predominantly pre-Permian age to the south. Four formations of Paleozoic age (Chicol, Tactic, Esperanza, and Chochal) comprise the Santa Rosa Group (Anderson and others, 1973). In Cuilco quadrangle, the oldest exposed formation of this group is the Tactic Formation, which is composed mainly of shale beds intercalated with minor carbonate and siltstone units and is at least 400 m thick.

Above the Tactic is the Esperanza Formation, although at places within Cuilco quadrangle it may be obscured because of extensive faulting (Sandstrom, 1978). The term "Esperanza" is used for a sequence consisting of less than 90% but more than 10% limestone. Within Chiantla quadrangle, Blount (1967) measured a tilted section 474 m thick. Siesser (1967) described a locality along the Interamerican Highway within Cuilco quadrangle where the Chochal overlies about 80 m of interbedded shale and limestone that appear to be lithologically equivalent to Esperanza.

Limestone and dolomite of the Permian Chochal Limestone overlie the Esperanza and Tactic. An incomplete 788-m section of Chochal was measured by Siesser (1967), although the estimated minimum thickness is about 1,000 m.

Orogenic movements affecting the Paleozoic units probably created the basins into which the terrestrial sediments of the lowermost Mesozoic unit, the Todos Santos Formation, accumulated. It unconformably overlies the folded and faulted Chochal Limestone. Todos Santos consists chiefly of interbedded conglomerate, sandstone, and shale. Anderson and others (1973) reported 1,120 m of Todos Santos near the type locality above the village of the same name. Lack of exposures prevented measurement of a section of Todos Santos in Cuilco, but a minimum thickness of 350 m has been estimated.

Marine conditions during Cretaceous time resulted in accumulation of the Ixcoy Formation, which is composed of limestone, dolomite, and carbonate breccia with less abundant calcareous wackestone, packstone, and a few beds of calcareous mudstone. Within Cuilco quadrangle, the contact between Todos Santos and Ixcoy has not been accurately defined. Poor exposures hampered Siesser (1967) from measuring the Ixcoy, although it undoubtedly attains a minimum thickness of 650 m, and possibly 1,000 m or more, as suggested by Blount (1967).

Crystalline rocks in the southern portion of Cuilco quadrangle are composed of both plutonic and metamorphic sequences. Although geologic relations suggest that intrusions as old as Precambrian and as young as Tertiary exist, most of the crystalline rocks are probably of Paleozoic age. The plutonic rocks include mainly granodiorite, quartz monzonite, and granite with less common diorite. Quartzo-feldspathic gneiss, mylonitic gneiss, and amphibolite compose the country rocks for these intrusive bodies.

Post-Cretaceous Volcanic and Sedimentary Rocks in Cuilco

Within Rio Cuilco Valley and along the trend of the Chixoy-Polochic fault zone several kilometres to the east lies a sequence of rocks called the Colotenango beds (Anderson, 1969; Anderson and others, 1973), which is composed of both sedimentary and volcanic units. These strata crop out for about 35 km, from the village of Cuilco at the western edge of Cuilco quadrangle to a point 0.75 km west of the town of San Sebastian Huehuetenango in San Sebastian Huehuetenango quadrangle (Fig. 2). They lie within a 1- to 4-km-wide band and are confined to the valleys of Rios Selegua and Cuilco except near Colotenango where they occupy an uplifted abandoned stream trace between Rio Selegua and Rio Cuilco. The greatest known thickness of the Colotenango beds is about 460 m, south of Ixtahuacan in eastern Cuilco.

Colotenango beds consist of a heterogeneous sequence of conglomerate, sandstone, and mudstone that grade into tuffaceous sandstone, lahar and volcanigenic rocks such as water-laid tuff, rhyodacitic crystal, vitric and lithic tuffs, and rare basalt (Anderson, 1969; Anderson and others, 1973). The conglomerate contains clasts of metamorphic and igneous rocks, volcanic rocks, limestone, and serpentinite, in almost any combination.

In Cuilco the Colotenango beds can be divided into distinctive units. Siesser (1967) described the lower unit as consisting of about 263 m of gently dipping "green beds" composed of interbedded volcanic ash, mudrock, sandstone, and conglomerate that crop out mainly in a belt south of Ixtahuacan stretching from Tunales to 1 km west of Estancia. They rest unconformably on a thin residual soil developed upon gneiss. The uppermost unit of the sedimentary sequence is defined as the uppermost cobble conglomerate underlying tuff and ash.

The volcanic units, which comprise the upper half of the Colotenango beds, crop out mainly north of Rio Cuilco along the wall above the valley floor. The units consist of rhyodacitic vitric, vitric-crystal, and crystal tuff and other pyroclastic units.

