Geodynamics of Iberia, supercontinent cycles and metallogenic implications

Geodinâmica da Ibéria, ciclos de supercontinentes e implicações metalogenéticas

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Abstract: The geodynamic evolution of Iberia since Neoproterozoic times illustrates the progression of the two last supercontinent cycles and the probable path to the next one. The Pangea supercontinent cycle shows features of Hercynian- and Alpine-type orogens both in terms of tectonothermal regime and geometry/kinematics. The combination of inherited and neo-formed components, namely those able to sustain long-lasting and/or recurrent rejuvenation of heat and mass advection in the lithosphere, explain the complexity and singularity of metallogenic processes and products observed in Iberia.

Keywords: Geodynamics, Iberia, Metallogeny, Variscides, Supercontinents.

1. Introduction: geodynamic evolution of Pre-Mesozoic Iberia

In the context of Global Tectonics, the geodynamic evolution of Iberia (Verá, 2004; Dias et al., 2013 and references therein) illustrates a possible model of supercontinent style (Ribeiro et al., 2012) persisting up to ca. 700 Ma. This model is usually composed by two Wilson cycles (lasting from ca. 200 to ca. 400 Ma each), the former progressing under conditions similar to Alpine-type orogens (e.g. Caledonides, Alpides) and the second one evolving comparably to Hercynian-type belts (e.g. Pan-African / Cadomian and Variscan). In Iberia, the Pannotia (1000 – 550 Ma; Fig. 1) and the Pangea (550 – 250 Ma) cycles illustrate this trend of geodynamic evolution during Pre-Mesozoic times. Indeed, the first (Alpine-type) Wilson cycle resulted from the opening and closure of an older ocean [Iapetus (750 – 400 Ma)] as a consequence of drifting followed by collision of some fragments of Rodinia (Fig. 1), the previous supercontinent (1100 – 750 Ma). However, remnants of Rodinia were fragmented later, requiring a significant long-lasting heating due to continental insulation. The subsequent reassembling of these fragments in the course of a succeeding Wilson cycle produced a Hercynian-type orogeny and generated the Pangea Supercontinent by joining again the older continent assemblage (Laurussia) to the younger one (Gondwana) via closure of the Rheic and subordinate oceans (500 – 250 Ma).

2. Global Geodynamic of Post-Palaeozoic Iberia and the next Supercontinent

The ongoing supercontinent cycle is critically illustrated by the evolution recorded in the course of Meso-Cenozoic times, which provide the basis to predict geodynamic developments in the following tens to hundred Ma. In fact: (1) the Alpide Wilson cycle started at ca. 250 Ma is almost completed, producing an Alpine-type orogen; and (2) the Atlantic Ocean, beginning its opening at ca. 160 Ma, appeared to have already initiated the closure path along
the SW Iberia Margin (Duarte et al., 2013). The nucleation of the Atlantic Ocean closure can propagate into the Indian Ocean, as suggested by the probable onset of an intra-oceanic subduction zone along the diffuse plate boundary zone between Australia and India, promoting the amalgamation of these two continental masses in the near future. Australia can also probably join other continents in a “Pangaea Reconstructed Supercontinent” some 100±50 Ma from now (Fig. 2).

Subduction initiation is a controversial issue that can be envisaged as a result of various processes acting independently or together, as follows: (1) transform across a passive margin that becomes active by cooling and collapse of older oceanic lithosphere propagation of a nearby convergent zone, as in SW Iberia; (2) differential slab-pull in the nearby subduction zone of eastern Indian Ocean under Eurasia that, northwards, evolving to a continental collision front of India under Eurasia, as happens in the young (< 50 Ma) oceanic lithosphere of Equatorial Indian Ocean [a possible modern analogue for the wide but short-lived Rheic Ocean – Nance et al., 2012]; and (3) collapse of passive margin by spontaneous subduction of old oceanic lithosphere. Notwithstanding the dispute regarding the relative importance and timing of these processes, subduction initiation at SW Iberia is for sure a turning point in the Atlantic Wilson cycle and a major step towards the ending path of the next supercontinent cycle. Accordingly, the Atlantic orogen will expectably be a belt with intermediate features between those that characterise the Alpine- and Hercynian-type orogens if a component of thermo-decay and ocean depletion is considered. This latter condition derives from the recurrent character of the Wilson supercontinent cycles progressing in a water-cooled convective Planet without affect its average volume. In these circumstances, the opening and closure of some of the oceans with opposite sign of forcing will tend to control the period and amplitude of each cycle oscillation. Both processes operate at an increasingly slow rhythm at global scale, but require, at smaller scales, a concentration of higher pressure convergent mechanisms that will lead to an ever primacy of Alpine-type regimes.

