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MOROCCAN HERCYNIDES: A SYNOPSIS. THE PALEOZOIC SEDIMENTARY AND TECTONIC EVOLUTION AT THE NORTHERN MARGIN OF WEST AFRICA

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ABSTRACT. The Hercynian belt extends through various parts of Morocco—in southern Morocco it comprises the mildly deformed Anti-Atlas belt, north of the West African craton; in northern Morocco, it is composed of the western and eastern Meseta domain and the Paleozoic inliers that pierce the folded Mesozoic and Cenozoic cover of the Atlas and Rif domains. Except for the Sehoul Block, which is characterized by a pre-Hercynian deformation of Late Ordovician age, southern and northern Morocco constituted an epicontinental shelf during Early Paleozoic time. This shelf was connected to continental zones southward, whence came detrital sediments. These sediments fine upward from the Ordovician to Silurian strata. During Early and Middle Devonian time, a carbonate shelf characterized the main part of present Morocco, although a deep and turbiditic basin was established in northern Morocco. There, the major deformation episode occurred during Late Devonian time, while the western Morocco and Anti-Atlas platform disintegrated and fault-delimited basins (Maider, Sidi-Bettache) formed. These basins closed progressively between the Late Visean and the Westphalian.

The Hercynian zones are strongly controlled by preexisting fracture zones, notably by several regional shear zones rooted on the former limits of the sedimentary basins. The general autochthony, inferred in the present discussion, of the Hercynian belt of Morocco does not exclude décollement levels in the crust. These characters are compared with those of the European External Hercynian zones and the North American Avalon and Meguma zones.

INTRODUCTION

Paleozoic strata crop out extensively in Morocco, within five main structural domains (fig. 1). The **Saharan domain** (Dorsale reguibate) is a part of the West African shield (Fabre, 1971). There, Lower Proterozoic series that were highly deformed and metamorphosed during the Eburnean orogeny (about 2000 Ma) are covered to the north by the undeformed Paleozoic rocks of the Tindouf basin, partially overlain by a thin Mesozoic-Cenozoic cover. In the **Anti-Atlas (pre-Saharan) domain,** the old basement and its Late Proterozoic cover were overprinted by the Panafrican orogeny between 680 and 570 Ma (Leblanc and Lancelot, 1980). Later on, the Latest Proterozoic and Paleozoic cover of the Panafrican belt was affected by a relatively mild Hercynian (= Variscan) deformation. The Mesozoic-Cenozoic cover is thin and

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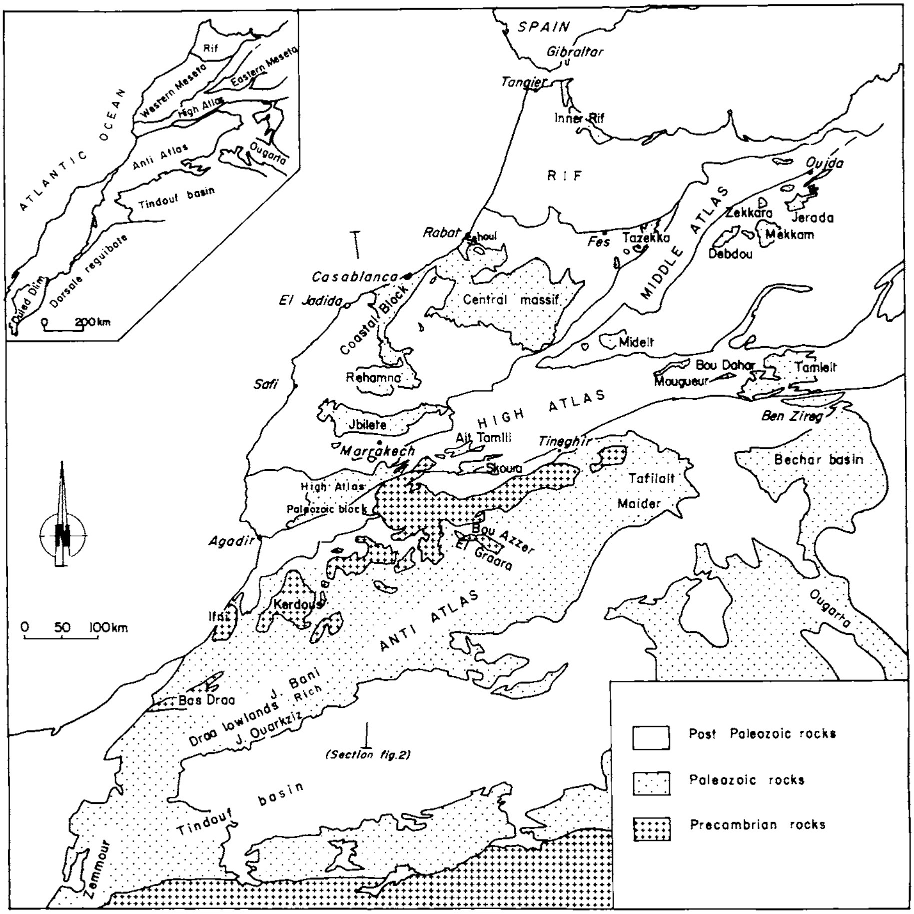

Fig. 1. The Moroccan Paleozoic massifs. Insert map: structural domains of Morocco.

undeformed. The **Meseta domain** is defined, following Gentil (1918), as the domain of the Hercynian chain, unconformably covered by undeformed Mesozoic-Cenozoic series. It is divided into two parts: the Moroccan and the Oran Mesetas, by a northeast-southwest Tertiary foldbelt: the Middle Atlas. The Moroccan (Western) Meseta is composed of three major Paleozoic massifs: Massif Central, Rehamna, and Jbilete, which emerge beneath their Mesozoic-Cenozoic sedimentary cover. In the Oran (Eastern) Meseta, the Mesozoic cover is less eroded, and the Paleozoic massifs (Jerada, Debdou, Mekkam, Midelt, et cetera) are more restricted. The **Atlas domain** runs across the Meseta (Middle Atlas) and between the Meseta and Anti-Atlas domains (High Atlas). There, the relatively thick Permo-Mesozoic and Cenozoic cover was folded during the Atlasic orogeny (Late Jurassic and Tertiary phases of folding). Paleozoic massifs are large inliers, either in the High Atlas (High Atlas Paleozoic block, Aït-Tamlil, Mougueur, Tamlelt) or in the Middle Atlas (Tazekka). Finally, the **Rif domain,** at the northern end of Morocco, is an allochthonous alpine belt thrust southward upon the Meseta. Paleozoic terranes are known in the inner part of the belt—the Nappes paléozoïques or Ghomarides, equivalent to the Betic Malaguides north of the strait of Gibraltar.

Geological correlations are easy between Paleozoic systems of the various Meseta massifs and, of course, within the continuous outcrop of the Anti-Atlas. In the Atlas domain, post-Hercynian shortening was weak and nowhere did it obscure the Hercynian structures of the Paleozoic inliers. Consequently, these Paleozoic inliers can be easily correlated with the Meseta and Anti-Atlas massifs and studied with them from the point of view of their Paleozoic evolution. This is not true for the Paleozoic nappes of the Rif. At the end of Carboniferous time, they were part of the Hercynian belt (Chalouan and Michard, 1985; Chalouan, 1986), but since that time they have been dissected by numerous alpine thrusts. Moreover, the whole Rif belt suffered large scale westward lateral transport along the northern edge of Africa since early Jurassic (Bourrouilh and Gorsline, 1979). Therefore the initial disposition and location of this Hercynian segment is questionable. Consequently, the Paleozoic Inner Rif will not be considered here. In this paper, we will describe the Hercynian evolution of Morocco south of the Rif thrusts, that is essentially in the Anti-Atlas, Atlas, and Meseta domains. Here we can study the southern margin of the western Europe-northern Africa Hercynian system. Roch (1950), Choubert and Faure-Muret (1956), Michard (1976), Hollard (1978), and Piqué (1983) successively summarized the Paleozoic evolution of this area, whereas Morin (1965, 1970, 1979) gave an exhaustive bibliography concerning this topic. We will focus herafter on the stratigraphic and tectonic aspects of this evolution.

Main Zones of the Moroccan Hercynian Belt

Previous studies allowed us to distinguish several zones within the Paleozoic basement of the area (Michard, 1976, p. 317–372; Michard and Piqué, 1980; Piqué and Michard, 1981; Piqué, 1983). According to their stratigraphic and tectonic evolution during Paleozoic times and especially on the basis of the timing and intensity of their Hercynian deformation, we define three main zones north of the Saharan shield (fig. 1):

1. *Anti-Atlas foreland belt.*—The northern margin of the Sahara (West-African) platform was weakly deformed during the Hercynian orogeny. Structurally, the Anti-Atlas is a broad anticlinorium. Its core is represented by several inliers, the "boutonnières" of Bas Draa, Ifni, Kerdous, et cetera, where Precambrian series crop out. Its flanks are

constituted by Latest Proterozoic and Lower Paleozoic strata and, finally, by the Carboniferous series of Tindouf (south) and Tineghir-Bechar (northeast) basins. The southwestern flank of the Anti-Atlas is marked by northeast-southwest kilometric folds (Jbel Bani, Rich). Toward the south, they continue in the Zemmour area, which is considered as the foreland of the Mauritanides belt (Sougy, 1969). In the eastern Anti-Atlas, the folds trend northwest-southeast. They are quite open and broad structures, and they extend into the Algerian Ougarta belt (fig. 1).

2. *Western Morocco Hercynian belt (figs. 1, 2).*—includes the main part of the Western Meseta (western and central parts of the Massif Central, Rehamna and Jbilete massifs) and the High Atlas Paleozoic block (figs. 1, 2). This zone shows strong structural and metamorphic gradients, so that the least deformed subdomains (Coastal block) are close to strongly deformed and metamorphosed domains (Central Rehamna). The major Hercynian exposed structures are anticlinoria with Lower Paleozoic strata in their core, trending northeast-southwest to east-west and synclinoria with Upper Paleozoic series. In the Northern Meseta, for instance (fig. 3), the classical structures recognized by Lecointre (1926) and Termier (1936) are from northwest to southeast: Casablanca anticlinorium, Ben Slimane synclinorium, Cherrat anticline, Rommani synclinorium, Khouribga-Oulmés anticlinorium, Fourhal synclinorium whose eastern part probably belongs to the Eastern Morocco belt (see below). These structures extend southward, with some changes in their width and trend, into the other Paleozoic massifs of the Meseta. In the whole area, Devonian diastrophism was weak, and the main deformation and recrystallization episode occurred during Carboniferous time, except in the northern Sehoul (=Rabat-Tiflet zone) which was folded during the Ordovician.

3. *Eastern Morocco Hercynian foldbelt.*—includes the easternmost part of the Western Meseta (Azrou-Zaïan area, Eastern Jbilete), some Atlasic inliers (Tazekka, Aït Tamlil), and those of the Eastern Meseta (Midelt, Debdou, Mekkam, Jerada). Hercynian deformation is characterized by early phases of folding and/or thrusting, ranging in age from Late Devonian to Late Visean. Synmetamorphic folding is dated at approx 360 Ma in Midelt area. There, metamorphic grade reached the albite-amphibolite subfacies. The folds are generally recumbent, with a western vergence. In the Zaïan area, the age of the first folding episode is poorly determined, somewhere between Middle Devonian and Middle Visean. It developed east-facing folds, contemporaneous with an upper greenschist facies. Between these two zones, the western Tazekka-Mrirt Zone was weakly deformed prior to Upper Visean. Over the whole area, after the Visean transgression, synsedimentary and gravitational nappes were emplaced, while andesitic volcanism was strong in the northeastern inliers from Tazekka to Jerada. Finally, folding, westward thrusting, and wrench faulting affected the domain during Upper Carboniferous, at approximately the same time as within the western Morocco belt. With

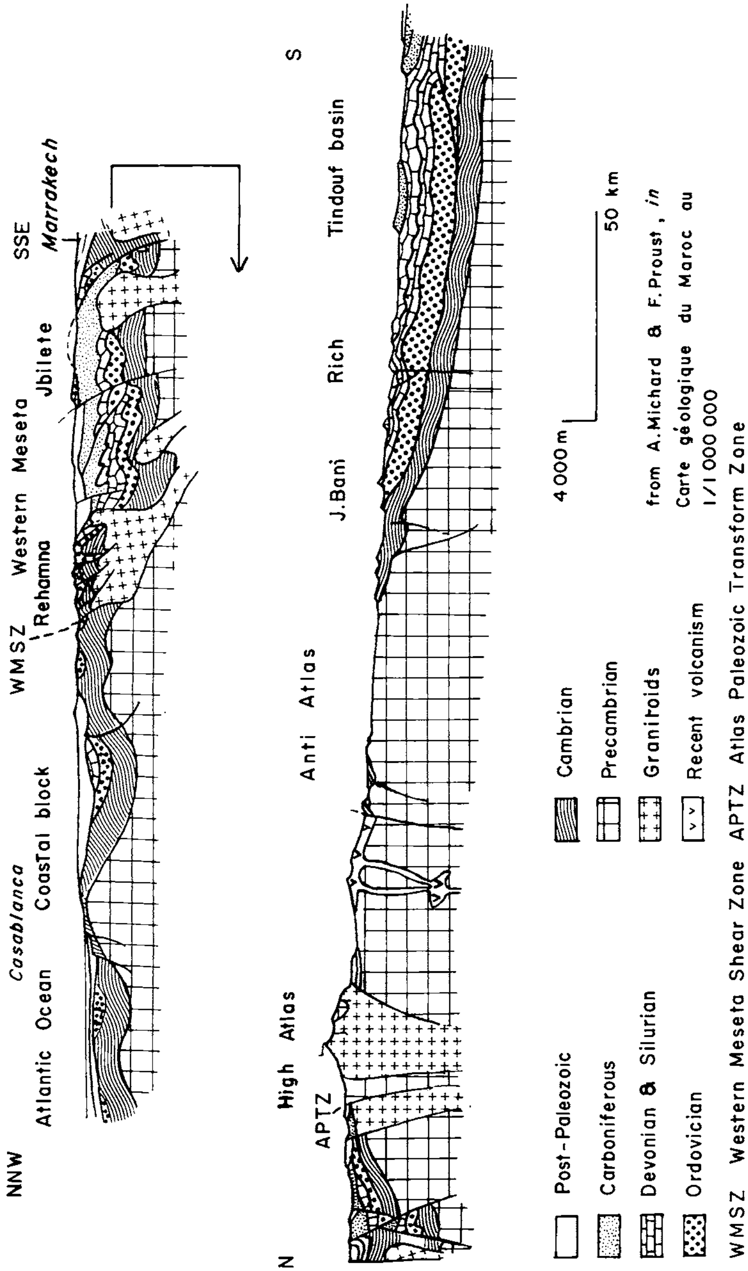

Fig. 2. Generalized geological section across Morocco (fig. 1).

