Abstract Volume
6th Swiss Geoscience Meeting

Lugano, 21st – 23rd November 2008

Apply! Geosciences
6th Swiss Geoscience Meeting 2008 - Lugano

sc | nat
Geosciences
Platform of the Swiss Academy of Sciences

SUPSI
University of Applied Sciences
of Southern Switzerland
Institute of Earth Sciences

14. Deep Earth – From Crust to Core: A Tribute to Peter A. Ziegler

Stefan Schmid, Jon Mosar, Gilles Borel & Pierre Dèzes

International Lithosphere Program (ILP)
Swiss Commission of the International Union of Geological Sciences (IUGS)

14.1

Examples of magmatic processes in the crust and mantle as seen by seismic tomographic imaging: continental rifts and mantle plumes

Achauer Ulrich

EOST-IPG Strasbourg, UMR 7516, Lab de sismologie, 5 rue René Descartes, F-67084 Strasbourg, France (ulrich.achauer@eost.u-strasbg.fr)

Two of the tectonic most active regions on continental plates are rift structures and plumes. Over the last twenty years seismic tomographic imaging projects have been carried out to look in detail at the upper mantle structure of some of these features to shed light on their geodynamic evolution and to figure out their role in the assemblage of continents.
In my presentation I will concentrate on the research of rifting structures and baby plumes related to ECRIS, namely the Limagne Graben/Massif Central and the Rhine Graben/Eifel plume.

The most important result of the seismic investigations in the French Massif Central at the beginning of the 1990' (French-German co-operative project Limagne 91/92) was the proof of an ascending material stream from larger depth (250km), which due to its geochemical and petrological characteristics and its appearance was classified as a plume and which confirmed an already 20 years earlier expressed hypothesis. The really new of the results were that for the first time the exact size and shape of this plume at upper mantle depths was determined, as well as the fact that no plume head ("mushroom") could be found. This led to the expression of "baby plume" for this kind of material up-streaming in order to differentiate this feature to the classical idea of a plume (such as the model by Shilling). The results from the Massif Central triggered similar seismic experiments in other regions of Central Europe with Variscan basement and recent volcanism and led to the proof of another such structure beneath the Eifel volcanic region. It is intruiging that both baby plumes seem to be closely related to parts of the large scale ECRIS system.

An overview will be given of the current state of affairs concerning the seismic research on rifts and baby plumes, as well as possible causes for their presence will be discussed.

14.2

Lithosphere extension : necking instability vs gravity driven spreading

Jean-Pierre Brun and Frederic Gueydan

University Rennes 1

Mechanical modelling substantiates that the modes of lithosphere extension –i.e. narrow rifting vs wide rifting- strongly depend on the existence of two main classes of lithosphere rheological profiles. "Cold and strong" lithospheres have Moho temperatures lower than c.a. 750°C –i.e. the temperature of brittle–ductile transition in mantle rocks- whereas "hot and weak" lithospheres have Moho temperatures higher than this critical value. Necking-type instability occurs preferentially in cold and strong lithospheres that have four-layer-type of strength profiles with the greatest strength located in the sub-Moho mantle. It gives birth to continental rifts that can evolve into passive margins and ultimately lead to continental breakup. Gravity driven spreading occurs preferentially in hot and weak lithospheres whose strength profile exhibits maximum strength at the base of upper brittle crust. It gives birth to wide rifts and core complexes, like in the Basin and Range of the western United States or in the Aegean. The applicability of these end-member-type models to natural systems is discussed from the point of view of Atlantic-type passive margins, in one hand, and backarc-type basins of the Mediterranean, in the other hand.