Short Wilson cycles can produce two main classes of orogenic belts with distinctive kinematics: (1) linear belts, such as Caledonides, if a previous structure and/or palaeo-transform system is favourably oriented relative to the younger forcing kinematic system; and (2) curved belts, like Alpides, produced by tessellation of reactivated sutures of different ages joined by neo-formed plate boundaries of divergent or transform type. In the first class of belts, oroclines can be generated by complex kinematics due to second-order block rotations; in the second class of belts, the curvature can be amplified by continued rotation of the tessellation components. In both cases, either the orocline, or the progressive curved structure are required by progressive adaptation of the kinematic behaviour of previous inherited structures to the new kinematic boundary conditions.

Long Wilson cycles can also generate different sets of belts, such as: (1) multi-linear mobile belts cutting across capriciously arrays of cratons; (2) curved mobile belts by moulding around rigid shields; and (3) collage of various terranes often developing irregularities along continental margins, as promontories, which are accentuated by progressive bending during subsequent convergent/collision stages. Paradigmatic examples of belts of sets (1) and (2) form the wide and geometrically complex Pan-African; the third set is adequately represented by Variscides. Consequently, we should conclude that the tectono-thermal regime of high to low thermal anomalies in
plates and plumes, and the geometric/kinematic boundary conditions of neo-formed and inherited structures are only weakly correlated, regardless of the duration of the corresponding Wilson cycle.

This approach to the complexity of geodynamic models can be refined. Returning to the example of Iberia, we first notice that some segments of geophysical anomalies reflect the structural fingerprint of previous orogenic belts; additionally, indirect seismic methods can image into depth the main tectonic features observed at surface. Often, these structural correlations correspond also to magnetic and gravimetric anomalies that follow an independent geometric pattern, suggesting a décollement of the Palaeozoic cover over a Cadomian or older basement. This is the case of the Central-Iberian Zone, where the overall pattern of young cover structures superposed on previous basement structures can simulate an orocline generation if interpreted in a monocycle perspective instead of a poly-cycle evolution; the same is valid for the South Portuguese Zone where the basement structure/architecture is probably related to Avalonian dynamics. It appears thus that Iberia behaved as a buffer plate at the crossing of Tethys- and Atlantic-type oceans during the last Wilson and supercontinent cycles, and probably during the present and ongoing ones as well. We must consider next the metallogenic implications of these interpretations.