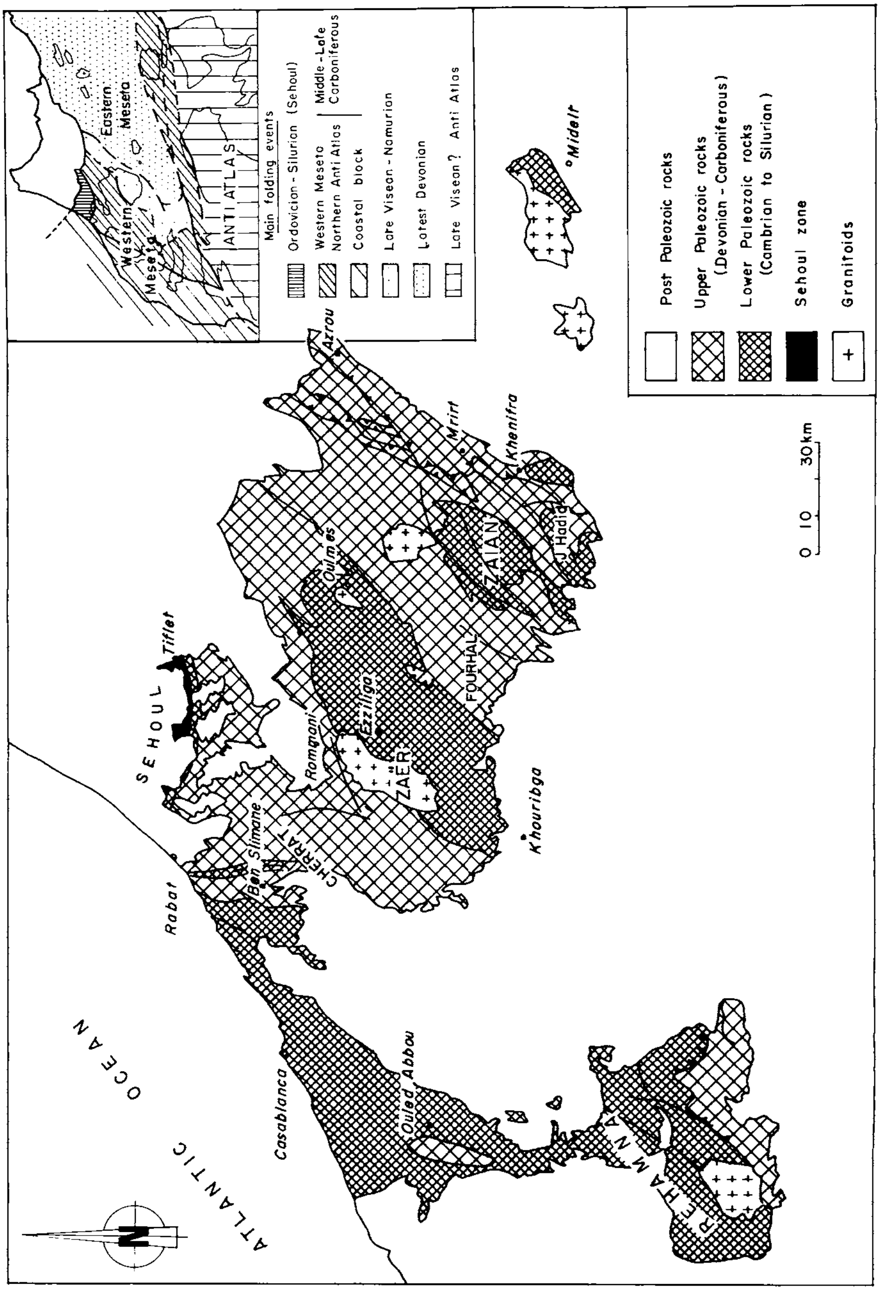

Fig. 3. The central Morocco Hercynides. Insert map: the main structural zones according to the age of their main folding event.

respect to the latter, eastern Morocco constitutes the Inner zones of the Moroccan Hercynian belt (Piqué, 1983).

PART 1—LOWER TO MIDDLE PALEOZOIC EVOLUTION

1. *The Precambrian Basement*

Precambrian series are widely represented in the Anti-Atlas (fig. 1). The older were affected by the main phases of the Panafrican orogeny. The younger, Latest Proterozoic in age, were deposited unconformably in a terrestrial environment (Choubert, 1963; Jeannette and Tisserant, 1977; Jeannette, Benziane, and Yazidi, 1981; Hassenforder, 1987). Latest Proterozoic times were marked by numerous disconformities delimiting successive lithostratigraphic groups: Anezi–Siroua–Saghro, Anela-Ouarzazate, "Adoudounian." The sedimentary facies of Anezi–Siroua–Saghro and Anela-Ouarzazate Groups are predominantly redbeds with important intercalations of volcanic materials such as ignimbrites, rhyolites, dacitic, and andesitic tuffs. The calc-alkaline nature of this volcanism has been related to Panafrican subduction (Boyer and others, 1978; Schermerhorn, Wallbrecker, and Huch, 1986). The clastic sediments became progressively finer, and the "Adoudounian" is represented mostly by carbonates with an intercalation of purple shales ("série lie-de-vin"). The first Cambrian fauna, composed of primitive trilobites, has been discovered inside the Upper Carbonates—"Calcaires supérieurs" of the "Adoudounian" (Hupé, 1952; Boudda and Choubert, 1972). North of the Anti-Atlas, the cores of some anticlines, at El Jadida (western Morocco), Goaïda, and Jbel Hadid (eastern Morocco) show azoic series over small areas. These series are attributed to the Late Proterozoic on the basis of their position below Cambrian strata and their volcanoclastic facies, very similar to those of Anti-Atlas, and they suggest that the same basement extends throughout Anti-Atlas and western and eastern Morocco.

2. *Cambrian Subsidence and Volcanism*

In Western Anti-Atlas, the classical Cambrian sections (Destombes, Hollard, and Willefert, 1985) are divided into two lithologically contrasted parts. Lower Cambrian is represented by a carbonate sequence in which stromatolitic dolostones and *Archeocyathus* limestones predominate. More and more detrital components occur in the upper part of the Lower Cambrian sequence. This clastic character is conspicuous in the "grès terminaux" (terminal sandstones). The overlying disconformable deposits are the thick (up to 1300 m) *Paradoxides* shales and graywackes. Lower Cambrian is represented at the very bottom of this formation, the main part of which is Middle Cambrian in age. Toward the top of the sequence, the shales grade to the *Conocoryphe* sandstones, which constitute the Tabanit ridge. In the eastern part of Anti-Atlas, Lower Cambrian is represented by thin detrital layers or is absent, and Middle Cambrian series are thinner than to the west. Upper

Cambrian is nowhere identified except in the Central Anti-Atlas (Destombes and Feist, 1987).

In the Atlas and Meseta domains, Lower Cambrian strata crop out locally (Rehamma, Jbilete, High Atlas, Zaïan area). They have the same facies as the coeval Western Anti-Atlas series. Middle Cambrian series, although generally thicker, are also similar to those of the Anti-Atlas, suggesting that the same marine basin, probably more subsident in the north, extended over most of Morocco. The thickness of the Middle Cambrian sequence is highly variable throughout the Meseta domain. In the western High Atlas, Cornée, Destombes, and Willefert (1987) described a Middle Cambrian graben, delimited by southwest-northeast trending normal faults. By the end of Middle Cambrian, the El Hank mature sandstones and quartzites indicate the shoaling of the basin. Upper Cambrian was recently dated in the lowest sandy argillites above the El Hank sandstones (Cornée and others, 1987; André and others, 1987).

Everywhere in Morocco, Middle Cambrian series show traces of volcanic activity. Several effusive centers are known in western Morocco (Gigout, 1956; Schaer, 1964; Destombes and Jeannette, 1966). They are outlined by thick complexes of andesitic and basaltic flows, volcanic breccias, and tuffites. Contemporary volcanic flows and tuffites are also described in eastern Morocco (Allary, Lavenu, and Ribeyrolles, 1976) and in the eastern Anti-Atlas (Destombes, Hollard, and Willefert, 1985). So far, this volcanism has been poorly studied. In the Anti-Atlas, it is a continuation of the Late Proterozoic volcanism (Boyer and Leblanc, 1977; Boyer and others, 1978).

At the northern end of western Morocco, the Rabat-Tiflet (=Sehoul) zone (fig. 3) shows a sedimentary sequence metamorphosed into the greenschist facies. The Lower member of this sequence is composed of alternating carbonates and graywackes ("Schistes à trous"), probably Lower to Middle Cambrian in age. The Upper member is represented by detrital and volcanoclastic rocks, where a Tremadocian fauna was recently discovered (see below).

3. *Ordovician Platform and the Sehoul Terrane*

Ordovician series crop out principally at the southern flank of the Anti-Atlas, from Jbel Bani to Ougarta, and in the north of Morocco, where they are found, like Cambrian series, in the Hercynian anticlinoria. In the Anti-Atlas, the type-sequence was described by Destombes (Destombes, Hollard, and Willefert, 1985), and four lithostratigraphic groups distinguished, all dated by abundant neritic faunas:

External Feijas argillites; Tremadocian-Llanvirnian
1st Bani sandstones; Llandeilian
Ktaoua clays; Lower Caradocian—Upper Ashgillian p.p.
2nd Bani sandstones; Upper Ashgillian p.p.

Sedimentological observations demonstrate a glacial origin for the sandstones and microconglomeratic siltstones of the Upper Asghillian.

They are related to the contemporary glaciation that affected Africa (Deynoux, 1985; Deynoux, Sougy, and Trompette (1985). North of the Anti-Atlas, the Ordovician sequences do not differ fundamentally from those described above. In western Morocco, Destombes and Jeannette (1966) described, for instance, the Oued Nefifikh sequence in the vicinity of Casablanca, which is easily correlated with 1st Bani sequence. A significant distinction appeared nevertheless between western and eastern Moroccan series during the Upper Ordovician: western Morocco was then characterized by coarse quartzitic deposits, and the Zaïan region, in eastern Massif Central, was marked by finer grained sediments (Asfar beds of Termier, 1936). Recently, Hamoumi (1988) recognized turbiditic sequences in the Ashgillian deposits of Eastern Jbilete. Similar variations, although less accentuated, are also known from west to east along the Anti-Atlas. More easterly, the Upper Ordovician sequences of the Atlasic inliers, namely Western Tazekka (Hoeppfner, 1977), Bou Dahar (Destombes, 1971), and Tamlelt (du Dresnay, 1965) show affinities with western series.

No effusive rocks are dated from Ordovician, except very locally in the lowest Ordovician of the eastern Anti-Atlas (Destombes, Hollard, and Willefert, 1985) and in the northernmost part of Meseta, in the vicinity of Rabat, where splitic flows are intercalated in Ordovician argillites and sandstones (Piqué, 1979). These effusive rocks could correspond to the contemporary volcanic series of southern Spain, more largely developed (Bard, 1977). North of these volcanic flows, the Rabat-Tiflet (Sehoul) zone is separated from the rest of Meseta by a tectonic contact. Above the series considered to represent Cambrian, fine sandstones and siltstones have recently yielded graptolites of Tremadocian age (Lopez, oral commun., 1985). The particularity of the whole series is to have been subjected to a low-grade metamorphism and folded prior to the emplacement of the Rabat-Tiflet granite, dated at 430 ± 2 Ma (Rb/Sr method, =1.42 10^{-11} y^{-1}) by Charlot, Rhalib, and Tisserant (1973).