14.3

Mediterranean Tectonics: IGCP 369 and Transmed Project

William Cavazza*

*Dept. of Earth and Geoenvironmental Sciences, University of Bologna, 40126 Bologna, Italy (william.cavazza@unibo.it)

The Mediterranean domain provides a present-day geodynamic analog for the final stages of a continent-continent collisional orogeny. Over this area, oceanic lithospheric domains originally present between the Eurasian and African-Arabian plates have been subducted and partially obducted, except for the Ionian basin and the southeastern Mediterranean. A number of interconnected, yet discrete, Mediterranean orogens have been traditionally considered collectively as the result of an "Alpine" orogeny, when instead they are the result of diverse tectonic events spanning some 250 My, from the late Triassic to the Quaternary. To further complicate the picture, throughout the prolonged history of convergence between the two plates, new oceanic domains have been formed as back-arc basins either (i) behind active subduction zones during Permian-Mesozoic time, or (ii) associated with slab roll-back during Neogene time, when during advanced stages of lithospheric coupling the rate of active subduction was reduced. The closure of these heterogenous oceanic domains produced a system of discrete orogenic belts which vary in terms of timing of deformation, tectonic setting and internal architecture, and cannot be interpreted as the end product of a single Alpine orogenic cycle.

Similarly, the traditional paleogeographic notion of a single -albeit complex- Tethyan ocean extending from the Caribbean to the Far East and whose closure produced the Alpine-Himalayan orogenic belt must be discarded altogether. Instead, the present-day geological configuration of the Mediterranean region is the result of the opening and subsequent consumption of two major oceanic basins -the Paleotethys (mostly Paleozoic) and the Neotethys (late Paleozoic-Mesozoic)- and of additional smaller oceanic basins within an overall regime of prolonged interaction between the Eurasian and the African-Arabian plates. Paradoxically, the Alps, long considered as the classic example of Tethys-derived orogen, are instead the product of the consumption of eastward extensions of the central Atlantic ocean, the middle Jurassic Alpine Tethys, and of the North Atlantic ocean, the Cretaceous Valais ocean.

REFERENCES

Cavazza, W., Roure, F., Spakman, Stampfli, G.M. & Ziegler, P.A., eds. 2004: The TRANSMED Atlas: the Mediterranean Region from Crust to Mantle. Heidelberg, Springer-Verlag, 141 pp. + CD-ROM.

Stampfli, G., Borel, G., Cavazza, W., Mosar, J. & Ziegler, P.A., eds. 2001: The Paleotectonic Atlas of the PeriTethyan Domain (CD-ROM). European Geophysical Society.

Ziegler, P.A., Cavazza, W., Robertson, A.H.F. & Crasquin-Soleau, S., eds. 2001: Peritethyan Rift/Wrench Basins and Passive Margins. Mémoires du Muséum National d'Histoire Naturelle, Paris, v. 186, 762 p.

14.4

Thermo-Mechanical Controls on Continental Intraplate Deformation

Sierd Cloetingh

VU University, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands

Polyphase extensional and compressional reactivation of basins is a common feature in basin evolution. To differentiate between the different modes of basin formation and reactivation of passive margins and extensional basins, the development of innovative combinations of numerical and analogue modeling techniques is key. In this paper we present an overview of our advancement developing and applying analogue and numerical thermo-mechanical models to quantitatively asses the interplay of lithosphere dynamics and basin (de)formation.

Field studies of kinematic indicators and numerical modeling of present-day and paleo-stress fields in selected areas have yielded new constraints on the causes and the expression of intraplate stress fields in the lithosphere, driving basin (de)formation. Temporal and spatial variation in the level and magnitude of intraplate stress have a strong impact on the record of vertical motions in sedimentary basins. Over the last few years increasing attention has been directed to this topic advancing our understanding of the relationship between changes in plate motions, plate-interaction and the evolution of rifted basins.

The actual basin response to intraplate stress is strongly affected by the rheological structure of the underlying lithosphere, the basin geometry, fault dynamics and interplay with surface processes.

Integrated basin studies show that rheological layering and strength of the lithosphere plays an important role in the spatial and temporal distribution of stress-induced vertical motions, varying from subtle faulting to basin reactivation and large wavelength patterns of lithospheric folding, demonstrating that sedimentary basins are sensitive recorders to the intraplate stress field. The long lasting memory of the lithosphere, in terms of lithospheric scale weak zones, appears to play a far more important role in basin formation and reactivation than hitherto assumed. A better understanding of the 3-D linkage between basin formation and basin reactivation is, therefore, an essential step in research that aims at linking lithospheric forcing and upper mantle dynamics to crustal vertical motions, and their effect on sedimentary systems and heat flow.

