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Recent Joints and their Tectonic Significance in the Coastal Range of Venezuela and in Curaçao[1]

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ABSTRACT

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Surficial joints are frequently grouped into three systems: two orthogonal systems that are approximately vertical (these are due to the neotectonic stress field) and one inclined system. The two vertical systems are divided by a smaller (maximum compression σ_1) quadrant. In the Coastal Range of Venezuela we have measured the orientation of 635 joints, found in 10 groups of 3 outcrops each, located on three north-south profiles across the Coastal Range (Los Caracas-Caucagua, Maiquetia-Tácata, and Puerto Colombia-Güigüe) and occurring in Mesozoic rocks and in Quaternary sediments. In addition, in Curaçao, 136 joints were measured in 6 outcrops in Quaternary reef limestone. The data were statistically evaluated according to the Kohlbeck-Scheidegger method. For the Coastal Range we obtained σ_1: N130°E/06° and σ_3: N80°E/0°, and there was no significant difference between σ_1 (and σ_3) in locations north and south of the La Victoria fault zone. For Curaçao, σ_1: N170°E/03°. The significant difference between the Coastal Range and Curaçao suggests that the boundary between the Caribbean and South American plates is located north of the Venezuelan coast. The orientation of σ_1 in the Coastal Range conforms to other tectonic elements which indicate that the South American plate is moving to the northwest in relation to the Caribbean plate.

ADDITIONAL INDEX WORDS: *Joint-set orientations, plate boundary, Morón fault, neotectonic processes, stress field, stress quadrant.*

INTRODUCTION

One of the most important questions in Caribbean tectonics concerns the relationships between the Caribbean and South American tectonic plates in the vicinity of the Venezuelan coast. This plate boundary was originally defined as a transform fault zone between the Lesser Antilles and western South America subduction zones (MOLNAR and SYKES, 1969). More recently, a complex fault system has been shown to exist between the Colombian-Venezuelan border, across the Venezuelan Andes, along the north-central Venezuelan coast, to Trinidad; this system is called the Boconó-Morón-El Pilar fault system, and consists of several fault zones and numerous converging and diverging faults (SCHUBERT, 1981). Along the north-central Venezuelan coast and also involving the central part of the Caribbean Mountains (Coastal Range and Interior Range), the Morón fault zone (Figure 1) forms a complex neotectonic system which extends to approximately 40 km north of the coast (SCHUBERT and KRAUSE, 1984). Field evidence, such as the topographic contrast along the coast, the straightness of the coast, and sporadic faulting on land, as well as seismicity, suggest that the Morón fault zone is an active part of the Caribbean-South American plate boundary, at least since the Late Tertiary. In order to better define the location of this plate

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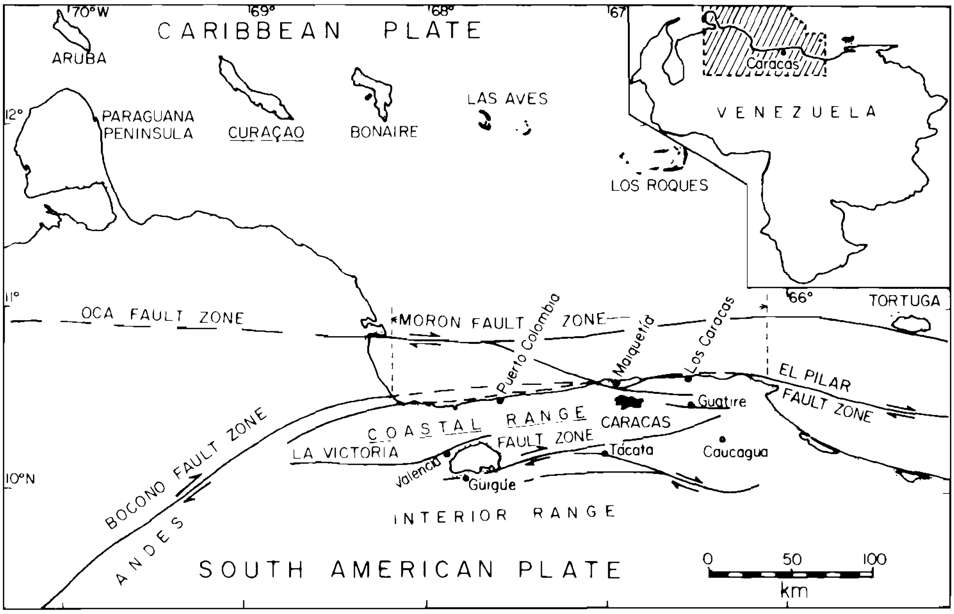

Figure 1. Index map showing the principal structural features of north-central Venezuela.

boundary, it is of interest to investigate the neotectonic conditions on the offshore islands (such as Curaçao) in connection with those in the Coastal Range of Venezuela and to the south of the Caracas and Valencia basins, which seem to be an expression of Quaternary faulting (SCHUBERT, 1982).