All over Morocco, unweathered, detrital biotites, common in Ordovician deposits, show that weathering was not efficient in the continental source land, corroborating the existence of a cold, subpolar climate on the Saharan shield, already suggested by sedimentological and paleomagnetic evidence. Other clastic minerals (quartz, white micas, clay minerals) have also originated, like the biotites, on the Saharan shield. From the Tindouf basin to Rabat, Morocco was the marine epicontinental shelf of the West-African continent. Over this shelf, except in eastern Morocco during Late Ordovician time, the sedimentation was characterized by neritic faunas, frequent bioturbation of the sediments, numerous local disconformities, and frequent storm deposits (Hamoumi, 1988). Apart from the clastic facies, some oolitic iron ores are present in several levels. Carbonates are rarely found. But, the epicontinental shelf did not remain uniform; during Upper Ordovician, the future eastern Morocco zone, or at least a part of it, was distinguished by its predominantly pelitic sedimentation from the western and easternmost parts of the shelf. At the end of the Ordovician, some indications in the Eastern Jbilete suggest this zone acted as a turbiditic basin, where several hundred meters of sediments were deposited.

4. *Silurian Post-Glacial Transgression*

In the Anti-Atlas domains, the beginning of the Silurian period was marked by a marine transgression which reached its maximum amplitude during Middle-Upper Llandoverian and is likely to be correlated with the melting of the Late Ordovician continental glacier. Platy sandstones constitute the first level of the Silurian sequence. They are followed by an uniform facies of graptolite shales and siltstones. Toward the top of this sequence, carbonate concretions and *Orthoceras* limestones are intercalated within the shales. Fine sandstones and *Scyphocrinites* limestones represent the uppermost Silurian-Lochkovian transition. This succession is characteristic of the Draa lowlands (Hollard, 1970). Elsewhere, Silurian series exhibit very similar facies. Most of the Silurian beds of northern Morocco are the same dark shales, with a pelagic fauna, that are found in the south. These monotonous graptolitic shales marked the maximum extension of the Silurian sea. They were deposited in relatively shallow water under euxinic conditions probably in the same setting (outer shelf) as the examples described by Berry and Wilde (1978). One particular facies is worth emphasizing in the Ouled Abbou region (western Morocco), where thin basaltic flows are intercalated in the Lower Silurian series (Cornée and others, 1985). No chemical study of this volcanism has been made, and its tectonic significance is therefore unknown. Throughout Morocco, the most striking difference between the Silurian series concerns their thickness, which is highly variable. They are thickest (1300 m) in the northern half of the Tindouf basin. Elsewhere, the usual thickness of the Silurian does not exceed 200 m, whether in the south (Zemmour and southern part of Tindouf basin; Deynoux, Sougy, and Trọmpette, 1985), in the east (Tafilalt; Hollard, 1970), or in the north (western and eastern Morocco: Destombes, Hollard, and Willefert, 1985). These thickness changes are indication of a north-south differentiation between the Pre-Saharan domain and the Hercynian domain itself after the Middle Cambrian.

5. *Lower and Middle Devonian Differentiation: Southern and Western Platforms versus Eastern Trough*

In southern Morocco, Lower and Middle Devonian strata are well represented on both sides of the Tindouf basin and in the Tafilalt-Maider area. After a progressive regression, the Sahara domain, south of the Tindouf basin, was subjected to continental conditions and covered by fluvial deposits (Beuf and others, 1971). In the northern part of the Tindouf basin (Draa Lowlands), Lower Devonian is represented by a thick series (1300 m at Assa), mostly detrital, composed of four successive sedimentary cycles, the so called "Rich" (fig. 4). Each Rich (Hollard, 1981) is constituted by platy limestones overlain by alternating beds of argillites and fine-grained sandstones and, at the top, by coarse and massive sandstones with lenticular cross-bedding. Their fauna belong to the Ardennan-Rhenan province. The Middle Devonian is represented by black, pyriferous limestones. Toward the east and northeast, the Lower Devonian sediments were more pelagic, and their clastic and terrigenous component decreases progressively. In the Tafilalt, Lower and Middle Devonian is almost exclusively represented by thin Goniatites limestones of the Hercynian-Bohemian facies (Hollard, 1981). Locally, at Hammar Laghdad (:Hamar el-Khdad), in the Tafilalt, a bioherm was established during Upper Emsian and Eifelian over a rise constituted by Lochkovian basaltic rocks.

In western Morocco, boreholes drilled in the Coastal plain show a Lower Devonian sequence 1000 m thick composed of dark, often pyritic shales (Barbu, 1977). Carbonate strata are intercalated within argillites from the Upper Emsian, and their relative importance progressively

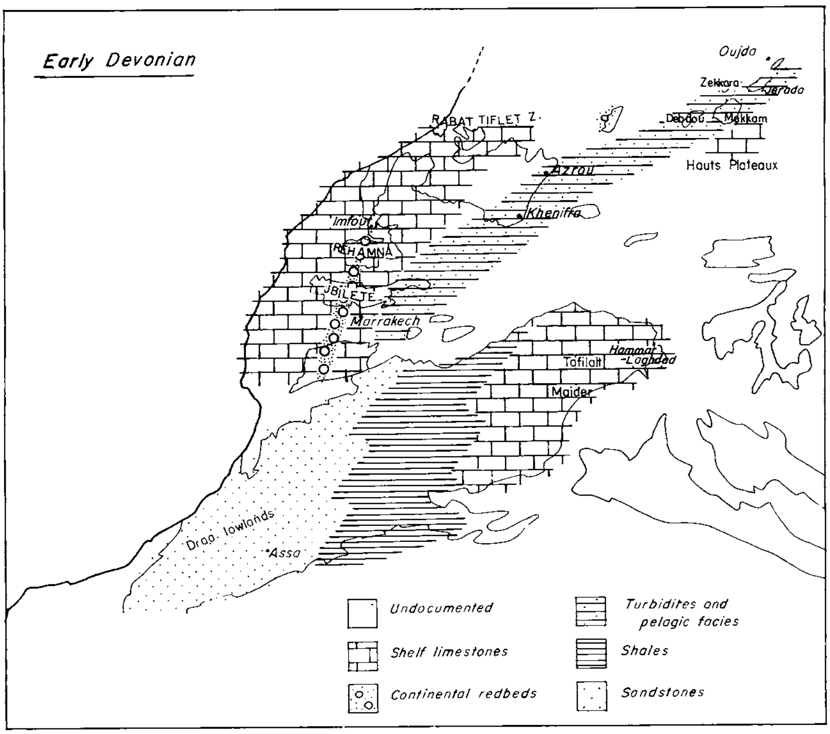

Fig. 4. Sedimentary facies in Northern Morocco during Early Devonian. Note: In figures 4 to 7 the series are shown in their present location.

increased. Middle Devonian was characterized by extensive development of reefal limestones. Other parts of western Morocco show a similar evolution. On the eastern margin of this region, a reefal alignment developed, trending north-northeast–south-southwest: the Imfout axis (Elloy, 1952). This rise was emergent in the south (Cornée, Destombes, and Willefert, 1987). Locally (Central Rehamna), terrestrial red beds and conglomerates unconformably overlie Middle Cambrian strata. Such data indicated a tendency to uplift all along western Morocco at that time, perhaps linked to compressive events (Acadian ?) developing outside Morocco. To the north, in the Rabat-Tiflet Zone, Lower and Middle Devonian limestones overlie Cambrian to Silurian strata and a late Ordovician granite. Hence, accretion of this zone to the rest of Meseta was achieved by Early Devonian time. Eastward in western Morocco, facies were more pelagic, but they still show important limy deposits, especially during the Middle Devonian (Hollard, 1967; Alberti, 1969; Piqué, 1979). A general regression occurred after the sedimentation of Lower Frasnian reefal limestones.

In the western part of eastern Morocco, in the Azrou area, Bensaïd (1979) and Bouabdelli (1982) described a Lower and Middle Devonian sequence composed of limestones with radiolarian cherts and, locally, an effusive mafic intercalation (Bohrmann, 1983). Ribeyrolles (1976) and Huvelin (1977), among others, showed that these facies extend southwestward into the Khenifra and Eastern Jbilete areas, where they are incorporated in late Early Carboniferous nappes. In the Azrou area, another allochthonous unit, the Bou Agri (Bouabdelli 1982) shows coeval strata with a different facies, a detrital and rythmic sequence, often amalgamated, including sedimentary breccias and slumped beds that suggest a proximal turbiditic emplacement. During late Early Carboniferous time, this Bou Agri unit was thrust onto the pelagic limestone basin already described. Regional considerations led Bouabdelli to propose that these detrital series were deposited east of the pelagic ones. A similar pattern has been recognized in the Eastern Jbilete, where the structurally higher units present the same flyschlike facies. In other words, a palinspastic restoration of the Carboniferous allochthonous units of eastern Morocco allows one to reconstruct the limits and the physiography of the Devonian sedimentary basin. This basin extended from Eastern Jbilete to Azrou. In its northwestern part, pelagic sediments were deposited, while turbidites characterized its southeastern part. Northeast of Azrou, the Debdou and Mekkam schists (Hoepffner, 1987) were recently proven to be Middle Devonian in age (Marhoumi and Rauscher, 1984). Stratigraphically, they correspond to the Azrou detrital sediments. All together these Devonian pelagic and turbiditic facies outline a subsiding basin which trends southwest-northeast, approximately from Marrakech to Oujda. Farther to the east, in the Hauts-Plateaux, the Paleozoic series do not crop out and cannot be directly observed, but indirect considerations can be invoked to determine which Devonian series are hidden beneath the Mesozoic cover. In the Jerada-Zekkara region, some early Carboniferous units are known (see below). One of them, the Zekkara olistostrome, contains exotic blocks (olistoliths) of Lower to Middle Devonian reefal limestones of southeastern origin (Hoeppfner, 1987), suggesting that, at least locally, the deep and turbiditic Marrakech-Oujda trough was bordered to the southeast during Lower and Middle Devonian by a carbonate shelf or by allochthonous units coming from such a shelf more to the southeast. The Marrakech-Oujda basin was located north of the pre-Saharan shelf domain, the northern limit of which was located somewhere under the present High Atlas. It was bordered to the west by another shelf domain in western Morocco, uplifted during Silurian and Early Devonian.

PART II—THE LATE DEVONIAN CRISIS: BASINS AND PLATFORMS AND THE EOVARISCAN PHASE

1. *Block-Faulting of the Anti-Atlasian Foreland*

In western Anti-Atlas, a thick (1300 m, Hollard, 1981), essentially pelitic sequence with silty layers and calcareous concretions was deposited during Frasnian and Famennian time in a subsident basin (Draa Lowlands). Toward the east, the Tafilalt and Maider region, formerly a shallow platform, was now characterized by a different environmental pattern (Hollard, 1981; Wendt, Aigner, and Neugebauer, 1984; Wendt, 1985). Two basins initiated there during Late Frasnian and developed during Famennian (fig. 5). They trended northwest-southeast (parallel to the Ougarta direction) and were limited by uprising blocks. Basins and platforms were characterized by different sedimentary facies and thicknesses: Maider basin, for instance, was filled during Late Devonian by 800 m thick clays with calcareous and sandy interbeds while its margins were outlined by slumps. The Tafilalt platform, on the other hand, was covered by 100 m of quartzose limestones and condensed cephalopod limestones. At the Devonian-Carboniferous limit, deltaic sandstones were deposited uniformly on platforms and basins in the southern part of the Tafilalt-Maider area whereas olistotromes characterized the northwestern Tafilalt (Wendt, Aigner, and Neugebauer, 1984).