Vertical motions in basins can become strongly enhanced, through coupled processes of surface erosion/sedimentation and lower crustal flow. Furthermore patterns of active thermal attenuation by mantle plumes can cause a significant spatial and modal redistribution of intraplate deformation, as a result of changing patterns in lithospheric strength and rheological layering.

Novel insights from numerical and analogue modeling aid in quantitative assessment of basin history and shed new light on tectonic interpretation, providing helpful constraints for basin exploration, including understanding and predicting vertical motions (eroded sedimentation record), source fill relationships, and heat flow.

14.5

From the Orogens of Europe to the Origin of the Arctic

David G. Gee*

* *Department of Earth Sciences, Uppsala University, Villavägen 16, Uppsala, SE-752 36, Sweden (david.gee@geo.uu.se)*

The younger orogens of Eurasia such as the Timanides, Caledonides and Uralides, reach northwards across the Arctic continental shelves into an ice-covered basin of ridges and troughs that comprises the least known ocean on Earth. If we are, one day, going to understand these orogens, we have to understand the Arctic Ocean; likewise, the origin of the latter will remain an enigma until we can identify and reconstruct the character of the continental and other fragments that are scattered around the basin. And there is really no way of understanding any of the pre-Vendian orogens until we've got the younger ones right!

EUROPROBE's concern for the major orogens of Europe, from the Uralides along the border of Asia to the Variscides of Iberia and the Atlantic margin (Fig. 1), provided the essential foundation for a new attack on the far north. Peter Ziegler played a key "Godfather's" role in EUROPROBE from birth, and helped deliver it's youngest child, TIMPEBAR. The TIMan-PEchora-BARents (and Kara) seas project sought to track the exposed Vendian and younger orogens northwards to the edge of Eurasian shelf and define their influence on the overlying hydrocarbon-bearing basins. We quickly learned that the

Neoproterozoic lithosphere of the eastern Barents Sea provides a remarkable foundation for the Russian sector of this shelf, with its vast late Paleozoic-Mesozoic troughs and gas reservoirs. But, we are still struggling with the Uralide sutures and the tectonics of Novaya Zemlya, the northern appendage of the Urals and barrier to the Kara shelf and northern part of the West Siberian oil fields (Fig. 2).

EUROPROBE neglected the Caledonides despite Peter's contributions to the Uppsala Caledonide Symposium in 1981. By the mid 1980's and EUROPROBE's birth, we were agreed on the vast lateral displacements of the Caledonian nappes in the Scandes and East Greenland and the remarkable late- to post-orogenic collapse of the orogen that extended far out across the Atlantic continental margins, beneath Mesozoic basins. How these allochthons were emplaced, with outboard oceanic terranes transported eastwards in the Scandes at least 400 km, remained a mystery until we recently began to understand the importance of a hot "extruding" complex (Seve Nappes), sourced from along the outer edge of the underthrusting Baltica margin. The collision of Baltica with Laurentia appears now to provide a singularly well preserved middle to lower crustal analogue for the Himalayas.

TIMPEBAR and subsequent work along the high Arctic margin of western Eurasia, and complementary studies of the Canadian, Alaskan and Russian sectors of the Arctic, are promoting new interpretations of the Phanerozoic orogens. These are stimulating reinterpretations of the Lomonosov, Mendeleev and Alpha ridges in the Arctic Basin, where recent seismic and potential field studies have helped to distinguish continental and ocean crust. As with climate science, there is an acute need to keep science clean of politics in these UNCLOS domains.

REFERENCES

Gee, D. G. and Stephenson, R. A. (eds) 2006: European Lithosphere Dynamics. Geological Society, London, Memoirs, 32.

