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JURASSIC-EARLY CRETACEOUS MAFIC DIKES FROM THE NORTH CHILEAN COASTAL CORDILLERA (23°-25°): INDICATORS FOR EXTENSION AND PALEOSTRESS

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INTRODUCTION AND METHOD

Dike systems provide valuable information for the analysis of deformation and paleostress. Similar to extension fractures dikes form during a short-term extensional event. It is assumed that dikes are oriented perpendicular to the least horizontal stress (S_{hmin}) (1,2). Stress directions derived from dike orientations are considered reliable, and they have been in the data set of the World Stress Map Project (3). One restriction is that dikes which intrude a preexisting regional joint set may be oriented oblique to S_{hmin} (4). This effect, however, is restricted to cases where the differential stress is small (5). Provided that a sufficient differential stress is present the possible angle between dikes and preexisting joints is small.

The North Chilean Coastal Cordillera is composed to >85% of Jurassic-Early Cretaceous volcanics and plutonics which are products of a continental magmatic arc. During the Late Jurassic-Early Cretaceous the main deformations took place (6) which are extensions perpendicular to the arc and arc-parallel sinistral strike-slip movements along the Atacama Fault Zone (7). During this time numerous dikes intruded, from which the paleostresses and deformations of the magmatic arc can be inferred.

Field work was carried out along three E-W sections through the Coastal Cordillera at 23°, 24° and 24°30'-25°S (Fig. 1). On partial sections of defined length the orientations and widths of all mafic dikes (n = 1068 dikes) have been measured. The total length of all sections is 25.6 km (Table 1). For each dike the length increase due to the classes of 10° was calculated as well as, in a second step, the sums of length increase of each directional class for intrusion of the dikes in directional each partial section were calculated. In this way for each partial section the principle extension direction and the amount of length increase was calculated. As the length of the partial sections is known the portion of the section formed by dikes and hence the extension (in per cent) could be calculated.

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RESULTS AND INTERPRETATION

Most dikes are steep with an average dip if 88° (Fig. 1); thus the dikes could be treated as vertical two-dimensional structures and no corrections due to non-vertical dip was necessary. The strike direction varies between NE and SE, E-W striking dikes are scarce. This indicates a general E-W extension i.e. perpendicular to the N-S trending magmatic arc. Along the single sections two main strike directions of the dikes can be distinguished: NE-SW and NNW-SSE (Fig. 2). Field observations show that the dikes of these different directions belong to at least two generations: (I) In several places NNW-dikes cut the NE-dikes which are thus older. Furthermore, along the northern section, the dikes run through a late Jurassic dioritic pluton (~160 Ma) which is intruded by a younger tonalite (~150 Ma); the NE-dikes are cut by the tonalite whereas the NNW-dikes run through both plutons. (II) The NE-striking dikes frequently underwent greenschist to amphibolite-facies metamorphism which is absent in the NNW-dikes. The younger set of dikes is present in all sections to similar amounts whereas the older set is best developed in the north whereas on the middle and southern section these dikes are quite scarce although present. The presence of two generations of dikes indicates that two extensional events occurred in the Jurassic magmatic arc of the Coastal Cordillera, an older event with NW-SE extension and a younger event with ENE-WSW extension.

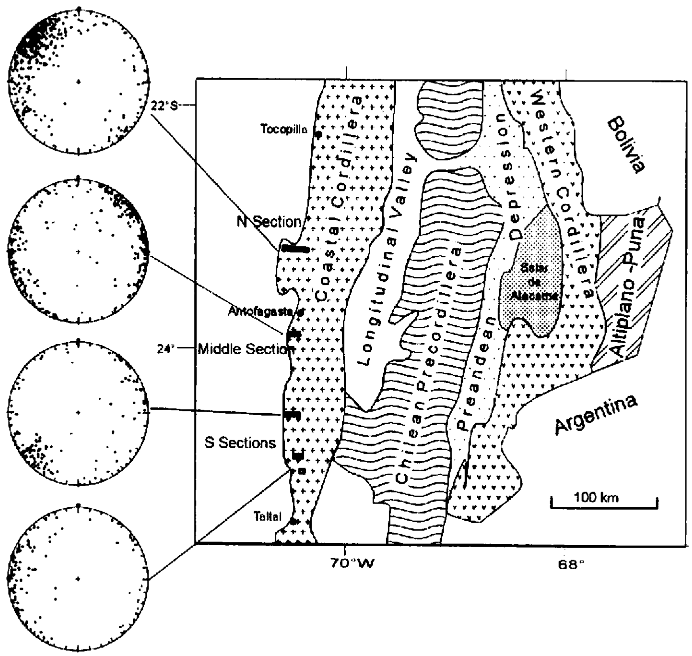

Fig. 1: Location of the studied sections and pole diagrams of the sections (lower hemisphere, N section 441 data, middle section 351 data, S section northern part 138 data, S section southern part 138 data)

Age data from the literature and K-Ar age determinations of dikes and host rocks suggest a Late Jurassic-Early Cretaceous age for the dikes. In the older dikes of the northern section secondary hornblendes yielded a K-Ar age of 146 ± 5 Ma which reflects the cooling after alteration and thus is a minimum age value. For the intruded dioritic plutons age data of ~170-150 Ma various methods) are reported (8; 9; 10) which constrains the maximum age of these dikes. From the northern section fresh hornblende of the younger dikes yielded a K-Ar age of 147 ± 6 Ma; from the south (24°-25°S) K-Ar ages of mafic dikes of 127-110 Ma have been reported by (9); as these data have been derived from materials with closing temperatures <250°C (K-Ar whole rock and plagioclase) it is suggested that they rather reflect the regional cooling than the intrusion of the dikes. From all the relevant age data it can be concluded that the intrusion of the dikes in the Coastal Cordillera took place during between 170 and 120 (Late Jurassic-Early Cretaceous), the older dikes should have a higher age than 140-150 Ma, the younger dikes a lower age than 150-140 Ma.

