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Southern Uralides and Variscides: comparison of their anatomies and evolutions

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Abstract

The Uralides and the Variscides are two Palaeozoic orogenic belts located on the eastern and south-western borders of the East-European Precambrian craton (Russo-Baltica), respectively. Both belts have common characteristics (nappe tectonics, opposite vergences on both sides) and have been formed within roughly the same time-span (500–270 Ma for the Variscides, 500–230 Ma for the Uralides). Nevertheless they exhibit striking differences in shape, preservation of ophiolites and island arcs, grade and type of metamorphism, and erosion level, which reflect different accretionary histories. The Variscides were formed by collision of large continental blocks involving major continental stacking and thickening, which resulted in strong heat production and related high-temperature metamorphism, crustal melting and late-orogenic denudation. The Uralides were formed by accretion of island arcs and micro-continents against a large East-European continent, associated with much lower heat production, low-temperature, high-pressure metamorphism, restricted crustal melting and minor erosion.

Introduction

The Uralides and Variscides are two large Palaeozoic mountain belts bordering the East-European Precambrian craton to the east and to the south-west (Fig. 1). They developed roughly during the same time span (500–270 Ma for the Variscides, 500–230 Ma for the Uralides) by closing of Palaeozoic oceans by subduction, collision of island arcs and continental blocks of different size, crustal stacking, thickening, relief generation and peneplanation.

The Variscan belt of south-western Europe, 3000 km long, 700–800 km wide, extends from southern Iberia to north-eastern Bohemia (Poland, Czechia, Slovakia). It is part of a much larger belt including the Appalachians, the Mauritanides and the Variscan belt of northern Africa. This large Palaeozoic belt results from a complex collision between large continents (Laurentia, Baltica, Africa) and also smaller ones in between (Avalon, Armorica) of African affinities. In south-western Europe, the Variscan belt has been strongly reworked and disrupted by Mesozoic and Cenozoic basin formation, oceanization and mountain building. The plate-tectonic history may be inferred from the study of some stable pre-Triassic massifs (Iberia, Corsica-Sardinia, French Massif Central, Armorican Massif, Ardennes, Rhenian and Bohemian Massifs). Further information, more difficult to interpret, is available from the Variscan massifs inside the Pyrenean, Alpine and Betic belts of Alpine age and from deep seismic surveys from the Paris, Aquitaine and Ebro basins. Restoration of the pre-Mesozoic Variscan puzzle and the relative position of the continents in Triassic time is still hypothetical (Fig. 2).

The Urals are an elongated N-S trending belt (3500 km, including the Nova Zemlya virgation), that extends southwards to the Aral Sea and probably continues toward the E-W trending Tien-Shan Palaeozoic belt. Its apparent narrowness (100–150 km) in the polar and cispolar parts is mainly due to the Siberian Meso-Cenozoic post-tectonic cover. In its southern broadest outcropping part, the width of the Urals is close to 500 km.

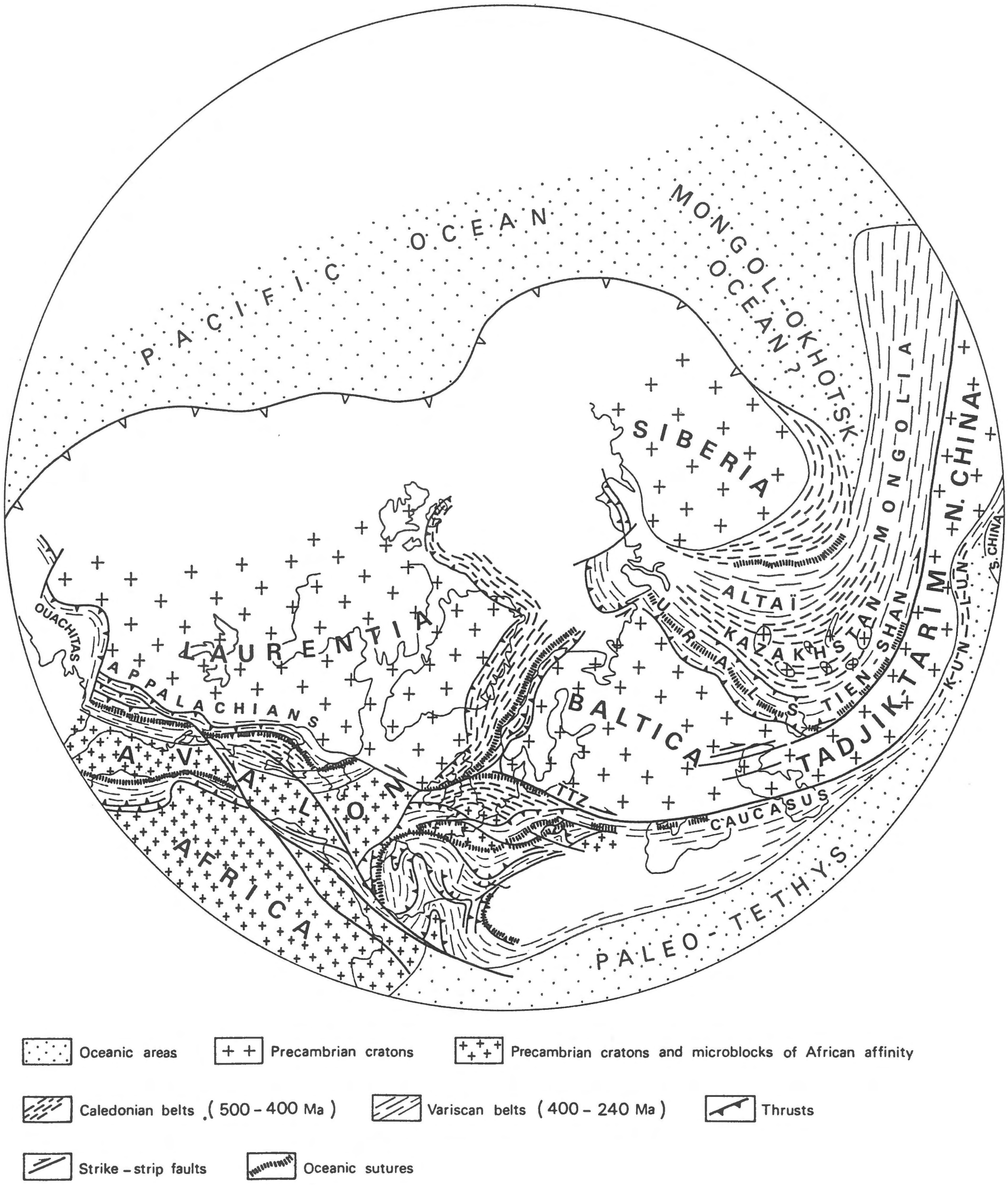

Fig. 1. Triassic reconstruction of the northern hemisphere showing main Palaeozoic belts (after J.L. Olivet, unpublished).

Unlike the Variscan belt the Urals have not been deformed since the Triassic except for very recent (Quaternary) uplift. They are also generally less eroded and oceanic crust and volcanic arcs are very well preserved, only slightly affected by metamorphism. Thus, the Urals are a key area to understand Palaeozoic plate tectonics.

The Urals result from eastward subduction of the East-European Palaeozoic passive margin below oceanic and island-arc crust and mantle followed by collage and collision of other island arcs and microcontinents coming from the east.