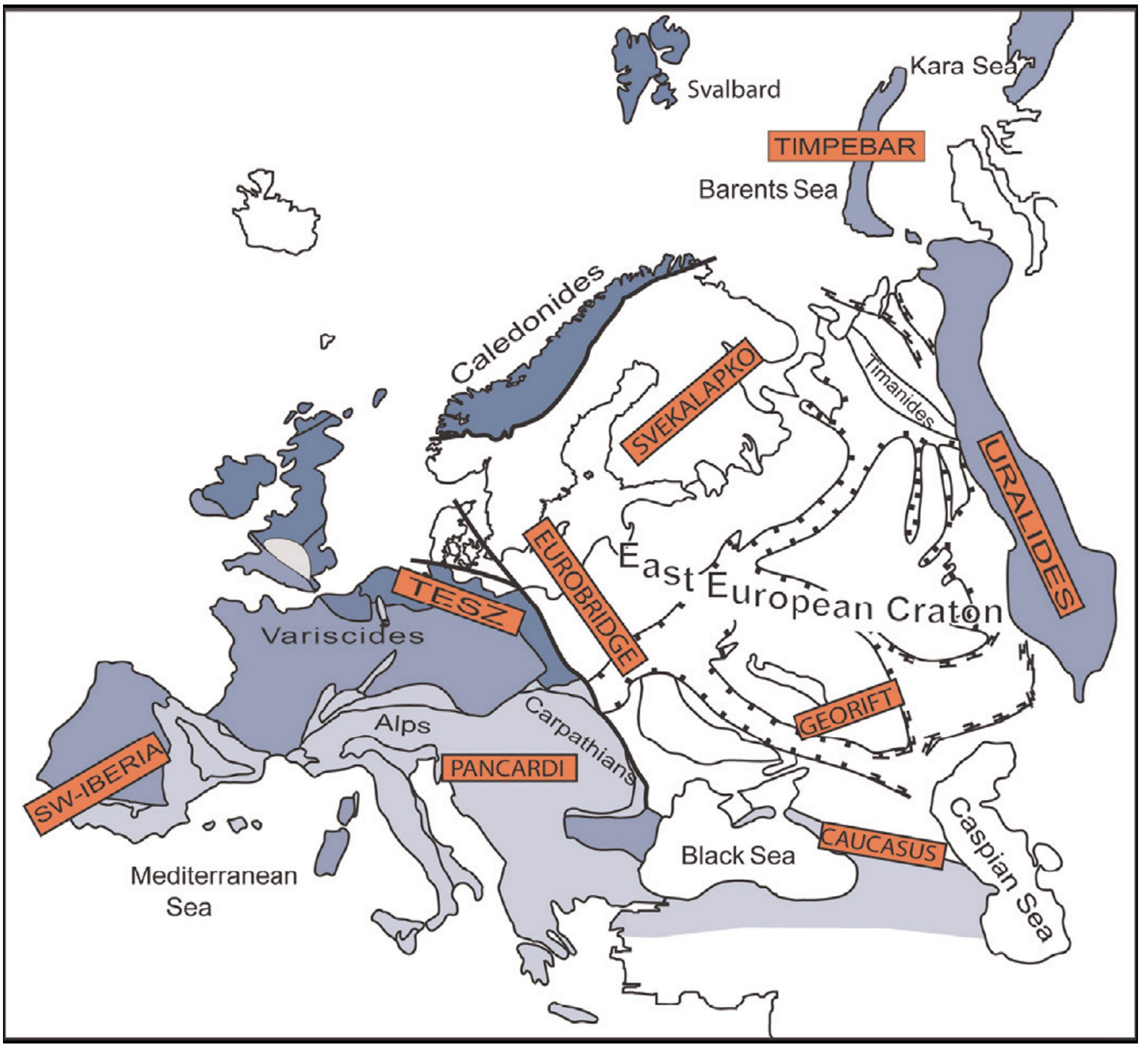

Figure 1. EUROPROBE projects (from Gee, D. G. and Stephenson, R. A. 2006)

