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# INTRODUCTION TO TERRANE ANALYSIS AND THE TECTONIC MAP OF PREMESOZOIC TERRANES IN CIRCUM-ATLANTIC PHANEROZOIC OROGENS

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Terrane terminology and its definition originated in the North American Cordillera. However, the Cordillera represents a special case in a wide spectrum of accretionary terrane orogens in which factors such as:

1) The relative motions between terranes may vary from orthogonal to highly oblique (exotic terranes). Where terranes originate and are accreted by orthogonal relative motions, neighbouring terranes may have similar geological records (proximal terranes) and may only be distinguished by the nature of the suture boundary, which represents telescoped oceanic lithosphere.

2) The stage of convergence may vary from simple ocean-continent convergence through magmatic arc-continent collision.

3) The depth of erosion, which relates to the tectonothermal state of the rocks exposed at the surface and the age of the orogen.

The Cordillera may represent an end member in the high degree of obliquity of the convergence producing exotic terranes, and in the limited amount of erosion. The deeper the level of erosion, the more the identification of terranes moves from stratigraphic/ paleontological/ paleomagnetic criteria to metamorphic / structural / petrological / metallogenic/geophysical properties. This requires modification of the original terrane definition, viz.

A TERRANE IS REDEFINED AS AN AREA CHARACTERIZED BY AN INTERNAL CONTINUITY OF GEOLOGY (including stratigraphy, fauna, structure, metamorphism, igneous petrology, metallogeny, geophysical properties, and paleomagnetic record) THAT IS BOUNDED BY FAULTS OR MELANGES REPRESENTING A TRENCH COMPLEX, OR A CRYPTIC SUTURE ACROSS WHICH NEIGH-

BOURING TERRANES MAY HAVE A DISTINCT GEOLOGICAL RECORD **NOT EXPLICABLE BY FACIES CHANGES** (I.E. EXOTIC TERRANES), OR MAY HAVE A SIMILAR GEOLOGICAL RECORD (I.E. PROXIMAL TERRANES) THAT MAY ONLY BE DISTINGUISHED BY THE PRESENCE OF THE TERRANE BOUNDARY REPRESENTING TELESCOPED OCEANIC LITHOSPHERE.

In applying this definition, it is **essential** that rock units of the **same age** be compared and that **facies changes be eliminated** as an explanation for different properties. As terrane concepts gained in popularity, examples have proliferated where terranes have been defined by comparing rock units of different ages (with distinct properties) or by ignoring the possibilities of facies changes. As a reaction to this approach, others have drawn attention to the similarities of units ignoring an intervening suture and have argued against the existence of terranes. Where neighbouring areas of the same age are distinct but facies changes cannot be eliminated at the present stage of knowledge, the conservative approach is to define them as "suspect terranes" until such time as they are proven to be true terranes or acquitted. This calls for careful application of the terrane definition bearing in mind the limitations inheritant in the use of each property. Limitations in the application of each property are outlined below.

STRATIGRAPHY. Distinct stratigraphies of the same age may be separated by a fault and yet be merely displaced portions of the same sedimentary environment, e.g. continental shelf; and the fault does not represent a suture. Clearly these distinct stratigraphies represent facies equivalents in a palinspastic reconstruction. Continental rise and miogeoclinal rocks are facies equivalents of one another, however, in some cases they are now separated by a fault and with the present state of knowledge it is impossible to show that they were formerly transitional into each other - in this case they may be termed "suspect terranes" until further work clarifies their relationships. On the other hand, the stratigraphic record of two areas may be very similar, for example two ocean floor sequences or oceanic platforms in the Pacific and Indian Oceans, and yet they are separated by a trench complex and so are separate terranes. Similarly two magmatic arc terranes may be separated by a trench and yet consist of very similar stratigraphic sequences.

PALEONTOLOGY. Faunal provinces are the most commonly used property in defining terranes, however, where these are controlled by environmental factors such as water depth or temperature, there is no a priori reason why they should coincide with terrane boundaries. This is especially the case for pelagic fauna, which may migrate onto the surrounding shelves with changes in water depth or currents. Thus, faunal provinces may alternate in one stratigraphic sequence in one terrane. Most useful are shallow marine or continental fauna that cannot migrate across deep, wide oceans. In application, such distinctions are very broad, and only add to the identification of terranes using other criteria.