On a larger scale it appears that the Urals are part of a much larger complex Palaeozoic belt which includes the Tien-Shan, the Kazakhstan, the Altaï and the Mon-

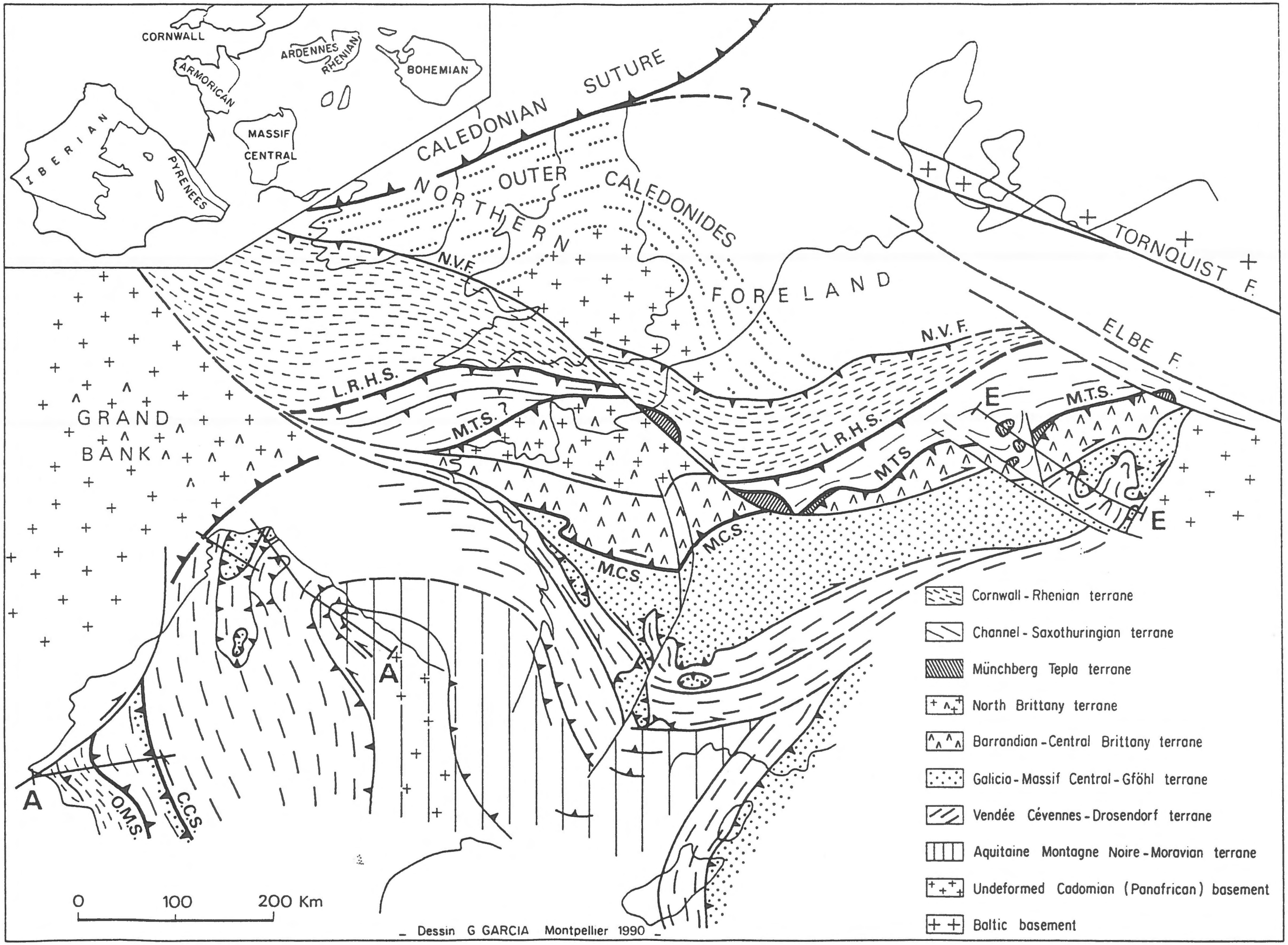

Fig. 2. Structural sketch map of the European Variscides with the trace of the Iberian section A (Fig. 3). CCS = Coimbra-Cordoba suture, OMS = Ossa Morena suture, MCS = Massif Central suture, MTS = Münchberg-Tepla suture, LRHS = Lizard-Rheno Hercynian suture, NVF = North Variscan Front.

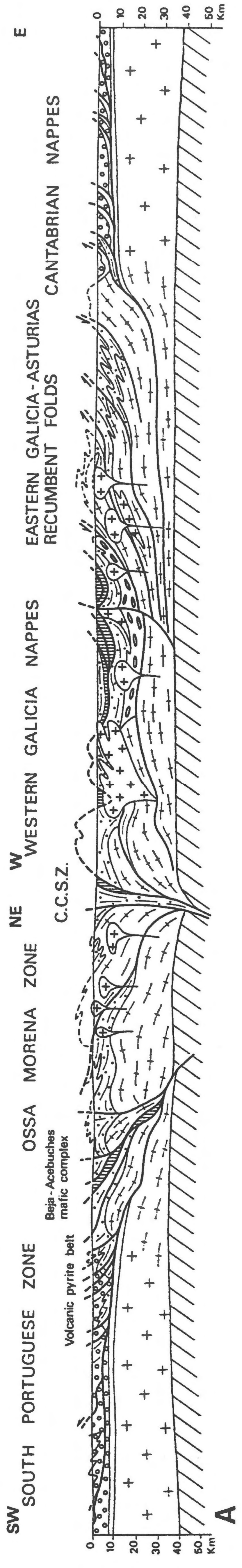

Fig. 3. Section through the Iberian Variscides. For location see Fig. 2. CCSZ= Coimbra-Cordoba Shear Zone.

golian belts that were formed between the East European and the Siberian (Angara) cratons around 550 to 230 Ma (Fig. 1).

Anatomies of the belts

The anatomies and the accretionary histories of the Variscides and Uralides have been studied in outcrops and also from deep seismic surveys (refraction and reflection) and are presented on the basis of the two most complete sections available: the Iberian section (700 km) through the Variscides, and the southern Urals section (500 km) through the Uralides.

In both sections deep seismic refraction and wide-angle reflection profiles show the Moho boundary (30–35 km for the Variscides, 45–55 km for the Uralides) relatively clearly, but the general absence of deep vertical reflection profiles (except 100 km in northern Spain) hampers the extrapolation of outcrop observations into the sub-surface.

The Iberian section

The Iberian section has been described in detail by Matte (1991; Fig. 3). It convincingly shows the two-sided fan-like shape of the Variscan belt involving two external foredeep basins characterized by fold, thrust and décollement tectonics with opposite vergences and outwards migration of the deformation from the oceanic sutures in space and time. The main differences between the northern and southern parts of the section are due to the arcuate shape of the Variscan arc.

On the northern concave side, nappes were displaced toward the centre of the arc during its progressive tightening, giving complex room problems (Perez Estaun et al. 1989). On the southern convex side, movements resulted in a combination of nappe displacement toward the south and south-west and sinistral strike-slip faulting (Crespo-Blanc & Orozco 1988).