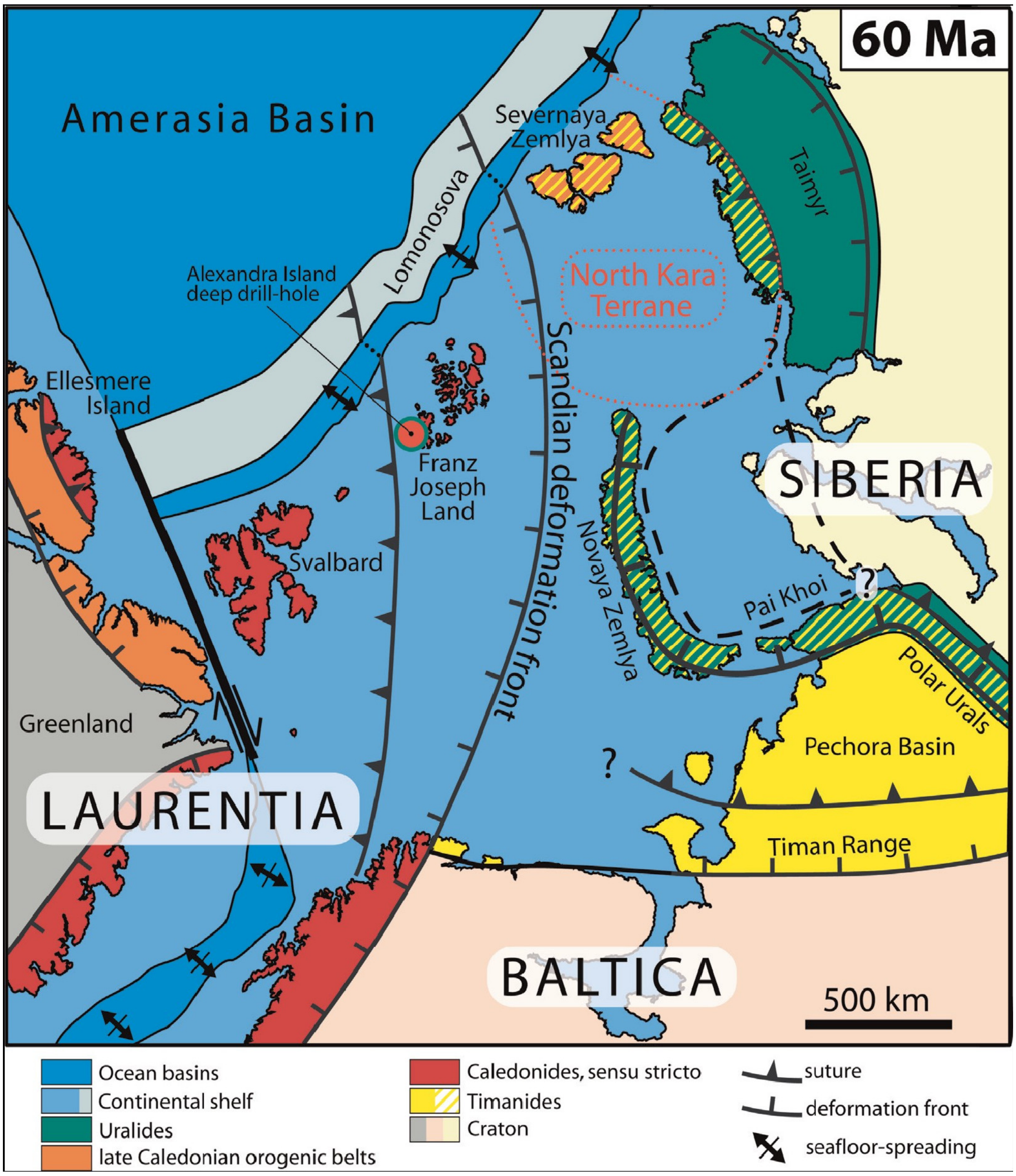

Figure 2. Tectonic elements of the western Eurasian Arctic in the Early Cenosoic, during initial opening of the Eurasian Basin and Norwegian-Greenland Sea.