PALEOMAGNETIC DATA. In general paleomagnetic data are most easily interpreted in stratified rocks that have suffered little or no tectonothermal effects. These conditions most often occur in relatively large terranes peripheral to the accretionary orogen and rarely within the orogen. Most terranes have suffered considerable deformation and this requires a thorough knowledge of the structural geology in order to subtract its effects. Metamorphism progressively modifies the paleomagnetic record and may make it difficult to identify the original signature. Chemical alteration has similar effects. Paleomagnetic data from plutons are of little use if the paleohorizontal is unknown. Paleomagnetic data that yields contrasts in paleolatitude are most amenable to terrane analysis. Rocks with similar paleolatitudes may or may not be separated by a suture. Differences in declination may add evidence to terrane identification using other properties.

METAMORPHISM. Most metamorphism post-dates docking of terranes and so adds little to terrane identification. Thus contrasts between metamorphic assemblages generally relates to facies changes. In metamorphic rocks, it is necessary to subtract the effects of metamorphism to derive the protoliths which may then be analyzed by stratigraphic criteria. High pressure-low temperature metamorphism is often associated with subduction zones and trench complexes, and if so can be used to define terrane boundaries. Contrasts in pre-docking metamorphism may add to terrane identification.

STRUCTURE. Most structural deformation is associated with docking and subsequent accretionary deformation and in this case is of little use in terrane identification. Terrane boundaries are faults, trench complexes and/or cryptic sutures and so outline terranes. Pre-docking deformation may aid in the identification of terranes.

IGNEOUS PETROLOGY. Igneous rocks may be divided into pre- and post-docking, and only the former may be used for terrane identification. Igneous rocks reflect their source regions and so there may only be a tenuous connection between them and the country rocks. Incongruous tectonic settings may add to the identification of terranes, but chemical affinities (calcalkaline-tholeiitic-settings may add to the identification of terranes, but chemical affinities (calcalkaline-tholeiitic-alkaline) may or may not be facies equivalents.

METALLOGENY. Metallogenic data may also be divided into pre- and post-docking stages and only the former are useful for terrane identification. Syngenetic mineralization may be applied terrane identification most easily because other types of mineralization often have a complex genesis. Contrasting mineralization may or may not be due to mineral zoning, i.e. facies equivalents.

GEOPHYSICAL PROPERTIES. Geophysical properties - magnetic, gravity, seismic - may be used to trace terranes and terrane boundaries once they are defined by other properties and only when the boundary has a geophysical expression. This requires that the near surface geophysical data be separated and analyzed spatially with respect to a terrane map and where correlations are found these may be extrapolated beneath overstep sequences and to depth. Care must be exercised where similar geophysical anomalies attributable to different causes merge, and where the geophysical properties within one terrane change due to facies changes in the geological properties. It is generally difficult to uniquely identify deep geophysical properties with terranes or terranes boundaries.

Terrane mapping has progressed from merely outlining the terranes to those depicting their tectonic settings. The Tectonic Map of Pre-Mesozoic Terranes in Circum-Atlantic Phanerozoic Orogen depicts Precambrian-Paleozoic terranes within circum-Atlantic Phanerozoic orogens on a Permian palinspastic reconstruction, i.e. a closed Atlantic Ocean. The base map is a transverse Mercator projection with the Equator along the axis of the closed Atlantic. The terranes are categorized by age and tectonic setting: autochthonous and imbricated basement/miogeocline, continental rise, oceanic lithosphere, oceanic sedimentary/volcanic sequence, volcanic/magmatic arc complex, intra-arc basin, periarc basin, trench complex, disrupted terrane (tectonic melange), metamorphic rocks of uncertain protolith, continental rocks of uncertain affinity, and continental rift rocks of uncertain affinity. Most oceanic terranes appear to represent small ocean basins rather than fragments of the main oceans. Also shown are post-accretionary stitching plutons, overstep sequences and accretionary diagrams for various sections of the orogens. The accretionary diagrams depict the rocks types and their inferred tectonic settings, the time of docking and the sense of pre- and post-accretionary movements, stitching plutons and overstep sequences.