The method of investigation was the measurement and statistical evaluation of the orientations of joints. Joints are assumed to be the expression of neotectonic processes (*see*, for example, the discusion in SCHEIDEGGER, 1982a) and can, therefore, be used in turn to deduce the nature of the contemporary geodynamic conditions of an area. The objective is to determine statistically the *preferred orientations* in any one region. In general, two preferred orientations are found that are nearly vertical, and one that is more or less horizontal. The contention is that the vertical joint sets are shear fractures in the neotectonic stress field; the smaller quadrant encloses the maximum, the larger quadrant the minimum principal compression direction. Thus, the compression directions can be ascertained. Inasmuch as the angle between "preferred" joint orientations is often near 90°, it is not always possible to state unequivocally which of the two orthogonal principal stress directions corresponds to a compression and which to a "tension." Nevertheless, the *orientation* of the stress field can be ascertained in any case.

Upon making the necessary investigations and evaluations, we were able to show that the geodynamic conditions do not change across the Coastal Range of Venezuela, when proceeding from the southern hills (Interior Range) to the sea. However, between the Venezuelan coast and Curaçao, a substantial change occurs which suggests that the plate boundary expected here does indeed have a fundamental influence.

FIELD CONDITIONS

For the purpose of our study, joint orientation measurements were taken in Curaçao at 6 localities (denoted A to F) scattered over the island (Figure 2), and in Venezuela along three north-south profiles across the Coastal Range, through the intramontane basin into the Interior Range. The first profile was laid roughly at the longitude of Maracay, the second at the longitude of Caracas, and the third at the longitude of Guatire (Figure 2). Measurements were concentrated around the locations marked 1 to 10.

In Curaçao, the countryside is a low-lying cactus desert with at least five uplifted Pleistocene coral

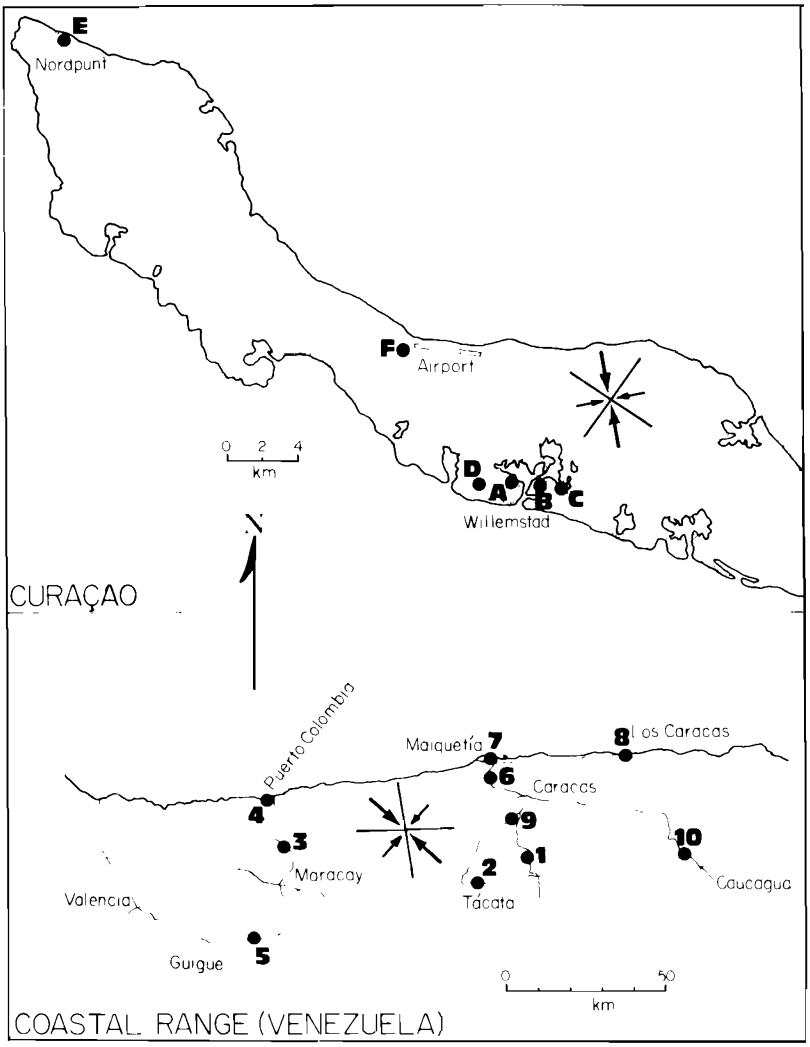

Figure 2. Sketch map of Curaçao and of north-central Venezuela, showing measurement localities (A-F in Curaçao, 1-10 in Venezuela), preferred joint strikes, and principal stress directions.