14.6

Evolution of continental structure from the Arching to the present: Views from the Canadian LITHOPROBE program

Alan Green*

Institute of Geophysics, ETH, HPP O 5.1, Schafmattstrasse 30, CH-8093, Zurich

Integrated multidisciplinary studies of geological targets on the Canadian landmass and adjacent continental margins have been LITHOPROBE's principal objectives since its initiation in 1984. The greatest effort has been directed towards an improved understanding of the structure and evolution of the key tectonic units that comprise the fundamental building blocks of the North American continent. Many of these tectonic units are exposed, thus allowing correlation between a broad spectrum of geophysical data with the surface geology and with geochronological and geochemical information derived from the surface rocks. At some locations, almost complete cross-sections of the crust have been exposed, whereas at others, it is possible to project the geology from the surface "down-dip" to regions of the crust that have been sampled by the geophysical observations.

Canada's vast geographic expanse and its diverse geology provided the opportunity to evaluate geological structures and processes throughout the history of the Earth. The oldest Arching tectonic units were the focus of studies in three regions of the giant Superior Province and in the Nain and Slave Provinces. Early Proterozoic crustal evolution was explored in the Trans-Hudson, Wopmay, Makkovik and Penokean Orogens, four of the best preserved examples of such orogenic belts. Middle Proterozoic rifting and orogenesis were examined along the Midcontinent (Keweenawan) Rift System and the Grenville Orogen, respectively. Finally, Late Proterozoic to Recent mountain building and tectonic processes were investigated at various locations in the northern Appalachians and southern and northern Canadian Cordillera.

The presentation will be mainly concerned with the results of LITHOPROBE multichannel seismic reflection studies. Seismic sections from many of the investigated Canadian tectonic units and from structures elsewhere will be compared in an attempt to understand crustal evolution through a large portion of Earth's history. Conclusions from this study include:

- crustal structural styles are very similar in the Palaeozoic, Proterozoic and Arching crystalline terrains;
- as a consequence, the rheological properties of the crust must have remained nearly constant from the Arching until today;
- plate tectonic processes very likely extended back to the Arching;
- the origin of deep crustal reflections can be explained by exposures of deep rocks at the surface;
- with a few exceptions, Moho is relatively flat, surprisingly so beneath the topographically rugged Cordillera;
- yet, the character of the Moho is highly variable;
- North American “basement”, supracrustal rocks and lithosphere project 100’s of km west beneath deformed rocks of the Cordillera;
- accreted terrains are typically thin - some are only a few km thick.

14.7

Thrustbelts and foreland basins

Roure François

Institut Français du Pétrole, 1-4 Avenue de Bois-Préau, 92852 Rueil-Malmaison Cedex, France, Francois.Roure@ifp.fr

Thrustbelts are usually characterized by a positive topography above the sea level, which is continuously modified by the conjugate effects of tectonic contraction or post-orogenic collapse, thermo-mechanical processes in the deep lithosphere and asthenosphere, but also by climate and other surface processes influencing erosion rates. Different types of sedimentary basins can develop in close association with orogens, either in the foreland or in the hinterland. Being progressively filled by erosional products of adjacent uplifted domains, these basins provide a continuous sedimentary record of surficial, crustal and lithospheric deformation at and near plate boundaries.
Thrustbelts and foreland basins host also famous petroleum provinces. Basin modeling tools are now more efficient to reconstruct palinspastic structural cross sections and compute the history of temperature, pore fluid pressure, fluid flow circulations and petroleum potential in these complex structural settings.
Selected integrated basin-scale studies in the productive Circum-Mediterranean thrust belts and basins, in Pakistan and the Americas, are used here to document the effects of structures inherited from former orogens, rifts and passive margins, active tectonics and mantle dynamics on the development of petroleum systems and long term evolution of synorogenic basins.

Strong coupling between the thrust belt and its foreland can occur at different times in both subduction-related (i.e. Cordilleran-type) or collision-related (i.e. Alpine-type) orogens, thus accounting for both early and late foreland inversion processes (Ziegler & Roure, 1996; 1999).
Since the mid 80's, deep crustal seismic imaging across many orogens such as the Alps, the Pyrenees and the North American Cordillera has provided direct controls on the deep architecture of the thrust systems (Roure et al., 1990), and a better understanding of the coupling between thin-skinned and thick-skinned tectonics, whereas since the 90's, mantle tomography is progressively documenting the occurrence or absence of lithospheric slabs beneath recent orogens (Cavazza et al., 2004).
In many thrust belts where neither deep seismics nor mantle tomography is yet available, the pending question is to know

whether slab detachment may account for rapid uplift and post-orogenic erosion of former foreland basins, as described in the Central Apennines and North Algeria, or if mantle convection and asthenospheric rise alone can account for post-orogenic uplift, as evidenced in the Alberta and Veracruz basins in Canada and Mexico, respectively (Roure, 2008).