2. *Transtensive Opening of Western Morocco Basins*

North of the Anti-Atlas, too, the Late Devonian was marked by uplifting of large blocks, separated from subsiding zones by active, normal faults. On these blocks, emergent at least locally during Late Frasnian and Early Famennian time, the Late Devonian transgression was accompanied, as in the Anti-Atlas, by a strong paleogeographic differentiation: the "révolution famennienne" (Piqué, 1975b). Uprising blocks (Coastal block, Rabat-Tiflet (or Sehoul) block and the Zaër rise: Piqué, 1975b, 1976a; Michard, 1976; Padgett, Ehrlich, and Moody, 1977) were bordered by elongated areas where chaotic facies (olistostroms, mudflows) and locally volcanic tuffs deposited (Piqué and Khar-

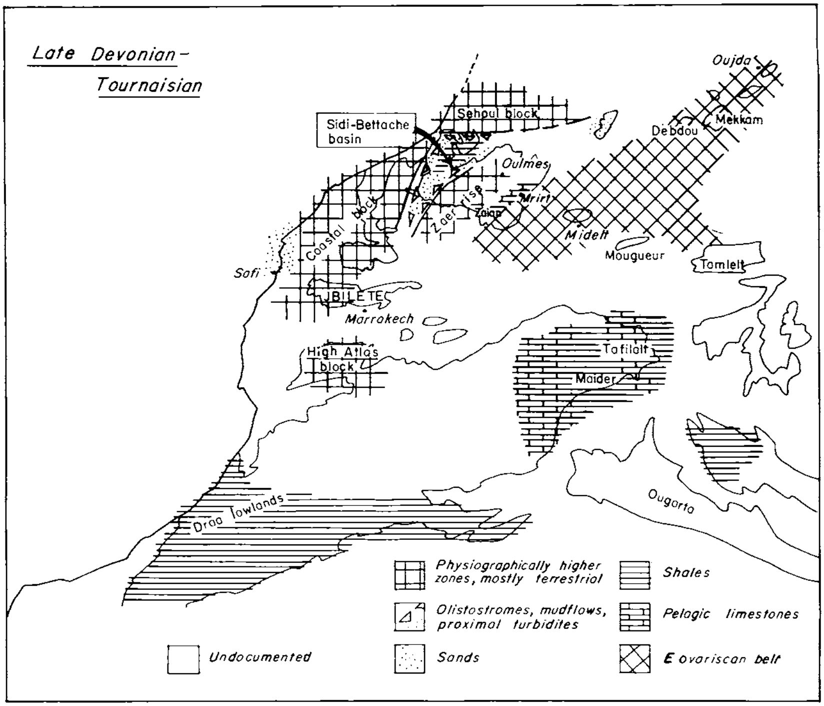

Fig. 5. Sedimentary facies in northern Morocco during Late Devonian and Tournaisian.

bouch, 1983). Most breccia elements are Middle Devonian limestones. Such chaotic breccias are known in western Morocco as "Biar-Setla conglomerates" (Termier, 1936, Piqué, 1979). They accumulated close to Late Devonian-Early Tournaisian synsedimentary normal faults, and they outline the limits of a sedimentary basin that began during Late Famennian, called the Sidi-Bettache basin (Piqué, 1979, 1984). It extended southward as far as Central Jbilete and High Atlas Paleozoic block (Bordonaro, Gaillet, and Michard, 1979; Cornée and Ferrandini, 1985) (fig. 5). Inside the basin, more distal facies (pelites, fine grained graywackes) accumulated. Paleontological data are not precise enough to determine the stratigraphical limit between Famennian and Tournaisian series, both of which show the same basinal lithologies. The thickness of the Famennian series probably attain several hundred meters. In contrast, the blocks outside the basin probably emerged at that time, except for the western Safi basin (Bäcker, Negroni, and Gendrot, 1965). There, a borehole reached fine quartzitic Famennian sandstones (260 m) and clays, below sandstones and carbonates of "Strunian" age (360 m).

3. *Eovariscan, Folding Phase of Eastern Morocco*

In eastern Morocco, regional deformations occurred repeatedly between the end of Devonian and Upper Carboniferous. Upper Devonian strata are not preserved, and it is difficult in many areas to decide whether or not the Lower and Middle Devonian trough persisted during Upper Devonian and which sedimentological facies characterized eastern Morocco during this period. Yet, some Upper Devonian strata have been preserved here and there. In the Debdou inlier, the youngest strata below the main unconformity is Givetian-Frasnian (Marhoumi and Rauscher, 1984). It shows the same turbiditic facies as the older series. In the Eastern Massif Central, the Late Devonian is represented in the allochthonous Mrirt unit by pelagic, condensed, and nodular limestones (Agard and others, 1955; Ribeyrolles, 1976) and by breccias and mudflows that evoke the western Moroccan "Biar Setla conglomerates" (Hollard and Morin, 1973). The Upper Devonian facies in eastern Morocco do not differ substantially from those of the Lower and Middle Devonian. They suggest that the Marrakech-Oujda trough persisted during the Late Devonian, with the same distribution of the facies; pelagic in its western part, turbiditic in its eastern part.

Eastern Morocco was affected, prior to Late Visean, by Eovariscan deformation. In the Midelt area, Clauer, Jeanette, and Tisserant (1980) showed that the regional metamorphism occurred at 366 ± 7Ma (Rb/Sr isochrons). This metamorphism was contemporaneous with two successive episodes of folding which developed a flat-lying polyphased foliation. The north-south trending folds (Vauchez, 1976) are recumbent to the west (Hoepffner, 1987). Recently, Huon (1985) studied the Debdou and Mekkam slates, involved in north-northwest–south-southeast recumbent folds verging westward. A contemporary low-grade metamorphism was dated by K-Ar method at 368 ± 8 Ma, corresponding exactly to the age of the Midelt deformation. Contemporary orogenic events (Bretonnic Phase) are known in Europe—western France (Rolet, 1982), Maures (Bard and Caruba, 1981)—as well as in the Internal Rif (Chalouan, 1986). In the Zaïan area (fig. 5), the Cambrian (?)—Ordovician quartzites and the Jbel Bouchot Middle Devonian limestones were deformed also by north-northwest–south-southeast folds before the Late Visean. These folds verge eastward, opposite to the west-facing Midelt and Debdou structures. The age of this folding is not accurately determined. This region is presently under re-investigation (Bouabdelli, in progress).

In the same eastern area, the allochthonous units (Ziar-Mrirt and Eastern Jbilete nappes) which are composed of Ordovician and Devonian series and were thrust westward during Upper Visean time do not show any traces of a pre-Visean penetrative deformation. If we admit that they rooted west of the Debdou-Midelt axis, the "Eovariscan" deformation affected only the easternmost parts of the former Marrakech-Oujda trough. Elsewhere in Morocco, recent observations in the Tamlelt inlier in the eastern Atlas (Hoepffner, 1987) suggest that the northern part of the inlier, which is composed of metamorphic rocks similar to the Midelt schists, could belong (with the Mougueur inlier) to an east-west trending segment of the Eovariscan belt.

To the west, how does the Eovariscan deformation decrease? Near Ezzhiliga, close to the limit between eastern and western Morocco, Cailleux (1985) described flat-lying thrusts that repeated Ordovician and Silurian quartzitic series before their folding. He tentatively referred this early thrusting to the deformation in the Zaian area. Nearby, 25 km north of Oulmès, Cogney (*in* Michard, 1976) discovered the angular discordance of Upper Visean limestones upon subvertical Famennian strata, which could correspond either to the Eovariscan compressive event or to vertical movements due to distention and block-faulting (Tahiri, personal commun.).

In conclusion, during Late Devonian time, eastern and western Morocco underwent distinct stratigraphical and structural evolutions. In western Morocco, after the shallow marine sedimentation that had characterized Middle Devonian to Early Frasnian time, epirogenic upwarping occurred during Late Frasnian and Early Famennian. A strong subsidence developed subsequently in part of the area (Sidi-Bettache basin). In eastern Morocco, marine sedimentation lasted, at least locally, as long as Famennian, and an Eovariscan deformation followed rapidly during Upper Famennian. The new belt lay between undeformed areas, the Anti-Atlas domain to the southeast and the western Morocco domain to the northwest. At the eastern margin of the latter (western foreland of the belt), some brittle deformation occurred. The Eovariscan phase of eastern Morocco was broadly contemporaneous with the sinking of the Western Sidi-Bettache basin. However, in view of the relatively large time span (10 Ma) determined for the age of the Eovariscan folding, this compressive deformation in eastern Morocco could correspond exactly either to the very initial stages or to subsequent stages of the basin development.

PART III—CARBONIFEROUS BASINS AND HERCYNIAN MIGRATING OROGENY

1. *Tournaisian Transition*

During Tournaisian time, most of the Anti-Atlas was covered by a shallow sea, transgressive since Famennian. Pelagic facies (Gattendorfia beds) were deposited, followed in the Draa and Ougarta area by the regressive Tazout sandstones. At the end of Tournaisian, the western and southern parts of the Tindouf basin, and perhaps the Tafilalt, emerged and provided clasts to the northern zones.

In western Morocco, the paleogeographic frame is far more complicated, with a regional disposition largely inherited from Famennian times. Uplifted blocks (fig. 5) were probably emergent, since they do not exhibit any Tournaisian strata, and their margins are outlined by littoral deposits (Lecointre, 1926; Piqué, 1979). Inside the Sidi-Bettache basin, Tournaisian marine facies overlie without any stratigraphic break the Upper Famennian sequences from which they are lithologically indistinguishable (table 1). At the basin margin, mudflows, olistostromes, and proximal turbidites suggest resedimentation phenomena down active fault scarps (see part II). Southward, in the Jbilete massif and in the High Atlas Paleozoic block, Mayol and Muller (1985) and Cornée and Ferrandini (1985) respectively described probable Tournaisian olistostromes and normal synsedimentary faulting along the eastern margin of the Coastal block, which had been previously interpreted as post-metamorphic thrust planes (Muller, Sougy, and El Hassani, 1983). In the Sidi-Bettache basin, these Upper Famennian-Tournaisian facies were contemporaneous with some volcanic and magmatic rocks, often bimodal. On the basis of the chemistry of the related lavas and dikes and particularly of their REE content, a tholeiitic to alkaline trend was determined (Piqué and Kharbouch, 1983; Kharbouch and others, 1985). Combined with sedimentological and petrographic arguments, this trend indicates a crustal distention, corresponding to a rift or a back-arc basin. In the center of the Sidi-Bettache basin, the Tournaisian is represented by distal facies of pelites and calcareous nodules, free of any magmatic intercalation (Piqué, 1984). Southern lateral equivalents of these distal facies could have formed in the lower parts of the Sarhlef Formation of the Central Jbilete as discussed below. In eastern Morocco, Tournaisian is represented by sandstones only in the Azrou area, which escaped the Eovariscan folding.

2. *Visean Basins and the Late Visean-Namurian Phase*

Anti-Atlas.—Lower Visean was marked again by a transgressive episode. In the Draa Lowlands, goniatite-bearing pelites and silts (Be-

TABLE 1

Formations and informal names of the Upper Paleozoic rocks

	Southwestern Anti-Atlas (Hollard, 1970 Conrad, 1972)	Sidi-Bettache basin (Piqué, 1979, 1984)			Central Jbilete (Huvelin, 1977 Aarab & Beauchamp, 1987)		northeastern Morocco (Hoepffner, 1987)
		western limit	western margin	center	western part	eastern part	
Lower Westphalian							
Namurian	Betana						Jerada beds
Upper Visean	Ouarkziz	Bou-Rzim			Sarhlef	Kharrouba	
Lower Visean	Betaina		Korifla				
Tournaisian	Tazout						
Upper Devonian	Draa lowland sequences	Ben-Slimane	Fouizir				Debdou slates

taina beds) were deposited (fig. 6). Continental influences increase southwestward. In the Tafilalt, on the contrary, local reef building occurred. During the Late Visean, the Jbel Ouarkziz approximately marked the northern limit of the Tindouf basin. It shows 800 m of detrital sediments: coarse sandstones, sometimes continental, and thick beds of bioclastic marine limestones. North of the Jbel Ouarkziz, Upper Visean deposits are not known either in the center of the Anti-Atlas or in the region that corresponds to the present High Atlas. We do not know whether these areas were continental, as suggested by the littoral facies displayed in the Jbel Ouarkziz, or if they were covered by the general Late Visean transgression, and their shelf sediments subsequently eroded. North of the Anti-Atlas, Upper Visean deposits are known here and there, from Ait-Tamlil (Jenny and Le Marrec, 1980), Skoura (Laville, 1980), and Tineghir (Michard and others, 1982) to Ben Zireg (Pareyn, 1961). At Skoura-Tineghir and Ben Zireg, coarse detrital sequences have accumulated locally since Early Dinantian, with kilometer-scale olistholiths, along east-west fault scarps. In the Ait Tamlil

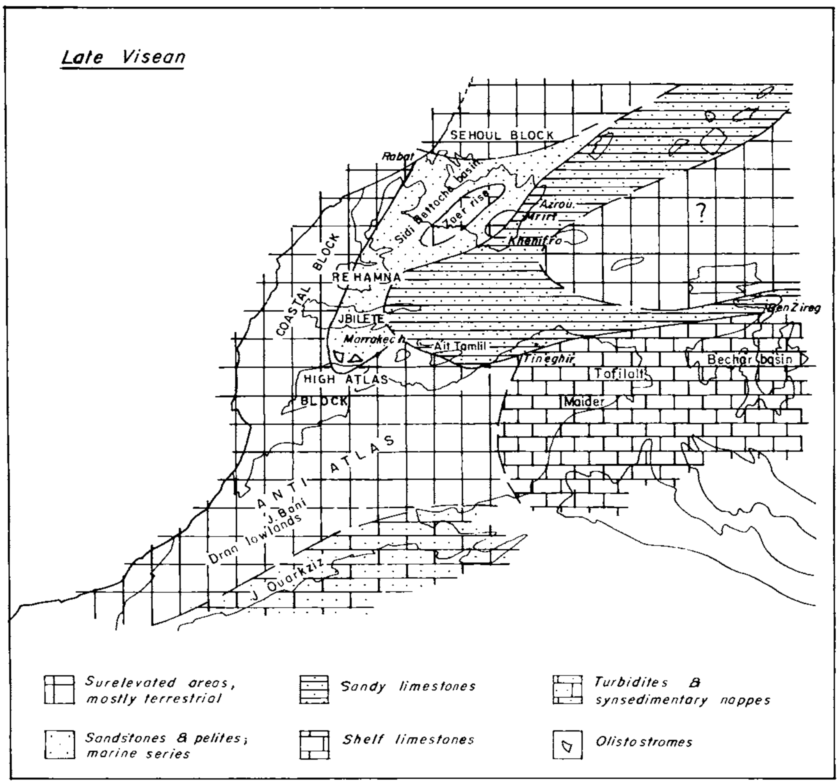

Fig. 6. Sedimentary facies in northern Morocco during Late Visean.