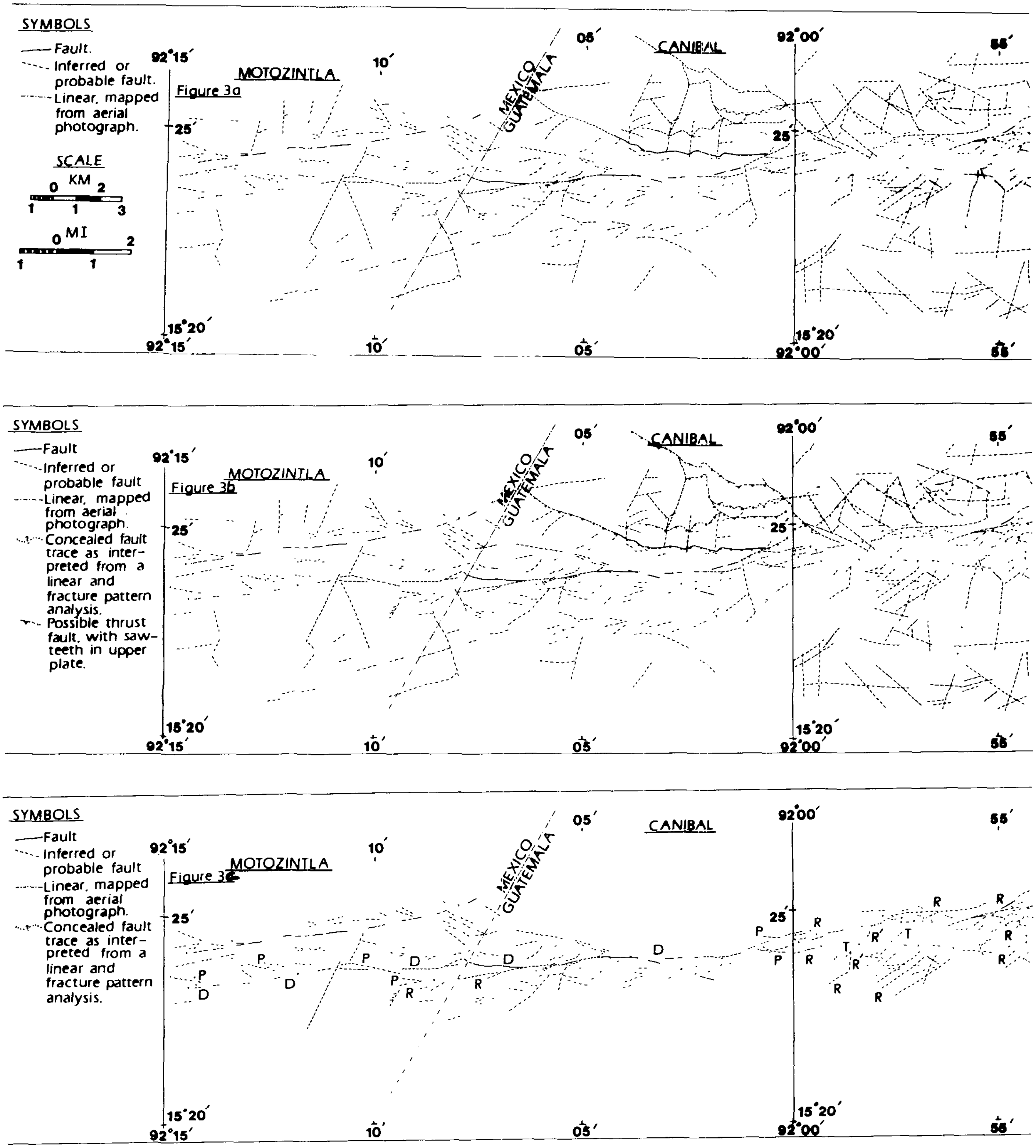


Figure 3. Maps of lineations in part of Canibal quadrangle and the region near Motozintla: Area *a* (upper map) is the base map showing all lineations that were observed; Area *b* (middle map) shows an interpretation of the lineations; Area *c* (lower map) is of those lineations possibly associated with the Chixoy-Polochic fault zone.

They extend from just north of the village of Cuilco eastward into San Sebastian Huehuetenango quadrangle. The thickness of the volcanic units varies from a minimum of about 100 m near Cuilco to at least 200 m above the green beds in the mountains south of Ixtahuacan. These deposits may once have been thicker and distributed over a somewhat larger area, but the greatest present thickness and width of the units are near Ixtahuacan, which may have been near the source area.

The age of the Colotenango beds is uncertain. Anderson and others (1973) described them as being directly related to uplift and volcanism along the Chixoy-Polochic fault zone. They considered the upper beds of this sequence to be post-Miocene(?) because the beds contain boulders of Miocene(?) volcanic rocks derived from the south.

McBirney (1963) described the volcanic rocks of southern Guatemala as falling into two principal groups. One group is composed of Pleistocene and Holocene eruptions restricted to a narrow line of central vents, with dominant rock types consisting of olivine basalt and pyroxene andesite. Large volumes of dacitic pumice have been erupted from some of the older vent complexes. The second older group (which McBirney, 1963, distinguishes) is mainly rhyolitic or dacitic tuffs and glowing avalanche deposits with intercalated lavas of basic or intermediate composition. These volcanic rocks compose a 50- to 70-km-wide belt, parallel to the Pacific coast, which formed during fissure-type eruptions, during late Miocene and Pliocene time.

Volcanic units found within the Colotenango beds appear to relate to McBirney's (1963) older group because they are mainly rhyolitic and dacitic tuffs and their existence within the Cuilco valley is quite possibly due to a local (fissure-type?) eruption as suggested by their distribution along a 35-km-long segment of the fault zone.

Younger Ash and Alluvial Deposits

Above the tuff units lie younger ash deposits, which form a conspicuous terrace level along Rios Cuilco and Selegua within Cuilco and San Sebastian Huehuetenango quadrangles. These deposits generally mantle low slopes within river valleys. They occur on both sides of the river, overlying tuff and crystalline and sedimentary rocks. This younger ash consists of friable, white or light gray to light brown lapilli and ash composed of pumice. The ash is more than 100 m thick west of the village of Cuilco, where it overlies an 80-m-thick deposit of alluvium. This deposit, and higher, younger alluvium along Rios Cuilco and Selegua, consist of sand- to boulder-sized debris of volcanic, crystalline, and sedimentary origin.

EXPRESSION OF THE CHIXOY-POLOCHIC FAULT IN WESTERN GUATEMALA AND MEXICO

Canibal Quadrangle

The expression of the Chixoy-Polochic fault zone as en echelon fractures in Cuilco quadrangle is distinct from its manifestation as a continous trace in adjacent areas to the east (San Sebastian Huehuetenango quadrangle) and to the west (Canibal quadrangle and the Motozintla region).

In the Canibal quadrangle (Fig. 3), the fault zone, which separates igneous and metamorphic rocks from distinctive pinkish-orange quartz porphyry and volcaniclastic rocks, crops out commonly as a single trace. The zone is marked by breccia, triangular facets, and photo linears. Near the Mexican border where the fault zone crosses Rio Salitre (Fig. 2), granitic quartz porphyry is juxtaposed against gneiss. From this point the fault appears to follow the channel of Arroyo El Aguacate westward into Mexico.