Source to sink studies are also necessary to define the spatial and temporal coupling between erosion, sedimentary transfer and deposition. Until recently, most efforts were devoted to high resolution seismostratigraphic studies coupled with core and outcrop descriptions of the synflexural/synkinematic sedimentary infill of the foreland basins. Today, however, GPS measurements and thermo-chronometers such as Apatite Fission Tracks and U-Th, can provide direct control on the uplift and unroofing history of the hinterland. Ultimately, new techniques must still be developed to provide information on paleo-elevations, which are essential for discriminating between different tectonic models, e.g. orogenic collapse and rollback, and which are also likely to control the boundary conditions (hydraulic heads) required for computing the pore-fluid pressure evolution and hydrocarbon migration in adjacent low lands (Roure et al., 2005).

Further understanding of the coupling between deep (mantle) and surface (climate) processes in orogens and adjacent foreland basins constitutes one of the main current challenges for Earth scientists, which will require access to well documented data bases to feed numerical models, involving a lot of integration and multi-disciplinary team work. International networks such as the Transmed (Cavazza et al., 2004) and ILP task forces and related workshops (Lacombe et al., 2007) may help to initiate these new collaborations. Pioneer work is currently done in Europe (Topo-Europe programme), where continental topography has been indeed widely impacted by the Alpine orogen and recent mantle upwelling in the Western Mediterranean and West European rift system.

REFERENCES

Cavazza, W., Ziegler, P. Spakman, W., Stampfi, G. & Roure, F., eds 2004: The Transmed Atlas: The Mediterranean region from crust to mantle, Heidelberg, Springer-Verlag, 141 p. +CD-ROM.

Lacombe, O., Lavé, O., Roure, F. & Vergés, J., eds. 2007: Thrust belts and foreland basins: From fold kinematics to hydrocarbon systems. Frontiers in Earth Sciences, Springer, 492 pp.

Roure, F. 2008: Foreland and hinterland basins: What controls their evolution? Davos Proceedings, Swiss Journal of Geosciences, in press.

Roure, F., Heitzmann, P. & Polino, R., eds.. 1990: Deep structure of the Alps. Mém. Soc. Géol. France, Paris, 156; Mém. Soc. Géol. Suisse, Zürich, 1; Vol. Sp. Soc. Geol. Italiana,Roma, 1, 350 pp.

Roure, F., Swennen, R., Schneider, F., Faure, J.L., Ferket, H., Guilhaumou, N., Osadetz, K., Robion, Ph. & Vendeginste, V. 2005: Incidence and importance of tectonics and natural fluid migration on reservoir evolution in foreland fold-and-thrust belts. In Brosse, E. et al., eds., Oil and Gas Science and Technology, Oil and Gas Science and Technology, Revue de l'IFP, 60, 67-106.

Ziegler, P. & Roure, F. 1996: Architecture and petroleum systems of the Alpine orogen and associated basins. In Ziegler, P. & Horvath, F., eds., PeriTethys Mem. 2, Mus. Hist. Nat., Paris, 15-46.

Ziegler, P. & Roure, F. 1999: Petroleum systems of Alpine-Mediterranean foldbelts and basins. In Durand, B., Jolivet, L., Horvath, F. & Séranne, M., eds., Geol. Soc. London. Sp. Publ., 156, 517-540.

14.8

Global Plate Reconstructions

Stampfli Gérard M.