inlier, olistostromes were deposited some time later at the front of gravity nappes. These series were deformed during the Middle Carboniferous (see below). Except at this northern limit, Hercynian folding is nowhere accurately dated in the Anti-Atlas. In the western Anti-Atlas, where folding is the most conspicuous, the oldest strata unconformably overlying the Cambrian to Devonian folded series are Cretaceous or, locally, Triassic. Southward, the Jbel Ouarkziz series are unfolded. Following Hassenforder (personal commun., 1986), the contrast between the folded Bani and Rich and the horizontal Ouarkziz series, separated by the thick, incompetent Upper Devonian series (Draa lowlands), corresponds neither to an unconformity nor to a strike-slip fault. It marks the southward decrease of the Hercynian folding which dies out in the Tindouf basin. In the eastern part of the Anti-Atlas (Tafilalt, Maider), Tournaisian and Lower Visean strata are folded quite mildly. There, too, no angular discordance allows us to date this folding which seems to die out eastward, within the Upper Carboniferous Bechar basin. Another approach has been tried. In the southwestern Anti-Atlas, Bonhomme and Hassenforder (1985) tried to determine, by Rb-Sr geochronology, the age of the low-grade metamorphism of Cambrian-Ordovician rocks. They suggest 370 Ma for a "pretectonic metamorphism" and 290 Ma for the regional deformation. These preliminary results have to be checked by other data. As a whole, the Anti-Atlas folding remains unsatisfactorily dated, and, of course, its description in this chapter does not carry any definitive assumption of its age. Anyway, all over the Anti-Atlas, Hercynian deformation remained weak. It developed only regional-scale structures and open folds, except in the southwest where an axial-plane cleavage appears in the deepest levels (up to Ordovician). According to Jeannette (Jeannette and Piqué, 1981), the regional pattern combines northeast-southwest sinistral strike-slip faults and associated en-échelon folds in the western Anti-Atlas; east-west folds and reverse faults in the central Anti-Atlas: and northwest-southeast dextral strike-slip faults in the Algerian Ougarta belt. This pattern could result from the north-south shortening of the Anti-Atlas during Upper Paleozoic.

Western and Eastern Morocco.—The Lower Visean is paleontologically dated only in the Sidi-Bettache basin. There, it is represented, over a thickness of several hundred meters, by the upper part of the Korifla Formation (table 1). South of Rabat, these layers contain intercalations of mafic flows and dolerite sills whose chemical trends are similar to those of the Tournaisian flows. In the Jbilete massif (fig. 6), where the same magmatic facies appear, the Lower Visean is probably represented in the Sarhlef series which will be described below.

As in the Tindouf basin, Upper Visean corresponds in northern Morocco to a general marine transgression which began, at least locally, as early as Middle Visean time. It was also a period of intense tectonic activity. It is described below first for western and then for eastern Morocco. In the center of the Sidi-Bettache basin, the Upper Visean deposits (Bou Rzim formation, Piqué 1984) rest conformably upon the Korifla formation. They are coarse and microconglomeratic sandstones, 2000 m thick, with calcitic cement. At the eastern margin of the Coastal Block, the Upper Visean series lie disconformably upon Upper Devonian sandstones (Destombes and Jeannette, 1966). Thus the Upper Visean sea transgressed outside the limits of the Tournaisian and Lower Visean Sidi-Bettache basin. Nevertheless, it is unlikely that the Sehoul, Coastal, and Zaër blocks were then totally covered by the sea, as stated by Termier (1936) for the Zaër region and suggested by Kelling and Mullin (1975) who described very shallow water sediments at the eastern margin of the Coastal Block. In the Coastal Block itself, we have at present no indication that allows dating of the main metamorphism and deformation, since the youngest deformed strata are Late Devonian, and the first unconformable series are Triassic. Whatever the age of the orogenic event, the Coastal Block was weakly deformed except at its eastern limit. There, a rough cleavage and a low-grade metamorphism (Piqué, 1979; Wybrecht and others, 1985) marked the development of the Western Meseta Shear Zone. This structural zone shows northwest-southeast to north-south en-échelon folds, north-south to northeast-southwest faults (Piqué, Jeannette, and Michard, 1980), and northeast-southwest thrust-wrench faults (Lagarde and Michard, 1986). Eastern units are displaced westward and southward relative to the Coastal Block. This dextral ductile transcurrent fault can be traced over 300 km from Rabat to the High Atlas Paleozoic Block (Cornée and Ferrandini, 1985) (fig. 6). It resulted from the reactivation of the former synsedimentary faults that bounded the Sidi-Bettache basin on the west. One single geochronological determination (Huon, 1985) indicates a 320 ± 7 Ma age for the metamorphism associated with the deformation of the Tournaisian series in the Western Meseta shear zone (Oued Yquem, 20 km southwest of Rabat). If further studies confirm this result, then the deformation of the western margin of the Sidi-Bettache basin would represent a Late Visean Phase.

In the central Jbilete massif, the Sarhlef series is classically attributed to the Upper Visean (Huvelin, 1977), although it could include Lower Visean and even Tournaisian strata (Bordonaro, Gaillet, and Michard, 1979). It is composed of fine sediments, with pyrrhotite and chalcopyrite, deposited in an anoxic environment. South of Marrakech, in the High Atlas Paleozoic Block, the Upper Visean facies are coarser, and Beauchamp and Petit (1981) showed synsedimentary faults and slumps, trending east-west and northeast-southwest, and outlining the southern limit of the subsiding basin. The Sarhlef series is deformed by folds trending northeast-southwest to north-south, associated with conjugate shear zones and syn- to post-metamorphic thrusts. This deformation is not dated stratigraphically nor geochronologically. It was described by Lagarde (1985) and Chemseddoha (1986) as heterogeneous northwest-southeast shortening. In the Rehamna and Jbilete massifs, synmetamorphic westward thrusting and dextral transcurrent shearing occurred (Hoepffner, Jenny, and Piqué, 1983; Lagarde and Michard, 1986; Bouloton and Le Corre, 1985). Others (Sougy, Muller, and Poutchovsky, 1978; Muller, Sougy, and El Hassani, 1983) insisted on the post-metamorphic displacements. In the eastern, Eovariscan zone of the Central massif, the Upper Visean sedimentary and structural evolution has been studied by Huvelin (1970), Allary and others (1972), and Bouabdelli (1982). In the Azrou-Khenifra area, Allary and others (1972) and Vieslet (Cailleux, 1983) described the Upper Visean transgression prograding since the Early (?) to Middle Visean over the eroded Eovariscan belt. Conglomerates, limestones, and argillites were deposited, followed by flysch and resedimented layers. In northeastern Morocco, calc-alkaline andesitic flows and breccias were deposited during the Late Visean. This volcanic activity lasted into Namurian; it is described below. In Azrou-Khenifra region, this Upper Visean series was overlain by two allochthonous units.

The Khenifra nappe, in the southernmost part of the area, is composed of almost the same material as the underlying autochthonous units (Jbel Bou Guergour), that is, Cambrian-Ordovician folded layers, unconformably overlain by Upper Visean strata. The whole nappe is affected by north-northwest-verging reclined folds with axial-plane cleavage dipping moderately southward, which are also present in the autochthonous units. The motion of the Khenifra nappe accompanied this post-Visean folding event and continued for some time; the total displacement does not exceed 20 km (Allary and others, 1972). The Ziar-Mrirt nappe lies more to the northwest, that is, in a more external position. It is constituted by discrete slabs of various size, scattered above an Upper Visean (and Namurian ?) wildflysch, which here terminates the autochthonous sedimentation. Allochthonous material involves Ordovician to Upper Visean units, differing by their facies and structure from the autochthon (Devonian flysch; lack of Eovariscan cleavage). The origin of these units in the southeastern part of the Mrirt basin is not precisely demonstrated. The nappe is thought to have been emplaced by gravity sliding at the very end of Visean (Huvelin, 1970; Allary and others, 1972). According to Allary and others, the Khenifra thrust predated the Ziar-Mrirt gravity sliding, but both nappes could represent at different structural levels the same Late Visean-Namurian compressive event. Anyway, the regional shortening lasted after the final emplacement of the nappes, which were refolded together with the autochthonous series. Then, during the Late Variscan event—Namurian to Westphalian (see below)—rough axial plane cleavage developed. Preliminary K/Ar dating by Huon (1985) on the Chellout allochthon, the northern equivalent of the Khenifra nappe, indicates a 330 Ma age for its main tectono-metamorphic development.

Southwestward, the Eastern Jbilete show a comparable tectonic evolution. The Upper Visean Kharrouba series is a turbiditic sequence whose base is unknown. While some authors (El Hassani, Tahiri, and Zahraoui, 1983) thought that an important tangential deformation affected this sequence, casting a doubt upon any palinspastic restoration of the sedimentary basin, others (Bordonaro, Gaillet, Michard, 1979; Bouloton and Le Corre, 1985) demonstrated that the Kharrouba series was, at least in part, the eastern time-equivalent of the Sarhlef series and that these two series were deposited in different parts of the same basin. The Kharrouba turbidites are overlain by an olistostrome and finally by allochthonous units emplaced from the east as gravity nappes (Huvelin, 1967, 1977). Their material is almost undeformed Ordovician sandstones and Devonian pelagic limestones and turbidites. They correspond to the Ziar-Mrirt nappes to the northeast and to the Aït Tamlil nappe to the southeast.

3. *Late Carboniferous. the Westphalian Phase*

In southern Morocco, the Tindouf basin emerged progressively, without any folding, during the Late Namurian (Conrad, 1972). Marine conditions persisted in the paralic Bechar basin during Lower Westphalien (Pareyn and others, 1971; Lemosquet, Pareyn, and Weyant, 1976), with alternating marine goniatite limestones and continental sandstones (fig. 7). A late or post-Westphalian deformation was active along the northeastern margin of the Anti-Atlas domain (Michard and others, 1982) and in the Bechar basin (Ball and others, 1975; Pareyn, Lemosquet, and Weyant, 1975), producing south-verging folds and flat-lying

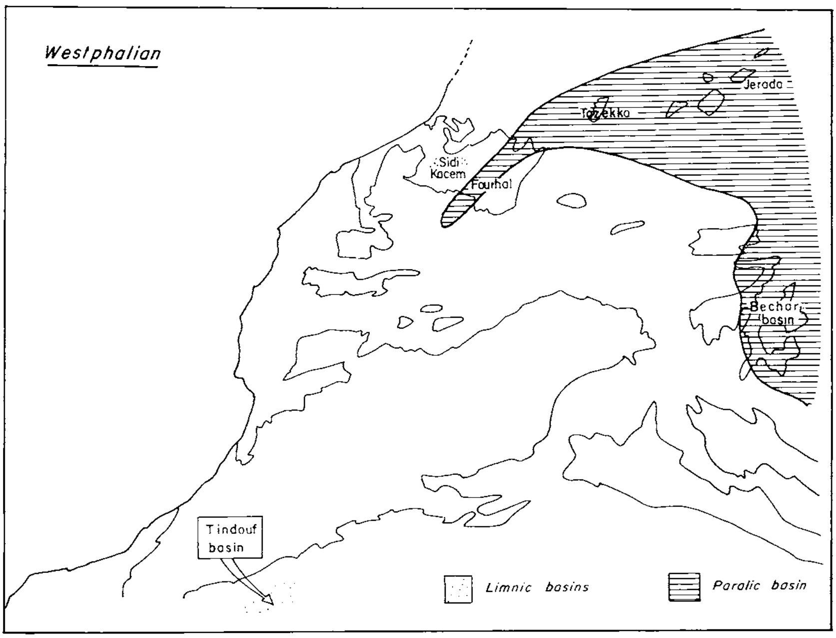

Fig. 7. Sedimentary facies in northern Morocco during Westphalian.

foreland thrusts. Folding in other areas in the Anti-Atlas domain (Jbel Bani et cetera) is not accurately dated (see above).