Motozintla, Mexico

The Chixoy-Polochic fault can be traced westward from Canibal (Fig. 3) as a photolinear that coincides with a tributary valley of Rio Bacanton. The fault appears to cut across Rio Bacanton rather than following the river valley, and passes through material described by Carfantan (1977) as meta-andesite and metarhyolite. It probably enters Rio Motozintla Valley at the village of Mazape and may lie in the valley of Rio Motozintla as far as the town of Motozintla where it appears to split into a northwest-trending segment and a west-trending segment.

San Sebastian Huehuetenango Quadrangle

East of the village of San Sebastian Huehuetenango, the fault occupies a zone of strongly brecciated rock, commonly about 100 m wide, composed of granule and larger sized breccias, cut by planar shear zones which locally dip north. Farther east, a more or less continuous band of shattered, commonly silicified Chochal(?) Limestone, tens of metres wide, marks the northern edge of the breccia zone. This zone coincides with offsets of seven streams, all of which record left-lateral displacement (Anderson and others, 1973). The maximum displacement is about 1 km.

Rock relationships along the fault west of the village of San Sebastian Huehuetenango are much less consistent and involve a wide variety of rocks, including plutonic and metamorphic rocks, Tertiary(?) tuff and conglomerate, and shale beds. Easily deformed shale beds in the Esperanza and Tactic Formations obscure the fault, although it can still be recognized by impressive breccia zones in limestone units exposed in stream cuts and landslides, ubiquitous fracturing in outcrops of tuff in Rio Selegua canyon, and sheared gravel and titled gravel beds at various localities along the highway.

Near the western end of this quadrangle, the Interamerican Highway turns northwestward and crosses the fault zone (Fig. 2). Here the fault zone is poorly exposed, although intensely sheared nondescript black shale may indicate its proximity. The fault appears to parallel the Interamerican Highway for a short distance before it continues west toward the village of Llano Grande (Fig. 2) on the western border of the quadrangle. There, several well-exposed east-west subsidiary faults record displacement of overlying Tertiary strata (Fig. 4). Moderately to steeply dipping beds can be found as much as 2 km south of the main zone.

Cuilco Quadrangle

Within the Cuilco quadrangle in the Ixcoy Formation, and to a lesser degree in Tertiary volcanic units, brecciation extends from just east of Ixtahuacan, westward to a point about 2 km east of the town of Cuilco. The exposures of brecciated rocks vary from as little as 2/3 m to 1/3 km. In general, breccia in the volcanics is composed of large boulders within a matrix of smaller fragments. Limestone of Ixcoy Formation (Cretaceous) is consistently highly smashed, with varying amounts of boulder-sized blocks within a matrix of smaller fragments and powdered limestone.