reef complexes and old beach terraces (SCHUBERT and SZABO, 1978). The northwest is hilly with a relief of 350 m above sea level.

In Venezuela, the countryside from the coast southwards consists of an east-west striking, highly dissected, Coastal Range (2765 m maximum elevation). Landslides are frequent, and the presence of large boulders in the river beds, and hanging boulder conglomerate deposits suggest alternating arid-humid climates during the Quaternary (GARNER, 1959; SCHUBERT, 1985). South of the Coastal Range there is an east-west striking intramontane depression which shows traces of recent faulting (La Victoria fault zone), to the south of which there is a lower east-west striking mountain range which borders the Llanos (Interior Range).

Geologically, along the coast there are Quaternary gravel and sand deposits belonging to the Cabo Blanco Group (WEISBORD, 1957). Although these deposits are very friable, they still support joints. The adjacent and subjacent bedrock consists of Late Mesozoic graphitic schists and metavolcanic greenschists of the Las Mercedes and Tacagua Formations (near Caracas), and graphiticactinolitic schists of the Nirgua Formation (near Puerto Colombia) (GONZÁLES, 1972; WEHRMANN, 1972).

The main rocks of the Coastal Range as well as the intramontane basin are phyllites and schists of the Late Mesozoic Paracotos Formation and quartz-mica and graphitic schists of the Late Mesozoic Las Mercedes and Las Brisas Formations, which are metamorphosed shelf sediments. Locally, granites were syntectically intruded into these rocks, all of which have been severely weathered.

THE JOINTS

Joints are well developed in all of the rocks mentioned above. As is usually found to be the case world-wide, such joints are independent of any tectonic features; thus, they cut through evident folds and concretions without regard to the structure.

As noted, the measurements were concentrated around locations A to F (Curaçao) and 1 to 10 (Venezuela) (Figure 2). In Curaçao each outcrop was considered individually; in Venezuela the procedure was to inspect three outcrops near each "location;" some 20 individual measurements were taken at each outcrop for a total of some 60 at each location. The measurements were made with either a Clar-type or a Brunton compass. The raw data were obtained with reference to magnetic north. In Curaçao, the declination is near 0°, but in Venezuela the data had to be corrected for a magnetic declination of 8°W.

Subsequently, the data were evaluated numerically according to the method of KOHLBECK and SCHEIDEGGER (1977). The latter consists of fitting Dimroth-Watson distributions to the measured data and determining the best-fitting parameters. In this fashion, the preferred joint orientations were found for each location. The results are listed in Tables 1 and 2. We use the standard representation: the preferred joint-set orientations (max. 1 and max. 2) are given by listing their dip direction (azimuth N-E) and dip angle); then we list the angle between the preferred directions as well as the σ_1 and σ_3 directions (azimuth of plunge and plunge angle); if it is assumed that the joints are shear fractures, σ_1 bisects the smaller quadrant. It should be noted that the identification of σ_1 and σ_3 as such is often uncertain, because the angle between preferred joint sets is generally very close to 90°, so that the smaller quadrant cannot always be identified reliably. For better visualization, the global results have been plotted on the maps of the areas (Figure 2). An inspection of the results shows that there is a systematic change in the orientation pattern between Curaçao and Venezuela. In Curacao, the greatest compression has an azimuth of N170°E, in Venezuela of N130°E.

If one considers Venezuela only, it is seen that there is no systematic change in the orientation pattern. In location 1, obviously, the σ_1 and σ_3 directions have been wrongly identified; of the others, only location 4 shows a substantial deviation from the regional pattern. Such occasional "anomalies" are, however, always expected.

In order to solve the question as to whether the locations north and south of the La Victoria fault zone yield different results, the respective locations were evaluated collectively. The results are also given in Table 2. Evidently, there is no essential difference in the orientation patterns of the two groups. Thus, the regional pattern embodied by the line labeled "All" in Table 2 is well established throughout the examined area. Incidentally, this is the same orientation pattern as was found for the joints in the Venezuelan Andes (SCHEIDEGGER, 1982b). However, the identification of the σ_1 and σ_3 directions given is reversed, but, as noted, this identification is always somewhat uncertain.