In northern Morocco, we have no proof that marine sedimentation persisted in the Sidi-Bettache basin after the earliest Namurian, represented in the youngest part of the central basin sequence (Termier, 1936). East of the Zaër rise, in the Fourhal "syncline," the youngest marine beds are dated as Early Westphalian (Hollard, 1978; Ben Saïd and others, 1980). The corresponding sedimentary basin was probably connected with the paralic basin of Tazekka-Jerada, where turbidite sedimentation lasted from latest Visean to early Westphalian (Hoepffner, 1987), associated with conspicuous volcanic activity (El Ghazi and Huvelin, 1981; Huvelin, 1986). The volcanic rocks, mostly andesitic, have a calc-alkaline nature, comparable to those of present island arcs. These magmatic series could indicate either Eovariscan fossil subduction (Kharbouch and others, 1985) or large scale intracontinental transcurrent faulting in a thickening crust (Kharbouch, 1982). Toward the top, the sequence is composed of finer-grained deposits, alternatively marine and continental. At Jerada, these paralic sediments bear coal. If their deformation is coeval with that of western Morocco, it predated the late Westphalian, which is represented by the unconformable Sidi-Kacem continental conglomerates, redbeds, and lacustrine limestones. In the center of the former Sidi-Bettache basin (Rommani syncline), deformation was weak, and no metamorphism is recorded. Both folding and metamorphism increase in the Khouribga-Oulmès anticline, the western margin of which corresponds to the former Zaër rise. The structural trend is highly variable, depending on location with respect to the former sedimentary structures, especially the basin limits. At Oulmès, the peak of the regional deformation is dated at 290 ± 6 Ma (Huon, 1985). Most of the granites that intrude the Moroccan Hercynides (app. 1) are Late Carboniferous in age, but their emplacement time varies from approx 330 to 260 Ma (Tisserant, 1977; Mrini, 1985; Rosé, 1987). The most ancient batholiths (330-300 Ma) belong to the calc-alkaline series of mantle-derived or mixed origin. They were emplaced successively in the Midelt zone, the southern border of western High Atlas (Jebel Tichka), and the western Central Massif (Zaër). Later on, synkinematic leucogranites were emplaced (300-265 Ma), and finally some post-kinematic monzogranites (290-260 Ma).

Finally, Morocco became entirely continental during Namurian and Westphalian time. Marine conditions persisted as late as the Westphalian in the easternmost part of the country, in the Bechar and Jerada paralic basins, and a narrow Fourhal trough, situated between emerging ridges in the Central Massif. The strong gradients and the rapid changes of the structural trends show that the Westphalian deformation was largely controlled by deep fractures which had determined the limits of the Dinantian basin. Obviously, the Westphalian deformation in northern Morocco was strictly intracontinental (Michard, 1976; Piqué, 1981a).

PART IV—STRUCTURE AND DEFORMATION OF THE HERCYNIAN BELT

In the preceding pages we have mentioned the structures produced by the successive folding events (Eovariscan, Late Visean, and Westphalian phases) within each tectonic zone (Anti-Atlas, Eastern Meseta, and Western Meseta belts). We want to focus now on the structure of the "finite" Hercynian belt as a whole, on the deformational processes and the related relative displacements of the intervening units.

1. *The General Pattern of Folds and Faults*

The orientation, distribution and geometry of folds and faults in the main part of the Moroccan paleozoic basement are schematically shown in figure 8 which needs the following comments.

A. Heterogeneous distribution of the deformation.—Areas of weak deformation contrast with narrower strongly deformed and highly metamorphosed zones. Upright, open folds associated with nearly vertical faults (essentially wrench faults) characterize the Anti-Atlas domain, which is the southern foreland of the Hercynian belt. A similar structure is shown in the westernmost part of the Coastal Block, which plays the role of a northwestern foreland for the belt. The Sehoul Block to the north was deformed during the early Paleozoic and also weakly affected by the Hercynian deformation. This deformation was concentrated in the roughly triangular domain of Eastern and Western Meseta.

Within this central part of the belt itself, deformation is unevenly distributed. Areas of upright, open folds and incipient cleavage, such as in some parts of Central Massif-Eastern Rehamna anticlinorium or western or eastern Carboniferous synclinoria, contrast with zones of reclined or recumbent folds, flattened and sheared in strongly foliated rocks. The exposed granites are associated with highly deformed zones which are shear zones between less deformed units. Some of these zones are located within the belt (Oulmès, Zaër, or Central Jbilete shear zones for instance), but the most important are located along its limits. The Western Meseta Shear Zone (WMSZ) runs along the eastern margin of the Coastal Block (Michard, 1969; Piqué, Jeanette, and Michard, 1980). It seems to be crosscut offshore from Rabat by the Rabat-Tiflet Shear Zone south of the Sehoul Block (Piqué, 1979; Cailleux and others, 1984). The Atlas Paleozoic transform Zone (APTZ, Michard, Cailleux, and Hoepffner, 1983) runs along the northern limit of the pre-Saharan foreland and involves the Tizi n'Test fault zone (Mattauer, Proust, and Tapponnier, 1972) and the Tineghir-Bechar thrusts (Michard and others, 1982). As mentioned above, these main shear zones correspond systematically to abrupt stratigraphical changes. They probably result from the re-activation during the Hercynian shortening of previous, synsedimentary (mostly extensional) structures. The Tazekka-Bsabis-Khenifra thrust zone runs almost exactly on the limit between the Eovariscan and Late Visean belt (Eastern Meseta) and the Late Variscan belt (Western Meseta) (Allary and others, 1972; Allary, Lavenu, and

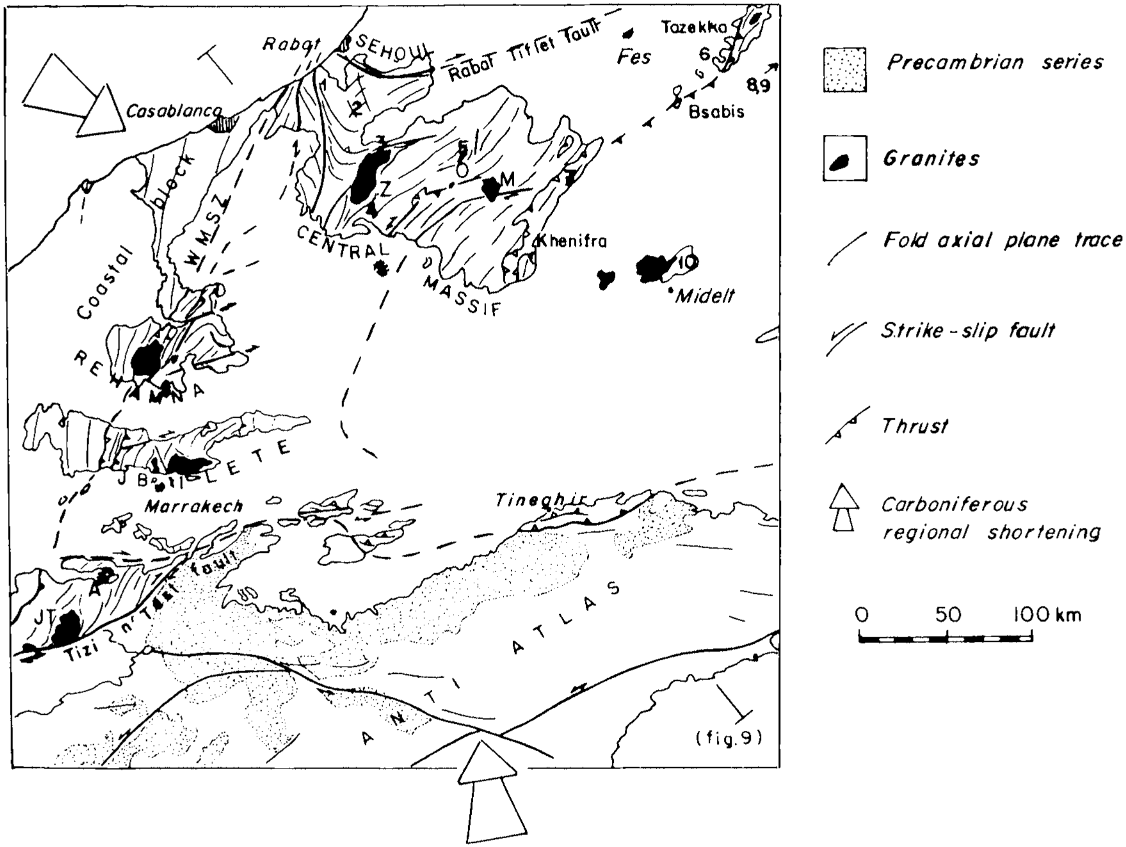

Fig. 8. Structural sketch of the central part of the Moroccan Hercynides: (1) to (10) locations of the samples analyzed in app. 1; (2) location of the granitoid massifs: Z = Zaër; O = Oulmès; M = Ment; JT = Jbel Tichka; A = Azegour.

Ribeyrolles, 1976; Hoepffner, 1978, 1987). It developed during both Late Visean and Westphalian shortening phases.

B. Mean direction of the Carboniferous shortening.—According to the direction of the fold axial surfaces, which parallel the flattening strain trajectories (cleavage orientation), and also according to the sense of wrenching along the steeply dipping shear zones, the mean direction of the Carboniferous shortening north of the APTZ was northwest-southeast, (fig. 8). South of this shear zone against the Anti-Atlas salient (Jeannette and Piqué, 1981) the shortening direction was rotated to north-northwest-south-southeast.

Conjugate sinistral and dextral faults, consistent with a northwest-southeast shortening, were reported, for example, by Allary and others (1972) in the Eastern Central Massif and by Lagarde (1985) in the Jbilete-Rehamna massifs. Along the northeast-southwest trending WMSZ, alternating dextral and sinistral movements are observed in the Rehamna massif, combined with thrusting (Lagarde and Michard, 1986). However, dextral movements dominate; they are documented by the Ben Slimane stripe south of Rabat (Piqué, 1979). Dextral displacements are also documented by en-échelon patterns along the Tizi n'Test Fault (Mattauer, Proust, and Tapponnier, 1972) and along the Rabat-Tiflet fault zone (Cailleux and others, 1984). Hence a major dextral shear directed east-west probably acted along the northern margin of the Saharan craton during Carboniferous time (at least from Late Visean to Stephanian).

The Late Devonian shortening direction was different from the later, Carboniferous one. In its present position, this Late Devonian direction trends east-northeast-west-southwest in most of the Eastern Meseta belt (Hoepffner, 1987).

C. Vergence of folds and thrusts.—The vergence of the Eovariscan (pre-Visean) folds is still poorly known. In the Midelt area, the recumbent folds are reported to verge eastward (Vauchez, 1976) and westward (Hoepffner, 1987). The Zaian reclined folds clearly verge eastward (Allary, Lavenu, and Ribeyrolles, 1976; Cailleux, 1983). Elsewhere, in Debdou, Mekkam, et cetera, general vergence is to the west (Hoepffner, 1987).

As far as the Carboniferous structures are concerned, they verge mostly northwestward (West Tazekka slices, Azrou-Khenifra nappes, Smaala thrust, Rehamna and Jbilete reclined folds, and associated thrusts). However, opposite vergences are also reported within the belt (Zaër area) (Cailleux, 1987) and moreover along its southern limit (Tineghir foreland folds and thrusts). The Central Jbilete massif offers a "flower structure" with associated thrust and wrench movements in the southern part of the WMSZ (Le Corre and Bouloton, 1987). Hence they do indicate pop-up structures of various scales, up to the continental scale of the whole belt.

2. *Deformation Mechanisms and Related Displacements*

In the study of the Moroccan Paleozoic belt, the analysis of minor structures (foliation, microfolds, et cetera) was introduced by the end of the 60's (Michard, 1967, 1968; Allary and others, 1972), and now it covers nearly the whole belt.

A. The importance of syn-metamorphic deformation mechanisms.—Except the synsedimentary nappes at the eastern margin of the Carboniferous basin, already discussed (Ziar-Mrirt, Eastern Jbilete, and Aït Tamlil nappes), most of the Carboniferous thrusts are related to the progressive, synmetamorphic evolution of deformation. This is true for the probably Late Visean Azrou-Khenifra nappes and was also demonstrated in Central Rehamna, where thrusting was combined with wrenching (Lagarde and Michard, 1986). In this part of the Western Meseta Shear Zone (WMSZ), deformation may be related to three superposed phases. The most important ones (D_1 and D_2) result in a main composite $S_{1\text{-}2}$ axial-planar foliation and in reclined, tight, or isoclinal folds verging westward and thrust toward the Coastal Block. The deformation was coeval with development of amphibolite-facies, Barrovian metamorphism. Rotated garnets indicate westward thrusting along northwest-southeast trending lineation in the eastern units of the thrust. However, stretching lineation rotates toward the northeast-southwest direction along the frontal tip of the thrust mass, that is, along the WMSZ itself, and the rotated garnets or kyanite there point to an important dextral wrenching component of strain. The hot deformation of the area is achieved by a D_3 phase (extensional crenulation cleavage, shear bands), which developed in the same regional stress field during the emplacement of the granitoids (leucogranites and monzogranitic plutons).