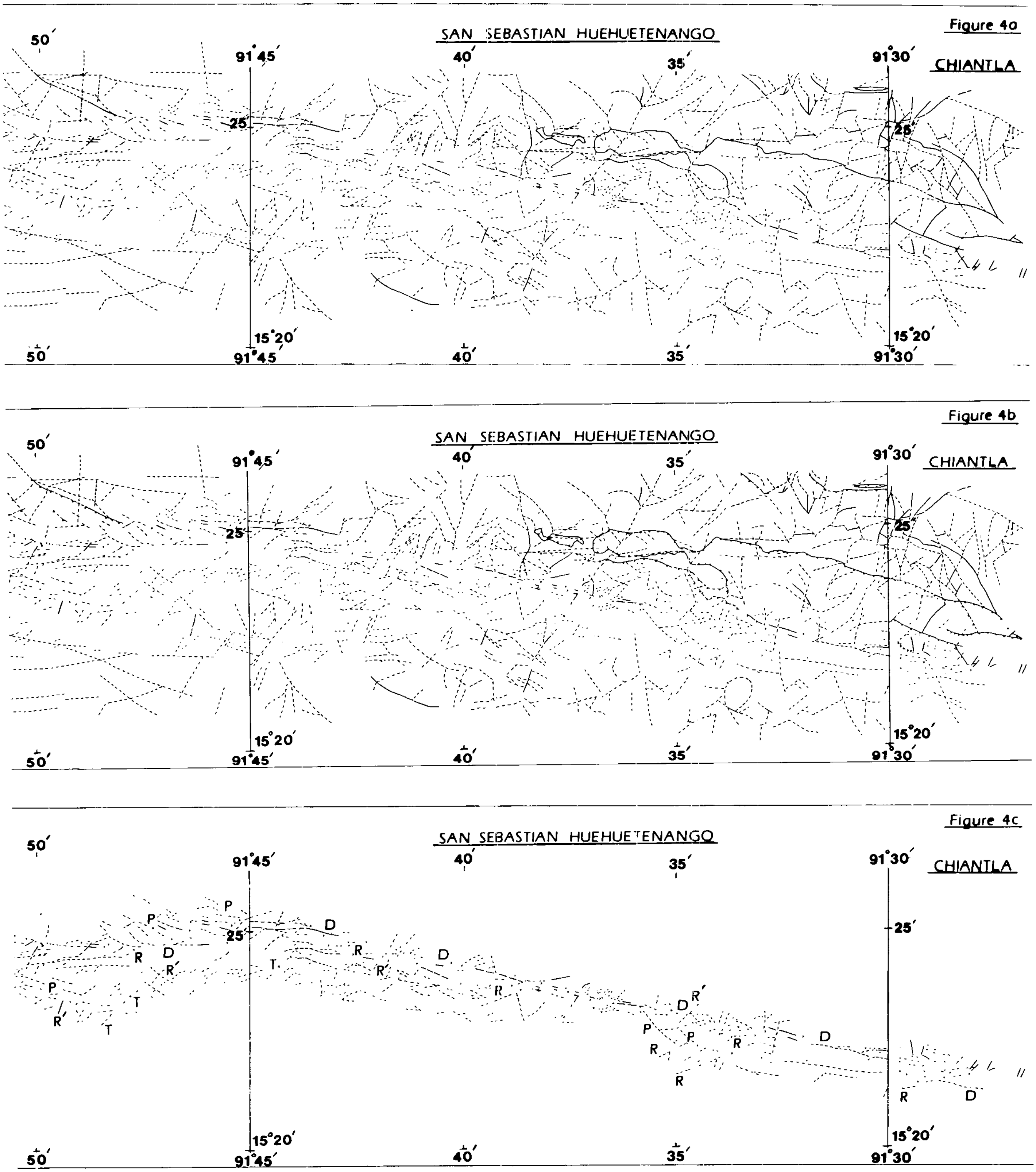


Figure 4. Map of lineations in part of San Sebastian Huehuetenango quadrangle and the western portion of Chiantla quadrangle: Area *a* (upper map) is the base map showing all lineations that were observed; Area *b* (middle map) shows an interpretation of the lineations; Area *c* (lower map) is of those lineations possibly associated with the Chixoy-Polochic fault zone.

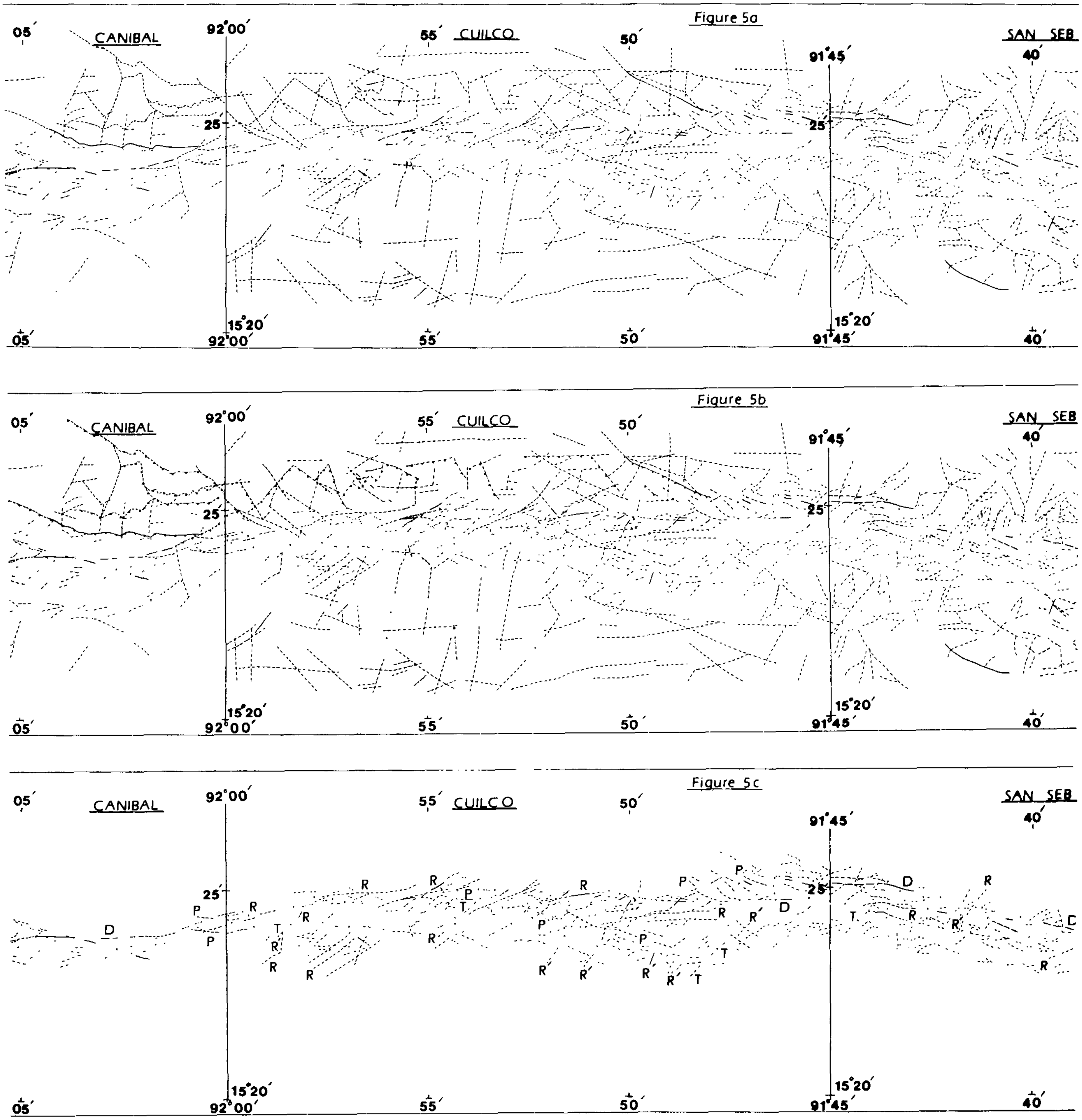


Figure 5. Map of lineations in part of Cuilco quadrangle. Area *a* (upper map) is the base map showing all lineations that were observed; Area *b* (middle map) shows an interpretation of the lineations; Area *c* (lower map) is of those lineations possibly associated with the Chixoy-Polochic fault zone.

Brecciation in the tuff is quite variable. In the valley of Rio Helado, 1 km east of Ixtahuacan, highly brecciated volcanic tuff 250 m thick crops out along the south wall of the valley. Material in this zone ranges from sand-sized grains up to blocks that measure several metres across. In constrast, tuff that crops out 1 km northwest of Cuilco in Arroyo El Zapote is brecciated in a zone that is only 1.5 m wide.