The average extension of the three sections is relatively constant (~14%, Table 1). However, within the sections the extension varies significantly, the values ranging between 78% and 0.2% (Fig. 4). This variations can be attributed to different crustal levels: the shallower the level the greater the extension by dikes. At deeper levels extension is rather accommodated by stocks and other plutons than by dikes; furthermore the highest extension values are found in the vicinity of major faults of the Atacama Fault Zone which, as zones of crustal weakness, deformed easier than more intact crustal portions.

The strong preferred orientation of dikes of one generation shows that differential stresses were sufficient for the opening of the dikes perpendicular to S_{hmin}. Thus, it can be concluded that the dikes are indicative of two different stress systems operating in the late Jurassic, an older one with S_{hmin} oriented SE-NW and a younger one with S_{hmin} in ENE-WSW direction. From the orientation of striae and stretching lineations on faults which are mostly subhorizontal it can be inferred that the stresses correspond to a N-S directed strike-slip system with σ_2 being vertical.

One uncertainty arises when inferring stress directions from the orien-

Table 1: Results of the analyses of the dikes measurements

Section	n	Total thickness (m)	Av. Thickness (m)	Spacing (m)	Length of section (m)	Extension m	Extension %	direction (°)
23°15'	441	520	1.2	13.0	5851	413	14	110
24°	351	1351	3.8	26.4	9537	1172	14	80
24°30'-25°S	276	1767	6.4	45.7	13037	1660	15	110
Total	1068	3637	3.3	23.3	25607	3385	14	100

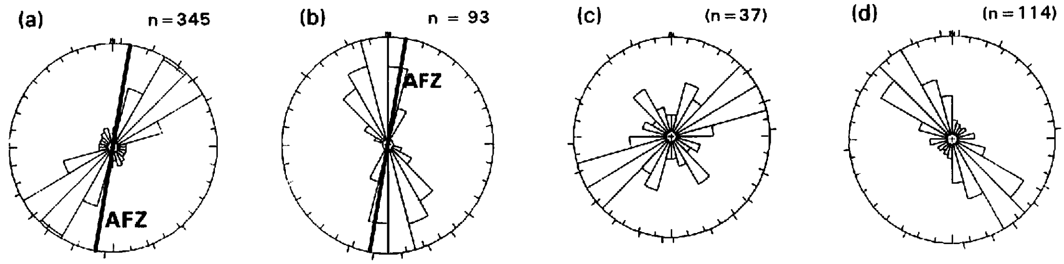

Fig.2 Examples for the orientation of of older (a, c) and younger dikes from the northern section (a, b) and the northern part of the suthern section (*AFZ* trend of the Atacama Fault Zone)

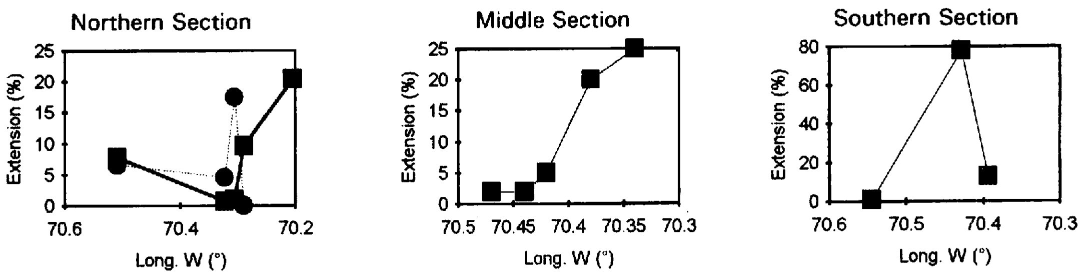

Fig. 3: Extension profiles of the sections shown in Fig. 1. For the northern section the data of older (circles) and younger dikes (squares)are represented separately

tation of dikes: If the blocks containing the dikes rotate about vertical axes after the intrusion of the dikes the absolute paleostress directions are incorrect. Paleomagnetic data show that the North Chilean Andes underwent clockwise rotation ~25° since the Late Jurassic. However, as the most of these rotational movements occurred after the Early Cretaceous (11; 12) a major influence of block rotations on the relative orientation of the two generations of dikes can be ruled out. Although rotation of single blocks cannot be excluded such a rotation should not be of major importance as the dikes of all sections have similar orientation. Thus it can be concluded that the change in the orientation of the dikes reflect a rotation of the principle horizontal stresses of ~70° during the Late Jurassic-Early Cretaceous.

The younger NNW-striking dikes can be interpreted as extensional fractures which originated during the sinistral movements along the Atacama Fault Zone which took place during the Late Jurassic and Early Cretaceous in several phases between 152 and 126 Ma (13). The sinistral movements result from strongly oblique subduction in a SE direction (14). The orientation of the older dikes is in apparent contradiction to this plate configuration. Possible reasons for this contradiction could be (I) that during the Late Jurassic the plate configuration changed fundamentally or (II) that the structures in the magmatic arc do not always reflect the direction of plate convergence. The first possibility seems unlikely as there are no other observations which could confirm a major change in the plate configuration. Thus, the second possibility seems to be more probable; if, for example, convergence rate is low a decoupling between the plates should be expected, and in this case other factors as, for example, absolute plate motions may become important for the deformations in the magmatic arc.

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