Therefore, in this particular area, deformation of the Meseta Paleozoic series was essentially achieved by ductile mechanisms, that is pressure solution-crystallization, rotation of grains, and, in the high-grade schists, intra-crystalline flow, and the main displacements occurred along the diversely orientated shear planes in the same "hot" conditions. Such relations of deformation and displacement to metamorphism are certainly valid for the whole belt. We have already mentioned the Azrou-Khenifra nappes and the Western Jbilete area (equivalent to the western and central Rehamna just described). In the Central Jbilete and the Oulmès (Western Central Massif) areas, recent studies (Lagarde and Choukroune, 1982; Lagarde, 1985; Chemseddoha, 1986; Aït Omar, 1985; Diot and others, 1987) confirm previous observations (Huvelin, 1977; Piqué, 1976b) and demonstrate the roughly syntectonic emplacement of the granites. The Oulmès calc-alkaline granite, for example, crystallized at 290 to 300 Ma (Mrini, 1985) in a sinistral transcurrent shear zone that controlled the coeval (Huon, 1985) synmetamorphic deformation of the Paleozoic units. Consequently the Carboniferous shortening of the belt was permitted by the thermal weakening of the basement and cover units, particularly along variously dipping shear zones.

B. Strain features and deep structure.—Finite strain measurements were collected mostly in the most metamorphic shear zones (Piqué, 1973, 1975a; Lagarde and Michard, 1986; Diot and others, 1987; Chemseddoha, 1986) but some also in the low-grade slates and associated rocks (Gratier, 1976; Wybrecht, 1984; Siddans and Michard, 1983). The latter data provide quantitative indications on the Hercynian shortening of the Paleozoic cover along a Rabat-Khenifra transect. Adding ductile flattening (strain data) to buckling deformation, we obtain minimum shortening values increasing from 15 percent in the western Coastal Block to 50 percent in the Central Massif, with a mean value of more than 33 percent for the whole Western Meseta transect.

The corresponding mean thickening value for the plastically deformed Paleozoic cover between the WMSZ and the front of Eastern Meseta is over 50 percent. This is probably far greater than the limited thickening of the continental crust underneath, the thickness of which did not exceed, at the end of the orogenic events, its present 30 km value (Van den Bosch, 1971; Makris , Demnati, and Klubmann, 1985). Hence we must imagine a detachment fault or several decollement levels between the folded, ductile cover and its more brittle basement. Such flat-lying deep faults may steepen upward, cutting through the upper, unmetamorphosed layers (compressive listric faults, for example, Behr and others, 1984; Cazes and others, 1985). An example of such a listric fault zone is provided by the WMSZ: the dip of the faults and related cleavage is steep in the northern part of the shear zone, where the WMSZ cuts across the highest levels of the folded cover, and flattens along strike toward the Rehamna structural and metamorphic culmination (fig. 9).

C. The related displacements.—We consider here tectonic displacements related to the relatively well-documented, Carboniferous deformation, not to the Late Devonian (Eovariscan) phase. The northwest-southeast shortening of the Western Meseta belt during Carboniferous time means two kinds of relative displacements (fig. 8): (1) bringing the limiting, less deformed blocks closer to one another, that is, essentially reducing the distance between the Coastal Block and the Midelt zone (Eastern Meseta Inner Zone), (2) moving a part (if not all) of these Meseta zones along the northern limit of the Pre-Saharan foreland, that is, along the APTZ.

The amount of displacement of the Midelt Zone toward the Coastal Block is unknown, because of the poorly constrained amount of displacement along the thrust faults and suggested deep décollements. A reasonable minimum value should be 100 km. Because these Meseta zones are oriented obliquely, en-échelon, relative to the Anti-Atlas, their Carboniferous deformation inevitably involved transcurrent movements along the APTZ, as previously advocated by Mattauer, Proust, and Tapponnier (1972). However, these movements should not be overestimated. There is stratigraphic evidence that the Coastal Block was probably not displaced more than about 100 km with respect to Anti-Atlas since Cambrian time. Namely, thick volcanics of Early to Middle Cambrian age are shown on both sides of the Tizi n'Test fault,

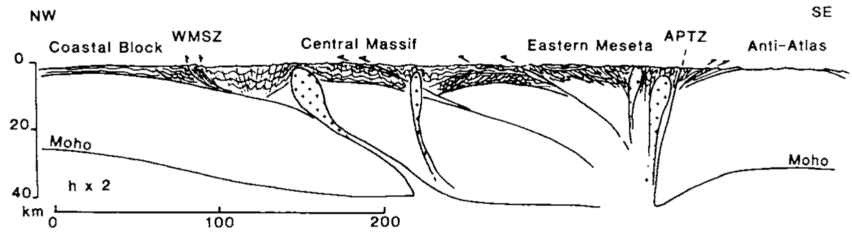

Fig. 9. Conceptual cross section of the Moroccan Hercynides at the crustal scale. For location, see figure 8.

and red conglomeratic sandstones of Early to Middle Devonian age crop on both sides of the northern branch of the north Atlas fault (fig. 8). According to Proust and others (1977), the Late Paleozoic displacement along the Tizi n'Test fault was 50 km, dextral. Along the fault zone north of the Western High Atlas, the Late Paleozoic displacement was probably still smaller (Gaillet, 1986). In order to accommodate the 100 km displacement of the Coastal Block with respect to the Midelt Zone, we must admit that the latter remained fixed during Late Paleozoic or even moved slightly westward along the APTZ. An Hercynian sinistral throw was actually documented along the Aït Tamlil segment (Jenny, 1983). Such opposite sense of movement along the northern limit of the Anti-Atlas foreland may be related to its irregular shape, with salients and re-entrants (conjugate fault zones trending west northwest-east southeast and east northeast-west southwest are actually known within the Anti-Atlas itself).

PART V—DISCUSSION AND CONCLUSION

1. *Sedimentary Evolution—The Margin of Africa*

A. From Late Proterozoic to Middle Devonian.—During this long interval, the Anti-Atlas and Western Morocco (with the exception of the Sehoul zone) roughly shared the same continuous sedimentation, the main points of which are:

1. Late Proterozoic, post-Panafrican continental redbeds and post-collisional volcanism.
2. Lower Cambrian shelf and Archeocyathus limestones.
3. Middle Cambrian volcanoclastic Paradoxides graywackes and shales, deposited on a subsiding margin.
4. Absence of Upper Cambrian deposits.
5. From Ordovician to Middle Devonian, a sort of positive megasequence from Ordovician sands to Silurian pelites and finally Devonian carbonates. This succession registered the progressive decrease of the amount of clastic material provided by the West African shield. The siliciclastic debris in the Lower Devonian, described by Beuf and others (1971) did not reach northern Morocco. In the eastern part of the Coastal Block, the Lower Devonian terrestrial redbeds and conglomer-

ates have a local origin (Piqué, 1979). In the southwestern Anti-Atlas, we have presently no indication of the paleocurrent pattern in the "Rich" sequences. Therefore, for the clastic supplies, one cannot exclude either a southern origin, in the West African shield, or a western origin, from surelevating tectonic lands (Acadian belt of North America ?).

This common evolution suggests that western Morocco and Anti-Atlas were parts of the same epicontinental shelf at the northern margin of the West African shield, as is consistent with their common paleoclimatic evolution, from subpolar to tropical conditions between Late Ordovician and Devonian. The Sehoul zone was not a part of this margin. It prolongates west (Schenk, 1980), or it originated east of Morocco and was accreted to western Morocco before Lower Devonian (Piqué, 1982).

During the period considered, eastern Morocco was not distinct from Anti-Atlas and Western Morocco. There also are known:

1. Lower Cambrian limestones
2. Middle Cambrian volcanoclastic thick series sometimes indistinguishable from Ordovician strata and described together under the name of Cambro-Ordovician.
3. Late Ordovician sandstones and Silurian pelites, which present broadly similar facies and thicknesses as the Western series.

On the contrary, during Lower and Middle Devonian a trough developed in eastern Morocco, trending roughly from Marrakech to Oujda. In the present stage of our knowledge, it is possible to distinguish a western part of this trough (Azrou and Jbel Bouchot areas, that is, the future autochthonous series during Lower Carboniferous) and an eastern part (Debdou-Mekkam zone) where some mafic flows are associated with turbiditic Devonian series. Lower Carboniferous allochthonous units (Azrou-Bou Agri, Ziar-Mrirt, and Eastern Jbilete nappes) originated in this eastern part of the Marrakech-Oujda trough. More easterly, a carbonate shelf, poorly documented, extended into the Hauts-Plateaux Zone.

Hence Eastern Morocco belonged to the northern margin of the West African shield at the beginning of the Paleozoic, but it was differentiated, as a subsiding trough, essentially since Lower Devonian. In other words, the northwestern African margin did not remain uniformly stable during the Early Paleozoic. A northeast-southwest zone of weakness, probably controlled by preexisting fracture zones in the basement, developed into the Marrakech-Oujda trough, separating the Devonian shelf into two parts: western Morocco on the one hand and Hauts-Plateaux and eastern Anti-Atlas on the other.

B. Late Devonian.—The late Devonian was a critical period in the evolution of the whole of Morocco. Rapid changes in the paleogeography, sedimentary environments, and structural evolution are interpreted to be the results of the progressive disruption of the Earlier Paleozoic shelf. In the Anti-Atlas, the disruption followed zones already faulted.

The facies distribution has been explained in eastern Anti-Atlas as the result of the disintegration of a passive continental margin, northwest of the Gondwana (Wendt, 1985). North of the Anti-Atlas, the Western Moroccan shelf underwent a comparable disruption; the Sidi-Bettache basin is coeval with the Maider basin. Nevertheless, olistostromes, proximal turbidites, and magmatic activity characterized the Sidi-Bettache basin margins in contrast to the fine clastic sediments of the Maider basin; these differences in the fault-induced facies suggest that the synsedimentary faults were more active in northern Morocco than in the Anti-Atlas.

During the Late Devonian, the broad contemporaneity of the distention in western Morocco and Anti-Atlas on the one hand with the shortening in eastern Morocco (Eovariscan phase) on the other suggests that a compressive component was active in the development of the Western and Southern Morocco basins. Several facts actually argue for a pull-apart origin for the Sidi-Bettache basin, developed in response to northeast-southwest regional compression. The general regime for the Moroccan crust should have been transtensional rather than purely tensional at that time. Therefore, Devonian Morocco cannot be portrayed as a passive margin like the present Atlantic margin off Morocco, for instance. On the contrary, it could evoke the Mesozoic setting of Morocco, when the elongated High Atlas basin acted as a wide sinistral faulted zone between the northwestern Meseta platform and the African shield.

C. Carboniferous.—The Dinantian pattern of subsident basins, folded belts, and emerged blocks was largely inherited from latest Devonian times. In northern Morocco, the Sidi-Bettache basin continued to founder, but the magmatic activity stopped during Lower Visean. In the southern prolongation of the Sidi-Bettache basin, in the Rehamna and Jbilete massifs, on the contrary, volcanism increased during the Late Visean, suggesting that local distention was more and more active toward the south. The Paleozoic block of High Atlas exposes the southern limit of these Dinantian basins; fault-induced chaotic Visean facies outline the shoreline of the basin, which was fed by uplifted zones situated to the south, at the emplacement of Anti-Atlas. The southern limit extended as far as the Skoura-Tineghir area. More easterly, the Ben Zireg region was on the contrary the northern limit of the Bechar basin, marked by chaotic facies which probably became finer southward.

In northern Morocco, the western basins (Sidi-Bettache basin and its southern prolongation) were probably connected eastward to another marine basin, individualized since Middle Visean upon the western part of the Eovariscan belt (former Devonian Marrakech-Oujda trough), and filled mostly with Upper Visean turbidites. The broad contemporaneity of this sedimentation and the beginning of the Late Visean deformation suggest these basins were syntectonic basins, principally controlled by transcurrent faults, in a transtensional regional regime. Progressively, during Namurian and Westphalian, these marine basins were reduced and closed. The Late Westphalian structures themselves were often controlled by the limits of the sedimentary basins.

2. *A Polyphased, Migrating Deformation*

Except for the Sehoul (Rabat-Tiflet) block at the northern limit of the belt, the Moroccan Hercynian belt broadly evolved in situ upon the northern margin of the African continent. Its folding occurred essentially during the 80 Ma span of time between Late Devonian and Late Carboniferous according to different schedules in its various domains.

South of the Tizi n'Test fault, the Anti-Atlas folds are ambiguously dated (Mattauer, Proust, and Tapponnier, 1972; Proust and others, 1977). If block-faulting occurred as early as Ashgillian and accelerated during Late Devonian, folding itself likely began during or after the Visean.

