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DEFORMATION OF IGNEOUS DIKES IN AND AROUND THE TICHKA GRANITE, HIGH ATLAS - MOROCCO

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In Morocco, north of the Anti-Atlas, as in the rest of North Africa, the non-metamorphic or weakly metamorphic Paleozoic formations are often pierced by small (10-15 km in diameter) granitic intrusions, with well developed metamorphic aureoles. The Tichka granite in the western High Atlas south of Marrakech is one of them and it has received a great deal of attention from geologists and petrologists, which is due to the complexity of the intrusion and to the excellent quality of the outcrops dissected by deep valleys in an arid climate.

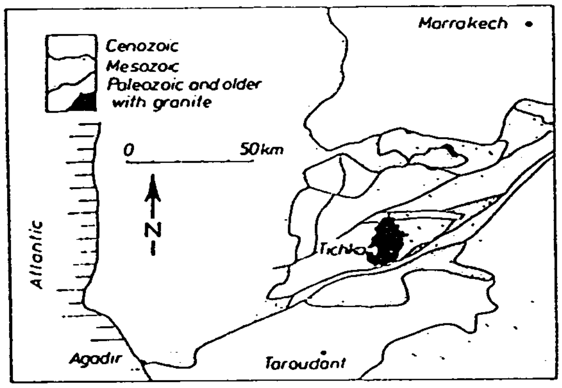

Fig. 1. Generalized geological map of SW Morocco with the Tichka granite

The formations surrounding the Tichka igneous complex are considered to be Cambrian with the possibility of some Infra-Cambrian. These weakly metamorphosed rocks contain graywackes, schists, limestones and considerable volumes of volcano-detrital material (tuffs, lapilli with few lavas) of andesitic to dacitic composition. As is the case in other deformed rock sequences, it is not easy to deduce the original thickness of the total pile or of the different lithological groups, especially as there are many indications of important lateral facies variations. We propose a total thickness of 3-5 km for the Cambrian, the volcanics often exceeding 1 km, whereas the limestone are locally a few hundred m. thick. In harmony with other Hercynian granites in Morocco the Tichka intrusion is considered to be of Carboniferous age. Radiometric age determinations by the Rb/Sr method give 305 and 318 $\pm$ 10 m.a. (Termier et al. 1972) The intrusion is remarkable for its petrographical heterogeneity; diorites, granodiorites, and granites are about equal in proportion, whereas gabbros are extremely rare. Contacts between the different igneous rocks are often sharp but they can also be transitional. Throughout the intrusion there are numerous lenses or slabs of metasedimentary inclusions, especially abundant in the south; they have undergone assimilation to a varying degree, but the lithologies are generally still recognizable. They range from several centimeters to more than a kilometer. On the whole, magmatic and metasedimentary inclusions form an interlocked elliptical pattern centered in the northern part of the intrusion (Lagarde and Roddaz 1983). These concentric structures are well marked on aerial photographs and on maps (G. and H. Termier 1981); they are also visible at the outcrop scale as a more or less pronounced vertical planar structure often well expressed in dioritic domains, whereas in many late granites they are lacking or so weakly developed that their identification is uncertain.

The elliptical structure is also (parallel and) concordant with the enclosing rocks and their structure on a general scale. In detail, however, the contact is often cross-cutting, sharp and generally vertical; in the N.E. occasional sheet-like apophyses up to 100 meters thick extend horizontally into the country rocks for one or two kilometers (Bizard and Ziegler 1955). On a small scale, the margin may be irregular and is sometimes transitional with migmatitic segregations of quartzofeldspathic material in the adjacent schists. The country and in metamorphic grade towards the granite contact, from regional greenschist (chlorite, epidote, actinolite, some biotite) to coarser schist with amphiboles, andalousite, sillimanite, staurolite, garnet or to marbles with pyroxene and garnet. Lagarde and Roddy (1983) have proposed from the study of strain patterns that the intrusion results from diapiric emplacement in a domain of transcurrent shear. For the moment the origin of all the magmatic rocks of the Tichka intrusion has not received a totally satisfactory solution. Using field evidence Vogel and Walker (1975) revealed the contemporaneity and close association of acidic and basic magmas. Vogel et al. (1976) and Scott and Vogel (1980) have shown that an origin by differentiation can be ruled out on the basis of major element and RE analysis. Scott and Vogel (1980) have suggested that the granite may represent crustal melts, the diorite a mixture of low SiO_2 granite gabbro of mantle origin.