Brecciation in Ixcoy Limestone is much more intense than in the volcanic tuff. In the area of Rio Agua Caliente, brecciation ranges from boulder-sized blocks that may measure metres across to sand- or silt-sized material. Landslides within this brecciated material are common.

Scattered slickensided fault surfaces crop out within the breccia zone at several localities. These commonly record dip-slip movement.

FRACTURES AND FRACTURE SETS IN POST-CRETACEOUS ROCKS

Within Cuilco quadrangle, a distinctive pattern of en echelon fractures occurs mainly in the Colotenango beds. The expression of the Chixoy-Polochic fault in these rocks is in constrast to fracture patterns to the east and west (Fig. 5). Lineations utilized to define the patterns were mapped on the ground and from aerial photographs, on which they were defined by changes in vegetation cover, saddles between ridges, abrupt changes in the slope of hillsides, and the existence of long, deep, and sometimes parallel systems of stream valleys. Most of these lineations occur on the northern slope of the Rio Cuilco Valley, although some lineations lie south of the valley.

The fracture patterns define four general trends. The first is composed of westerly to northwesterly trending fractures that parallel reverse faults that were mapped within Canibal quadrangle (T. H. Anderson, 1976, unpub. data). In the Cuilco quadrangle, the distribution of Ixcoy Formation and Todos Santos Formation along the northern wall of the Cuilco Valley suggests the existence of similar reverse faults. These reverse faults are not considered to be directly related to existing strike-slip fracture patterns, and they are not included in Figure 6.

The 253 remaining lineations from area C of Figure 5 are plotted on two rose diagrams in Figure 6. Figure 6A is constructed by plotting the number of the linears within 4° intervals versus the total number. Figure 6B is a plot of the total length of lineations within each 4° interval against the total length of all lineations (149.5 km). The percentage increase of a particular trend from the upper to lower diagram implies the existence of long lineations within that group. Similarly, a decrease in percentage of a trend from the upper to lower diagram implies the presence of short linears within the group.

The plotted fracture patterns of Figure 6 distinguish a series of high-angle northwest-trending lineations located in the central and easternmost portions of Cuilco, whose straight traces suggest steep dips, but which do not appear to be related to reverse faults. These linears lie within N58°-86°W with a break (accentuated in the lower diagram) around N76°W. Thus within this northwesterly trending group, two sets of fractures probably exist. The first trends N78°-86°W and represents those linears with the greatest individual lengths. The second set trends N58°-74°W and is composed of shorter linears.

Most lineations trend within N54°-86°E with several drops in the frequency of the linears within this range. If plotted to emphasize length, the trends are distinguished, although not strongly. Not only do a large number of lineations fall within this interval but also the lengths of these linears are greater if compared to the remainder. The longest individual linears are within this group, with four fractures having lengths of as much as 5 km. These northeast-trending linears comprise a series of en echelon fractures that can be traced from the western border of the quadrangle eastward to the San Sebastian Huehuetenango border (Fig. 5).

A second group of northeast-trending lineations exists within N34°-50°E. These fractures are more strongly defined in the upper diagram of Figure 6 than in the lower, which indicates their abundance but short length.

Finally, a small number of east-west linears fall within N86°-94°E occupying an area of 4° on either side of the east-west trend. Although Figure 6A indicates the number of linears occupying this range as being equivalent to that of any of the previous sets already described, Figure 6B shows that the lengths of these fractures in this east-west trend are less than in other directions.

COMPARISON WITH MODEL STUDIES

Similarities between shear zones of various scales have been recognized since the early days of structural geology and used in model studies of tectonic processes. Tchalenko (1970) performed what is called the Riedel experiment (Cloos, 1928; Riedel, 1929) in which a clay paste (such as kaolin) is placed over two adjoining horizontal boards. As one board is slowly moved past the other, a characteristic en echelon fracture pattern develops within the overlying clay slab.

Tchalenko (1970) observed five stages of development in the en echelon pattern (Fig.

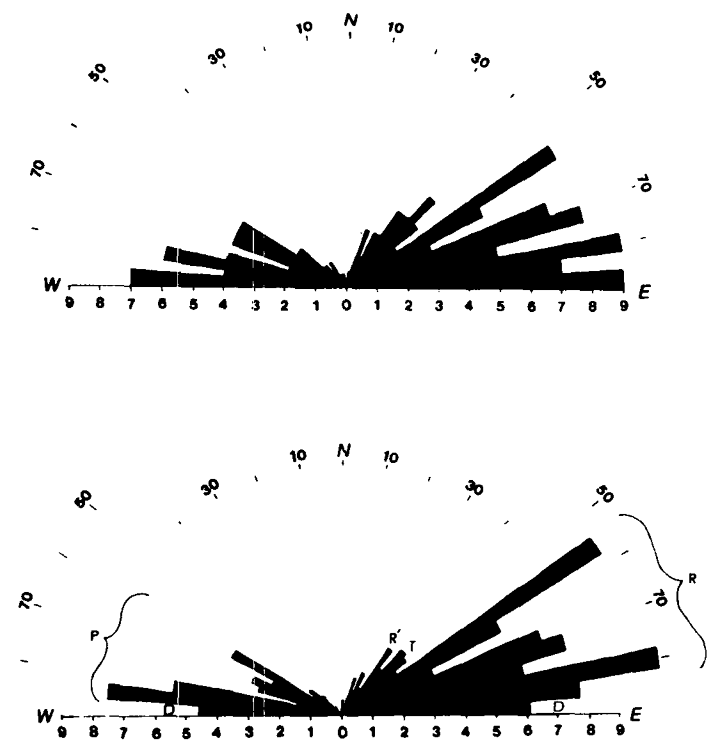


Figure 6. Rose diagrams of selected linears. Upper rose diagram is constructed by plotting the number of linears with 4° intervals versus the total number; the lower diagram is a plot of the total length of lineations within each 4° interval against the total length of all lineations (149.5 km).