The northern part of the Iberian section, from the Cantabrian nappes to the ophiolitic nappes of western Galicia, is a key area to understand the accretionary history of the Variscan belt as it is one of the rare places where oceanic crust and mantle are preserved as large allochthonous slabs (north Portuguese and north-western Iberian massifs). The arrangement of the different units in the nappe pile suggests a pre-collisional plate-tectonic setting as proposed in Fig. 4. Westward oceanic subduction resulted in obduction of oceanic crust and mantle onto the thinned Upper Ordovician-

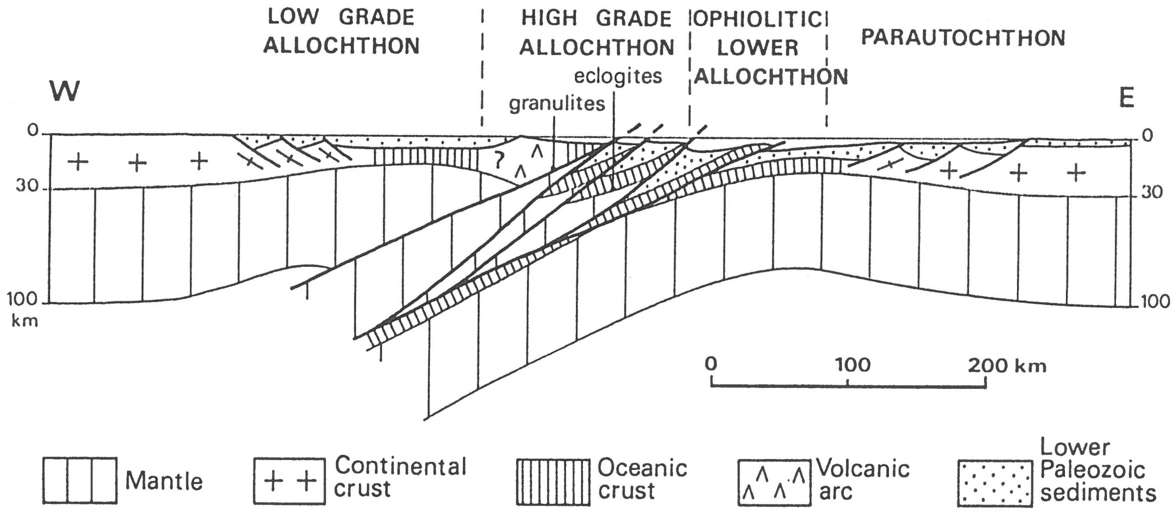

Fig. 4. Possible pre-collisional plate-tectonic setting of the western Iberian – North Portuguese ophiolitic allochthonous complexes.

Silurian continental margin which suffered from HP-LT metamorphism at about 390–420 Ma (Schäfer et al. 1993, Dallmeyer et al. 1991).

The pre-Palaeozoic basement of this passive margin is built of thick turbiditic sediments that were folded but not strongly metamorphosed before the Cambrian and of some massifs of panafrican granitoids, dated around 600 Ma, that are covered by acid volcanoclastics.

The root of the allochthonous oceanic slabs, i.e. the Palaeozoic oceanic suture, lies west of the Galician coast and can be observed within the NW-SE trending Coïmbra-Cordoba shear-zone (CCSZ) in which slivers of mafic eclogites occur.

After suturing, the margin was progressively folded and thrust between 380 and 290 Ma involving a minimum shortening of about 250 km (Perez Estaun et al. 1991).

A comparable scenario probably applies to the southern Iberian area (Sierra Morena) although the widespread obduction of oceanic crust that characterizes the northern part is missing here. Closure of an oceanic basin by eastward subduction below an Andean type margin probably occurred in Middle Devonian times. The Acebuches amphibolite complex of oceanic affinity (Bard & Moine 1979) situated between the Sierra Morena and the South Portuguese zone could represent the remains of an oceanic suture.

The southern Urals section

The Southern Urals, which constitute the widest part of the belt, are relatively well exposed between the Bashkirian and Kazakhstan plains with heights varying between 600 and 1500 m (Fig. 5). Deformation has affected rocks from Precambrian to Triassic age. The belt has been eroded before the Jurassic and covered by unconformable horizontal continental deposits. The structural trend of folds and thrusts is roughly N-S, turning to NE-SW to the north in the central virgation of the Urals. Though the most conspicuous structures are west-vergent nappes and thrusts, the belt is bivergent: east of the so-called Magnitogorsk synform, folds and thrusts face east. All the large structures (antiforms, synforms, main faults) are relatively cylindrical and may be followed along strike over hundreds of kilometres, with a slight axial plunge of the folds to the south.

A section from Sterlitamak to Kartali (Fig. 6) cuts the following structural units from west to east:

The Uralian foredeep in which thick Upper Carboniferous to Triassic shallow-marine sediments (mainly carbonates) reaching 5–6 km in thickness have been deposited in transverse basins oblique to the general N-S trend of the structures. Parts of the Upper Carboniferous and Permian deposits exhibit molassic facies derived from the Urals mountains farther to the east.