COMPARISON WITH EARTHQUAKE DATA

One would like to search for a method of identifying the compressional quadrant in the neotectonic stress field more reliably than by the "size" of the stress quadrants. Such a possibility offers itself if one compares the results from joint orientation measurements with earthquake data. In this connection, PENNINGTON (1981) has given a list of South American fault plane solutions. Those that concern our area are shown in Table 3.

It is quite clear that the majority of σ_1 axes lie in the northwest-southeast quadrant; indeed, a computer evaluation of the data (by a method analogous to that of KOHLBECK and SCHEIDEGGER, 1977) yields for the best fitting σ_1 (azimuth NE/plunge): $117\pm33/26\pm4$. Although the error is rather large, the identification of the southeast quadrant as the compression quadrant is quite definite. This shows that the identification of the latter made formally as the *smaller* quadrant between joint orientations as given in the body of this report, is correct.

CONCLUSIONS

Field measurements of joint orientations in northern Venezuela and Curaçao have again demonstrated that such joints can be used for the study of the neotectonic stress field. At least the orientation of

Table 1. Joint Orientation in Curaçao.

Locality	No. of Joints	Max 1	Max 2	Angle	σ_1	σ_3
A	21	35±20/85±19	302±18/84±18	87	168/8	78/0
B	23	61±18/88±16	322±29/80±20	81	192/9	101/5
C	24	14±36/88±27	121±10/85±9	74	248/6	338/2
D	24	107±26/90±24	23±10/85±10	83	155/3	245/4
E	21	212±29/86±20	120±26/89±16	88	346/4	76/2
F	23	298±18/89±17	10±32/87±24	72	244/2	154/3
All	136	34±12/88±9	304±12/88±9	90	170/3	260/0

Table 2. Joint Orientation in the Coast Range of Venezuela (assumed declination: 8°W).

Locality	No. of Joints	Max 1	Max 2	Angle	σ_1	σ_3
1	67	69±13/89±11	334±18/88±15	86	202/2	112/0
2	85	39±22/88±15	296±21/65±13	80	171/21	75/14
3	65	355±16/83±17	83±12/78±12	86	309/3	218/13
4	64	58±12/80±10	145±15/88±12	88	191/6	282/8
5	64	21±24/86±19	108±16/89±14	87	155/2	245/4
6	75	26±14/89±13	290±10/87±9	84	158/3	68/1
7	23	48±19/81±17	108±15/86±13	59	168/5	258/8
8	65	189±19/83±15	276±14/87±12	86	322/3	53/7
9	64	250±8/86±8	345±8/75±8	86	117/13	209/7
10	63	252±9/89±7	350±20/78±17	83	120/10	211/7
All	635	82±6/90±4	358±9/82±6	84	130/6	220/5
North (3, 4, 6, 7, 8)	292	89±10/86±6	11±14/88±8	78	320/2	230/4
South (1, 2, 5, 9, 10)	343	350±12/78±8	259±8/86±6	89	124/11	215/6

Table 3. Fault Plane Solutions of Venezuela Earthquakes (after PENNINGTON, 1981).

Date	Lat N	Long W	Depth.km	σ_1	σ_3	B-axis
				Venezuelan Andes		
67/12/21	7.0	72.0	29	105/5	12/15	211/74
68/05/13	9.0	71.0	29	298/11	186/64	32/25
70/01/27	7.5	72.0	49	90/21	270/69	0/0
				Coast Range		
67/07/30	10.6	67.3	0	127/4	218/01	15/85
70/05/19	10.9	68.0	15	33/1	302/47	145/43
75/04/05	10.1	69.6	36	338/0	68/14	248/76

the principal stress directions (if not unequivocally the *sign* of the stress) can be obtained from such measurements.

Northern Venezuela is subject to a homogeneous compression with an azimuth of N130°E. This agrees with the stress direction determined in fault plane solutions of Venezuelan earthquakes. The stress field is not influenced by the presence of such features as the Coastal Range or the La Victoria fault zone.

In Curaçao, the maximum compression has an azimuth of N170°E. This fact indicates that Curaçao belongs to a different neotectonic province than Venezuela; the orientations of the neotectonic stress field is entirely different in the two regions. This observation supports the existence of a plate boundary north of the Venezuelan Coast Range.

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