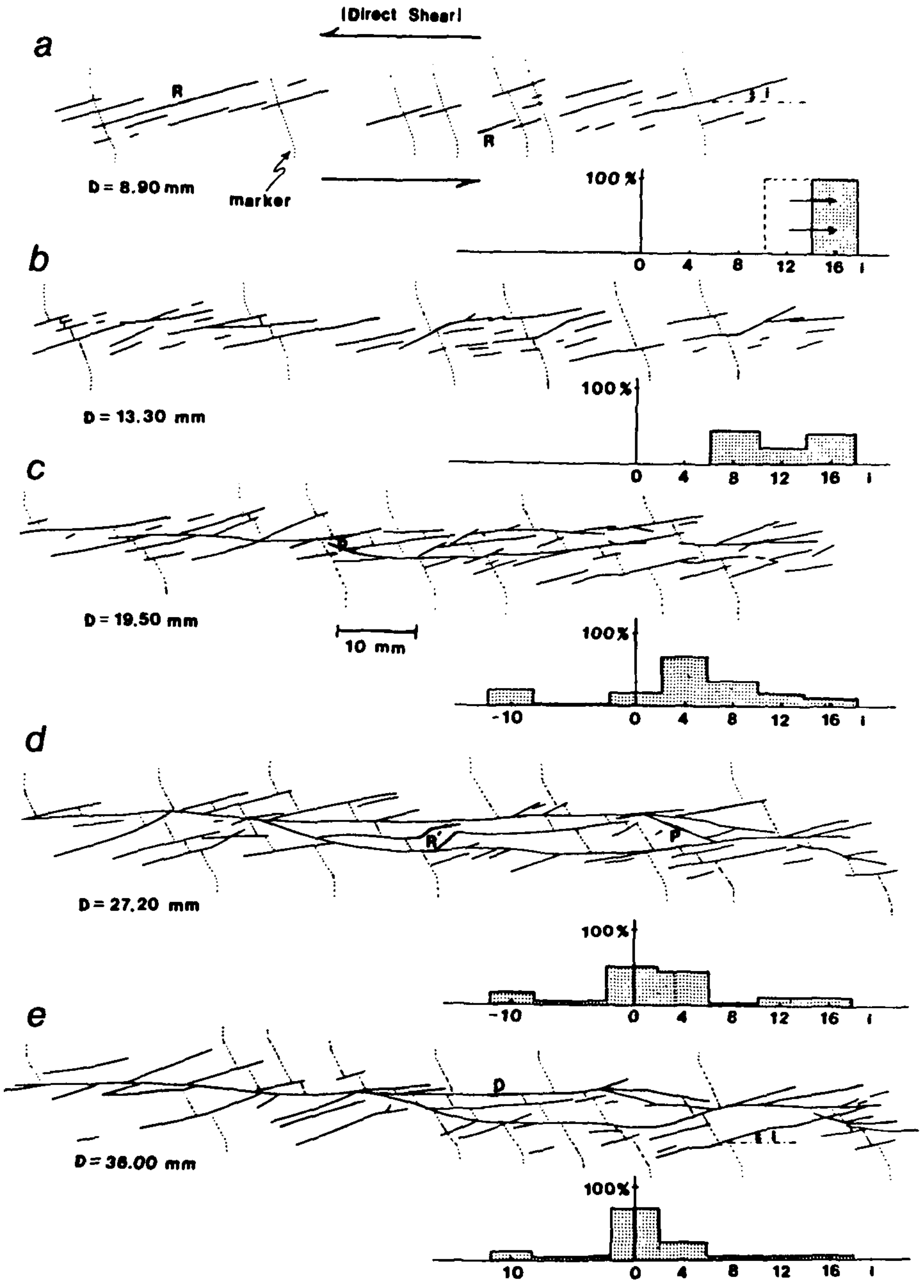


Figure 7. Sequence of structures in the Riedel experiment. i = inclination of shear in degrees with respect to general direction of movement. R = Riedel shear. R′ = conjugate Riedel shear. T = tension shear. P = "thrust" shear. D = principal displacement shear. (a,b,c,d,e) = stages in the deformation process. Adapted from Tchalenko (1970).

7) when using kaolin with a 56% water content. During the development of these shears, the proportion of board movement, or total displacement (D), taken up by movement on the individual shears (d) can be directly measured. These displacements can be plotted against the inclination (i) of the shears to the general movement direction in histograms (Fig. 7) and indicate the cumulative displacement (d_i) that has occurred along the shear groups.

Tchalenko (1970) observed that initial movement of the boards causes homogeneous strain in the region of the future shear zone. Circles inscribed on the clay are transformed into ellipses, indicating that deformation is of the simple shear type. This pre-peak stage deformation (not shown in Fig. 7) is followed by stage *a*, or what is called peak structure. During this stage the Riedel shears (R) first appear at an average inclination of 12° ± 1°, but quickly become rotated to a maximum inclination of about 16°. The amount of board displacement accommodated by individual shears rises from 0 to 50%. A second set of shears, the conjugate Riedel shears (R′), form at an inclination of 70° ± 1° and may appear simultaneously or just prior to the Riedel shears. During this stage, tension (T) fractures may also form in addition to, or in place of, Riedel shears. They develop at an inclination of about 45°.

Post-peak structure (stages *b* and *c*) is associated with the drop in shearing resistance from peak to residual strength value. The R and R′ shears formed at peak strength become unfavorably oriented to maintain large relative motions. The R′ shears respond passively to post-peak deformation by rotation and distortion because they are nearly perpendicular to the direction of movement. The R shears extend into undeformed material on either side of the shear zone where their relative displacements are reduced toward zero from the maximum in the central part of the shear zone. Some R shears extend into a more horizontal direction, with a few new shears appearing at about 8°. The amount of total displacement accommodated by these shears attains about 75%.