The dikes

A marked feature of the Tichka intrusion and its envelope is the presence of numerous dikes.

The dikes in the envelope

The Paleozoic of the High Atlas, which extends in an W.-E. direction from the couloir d'Argana to the river n'Fiss for about 70 km and by about 30 km in a N/S direction, is cut by numerous dikes of varying structural relationship, with compositions from basic (with olivine and pyroxenes) to acid. Most dikes appear to be vertical (the outcrop pattern may have some part in this); however, in the vicinity of the Tichka granite, especially where they are more numerous, they are also often horizontal. No systematic analysis of their orientation has been made but it seems that the great majority are more or less parallel with the general structure (folds, schistosity) with a second group at right angles, whereas only a small number have no particular relationship with the structure of the enclosing rocks.

In the vicinity of the granite, the thickness of the dikes is variable, in general a few meters or decimeters. For the moment insufficient data on intersections prevent the establishment of a time sequence of a thrustful emplacement with any confidence. Nevertheless, the basic dikes apparently always cut the andesitic ones. Many observations demonstrate that dike intrusion occurred after the main structural development (many dikes cut across folds, schistosity and deformed conglomerates Fig. 2). In the marbles, near the granite, the dikes do not maintain their post-deformation character. They are deformed, folded and stretched into boudins, but it is still possible to see that they cut across older folds (Fig. 2) When two sets of dikes intersect, even the youngest presents evidence of post-intrusion deformation, occasionnally very severe (Fig. 2) Near the granite most dikes present post-magmatic mineralogical re-equilibrations. It is not easy to separate modifications related to normal post-

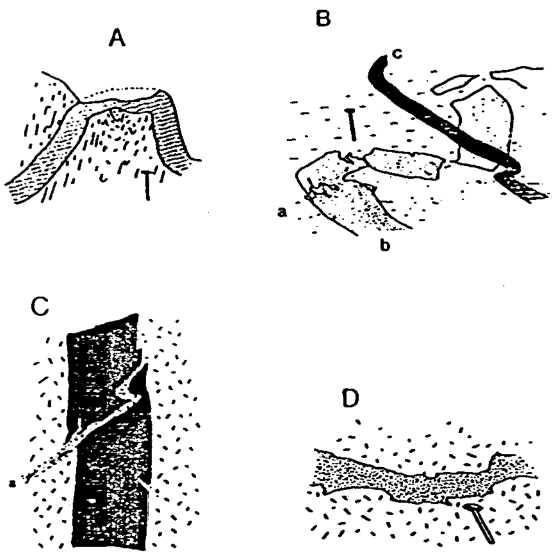

Fig. 2 A. Basic dike cutting folded metasediments near the margin of the Tichka granite. Assif n'Ait Tament, N of Tisgane
B. Two generations of folded basic dikes (b intersecting c) in a large calcareous xenolith with streched pyroxenic horizon (a), near the southern contact of the Tichka granite N of Kma, Ida Oukays.
C. In the Tichka granite, an old dike (probably generation H) is cut by a granitic vein (a) which has carried small fragments of the dike. Amendrech.
D. Dike of the oldest generation (H), with non planar geometr without chilled margins cutting granodiorite. Asif n'Fiss; SE of Azmou n'Guenfis.
In each drawing the scale is given by the ham.

magmatic and hydrothermal activities from those associated with thermal metamorphism. In some cases, however, wide development of biotites partly at the expense of magmatic amphibole in the dikes is demonstrably due to thermal and metasomatic activity associated with the main intrusion. Elsewhere, the dikes are deformed in the marbles or in the schists and it seems logical to relate their metamorphic, post-magmatic paragenesis to contact metamorphism which develops in harmony with the intensity of deformation. In conclusion for the dikes within the granite envelope, it is clear that they have intruded rocks that were already deformed, at temperatures high enough to provoke some mineralogical and structural transformation.