3. Metallogenic implications for Iberia compared with other orogens

In Iberia, a wide variety of ore-forming systems can be observed, some of them presenting ore assemblages, average grades and/or tonnages consistent with their classification as world-class deposits. As broadly accepted, the development of these systems is controlled by many local/regional features, but the fundamental geological processes ruling their generation and evolution are decisively influenced by indirect factors, which primarily depend on the geodynamic framework that can sustain long-lasting and/or recurrent rejuvenation of heat and mass advection in lithosphere. Therefore, it is not fortuitous the fact that most significant metallogenic periods in Iberia are bracketed by the following time-windows: (1) Proterozoic-Cambrian (ca. 560-540 Ma), overlapping Cadomian events (ca. 587-532 Ma) to which several metamorphic, magmatic and magmatic-hydrothermal ore-systems are associated; (2) Eo-Variscan, embracing the Cambrian-Ordovician (ca. 530-470 Ma) and Lower to Middle Devonian (ca. 390-370 Ma) intervals, and characterised by the progression of diverse sedimentary, exhalative-hydrothermal, volcanogenic and magmatic processes able to generate a variety of settings suitable for the development of quite different ore types, culminating at ca. 430 Ma and 350-345 Ma, respectively; (3) Meso-Variscan (ca. 340-315 Ma), with particular prominence to the ca. 320-315 Ma time-span, and comprising all the synorogenic processes involved in extensive geochemical redistributions via large-scale fluid flow correlative of regional metamorphism (and crustal anatexis) and shear zone nucleation/propagation, as well as of those triggered by processes depending on the establishment of inverse temperature gradients imposed by tectonic stacking; (4) Late-Variscan (ca. 312-270/260 Ma), encompassing magmatic-hydrothermal ore processes sustained by the shallow emplacement of large volumes of late to post-orogenic granites, followed by widespread hydrothermal activity in the upper crust that was supported by a high heat flow regime settled after ca. 300 Ma and lasting for several tens of Ma, being thus responsible for a refinement of early geochemical redistributions and leading to an assortment of epigenetic ore types controlled by a profuse network of strike-slip fault zones; and (5) Eo-Alpine (at ca. 150 Ma and ca. 75-65 Ma), involving a poly-phase rejuvenation of epigenetic hydrothermal processes closely related to the reactivation of pre-existing fault/shear zones conveniently oriented to the stress fields caused by the Atlantic opening and the continental collision between Apulian sub-plate with Europe, respectively. In other words and briefly illustrating with selected examples, the metallogeny of Variscides contains pristine components generated and reworked during the Variscan cycle such as: the major province of Iberian Pyrite Belt (IPB), whose development was favoured by roll-forward of the SW Iberia subduction and root zone at the Iberia/Avalonia plate boundary; a number of distinct metallogenic belts in the Ossa-Morena Zone, placed along the hanging-wall and retro-wedge of the very same root zone; several alignments of W(-Sn) ore-systems in internal zones of the orogen related to poly-phase emplacement of granite bodies; and a wide variety of epigenetic ores controlled by different structural arrangements but clearly dominated by shear/fault zones subjected to multiple reactivation events and long-lived hydrothermal activity. These pristine components benefited from previous crustal geochemical fine-tunings (namely from mass-recycling processes that led to “specialised-crustal domains”) and/or developed over tin belts of Cadomian age at high angle trends. This could explain several particular features observed in Iberia, such as the close relationship between some types of shear-controlled Au-ores and the Neoproterozoic successions enriched in black schists, or the singularity of the Neves-Corvo deposit where a Sn and Cu metal contribution, additional to the hydrothermal massive sulphide component typical of the IPB, relates with a magmatic source that may well be associated to the partial melting of an Avalonian granite source of probable Cadomian-related age. Furthermore, the presence of even more peculiar types of mineralization, such as the unique Almadén Hg deposit, strongly suggests a heterogeneous and anisotropic sub-continental upper mantle besides the well-defined crustal heterogeneity and isotropy, both intensively reactivated and/or reoriented during the Variscan cycle.

Finally, to increase the complexity of metallogeny compared to that of geodynamics, two distinct regimes can be contrasted. On one end, the continuous reworking and concentration role of crustal metal contents performed by Variscan dynamics; under this regime, metallogenesis take
place on a polygenic environment developed over a poly- 
orogenic setting, leading to a large diversity of ore types 
that form accumulations of variable dimension. On the 
other end, the Pan-African dynamics tend to play a 
diffusion (or dispersion) role regarding the metal contents 
of belts with this age, relative to the rich (commonly high- 
grade) and quite varied ore bodies sited in the adjoining 
cratons.

Acknowledgements and postscript

The authors are grateful to many Portuguese and foreign 
specialists of numerous disciplines for their insightful 
comments and fruitful discussions kept all over the years. A 
complete list of references would be longer than the text 

itself. Therefore, we assumingly decided to avoid extensive 
quotation, bearing in mind that we will have soon the 
opportunity to complete a final version of the paper, 
contribute to an open discussion of the themes that we are 
trying to approach under the spirit of the “Multiple Working 
Hypotheses” of T.C. Chamberlin (1890). This is a 

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890 p.