With the passive response of R′ shears and the decrease in motion along R shears, Tchalenko (1970) observed the formation of new shears called P, or thrust shears, because oblique motion can at times occur along this shear. These are symmetrical to the R shears about the direction of motion, forming characteristic "bull nose" structures (Skempton, 1966). More than one-half of the shears are now inclined at 4°, with the majority of the total movement at this stage accommodated by displacements along shears.

Tchalenko (1970) described stage *d* as the pre-residual structure, in which the first continuous horizontal shears, the "principal displacement shears" (D shears), are formed. They isolate elongate lenses of essentially passive material between them. Most shears are now inclined at 4° or less.

When stage *e* (the residual structure) is reached, the combination of displacement along the R and P shears leads to the formation of the D shears oriented parallel to the direction of motion. The active portion of the shear zone reduces in width until all movement is along a very narrow zone or on a single slip surface.

In the Riedel experiment, the over-all strain is controlled and measured, but in the case of earthquake faulting, rates of movement are commonly unknown. However, a growing body of evidence indicates that surface displacements occur over a time period well in excess of the actual duration of the underlying bed-rock rupture, as a result of the time required to transfer the energy of motion to the surface (Scholz and others, 1969).

With earthquake faulting, it is not usually possible to follow the structural evolution continuously, as in the Riedel experiment. Commonly, observations pertinent to a structure have been made sometime after the main shock, when most of the movement has been completed. However, even then, detailed mapping may reveal segments that have undergone different amounts of relative displacements, and, if conditions are favorable, a time sequence and stages of structural evolution may be distinguished. Such is the case for the Dasht-e-Bayaz earthquake of 1968 in Iran as described by Tchalenko (1970) and Tchalenko and Ambraseys (1970).

The segment of the fault studied by Tchalenko (1970) and Tchalenko and Ambraseys (1970) was a zone 2 to 3 km wide and 25 km long, located in Quaternary deposits in the Nimbluk Valley. Maximum relative displacements in the valley were 4.5 m left-lateral and 2.5 m vertical.

Tchalenko (1970) showed that this segment of the fault could be described at three distinctive stages of structural evolution, the peak structure (stage *a*), the post-peak structure (stage *c*), and residual structure (stage *e*). Stage *a* at the fault segment showed over-all displacements of about 150 cm along the earthquake fault. For stage *c*, about 250 cm of displacement was observed and, finally, stage *e* showed displacement of 300 cm along the earthquake fault. Tchalenko (1970) also described fossil shear zones, which formed in the past but are now inactive. These displayed comparable structures. In the Riedel experiments, Tchalenko (1970) observed the length of the shears as being less than or equal to 5 cm, whereas those in the earthquake fault were measured in metres to hundreds of metres.

The similarity between the fractures described by Tchalenko (1970) and those observed in Cuilco (compare Figs. 7 and 5C) is strong. The fractures in the region between 91°55′ and those in the western border of the quadrangle closely resemble stage *b* of Figure 7, whereas those in the remainder of the quadrangle more closely resemble stage *c*.

This interpretation of the fractures in Cuilco suggests that the fractures in Figure 6 may be correlative to R, R′, P, T, and D shears. Thus the northeast-trending linears within N54°-86°E in the lower diagram are considered to be comparable to R shears. These R shears are inclined between 4° and 36°, equal to about twice the maximum observed by Tchalenko, which was 16°. Two other northeast-trending shear sets are also present. The first, within N42°-50°E, would appear to correspond to the T shears if they are defined as being inclined at 45° ± 5°. The second set, less than N38°E (or the equivalent of greater than 52° inclination), are probably R′ shears. The inclination of R′ shears is defined to be $90°-\Phi/2$, where $\Phi/2$ is the inclination of the R shear. Because the range of inclination for the R shear in Cuilco is between 4° and 36°, the minimum angle for the R′ shear is 90°-36°, or 54°. This compares well with the angle of 52° observed.

The northwest-trending linears lie within N58°-86°W, equal to an inclination of −32° to −4°. The P shear is symmetric with the R shear about the direction of motion (Fig. 7). Because the R shears are inclined between 4° and 36° in Cuilco, the symmetry of these to the northwest-trending P shears is readily seen.

The remaining set of linears lies within N86°-94°E. These east-west–trending lineaments correspond to the D, or incipient principal displacement shears.

In the region of the Dasht-e-Bayaz earthquake, Tchalenko (1970) and Tchalenko and Ambraseys (1970) were able to measure horizontal displacement along the fault (4.5 m) and displacement along individual shears (1.5 to 3 m) observed in Quaternary cover. In the Chixoy-Polochic fault in Cuilco quadrangle, the shears observed in the volcanic cover record the structural evolution of the fault. The shears indicate that motion along the buried Chixoy-Polochic fault has occurred since emplacement of the Colotenango beds. However, it was not possible to directly measure any displacement across the shears, so the amount of motion can only be estimated. In the estimates, thickness of the volcanic cover is important. Scholz and others (1969) have stated that surface motion occurs over a time in excess of the actual duration of the underlying bed-rock rupture, as a result of the time required to transfer the energy of motion to the surface. Therefore cover rocks across the fault not only affect the time of surface displacement, but also affect the amount of surface motion. Thus the deeper the bed-rock fault is buried, the greater the rupture that is required before any surface expression is observed.

If it may be assumed that the thicknesses of cover rocks in Cuilco and Nimbluk valleys are comparable (that is, varying from a few tens to a few hundreds of metres), then a comparison of the observed shear lengths may provide insight into the magnitude of fault displacement. In the Nimbluk Valley, Tchalenko (1970) and Tchalenko and Ambraseys (1970) measured shear lengths from metres to hundreds of metres, and actual fault motion of 4.5 m. Within Cuilco quadrangle, shears were observed with lengths varying from hundreds of metres to almost 5 km. To produce the en echelon shear pattern observed in the Colotenango beds, the authors suggest that total displacement along the buried Chixoy-Polochic fault has probably amounted to at most a few thousands of metres.

