AN OROGENIC MODEL CONSISTENT WITH EARTH EXPANSION

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> *"Most heresy is false; yet latent*
> *within it are the gems of the age"*
> (S.W.Carey, 1983)

INTRODUCTION

Since the dawn of plate-tectonics theory, almost 30 years ago, a vaste amount of evidence has accumulated that has continuously necessitated correction of its paradigms. Anyhow, the basic principle - subduction on a constant-radius Earth - remained unaltered being assumed by the majority of Earth scientists. Still there is a little community of 'heretics' who question the unanimously accepted 'truth', the more so as , until now, there has been no peremptory proof either in favour or against a constant-radius Earth through geological time. It is beyond the scope of this paper to provide evidence in favour of Earth expansion. What we shall try to show is that orogeny may well be understood without any implication of subduction and with only subordinate participation of lithospheric compression. Yet, we are aware that beside direct evidence this is what the Earth expansion hypothesis needs most in order to increase its credibility.

STRIKE SLIP VERSUS SUBDUCTION

Notwithstanding the revolution in Earth sciences triggered in the early sixties by the evidence of ocean spreading, the general rules of orogeny are still poorly known. Plate-tectonics theory took over from older theories the crustal-shortening concept and elaborated a general model according to which spreading along ocean ridges is compensated by progressive closure of old oceanic basins, eventually followed by collision of continental blocks. Initially this process, whereby island arcs and/or orogenic belts are being created,was thought to take place by orthogonal plate convergence across subduction zones (Dewey and Bird,1970; Figure 1a).This scenario best accounted for some of the most obvious structural patterns (fold and thrust vergencies in particular) which imply tectonic transport *across* the strike of the orogen.However, it came out very soon that beside such

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patterns, orogen-parallel strike slip is likewise common in folded belts and arcs (Fitch, 1972), thus proving tectonic transport also *along* the orogen and forcing plate-tectonics theory to reconsider its earlier expectations. The first attempts to accommodate orogen-parallel displacements along strike-slip faults with the basic principle of plate tectonics assumed initiation of the faults in order to permit 'tectonic escape' in regions of strong convergence (Figure 1b). Under certain circumstances and over restricted areas such

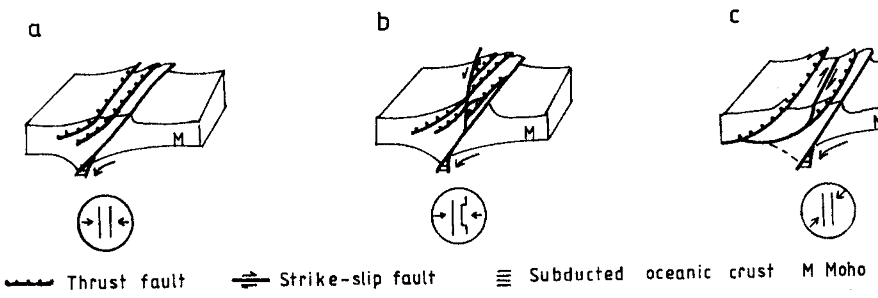

Figure 1. Three plate-tectonic models of orogeny successively developed in order to keep up with growing new evidence.