Université de Lausanne, Institut de Géologie et Paléontologie,
Anthropole 1015 lausanne
gerard.stampfli@unil.ch

To construct reliable palinspastic models of the Earth major geological elements (basins, mountain belts, continental margins...), plate tectonics constraints must be taken into consideration, besides others elements such as faunal distribution or paleomagnetic data. The work of P. Ziegler over his long carrier has provided in depth investigations of these geological elements in many areas of the world, resulting in state of the art paleogeographic maps of the western world. These geological investigations are the prime material on which plate tectonic models for the past can be built.

Plate tectonic concepts allow to assess the kinematics of displacements of terranes and continents, keeping in mind that these continental entities are part of larger plates. For most continents/terranes, thousand km scale transport can be demonstrated, and used to construct paleogeographic models. These usually consist in simple continental drift models, and therefore, are poorly constrained in term of plate velocities. In such models it is not unusual to find velocities over 50 to 70 cm/y (usually based on paleomagnetic data), which are not acceptable in term of plate tectonics, mainly when they involve large continents like Gondwana. Plate tectonic concepts have been systematically applied to our global palinspastic models moving away from pure continental drift, not constrained by plate limits, to produce a model that finally is more and more self-constrained. In this approach inter-dependant reconstructions are created from the past to the present. Except during collisions, plates are moved step by step, as single rigid entities. Lithospheric plates are constructed by adding/removing oceanic material (symbolized by synthetic isochrones) to major continents and terranes.

In the last years we changed our tools and moved into GIS softwares and built a geodynamic database to support the reconstructions, and the model was, and still is, extended to the whole globe, spanning the earth history from 600 Ma to 20 Ma, with average steps of 15 Ma.. Our high precision reconstructions allow to measure many geological features in time and space, starting with plate velocities. It is also possible to evaluate the changing space for the world oceanic volume, as oceans are reconstructed in time and their depth can be assessed in function of their age. It is also possible to measure the changing length of mid-ocean ridges and active margins, giving an insight into volcanic activity and thus potential climate changes. The areas of continental masses versus their position in latitude can also be measured. These figures can be confronted to existing paleoclimatic data and eustatic sea level curves, in order the assess the impact of plate tectonic versus short term climatic changes.

14.9

Style, timing, and controls on European intraplate basin inversion in the Late Cretaceous-Paleocene

Randell Stephenson

(VU University Amsterdam, Netherlands; University of Aarhus, Denmark; and University of Aberdeen, United Kingdom)

Peter Ziegler was coincidentally the first geologist I met (except for Sierd) upon my arrival in Europe in mid-June 1989. Peter probably won't remember it but (somehow) I joined up with him and some others at Marseille airport and hitched a ride to a conference we were all attending at Arles. On the way, as we passed outcrops at 120 km/h, I received my first "lecture" on the far-field effects of the Alpine orogeny. Intraplate deformation in Europe was to become one of the main guiding themes of my subsequent career, with Peter as an important mentor in the process. So that more or less covers the "timing" part of this presentation not to mention the "style", which is unique. About "controls", though, it seems that some aspects of the inversion of European basins may not be purely controlled by Alpine (Africa-Europe collision) processes but also by what was happening on other European plate boundaries. Lately, my colleagues at the University of Aarhus and I demonstrated a causal relationship between an abrupt change of European intraplate deformation style and North Atlantic continental rifting at ≈62 Ma. The rifting involved a left-lateral displacement between the North American-Greenland plate and Eurasia, which we think may actually have initiated the observed pause in the relative convergence of Europe and Africa that Peter knows well (as does Pierre). The associated stress change in the European continent was significant and can possibly explain the sudden termination of ≈20 Myr of Late Cretaceous to earliest Paleocene contractional intraplate deformation within Europe to be replaced by low-amplitude intraplate stress-relaxation features. Coincidentally, the pre-rupture tectonic stress may have been large enough to precipitate continental break-up, without the necessity of invoking a thermal mantle plume (viz. Iceland) as a driving mechanism. I'll close with some words about the Dniepr-Donets Basin (and Donbas Foldbelt) – Peter was with me on my very first visit to Ukraine in February 1992 – and how this basin was "inverted" during the same Late Cretaceous-Paleocene time frame as those further west.