Within the folded belt itself (Atlas and Meseta domains) a striking element of the Hercynian evolution is the westward progression of the deformation during Late Devonian and Carboniferous. The main episodes occurred at 360 Ma (Eovariscan Phase) in easternmost Morocco, in Midelt, Debdou, et cetera, 330 Ma (Late Visean Phase) in Tazekka, Azrou, and possibly central Rehamna and Jbilete, and 290 Ma (Late Westphalian to Stephanian Phase) in central Morocco, in Oulmès et cetera. During the same time span, preliminary results (Huon, 1985) would suggest that the Sidi-Bettache basin was closed progressively by Late Visean deformation, as shown along its margins, followed by Late Westphalian deformation in the central parts of the basin. Presently available, especially radiometric, data are still too scarce to decide whether this westward progression of the main deformation progressed westward from internal to external zones as separate folding phases or as the continuous propagation of a compressional wave. Anyway, whatever the answer to this problem, it must be emphasized that a similar evolution characterizes other regions in the external zones of the European Hercynides such as the German Schiefergebirge (Ahrendt and others, 1983) and the Ardennes (Piqué, Huon, and Clauer, 1984), both characterized by centrifugal displacement of the main deformation toward the foreland. Note the Moroccan foreland relative to this folding migration is the western Coastal Block.

3. *Allochthonous or Rooted Structures?*

Various Hercynian thrusts have been described in Morocco, either resulting from Late Visean synsedimentary sliding in eastern Meseta (Huvelin, 1967; Allary and others, 1972), or from Late Carboniferous late or post-folding shear, in Western Meseta (Michard, 1969; Cailleux, 1976; Hoepffner, Jenny, and Piqué, 1975). Some workers, following Sougy (1976), advocated for a complete allochthony of the main part of the Hercynian belt, which would result in a great complexity of the tectonic domain. Our way of thinking (Piqué, 1981a) agrees that some restricted late- or post-metamorphic overthrusts do exist in western Morocco (Michard, 1969; Piqué and others, 1982, Cailleux, 1976) but argues that most of the thrusts have a restricted extent.

Yet, the relative autochthony of the outcropping Paleozoic series with respect to one another does not exclude a deep décollement of the whole, increasing from west to east during the folding event itself. Michard and others (1983) proposed that the main steep reverse faults of northern Morocco could become flat-lying and merge at deeper levels along ductile décollement planes (fig. 9). This hypothesis is compatible with the observed structures and the strain data for the western Morocco Hercynian belt. It would have to be checked with seismic reflexion profiles like those in northern France where similar deep structures are now described (Cazes and others, 1985). Such a concept of deep-seated, synfolial listric thrusts, at least partly related to the former synsedimentary structures, is entirely distinct from superficial, post-metamorphic thrusts, unrelated to the paleogeographic pattern.

4. *Regional Correlations and Plate Tectonics*

In the Paleozoic evolution of Morocco, as summarized above, many points call for a comparison with the contemporary evolution of western Africa (Mauritanides), western Europe, and the eastern Appalachians. On the basis of paleomagnetic reconstructions, these regions are generally thought to have neighbored Morocco during the Paleozoic (Van der Voo and French, 1974). Keeping in mind that such reconstructions are never precise, we would simply emphasize here some geological constraints that could contribute to an objective discussion of the problem. While the Hercynian belt of Morocco, except the Sehoul block, clearly belongs to the northern margin of the West African shield, the Mauritanide belt is described (Sougy, 1962, 1969; Villeneuve, 1982; Lécorché, 1983; Lécorché and Dallmeyer, 1987; Dia, 1987) as a Panafrican belt subsequently thrust after Middle Devonian upon the African shield. These two belts differ in at least two important characteristics: (1) their opposite vergence-to the east in the Mauritanides and to the west in most of the Moroccan Hercynides; (2) their structural position with regard to the cratonic basement—a general allochthony in the Mauritanides and a relative autochthony, not incompatible with a deep décollement and lateral displacements in the Hercynides. It is thus clear that these two belts do not extend into each other. If Western Anti-Atlas with its noticeable deformation and its eastern vergence is the northern extension of the Zemmour and thus corresponds to the foreland of the Mauritanides, one would have to admit that prolongation of the folded belt extends under the coastal plain as far north as Agadir. No indication for a northern extension of the Mauritanides in the continental margin of northern Morocco is furnished by oceanological studies; perhaps the Mauritanides belt ended at the latitude of Agadir against a transcurrent regional faulted zone.

With Europe, the similarities are often strong and recognized early on (Gentil, 1918; Lecointre, 1926). They concern western "Stable Europe" as well as the more recently displaced Paleozoic blocks of southern Europe and the western Mediterranean. Concerning these southern blocks, we have presently no indication from reliable paleomagnetic analyses of the Paleozoic location of Morocco and especially eastern Morocco relative to the Paleozoic blocks of the western Mediterranean-Inner Rif and Betic, Kabylia, Calabria and Sicilia, Corsica and Sardinia. The only possible approach, already followed by Bourrouilh and Gorsline (1979), is to compare Paleozoic and Hercynian evolution of these regions and to determine their relative disposition from their common geological features. A discussion of the whole geological evolution of each Paleozoic block is of course beyond the scope of the present paper, but a summary has been presented by Bourrouilh and others (1980) and discussed in part by Vai and Cocozza (1986) and Chalouan (1986). One could try tentatively to draw from Marrakech to Oujda and more easterly to Kabylia and Calabria (in their assumed Paleozoic location) an elongate and relatively narrow zone of weakness, the Northwestern Gondwana mobile zone. This Zone was characterized at least during Devonian and Carboniferous time by repeated deep basin sedimentation and by orogenic events, the most important being the Late Devonian Phase. It separated the African cratonic area from the Hercynian orogenic belt of central and western Morocco. In that sense, it constitutes the southern limit of the European-North African Hercynian belt.

Western Morocco corresponds in several ways to southern Iberia. Both regions were characterized by the development of comparable Late Devonian and Carboniferous basins, where a bimodal magmatism was active, contemporaneous with pyritic deposits (Bordonaro, Gaillet, and Michard, 1979). Farther to the north, the same tectonic zone reappears in northern Europe, from the French Massif Armoricain to the German Variscan Externides (Piqué, 1981b). In other words, western Morocco, with its general centifugal vergence, the development of Lower and Middle Carboniferous basins, and the production of important granitic bodies, corresponds to the Saxo-Thuringian zone of northern Europe. It swings into line with this zone along the Ibero-Armorican Arc. At its southeastern margin, this block was separated from the African continent by the above mentioned northern Gondwana mobile zone.

On the other side of the present Atlantic ocean, the Avalon zone is composed of several areas at the eastern margin of the Appalachians, from southeastern Newfoundland to Florida, that shared a comparable evolution during Late Precambrian and Early Paleozoic times (Williams, 1964), revealing a common African origin. They docked on North America (Rodgers, 1970; Williams and Hatcher, 1982) at different times during the Paleozoic. The stratigraphic and sedimentological evolution of the areas that constitute the Avalon zone is similar to the evolution of Morocco during the latest Precambrian and earliest Paleozoic time (Strong, 1979; O'Brien, Wardle, and King, 1983), suggesting that all these regions belonged at that time to the same continent (Rast and Skehan, 1983; Piqué, 1981c). These similarities vanished during the Ordovician. The importance of the alkaline magmatism from Ordovician to Devonian times, for instance in southern Massachusetts (Hepburn, Hon, and Hill, 1985), Rhode Island (Hermes and Zartman, 1985), and northern Nova Scotia (Keppie and Dostal, 1980) indicates an anorogenic, within-plate tectonic setting and suggests these regions were submitted at that time to a crustal distention during which they separated more or less completely from the African plate.

Southeast of the Avalonian part of Nova Scotia, the Meguma zone (Schenk, 1971; Keppie, 1982) is composed mainly of the Cambro-Ordovician Meguma Group, overlain by thin Silurian and Devonian strata. The Meguma Group was described as a very thick clastic sequence deposited in a deep-sea environment on a progradational continental embankment. The origin of the clastic debris, as stated by Schenk (1980), could be the West Africa shield. Now, comparable rocks crop out in northern Morocco, in the Sehoul zone. They are Cambro-Ordovician in age and interpreted as deep-sea fan deposits. Schenk (1971) was the first to emphasize the similarities between the Meguma and Sehoul zones, while Piqué (1982) compared the Sehoul zone with the Paleozoic blocks of Western Mediterranean. On the other hand, geophysical data suggest that rocks similar to those of the Meguma Group underlie the Tail of the Grand Banks of Newfoundland and the South-Portuguese Zone (Lefort, 1983).

It is thus likely that during Cambrian and Ordovician times, the blocks constituting the Avalon zone began to separate from Africa. At that time, the Meguma and the Sehoul zones, and possibly the South-Portuguese zone, outlined the same tectonic setting: a continental embankment around northwestern Africa. The deformation of this rifted margin occurred at different times, latest Ordovician-Silurian in the Sehoul zone, Silurian-earliest Devonian in the Meguma zone. Later on, the opening of the Upper Devonian-Lower Carboniferous subsiding basins in Maritime Canada and their deformation during Westphalian occurred contemporaneously with the similar evolution described above in Morocco. In New England, too, the Alleghanian movements were restricted to the southeastern part of Avalon (the Narragansett basin: Skehan and Rast, 1983; Hepburn, Hon, and Hill, 1985), but deformation was at the Carboniferous-Permian limit, slightly later than in Morocco. This Late Carboniferous deformation of the eastern Appalachians is related, with the Hercynian orogeny in Morocco, to the last stages of the North America-West Africa collision, which also affected farther to the south of the southern Appalachians (Secor and others, 1986) and the Mauritanides (Lécorché and Dallmeyer, 1987).

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APPENDIX 1

The Hercynian granitoids. Petrographic types from Rosé (1987); isotopic datings and Rb/Sr initial ratios from Mrini (ms), referred as M, and Tisserand (ms), referred as T. for location, see figures 3 and 8

Location	Petrographic Type	Origin	Rb/Sr	Age (Ma)	Reference
Central Massif					
Zaër	Calcalkaline granite	Mixed	(0.705)	303 ± 13	M
	Leuogranite	Crustal	(0.709)	279 ± 11	M
Oulmès	Leucogranite	Crustal		271 ± 7	T
	Leucogranite	Crustal	(0.717)	262 ± 4	M
Ment	Calcalkaline granite	Mixed	(0.705)	279 ± 6	M
	Leucogranite	Crustal	(0.715)	270 ± 3	M
Rehamna					
Western batholith (Sebt)	Monzogranite	Mixed	(0.705)	266 ± 3	M
		Crustal	(0.710)	264 ± 4	M
Eastern apex	Leucogranite	Crustal	(0.706)	275 ± 7	T
Jebilet					
Central batholith (Bramram, Bamega-Tabouchant)	Granodiorite	Mixed		344 ± 20	M
	Granodiorite	Crustal	(0.708)	332 ± 5	M
	Leucogranite	Crustal	(0.712)	306 ± 17	M
Eastern batholith	Calcalkaline granite	Mixed		319 ± 10	T
Western High Atlas					
Jebel Tichka	Granodiorite	Mantle	(0.700)	312 ± 3	T
	Granodiorite	Mixed	(0.707)	319 ± 9	T
Azegour	Monzogranite	Mixed	(0.705)	271 ± 3	M
Eastern Meseta belt					
Western Midelt batholith (Bou Mia)	Monzogranite	Crustal	(0.715)	315	T
	Leucogranite	Crustal	(0.708)	290 ± 3	T
Eastern Midelt batholith (Aouli, Mibladen)	Granodiorite	Mixed	(0.705)	336 ± 17	T
	Calcalkaline granite	Crustal	(0.710)	309 ± 5	T
	Monzogranite	Mixed	(0.705)	294 ± 5	T
	Leucogranite	Crustal	(0.720)	271 ± 3	T
Debdou-Mekam	Monzogranite	Mixed	(0.705)	284 ± 7	T
Terni-Mazgout	Leucogranite	Crustal	(0.720)	266 ± 9	T

Appendix 2

Isotopic data of metamorphic rocks. The age of the metamorphic event is determined by the age of the newly formed minerals. For weakly metamorphosed rocks it is necessary to analyze fine fractions in order to avoid the influence of old detrital minerals where the isotopic rehomogenization is not complete (Huon, 1985). Consequently, the size of the representative fractions increases when the metamorphic grade increases.

	Localities	Metamorphic Grade	Analysed Size Fractions (μm)	Age (Ma)
1	Oued Yquem	very low-grade	0.4–0.8	320.7 ± 7.3
2	Oued Korifla	very low-grade	<0.5	345 ± 7.4
3	Tiddass	diagenetic zone	<0.2	345.3 ± 7.5
4	Fourhal	very low-grade	<0.5	289.3 ± 6.3
5	Oulmes	low-grade	1–2	294.7 ± 6.7
6	Tazekka (Ordovician slates)	low-grade	1–2	329.3 ± 7.1
6	Tazekka (Visean pelites)	diagenetic zone	<0.2	300.2 ± 6.7
7	Azrou (Ordovician slates)	low-grade	0.6–2	333.6 ± 7.8
7	Azrou (Visean slates)	very low-grade	<0.5	330.1 ± 5.9
8	Debdou	very low-grade	<0.4	372.3 ± 8.1
9	Mekkam	low-grade	<2	368.3 ± 7.9
10	Midelt	low-grade	<2	366 ± 7

Samples 1 to 9: K/Ar method (Huon, 1985); 10: Rb/Sr method (Tisserant, 1977; Clauer and others, 1980). For location, see figures 3 and 8.

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