interpretations may actually apply. Yet, examples cited from Central Anatolia, south-eastern Asia and elsewhere clearly show that expulsion of continental blocks takes place along conjugated sets of faults, of which only some are sub-parallel to the strike of the orogen. The disposal reminds, however, of a pure shear mechanism, whereas orogen-parallel strike-slip faults that can be followed for thousands of kilometres along strike are in domains of simple shear.Moreover, the 'tectonic escape' model assumes nucleation of strike-slip faults at an advanced stage of crustal collision, in the late history of orogenic evolution. For true orogen-parallel strike-slip systems this assumption is contradicted by field evidence which suggests at least coeval evolution of contractional structures and deformation attributed to strike slip. As orthogonal-type subduction was unable to explain such coexisting features in the deformational field, the concept of 'oblique subduction' has been propounded. It assumes oblique plate convergence and its resolution into an orthogonal component of motion that creates the dipping faults "necessary for subduction" (Sleep,1992) and a parallel component, manifest as strike-slip faults. Searching for a unique transmission mechanism for such a combined motion, Oldow et al.(1990) have proposed that thrusting and strike slip occur along spatially segregated listric surfaces that merge downwards into a sole sub-horizontal decollement zone near the base of the crust (Figure 1c).In current plate-tectonics reasoning the corollary of 'oblique subduction' is 'terrane accretion'.It assumes that slivers of continental crust, so-called 'terranes',are separated by rifting from "mother" continents, incorporated into oceanic plates and successively 'accreted' by oblique subduction onto active continental margins where they are bounded by strike-slip faults. This interpretation best conforms with the observed ubiquity of longitudinal strike-slip faulting in 'collisional' orogens and island arcs, saving at the same time the alleged process of subduction.

Contrary to customary thinking in terms of collisional tectonics, we have supported the idea that megashears of the crust (i.e.strike-slip systems of continental or global importance) may have caused "by their simple activity the formation of orogenic belts" (Strutinski, 1987). This idea was later more extensively treated and opposed to subduction-related orogenic models (Strutinski, 1990). There is now growing evidence in favour of our strike-slip model of orogeny coming especially from structural data that in plate-tectonics interpretations are regularly misinterpreted or ,at most, "not well understood". Thus stretching lineations in metamorphic rocks, almost unanimously accepted as markers of tectonic transport, clearly show that, without exception, orogen-parallel tectonic transport precedes, is coeval with and sometimes even outlasts tectonic transport across the orogen (Ellis and Watkinson, 1987 and references cited herein; Piasecki, 1988; Strachan et al., 1992), pointing to the *relatively late and episodic occurrence of a shortening component in mountain building*. This is in evident contradiction to plate-tectonic models that are tempted to ascribe orogen-parallel movements to a late phase of orogenic evolution, as it makes no sense to place subduction and shortening related to it at a moment when the greatest part of orogeny has already unfolded. Yet, seismic anisotropy patterns emphasize that during orogeny flow within the mantle must have been likewise parallel to the strike of folded belts (Ramananantoandro, 1988; Vauchez and Nicolas, 1991), being in perfect accordance with the findings of surface geology.

Space limitations do not permit an extensive treatment of the flaws of plate-tectonics theory regarding orogeny. It should, however, be mentioned that there are numerous aspects related to the inferred existence of palaeo-oceans, arc magmatism, timing of obduction, palaeo (bio) geography and to other topics that point to the debatable status of subduction as a fundamental mechanism of lithospheric motion and deformation.

OROGENS - MEGASHEARS OF THE CRUST

One of the most fertile papers in improving our ideas regarding orogeny was that of Tchalenko (1970) on similarities between shear zones of different magnitudes. It was really striking to learn that shear-zone structures are essentially the same on a regional scale and down to the magnification limit of the optical microscope. What was nearer as to suppose that even on continental or global scale things should not be very different?

Our model of orogeny predicts that differential movements in the asthenosphere induce shearing in the overlying lithosphere that proceeds in a similar manner to the shear-box experiments of Tchalenko (1970). The first stage of shearing, consisting of an almost homogeneous straining, produces stretching and a thinning out along the future shear zone. Other than in model experiments this stage lasts very long, in fact tens of millions of years, due to the very slow increment of shear stress and to the rheologic behaviour of the deeper crust and upper mantle. At the surface the thinning out implies subsidence and the formation of elongated troughs, i.e. geosynclines. The frictional drag exerted by the differential asthenospheric flow continually decreases upwards according to decreasing temperature and rheologic behaviour of rocks. This movement may best be visualized by two adjoining decks of cards progressively 'sheared' along their length in opposite directions (Figure 2). It is important to note that ,other than in plate-tectonic models, in our model deformation accompanied by metamorphism begins at this early stage of orogenic evolution, an assumption that is in full agreement with field evidence. It is obvious that foliation created during this stage must be flat-lying and more or less sub-parallel to the bedding within the geosynclinal pile. This is exactly what has been observed (e.g. Hanmer, 1981; Piasecki, 1988; Strachan et al., 1992).