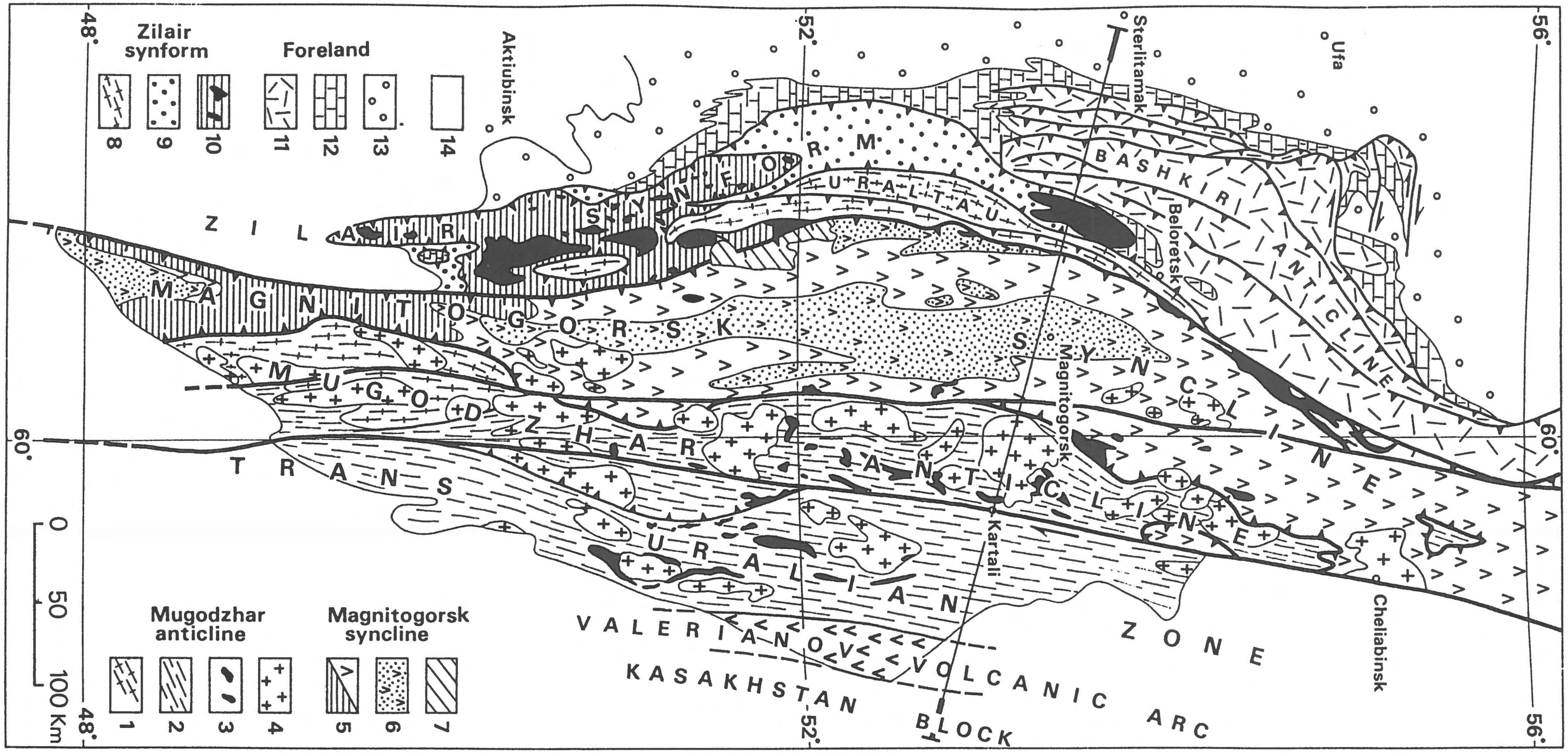

Fig. 5. Tectonic sketch map of the southern Urals (with location of the cross-section Fig. 6.): 1) Precambrian basement, 2) Lower-Middle Palaeozoic shelf-sediments, 3) Ultra-mafic rocks, 4) Granitoids, 5) Oceanic and arc crust, 6) Volcano-clastics (Devono-Carboniferous), 7) Unconformable continental Jurassic, 8) Gneisses of the Uraltau dome with HP metamorphism, 9) Zilair flysch (Upper Devonian), 10) Oceanic crust and mantle, 11) Proterozoic (mainly Riphean) sediments, 12) Shallow-marine sediments of the East-European margin (Ordovician to Lower Carboniferous), 13) Upper Carboniferous and Permian carbonates and molasses of the Uralian foredeep, 14) Cretaceous to Quaternary post-Uralian cover.

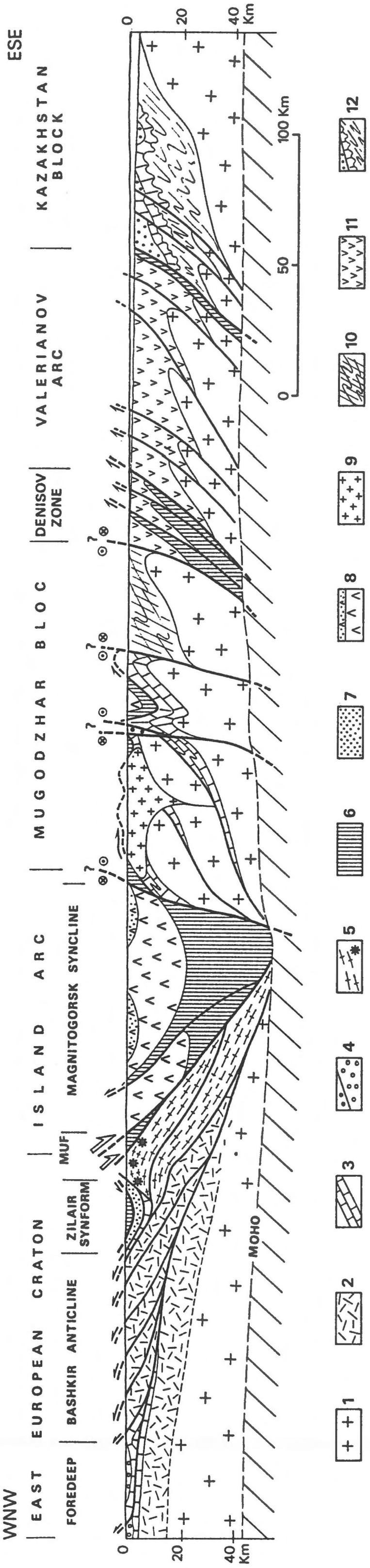

Fig. 6. Schematic section through the southern Urals. 1) Precambrian basement, 2) Riphean sediments, 3) Shallow-marine Lower-Middle-Palaeozoic sediments, 4) Permo-Triassic, 5) Uraltau gneisses with HP metamorphism (*), 6) Oceanic lithosphere, 7) Zilair flysch (Upper Devonian-Lower Carboniferous), 8) Magnitogorsk volcanic island arc, 9) Granites, 10) Pelitic Lower Palaeozoic, 11) Valerianov volcanic arc, 12) Devono-Carboniferous shallow-marine sediments unconformable on the Caledonian Kazakhstan fold belt. MUF= Main Uralian Fault.

The foredeep is rich in oil and gas that are mainly trapped in the Devonian to Permian carbonates but also in terrigenous sediments (Puchkov 1993). This area is characterized by thin-skinned deformation involving various décollement levels (Kazantseva & Kamaletdinov 1986).

The Bashkir anticlinorium is an anticlinal thrust stack essentially built of thick (12 km) Riphean (Upper Proterozoic) shallow marine sediments (carbonates, shales and sandstones). Underlying crystalline rocks crop out in some anticlines more to the north but the relationships between this metamorphic basement and the low-grade Riphean sediments are unclear. The anticlinal stack is composed of several thrust sheets with some Lower Palaeozoic sediments squeezed in between. The less competent rocks locally show a prominent eastward dipping cleavage.

The Zilair synform comprises a thick sedimentary sequence with from bottom to top:

a. shallow marine parautochthonous deposits (carbonates and clastics) of Ordovician to Devonian age, and
b. the 5000 m-thick Zilair flysch (Upper Devonian to Lower Carboniferous), probably largely allochthonous.

This sequence is overlain by the Kraka klippe essentially composed of oceanic mantle rocks resting on a serpentinite base.

The Zilair synform is characterized by a fanning of the slaty cleavage, a down-dip stretching lineation, and opposite vergence of folds on both sides. A westward dipping back-thrust separates the Zilair synform from the Uraltau antiform to the east.

The Uraltau antiform is a narrow and elongated N-S trending gneiss dome with a flat-lying foliation and transverse stretching lineations. Rocks differ from those of the Bashkir anticlinorium. The Uraltau antiform is composed of two gneissic units.

Near Bieloretsk (Fig. 5), gneisses and micaschists are unconformably overlain by low-grade Ordovician conglomerates. The micaschists yield a plateau age on muscovite of 550 Ma (Matte et al. 1993). The significance of this metamorphism, known as the pre-Uralides event (Zonenshain et al. 1984), is still unclear.

Further to the south, high-pressure metamorphic rocks (blue schists and eclogites) are well exposed all along the Sakmara river. The relationships between these two units are unclear, but it is likely that the HP unit has been thrust over the pre-Ordovician gneisses. This HP metamorphic event has been dated by

$^{39}Ar/^{40}Ar$ at about 380 Ma (Matte et al. 1993). The quartzites of the HP complex show a well-developed E-W linear texture and a strong fabric related to westward ductile shearing. The Uraltau antiform is interpreted as an anticlinal stack folding the main basal thrust of the oceanic klippe.