The dikes in the granite

In the Tichka granite numerous dikes vary in structure and in composition, from granitic through andesitic to doleritic. They are generally vertical, intersect sedimentary inclusions, granitic and dioritic foliation, but some are also parallel with the latter. The dikes in the granite, in general terms, may be grouped into three main classes, on the basis of cross-cutting relationships, lithology and structure. Their thickness varies from more than 10 meters to a few decimeters. Good exposures with many intersections allow the establishment of time sequence of intrusion. The oldest generation (H generation) is composed of a variable group of dominantly light-coloured micro-crystalline rocks, followed by light grey, finely crystallised dikes including porphyries (K generation), then by darker ones (L generation). Thin sections confirm this classification but reveal differences and transition not suspected during field work. The tendency of evolution from microcrystalline rocks of granitic to dioritic composition, to basic, vitric rocks with olivine and pyroxene through porphyritic and non-porphyritic andesites is confirmed. These classes are not homogeneous; intermediate types are present, and it is probable that the evolution from acid to basic was not linear, but included several recurrences. Field evidence shows that all dikes were emplaced in the late stages of plutonic crystallization while the main dioritic to granitic body was evolving from a crystal mush to a solid rock. The simultaneous presence of magmas of different composition is illustrated by the common occurence of amoebic contacts between dikes and granitic or granodioritic rocks (Vogel and Walker 1976). The older set of dikes (H) is often cut by aplitic, pegmatitic and granitic veins (see also Vogel and Walker 1976). In one case, a microdioritic, vertical dike with sharp contacts against the granite was observed to be cut by a late granitic vein which has carried away fragments of the dike into the enclosing granite. At the time of dike intrusion, the granite has enough rigidity to fracture but still contained nearby enough fluid material, which intruded the granite, cut the dike and removed some dike chips.

In the granite pluton as a whole the last stage of thermal and rheologic evolution is illustrated by dike behaviour in the granitoid rocks. The youngest dike generation is nearly always vertical with sharp parallel contacts and well developed chilled margins; they can easily be followed for several km sometimes as single dikes, or in swarms of 8 to 10 members. In the region of the Tichka Plateau they trend E/W, cutting the internal structure of the granite and its envelope. Within the granite, they have not been deformed after their intrusion, in opposition to the situation in the marbles of the envelope. The K dikes display a fairly regular disposition, either transecting the granite structure or parallel to it; their margins are either straight or irregular; the grain size decreases slightly towards the contacts. The oldest generation commonly (H) presents non planar geometry, subparallel to the internal structure of the granite, but it does not exhibit the mineral alignment due to post-intrusion events that has been described by Pitcher and Berger (1972) in the Donegal granite. We do not assign the wavy aspect of early Tichka dikes and the non-parallelism of their margins to folding or movements in the granite after their emplacement; we believe that their geometry and crystallization are related to the conditions of intrusion in a medium where temperatures of the dikes and of intruded material were similar. The cooling body was not rigid enough to be brittle. We believe that their geometry and crystallization history are related to the low contrast in rheology and temperature between the intruding material and host rocks.

Conclusion

The synplutonic dikes which cut the Tichka pluton and its sedimentary envelope can be used as geometric and temporal references for its late kinematic and thermal evolution. When the first dikes were emplaced, the granite and granodioritic material had not totally crystallized; the dike contacts are often irregular and the dikes are cut by aplitic, pegmatitic, granitic veins. With time, the granite acquired more rigidity and the dike geometry became more planar. In the last stage of its evolution, the pluton was still mobile with respect to its envelope, and ascended without internal deformation. After dike emplacement, ductile deformation is confined to the marbles, with intense folding and boudinage near the contact. Late deformation is concentrated within the marbles, due to their rheological properties under such a thermal regime. Where marbles lack, the deformation takes the form of fault zones cutting across the Paleozoic formations. These brittle structures are not easily separated from those related to the development of normal faults of Triassic age or from those accompanying the formation of the Atlas Range during the Cenozoic. During its last phase of intrusion, the Tichka granite moved upwards as a rigid piston with little internal deformation, while ductile structures formed within its envelope. No regional dextral ENE transcurrent shear component (Lagarde and Roddaz 1983) has been detected in the granite after the emplacement of the first dikes.

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