In a second stage the increasing shear stress cannot be accommodated any further by primary homogeneous straining, so that some kind of a ductile 'rupture' must occur at depth. The first Riedel shears will appear, significantly increasing the stretching component

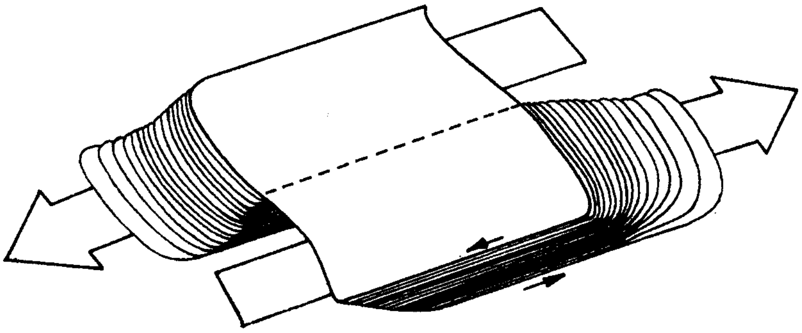

Figure 2. Shearing of the lithosphere above differential asthenospheric motion during the first stage of orogeny, as visualized by two adjoining decks of cards. The regime along the future zone of rupture is tensional.

of the motion. At surface level this means acceleration of subsidence in the geosynclinal furrows. The advanced stretching also produces tension gashes, the more so if there is also a tensional component beside simple shear, like in the present-day Gulf of California. These fissures may reach down to the updomed mantle, constituting conduits along which mantle material ascends giving birth to the ophiolite suite.At this stage metamorphism is (Riedel-) fault-bounded, meaning that it is restricted to steep-dipping zones and characterized by sub-vertical foliations, lineations remaining, however, sub-horizontal (compare the observations of Hanmer,1981; Piasecki,1988; Strachan et al.,1992).

The following stage in the evolution of an orogen is characterized by the initiation of principal displacement shears (Y-type shears, according to Tchalenko,1970) that most probably correspond to the 'late' orogen-parallel strike-slip faults visible at the surface. Shear-heating at depth begins to drive crustal anatexis (Sylvester,1988), and mixing-up of crustal melts with mantle material gives birth first to gabbro-dioritic and later on ,as melting proceeds, to granodioritic-tonalitic or granitic magmas. These will start to ascend diapirically, initiating the upheaval of orogens and eventually triggering folding and thrusting as well as, in the flanking basins, the formation of accretionary wedges. In plate-tectonics considerations these processes are conventionally ascribed to subduction-related compression, whereby 50 to 80% shortening is implied.Yet, one should recall that laboratory-model studies on transpression (reviewed by Sylvester,1988) all show that fault-bounded welts are forming above principal displacement zones,due to the accommodation of the component of shortening strain by uplift.Field relations observed along convergent strike-slip faults are consistent with these model experiments, evincing the upward flattening of fault planes and their conversion into oblique-slip thrust faults (Sylvester and Smith,1976; Strutinski,1987), along which crustal stacking occurs.We see no reason why this should not apply also to the orogen as a whole ,that, according to our model, is a shear system at least one order of magnitude greater than a common strike-slip fault.It should not be very difficult to prove that during the last stage of evolution shear heating not only triggers magmatism and related diapirism, but also implies crustal expansion ,thus constraining pure strike slip or transcurrency to turn into transpression. Swallowing of crust, be it oceanic or continental, is not required by our model. Instead, a steady transition from transtension to transpression is emphasized to be the main characteristic of evolving orogenic belts.