The Main Uralian Fault (MUF) separates the high-grade rocks of the Uraltau zone to the west from the anchizonal volcano-clastics and volcanics of the Magnitogorsk syncline to the east. Hardly visible in the field, this fault is marked by shreds of peridotites and serpentinites indicating eastward directed shear. The low-angle eastward dip of this major fault is documented further to the north in the Middle Urals by a seismic reflection profile (Zonenshain et al. 1991). The MUF is a main suture zone and the root of the oceanic klippes situated to the west. This suture has been reactivated as a major normal fault which assisted to the unroofing of the HP metamorphic rocks of the Uraltau antiform.

The Magnitogorsk syncline is a large structure (100 x 900 km) with a flat relief (average height 400–600 m) composed of volcanic and volcano-sedimentary rocks (Koroteev et al. 1993). This syncline is built from bottom to top of:

a. an ophiolitic crust (sheeted dyke complex and oceanic basalts). An excellent section of these oceanic rocks crops out at the southern extremity of the Urals (Schuldak complex).This sequence could represent the equivalent of the oceanic crust which is lacking in the western oceanic klippes which are essentially composed of harzburgites and lherzolites,

b. an island-arc complex (mainly andesites),

c. an overlying sedimentary and volcano-sedimentary sequence preserved in the axis of the synform (tuffs, turbidites, limestones interbedded with trachytes and rhyolites).

Only the upper part of the volcanic succession is present in the mentioned section (andesites and overlying sediments). The lower oceanic part (gabbros, sheeted dyke complex, basalts) is preserved along-strike in the southernmost extremity of the Urals (see Zonenshain et al. 1984 for a detailed description). The age of this succession is Early-Middle Devonian for the sheeted dyke complex and the tholeiitic basalts (Shuldak complex), Middle-Late Devonian for the island arc, and Late Devonian-Early Carboniferous for the overlying sediments.

The most striking tectonic feature of the Magnitogorsk synform is the very mild deformation (only locally a spaced vertical fracture cleavage has been observed). Over large areas, beds are subhorizontal and do not show any trace of either internal deformation or metamorphism.

The East-Uralian-Mugodzhar antiform. The northern part of this area is made of autochthonous shelf sediments (mainly carbonates) that were deposited between the Ordovician and the Early Carboniferous. They are overlain by Devonian allochthonous rocks of oceanic affinity (serpentinites and island arcs volcanics). The root of this slab is probably situated at the boundary with the Magnitogorsk synform, thus implying displacements towards the east. The thrust separating allochthonous from autochthonous rocks is folded by upright F_2 kilometre-scale N-S trending folds, but also in this case the internal deformation is only minor (no cleavage related to F_1 or F_2).

One striking characteristic of this antiformal area is the presence of granitoids which are mainly of oceanic origin (plagiogranites) or related to subduction (calk-alkaline). HT-LP metamorphism has locally been observed to surround them.

The southern part of the area (Mugodzhar) consists basically of a pre-Palaeozoic basement. Ages as old as 2100–2500 Ma are reported for gneisses (Zonenshain et al. 1984). For this reason the East-Uralian-Mugodzhar anticline has been considered by most of the authors to be part of a continental block in contrast to the oceanic nature of the Magnitogorsk syncline.

The Cheliabinsk-Kartali fault is a 500 km-long, straight feature that separates the East-Uralian from the Trans-Uralian zones. Elongated narrow basins containing continental Triassic sediments occur along the fault trace. Offset on this major fault probably took place in Late Uralian times in a lateral (possibly dextral) sense. It was rejuvenated during the Quaternary as evidenced by morphologic control on recent lakes.

The Trans-Uralian zone is largely covered by Mesozoic sediments and most of the rocks are only known from wells. Its western part consists of a long (500 km) volcanic belt, the Valerianov belt, made of calc-alkaline volcanics (dacites, andesites, basalts) intruded by diorites. The ages of the volcanics range from Late Visean to Late Carboniferous. The Valerianov belt is considered to be an Andean type margin (Zonenshain et al. 1991). The eastern part of the Trans-Uralian zone is mainly composed of shallow-marine sediments (limestones, sandstones and siltstones) of Late Devonian and Carboniferous age. These sediments unconformably overlie further to the east in

Kazakhstan older rocks which experienced an early Caledonian deformation and metamorphism.

Similarities and differences

The main characteristics of the Urals and Variscides are summarized in Table 1. The two belts show some similarities as well as some striking differences.

Similarities

- The two belts look similar in section with a fan-like arrangement of the thrusts which are roughly of the same size (Figs 3, 6).
- The western part of the Uralian section and the north-eastern part of the Iberian section particularly show common characteristics:
  a. thick sedimentary pre-Palaeozoic sequence is involved in the thrusting,
  b. the underlying high-grade Precambrian basement does not outcrop,
  c. the Lower-Middle Palaeozoic sediments show a comparable evolution from shelf deposits in the external zone to increasingly deeper sediments towards the internal zones.
- Both belts exhibit foredeep basins filled with flysch-like to molassic deposits (Lower-Middle Carboniferous for the Variscides, Upper Carboniferous-Permian for the Uralides).
- Ophiolitic nappes are present in both belts as the uppermost unit of the nappe pile.
- Both belts show an early stage of high-pressure metamorphism which occurs in the oceanic rocks and in the underlying thinned continental margin.

Differences

The main differences are :

- *Shape.* The Uralides are a 3500 km-long linear belt, with only two slight virgations in the Middle and Cispolar Urals. The Variscan belt is characterized by its pronounced arcuate shape, the so-called Ibero-Armorican arc.
- *Strike-slip faults.* In the Variscan belt the main strike-slip faults show opposite movements on both sides of the Ibero-Armorican arc, like in the western Himalayan virgation (Matte 1986). In the Urals the strike-slip faults are very long and straight. Large horizontal movements along the belt may have occurred by oblique convergence and subduction rather than by intra-continental impingement of an indenter as in the Variscides or the Himalayas.
- *Calc-alkaline volcanism.* In the southern Urals two well-preserved main volcanic arcs were built in Silurian-Devonian and Carboniferous times, which is a main difference with the European Variscides where there is no well-characterized calc-alkaline volcanism related to oceanic subduction. This could be due either to the deep level of erosion or more likely to the small size of the Galicia-Massif Central ocean which was probably consumed quickly by a short-lived oceanic subduction.
- *Type and grade of metamorphism.* The European Variscan belt is characterized everywhere by a medium to high-grade metamorphism including granulite facies, developed not only in the ophiolitic nappes (HP granulites) but also in the autochthonous lower crust (MP to LP granulites; Pin & Vielzeuf 1983). An early high-pressure event (430–400 Ma) is present in the internal allochthonous units including ophiolites and rocks of the continental passive margins thinned during the Silurian. This early event is generally overprinted by medium-pressure (380–350 Ma), and finally low-pressure metamorphism (320–300 Ma). The latter is a peculiar 'hercynotype' characteristic of the Variscides (Zwart 1967). It is mainly found in gneiss domes outcropping in relatively external parts of the Variscan belt such as the southernmost Massif Central (Den Tex 1975), or the central Pyrenees (Zwart 1963).
  The Uralian belt is characterized by an LT-HP to UHP metamorphism (Dobretsov 1991). High-pressure metamorphic rocks crop out along the entire belt (2000 km) and follow the main western suture zone which is the root of the largest oceanic klippes (Puchkov 1989). In the Southern Urals this LT-HP metamorphism has been dated around 380 Ma (Matte et al. 1993). It was not followed by an HT-LP event like in the Variscides and has been fossilized due to very fast uplift.
- *Granitoids.* In the Variscides, the direct consequence of the HT metamorphism was the production of numerous granites between 360 and 300 Ma (Lagarde et al. 1993), essentially resulting from the melting of the continental crust, including sediments. Most of these granites are concentrated in the thickened continental crust below the Galicia-Massif Central oceanic nappes. They have an external position to the east and to the south of the

Table 1. Characteristics of Uralides and Variscides compared.