CONCLUSIONS

Movement along the Chixoy-Polochic fault since the accumulation of the volcanic beds is recorded not as a single principal displacement shear as in most of the region near the towns of San Sebastian Huehuetenango, Canibal, and Motozintla, but as a series of en echelon fractures extending the entire length of the Cuilco quadrangle within Rio Cuilco Valley. Geomorphic evidence for movement within the Colotenango beds includes a complicated system of linear drainage valleys, saddles, subtle breaks in slope, changes in vegetation and soil color that probably reflect disturbance of ground-water regime, and zones of coarse breccia. No values for the amount of motion along these linear features could be measured. However, if lineations observed on the ground and on aerial photographs are the reflection of motion along the buried Chixoy-Polochic fault, these probable fractures can be likened to those of the Riedel experiment, and the amount of movement can be estimated. The fracture pattern represented in the Cuilco quadrangle resembles that observed in stages *b* and *c* of Figure 7. The fracturing in the volcanic sequence in Cuilco Valley acts similarly to that in the Riedel experiment in that the fracture pattern is the result of transferral of a percentage of the total displacement that has occurred along the fault. Because there appears to be no coalescense of the fractures into a single principal displacement shear, the amount of motion which has occurred along the fault since the emplacement of the volcanic rocks (Miocene to Pliocene?) is likely small, probably at most a few kilometres, which is close to the 1-km displacement observed along offset streams by Anderson and others (1973) in San Sebastian Huehuetenango. Therefore, proposed displacement of 100 or more kilometres within this fault zone must be older than the volcanic rocks in Cuilco. Earlier displacements may be responsible for some of the intense brecciation recorded in the Ixcoy Formation but not found within the volcanic strata.

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REFERENCES CITED

Anderson, T. H., 1969, Geology of the San Sebastian Huehuetenango quadrangle, Guatemala, Central America [Ph.D. thesis]: Austin, Texas, University of Texas, 219 p.

Anderson, T. H., and others, 1973, Geology of the western Altos Cuchumatanes, northwestern Guatemala: Geological Society of America Bulletin, v. 84, p. 805–826.

Blount, D. N., 1967, Geology of the Chiantla quadrangle, Guatemala [Ph.D. thesis]: Baton Rouge, Louisiana, Louisiana State University, 135 p.

Burkart, B., 1978, Offset across the Polochic fault of Guatemala and Chiapas, Mexico: Geology, v. 6, p. 328–332.

Carfantan, J. C., 1977, La Cobijadura de Motozintla-Un paleoarco en Chiapas: Universidad Nacional Autonoma de Mexico, Instituto de Geologia, v. 1, p. 133–137.

Cloos, H., 1928, Experimente zur inneren Tektonik: Centralblatt für Mineralogie und Paleontologie, v. 1928 B, p. 609–621.

Holcombe, T. L., Vogt, P. R., Matthews, J. E., and Murchison, R. R., 1973, Evidence for sea-floor spreading in the Cayman Trough: Earth and Planetary Science Letters, v. 20, p. 357–371.

Horne, G. S., Clark, G. S., and Pushkar, P., 1976, Pre-Cretaceous rocks of northwestern Honduras: Basement terrane in Sierra de Omoa: American Association of Petroleum Geologists Bulletin, v. 60, p. 566–583.

Kesler, S. E., 1971, Nature of ancestral orogenic zone in nuclear Central America: American Association of Petroleum Geologists Bulletin, v. 55, p. 2116–2129.

Kupfer, D. H., and Godoy, J., 1967, Strike-slip faulting in Guatemala [abs.]: American Geophysical Union Transactions, v. 48, p. 215.

McBirney, A. R., 1963, Geology of a part of the central Guatemalan cordillera: California University Publications in Geological Sciences, v. 38, p. 177–242.

Meyerhoff, A. A., 1966, Bartlett fault systems: Age and offset: 3rd Caribbean Conference Transactions, p. 1–9.

Muehlberger, W. R., and Ritchie, A. W., 1975, Caribbean-Americas plate boundary in Guatemala and southern Mexico as seen on Skylab IV orbital photography: Geology, v. 3, p. 232–235.

Perfit, M. R., and Heezen, B. C., 1978, The geology and evolution of the Cayman Trench: Geological Society of America Bulletin, v. 89, p. 1155–1174.

Riedel, W., 1929, Zur Mechanik geologischer Bruckerscheinungen: Centralblatt für Mineralogie und Paleontologie, v. 1929 B, p. 354–368.

Sandstrom, M. A., 1978, Stratigraphy and structure of Chochal Limestone, El Tapon canyon area, Cuilco quadrangle, Guatemala [M.S. thesis]: Pittsburgh, Pennsylvania, University of Pittsburgh, 137 p.

Scholz, C. H., Wyss M., and Smith, S. W., 1969, Seismic and aseismic slip on the San Andreas fault: Journal of Geophysical Research, v. 74, p. 2049–2069.

Schwartz, D. P., Cluff, L. S., and Donnelly, T. W., 1979, Quaternary faulting along the Caribbean North-American plate boundary in Central America: Tectonophysics, v. 52, p. 431–445.

Siesser, W. G., 1967, Geology of the Cuilco quadrangle, Guatemala [M.S. thesis]: Baton Rouge, Louisiana, Louisiana State University, 87 p.

Skempton, A. W., 1966, Some observations on Tectonic shear zones: First Congress of International Society of Rock Mechanics Proceedings, Lisbon, v. 1, p. 329–335.

Tchalenko, J. S., 1970, Similarities between shear zones of different magnitudes: Geological Society of America Bulletin, v. 81, p. 1625–1639.

Tchalenko, J. S., and Ambraseys, N. N., 1970, Structural analysis of the Dasht-e-Bayaz (Iran) earthquake fractures: Geological Society of America Bulletin, v. 81, p. 41–60.

Williams, H., 1960, Volcanic history of the Guatemalan Highlands: California University Publications in Geological Sciences, v. 38, p. 1–86.

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