THE GEOTECTONIC FRAMEWORK OF OROGENS

In a recent paper Murphy and Nance (1991) distinguished between two different types of orogenic belts, so-called interior orogens, supposed to be the product of continent-continent collisions after 'contraction of interior oceans', and peripheral orogens regarded as being due to subduction of 'exterior oceans'. This duality of orogens seems to be a well established fact, being acknowledged also by our model of orogeny. The difference is, however, that, according to our view, peripheral orogens are only restricted to the actual border of the Pacific and did not occur before the breakup of Pangaea. Therefore we shall term them circum-pacific orogens. The other main type of orogens is not strictly restricted to a specific geological period, but its importance seems to be decreasing in recent times. According to Carey (1983) orogens of this type were born equatorially and have been, at least in part, globe-girdling. We shall refer to them as equatorial orogens.

a) **Equatorial orogens.** Their palaeomagnetically proven equatorial position has been regarded by Carey (1983) as being due to, or, at least, concordant with an equatorial sinistral torsion, thought to represent the combined effect of gravity and rotational inertia. Instead of a sinistral torsion we assume an easterly directed asthenospheric current, similar in direction, but opposed in sense, to the equatorial ocean currents.Such a current in a globe-enveloping asthenospheric layer may be inferred by analogy with the latitudinal disposal of the atmospheres on Jupiter and Saturn. This disposal is due to differential zonal motion that shows greater - in the case of Saturn significantly greater - wind velocities in the equatorial zone as compared to higher latitudes (Figure 3). As a consequence the equatorial zone must be "sheared off" sinistrally against the northern, and dextrally against the southern, tropical zones. On Earth shearing produced in the lithosphere above the implied asthenospheric current is inferred to be the motor that drives equatorial orogeny. Scattered palaeomagnetic data and shear sense indicators from literature accessible to the present author (Badham,1982; Bachtadse et al.,1983; Mawer and White,1987; Piasecki,1988; Crespo-Blanc,1992;Strachan et al.,1992) may indeed be cited in support of the interpretation of the Caledonian and Hercynian fold belts as originating above equatorial asthenospheric currents. At present only sinistral shear is acknowledged for the Caledonian

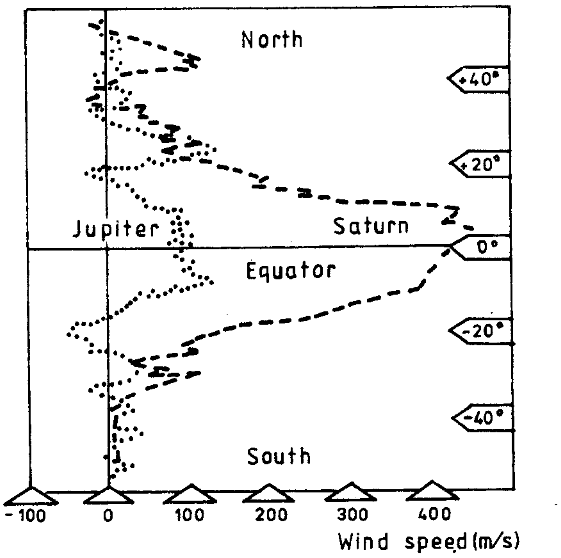

Figure 3. Wind pattern of the Jupiter and Saturn atmospheres (after Dorschner,1986).