The major cratonic terranes and their miogeoclines around the margins of the circum-Atlantic Paleozoic orogens are structurally separated from the magmatic arc and oceanic terranes, which occur in the internal and uppermost structural parts of the various orogens. Disrupted terranes, mainly consisting of blocks of ophiolite, oceanic and periarc rocks set in a foliated matrix of miogeoclinal and continental rise affinities, generally occur along the margins of the major cratonic terranes. Precambrian rocks in the major cratonic terranes bordering the circum-Atlantic Phanerozoic Orogens show a wide range of age: Archean, Early Proterozoic and Middle Proterozoic (Grenvillian) occur in Baltica, Laurentia and South America - - Grenvillian is absent in north-western Africa. Continental terranes with Archean-Proterozoic basement are scattered throughout the circum-Atlantic Phanerozoic orogens, however the widespread distribution of such rocks in the surrounding major cratonic terranes indicates that the age of the basement alone is not a unique feature for distinguishing kinship. The Late Precambrian terranes are limited to the southeastern part of the map: central/western Europe, southern British Isles, southeastern Appalachians, northwest Africa and northern South America and were accreted in Late Precambrian - Cambrian orogens. These latter orogens were developed across Precambrian rocks ranging from Archean to Middle Proterozoic and their accretionary activity overlapped the time span for the opening of Iapetus, suggesting that they originated in separate oceans. Magmatic arc and periarc terranes are well preserved in some of the Late Precambrian - Cambrian orogens in contrast to their poor representation in the Paleozoic orogens. As magmatic arcs lie on the upper plate, they would probably be removed by erosion following continental collision. Thus, their preservation in the Late Precambrian-Cambrian orogens suggests that such collisions did not occur. Overstep sequences across the Late Precambrian terranes may become miogeocline relative to the Phanerozoic orogens. Most of the identified Paleozoic, ophiolitic, magmatic arc and oceanic terranes in the circum-Atlantic Phanerozoic orogens appear to have formed during the Cambrian-Ordovician, with relatively few such terranes of Silurian-Carboniferous age occurring mainly in western and central Europe. This suggests that Iapetus was essentially closed by the end of the Early Paleozoic. This is supported by the presence of distinct faunal provinces in the Cambrian-Ordovician followed by a cosmopolitan fauna in the Silurian-Devonian. Late Paleozoic orogenic activity is inferred to be mainly transpressive along the vestiges of Iapetus, while convergence was still taking place in the Variscan orogen. The scale of Late Paleozoic transcurrent and rotational movements is presently uncertain and several widely divergent models based upon paleomagnetic data are current.

The accretionary history of pre-Mesozoic terranes in Circum-Atlantic Phanerozoic orogens may be broadly divided into:

(1) terranes located in northwestern Africa, central/western Europe, southern British Isles, southeastern Appalachians and northern South America, which were accreted during the latest Proterozoic-Cambrian during the Pan African-Cadomian Orogeny;

(2) terranes located in the Appalachians, the Caledonides of Greenland, Svalbard, Scandinavia and the British Isles, and the Variscides of central/western Europe and northwest Africa, which were mainly accreted during the Early Paleozoic with a few accretionary events occurring in the Devonian-Carboniferous (mainly in the Variscides);

(3) terranes located in the Alpine and Andean orogens many of which still retain evidence of their Late Paleozoic overstep sequence.

Some terranes have suffered a poly-orogenic history involving alternating accretion and dispersion. Palinspastic models for Precambrian-Early Paleozoic are presently poorly constrained by paleomagnetic data. However, the following tentative model may be proposed when paleomagnetic data is combined with paleontological and tectonic data from the map of pre-Mesozoic terranes in circum-Atlantic Phanerozoic orogens:

(a) latest Proterozoic-Cambrian separation of Godwana and Baltica from Laurentia is constrained by contemporaneous passive margin sequences and took place concurrently with convergence along an ocean-continent (± island arcs) boundary in Pan-African orogens along the South America margin of Gondwana;

(b) Ordovician-Silurian sinistral convergence of Baltica and Gondwana (?South America) with Laurentia ended with the virtual elimination of Iapetus which is constrained by the presence of similar, Late Silurian freshwater vertebrates on both Baltica and Laurentia and Early Devonian, Eastern Americas brachiopod Faunal Realm in Laurentia and northern South America;

(c) Devonian-Carboniferous dextral convergence across the Variscides and the Appalachians may be related to anticlockwise rotation of Gondwana relative to Laurentia.

Within this general scenario, the geological record of individual terranes provides some constraints upon their origin. The terrane map provides the base of other thematic maps, showing metamorphic and structural data, for example.