	VARISCIDES	URALIDES
Shape **Length** **Width**	Sinuous 2,000 km (Western Europe) 600 - 800 km	Linear 3,500 km max 500 km
Ophiolites	Badly preserved Age: 500 Ma (southern suture), 370 Ma (northern suture)	Widespread and well preserved Age: 450 - 400 Ma
Volcanic arcs	Not well defined	Well developed: 450 - 380 Ma (Magnitogorsk island-arc), 350 - 290 Ma (Valerianov arc)
Nappes,thrusts **Strike-slip faults**	Well developed, 380 - 300 Ma Well developed, 340 - 290 Ma	Well developed, 300 - 250 Ma Highly probable
HP metamorphism	HP-HT (eclogites) well developed, 420 - 400 Ma. HP-LT (blueschists) scarce	HP-LT well developed, with eclogites and blueschists, around 380 Ma
HT, MP or LP metamorphism	Very well developed, accompanying or outlasting deformation (370 - 300 Ma). Extensive development of HP granulites in the ophiolitic nappes (380 Ma), and of MP to LP granulites at depth in the autochthonous lower crust (310 - 290 Ma)	Local development around granitic intrusions in the Mugodzhar zone
Granites	Very abundant, mostly in the thickened continental crust below ophiolitic nappes. Mostly of crustal origin resulting from the wet melting of the middle crust (360 - 300 Ma), or dry melting of the lower crust (320 - 280 Ma)	Present in the internal parts, east of main suture (360 - 260 Ma). Mostly related to oceanic crust (plagiogranites), or to arc building (calc-alkaline)
Tectonic denudation	Very important, due to large décollements on normal low-angle faults; fast uplift	Very weak except in the Uraltau zone, west of the Main Uralian Fault
Present-day heat flow	Very high : 60 - 70 mWm^{-2}, due to abundance of crustal granites	Very low: 20-30 mWm^{-2}, mainly in the central part built of mafic and ultramafic rocks
Mechanisms of mountain building	Collision of large continents with important and long-lasting thickening of continental crust and melting of wet and thick sediments, deposited on a previously thinned continental margin	Subduction of a dry and cold lithosphere with thick sediments or crystalline basement below oceanic and arc crust. Weak collision of small continental blocks and volcanic arcs with the East-European continent

suture trace. So far a relationship between granite production and oceanic subduction could not be established in the Variscides.

In the Uralides the granitoids have a different setting. They have an internal position relative to the Main Uralian suture, and most of them are located to the east of the Magnitogorsk volcanic arc. They seem to be related to either oceanic crust (plagiogranites) or to oceanic subduction. S-type (sediment-derived) crustal granites and particularly two-mica granites, characteristic of the Variscan and Himalayan belts, are lacking here, and there are no granites emplaced in the continental crust below the oceanic nappes on the western side of the Urals.

– *Level of erosion.* At present the Variscides are characterized by a deep level of erosion. Some intramontane basins of Late Carboniferous age unconformably cover mesozonal rocks (sometimes down to the sillimanite isograd in the most internal zones). Very high-grade rocks (HP granulites) crop out close to Permo-Triassic basins. Consequently in the ophiolitic nappes the upper part of the oceanic crust (basalts and sediments) is rarely preserved. Tectonic denudation by large-scale, normal, low-angle faulting during continental stacking (Perez-Estaun et al. 1991) and later (Malavieille et al. 1990) helped to unroof the deeper levels of the crust.

The Uralides are much less eroded and consequently exhibit excellently preserved oceanic crust and mantle as well as volcanic arcs. Except for the narrow HP belt following the major suture, most of the rocks are epizonal or even anchizonal throughout the belt.

– *Depth of the Moho.* The Moho discontinuity can be well defined in the Variscides by reflection and refraction seismic methods (Meissner et al. 1991). Except for areas below the major Meso-Cenozoic basins where the crust is thinner and the Tertiary mountain belts where it is thicker, this surface is very flat and the average thickness of the crust in the Variscides is between 30 and 35 km.

It is well known that the Urals have a root. From refraction profiles and gravity surveys (Rybalka et al. 1993) it appears that the thickness of the crust varies from 40 km in the East European platform west of the Urals down to 55 km below its central mafic part (Magnitogorsk syncline). This deepening of the Moho towards the central part of the belt has been also confirmed by a recent wide-angle reflection survey in the Middle Urals (Thouvenot et al. 1993). Nevertheless this peculiar characteristic is possibly unrelated to the Uralian evolution, but due to later deformation (of Tertiary up to recent age). Continental deposits of Jurassic age unconformably overlie the Uralian structures. The pre-Jurassic peneplain is incised by river canyons (like the Sakmara) indicating neotectonic uplift.

Discussion

The western side of the Southern Uralides (Fig. 7) and the south-eastern side of the Variscides (Fig. 8; eastern part of the Iberian section and French Massif Central; Matte 1991) show a comparable evolution resulting from oceanic subduction followed by obduction of oceanic crust onto a continental passive margin. The main differences are:

– The existence in the Southern Urals of a well-characterized mature island arc which is lacking in the Iberian Variscides. This could be due to differences in the size of the respective consumed oceans and consequently to a different duration of the oceanic subduction.

– A more important and long-lasting crustal stacking below the ophiolitic nappes in the south-eastern Variscides (Fig. 8).

– A much stronger heat production and crustal melting in the south-eastern Variscides. This is due to the overthickening of a previously strongly thinned margin on which were deposited thick and wet Palaeozoic sediments. During thermal relaxation abundant crustal granites were extracted from the middle and lower continental crust (350–300 Ma). This thick and hot crust collapsed during Late Carboniferous to Permian times with an important tectonic denudation.

Conclusion

The *Uralides* and *Variscides* have been built as a consequence of a Palaeozoic cycle of convergence, including oceanic subduction, continental subduction, continental stacking, orogeny, erosion and peneplanation like most other Phanerozoic mountain belts.