orogen, whereas for the Hercynian belt some authors assume dextral shear against Gondwana (e.g.Badham,1982), while others substantiate sinistral shear against northern (stable) Europe(e.g.Bachtadse et al.,1983). The Alpine orogen is much more complicated due to intervening ocean spreading. Carey (1983) assumes only sinistral shear along it ('Tethyan torsion'). Yet, there are at lest some indications that dextral shear was likewise operative in the Dinaric (southern) branch of the Alpine orogen (Bébien et al.,1986). In chronological order the equatorial orogens all left their initial position, clearing the way for the next orogenic cycle. This appears to be due to the spinning of the asthenospheric current about the changing rotation axis of the Earth (Figure 4), a motion that cannot be obeyed by the relatively brittle lithosphere. There are some hints that zonal motion is still active, even if not precisely at 0° latitude but some 15° more to the north. Here we may observe the pronounced easterly bowing of the Mariana arc-trench system of the Pacific and the shear-bounded Caribbean 'plate' with its frontal arc-trench system of the Lesser Antilles. Both situations suggest the existence of an easterly flowing asthenospheric current beneath them.

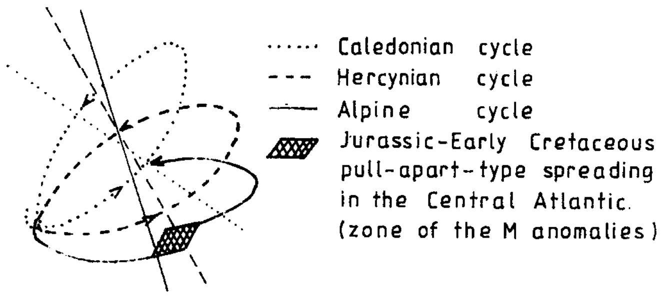

Figure 4. Inferred spinning of the asthenospheric equatorial current about the changing rotation axis of the Earth from Caledonian to early Alpine times.

b) **Circum-pacific orogens** may represent the alternative of orogeny to Earth expansion. However, here too shearing is the relevant factor. It seems that this is due to a counterclockwise rotation of the Pacific plate against surrounding continents and island arcs. Benioff zones ,trenches and volcanic arcs make up a trinity that characterizes circum-pacific orogens in their last (diapiric) stage of evolution that begins with the emplacement of large batholithic intrusions. The volcanic front is situated inland from the batholithic alignment (e.g. Peruvian Andes), that, in modern arc-trench systems is supposedly marked by the so-called non-volcanic outer arc or outer high characteristically evidenced by a positive gravity anomaly. Moreover, it may be observed that this outer high approximately halves the distance between the trench and the volcanic front. Other than in plate-tectonic models dimmed by the compression assumption,we herewith claim that both the trench and the volcanic arc are created essentially due to tensional stresses in the lithosphere that occur most probably as a rebound to the diapiric upheaval performed in between. That volcanic activity must be linked to normal faulting, and that, on the other side, trenches are as well characterized by normal faulting is all but new wisdom. Yet, in spite of having both a tensional character, volcanic arcs and trenches are very dissimilar, due to striking differences in their heat fluxes. Under the arc tensional faulting enables overheated (and decompressed) crust-mantle material to escape to the surface so that isostatic equilibrium is maintained.Under the cold trench there is nothing hot to escape, so the trench bottom sags down and the isostatic equilibrium is broken. However, recent data coming from submersible investigations of trench bottoms point to the presence of "overpressurized water oozing out from the zone of contact between plates" (Cadet et al.,1986; see also Mascle et al., 1986). Do we have to do here with a dewatering conduit of the mantle whose tap is switched on as soon as diapiric processes set in? And if so, might overpressurized waters have something to do with the so disputed topic of earthquake generation along Benioff zones?

CONCLUSIONS

Except for this earthquake generation along Benioff zones, that is taken by plate tectonicists as (circumstantial!) evidence in favour of subduction of oceanic lithosphere under continental lithosphere, and hence of an essentially compression-related evolution of orogens, geological field evidence as well as an increasing amount of geophysical data point to the fact that orogens are megashears of the lithosphere that have nothing to do with closure of oceanic basins. Thus closure may be an artefact as well as the alleged Tethys, Rheic, lapetus and older oceans leading to the perspective that ocean spreading may not be compensated spatially, hence lending support to the Earth expansion hypothesis.

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