Shortening normal to the belt continued in the Urals until the Late Permian-Early Triassic, like in the southern Appalachians. This is somewhat later than in the Variscides where the same period is dominated by brit-

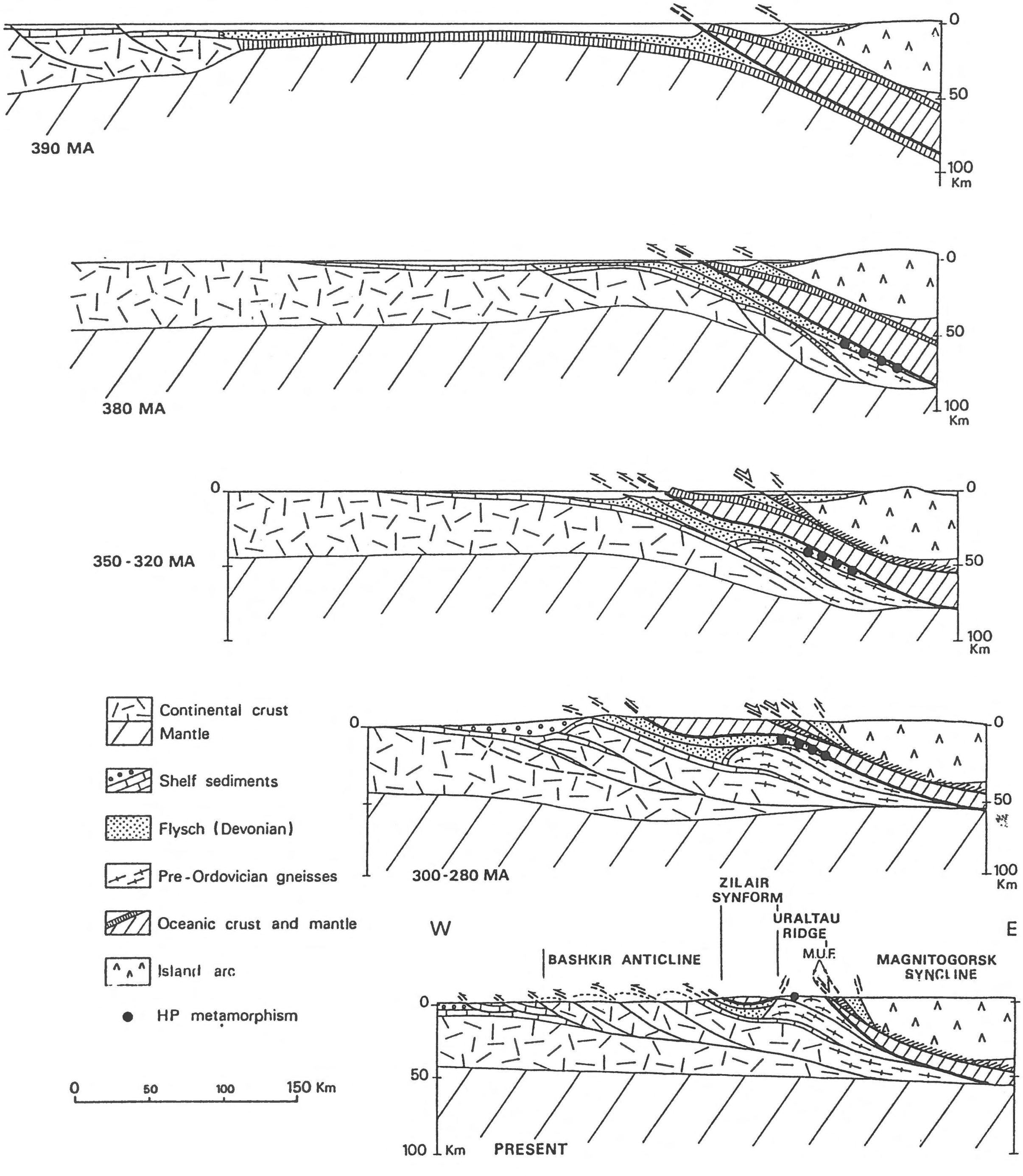

Fig. 7. Tectonic evolution of the western part of the Southern Urals showing the possible mechanism of unroofing of the HP metamorphic terrain.

tle tectonics including large-scale strike-slip faulting (Arthaud and Matte 1977).

The main differences between Urals and Variscides are probably due to the respective sizes of the colliding continents (Fig. 1):

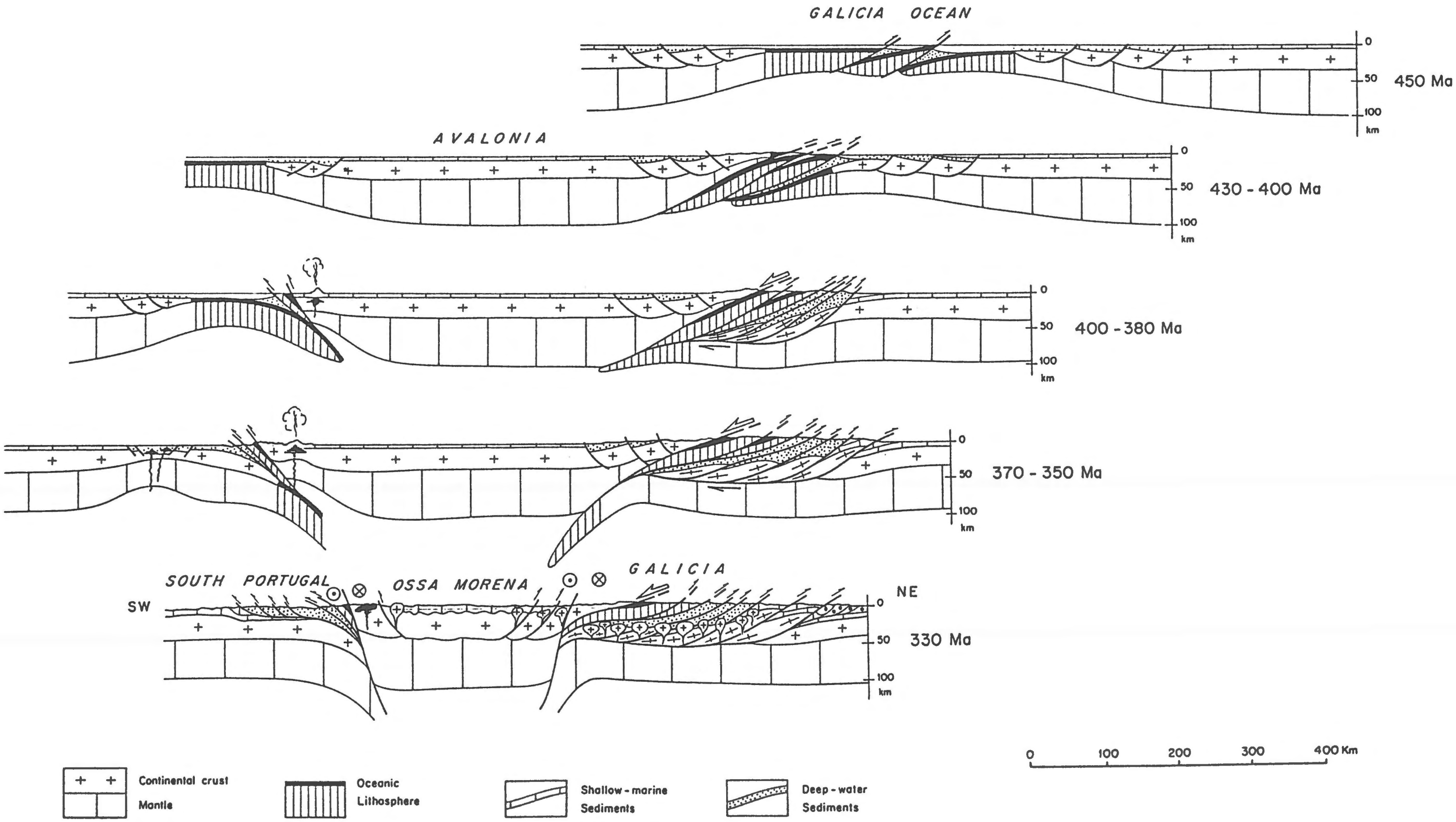

Fig. 8 Schematic cartoon showing the possible Palaeozoic convergent history of the Iberian Variscides.

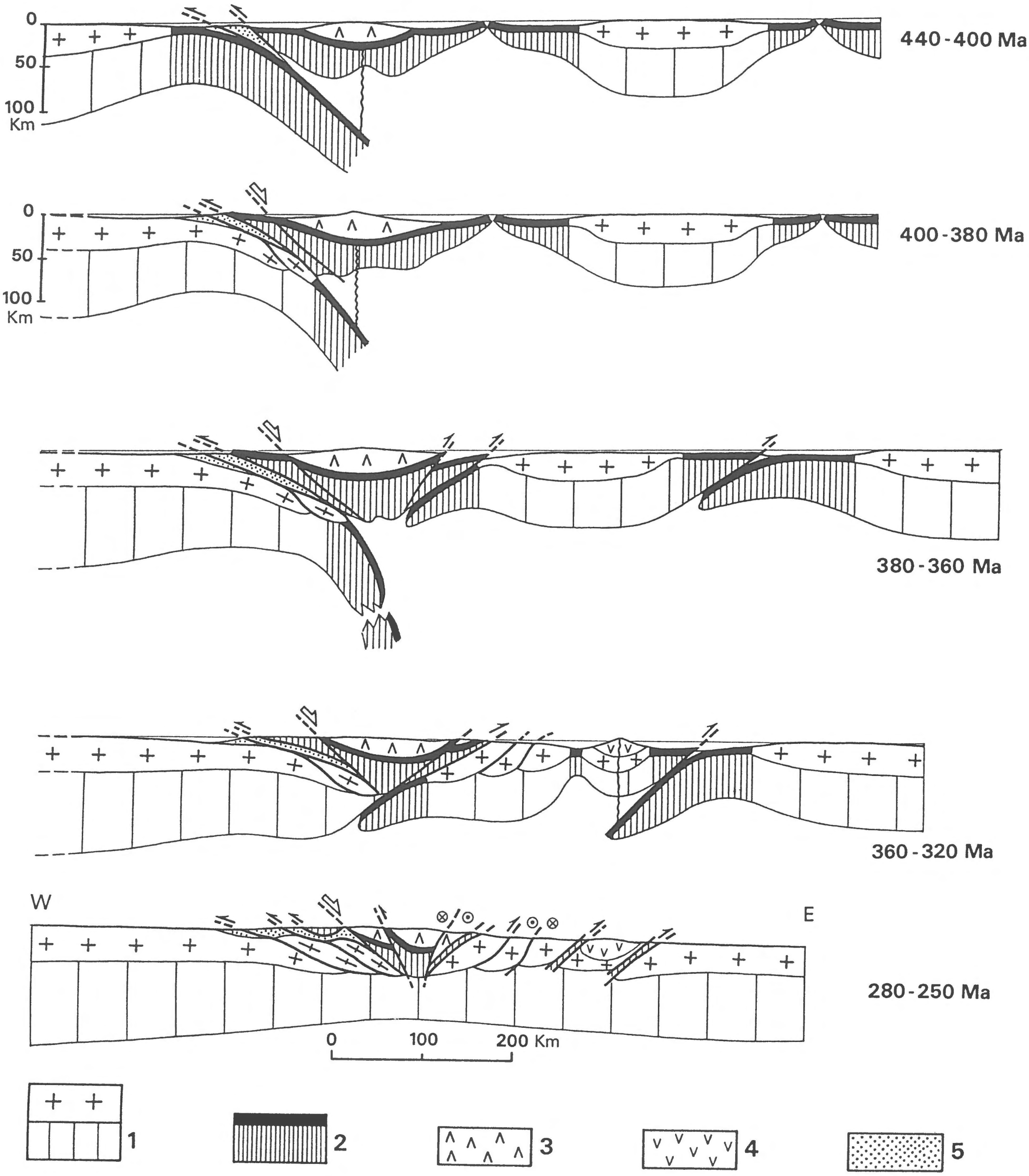

Fig. 9. Schematic cartoon showing the possible Palaeozoic convergent history of the Southern Urals : 1) continental crust and mantle, 2) oceanic crust and mantle, 3) Magnitogorsk island arc, 4) Valerianov volcanic arc, 5) flysch.

The *Variscides* were sandwiched between large Precambrian cratons: Laurentia-Baltica and Africa and consequently suffered a very strong and long-lasting post-collisional intracontinental deformation.

The *Uralides* are not sandwiched between two large Precambrian continents but constitute the westernmost part of a very broad Palaeozoic orogen extending up to the Angara craton. The Uralian evolution proper results mainly from eastward subduction, first of oceanic lithosphere (Silurian), and subsequently of the East-European cold and thick continent (Devonian), below the oceanic mantle. This early 'Oman' stage (Michard et al. 1989) responsible in particular of the HP-LT metamorphism (380 Ma) was not followed by a large continent-continent collision as for the Variscides but by accretion of island arcs and small continental blocks like the Mugodzhar and the Kazakhstan blocks during the Carboniferous. The Magnitogorsk volcanic arc was first accreted to the East-European margin by continuing eastward subduction forming a main suture zone, the Main Uralian Fault. This early thrust played later as a huge east-dipping normal fault which helped in the unroofing of the HP terrain of the Uraltau ridge (Matte et al. 1993). This extension was possibly due to the high density of the rocks contained in the Magnitogorsk syncline (ocean and arc crust and mantle) and to a probable free boundary farther east (opened oceanic basin until the Middle Carboniferous; Zonenshain et al. 1991).

If we take the eastward vergence of thrusts and nappes in the eastern Urals (east of the Magnitogorsk syncline) into account, it is likely that the Mugodzhar and Kazakhstan continents were accreted to the previous building by opposite westward lithospheric subduction (Fig. 9). This change in the sense of subduction would be comparable to the one that occurred in Taiwan (Shemenda et al. 1992). The Valerianov volcanic arc was probably formed by the same mechanism during the Middle and Late Carboniferous.

The lack of important continent-continent collision explains very likely the LT type of metamorphism, the low degree of crustal melting and consequently the quasi absence of crustal granites in the Urals. It also explains the general low degree of denudation and the excellent preservation of the ophiolites and island arcs which makes the Urals a key area to understand better the Palaeozoic plate tectonics.

Acknowledgements

This paper is a tentative attempt to clarify the structure and the evolution of the Uralian belt by comparison with the Variscan belt of south-western Europe. Though extensively studied by Russian teams, the Urals are still largely unknown to western geologists as most of the literature is published in Russian and the detailed geological maps are still not available. The international Europrobe Urals project financed by the European Science Foundation, Strasbourg, offered a first opportunity to have close contacts with Uralian geologists and geophysicists.

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