Program and Keynote Abstracts

Penrose Conference

Comparative evolution of past and present accretionary orogens: Central Asia and the Circum-Pacific

THE GEOLOGICAL SOCIETY OF AMERICA®

September 4 – 10, 2011
Urumqi, Xinjiang, China

FOREWORD

The Central Asian Orogenic Belt (CAOB, also known as Altaids) is one of the largest accretionary orogens on Earth and evolved over some 800 million years from the latest Mesoproterozoic to the early Triassic. It contains a record of geodynamic processesduring major Phanerozoic continental growth. There has been much discussion about its evolution over the last 20 years, and models range from a single, giant arc system to accretion of multiple arc/backarc systems. The CAOB crust appears to comprise long chains of arcs and slices of older continental crust that extend for several hundreds to thousands of kilometers. Amalgamation of these linear crustal elements and their interactions with continental margins generated considerable Phanerozoic continental growth. Its large size from the Pacific to the Urals and its extent across many countries and language barriers has complicated orogen-wide comparisons and correlations. Current tectonic models are largely speculative, but most see analogues with modern accretionary orogens. In view of the discovery of world-class mineral deposits, a wealth of new age and isotopic data, and much improved possibilities for international cooperation, it is now timely to discuss and compare the formation of the CAOB with that of modern accretionary orogens such as the multiple arc terranes of the circum-Pacific in Indonesia, Melanesia, Taiwan, Japan, Alaska, and California. Such a multidisciplinary in-depth comparison will spur research and stimulate thinking about the CAOB tectono-magmatic evolution, new concepts for accretionary orogeny in general, and new strategies for finding mineral deposits. This meeting will thus provide a unique forum to discuss what is known about the CAOB within the context of the archetypal accretionary orogens and, at the same time, bring together Asian, Russian and Western geoscientists.

Following overview talks on the circum-Pacific orogens and components of the CAOB, key speakers will address the issue of accretionary orogeny from the viewpoint of different expertises and methodologies, and these will be discussed, and shown on posters, with all participants during a 3-day field trip across the Chinese Tianshan orogen in NW China and a subsequent 3-day meeting in Urumqi, capital of the Xinjiang Uygur Autonomous Region. Emphasis will be on process-oriented comparisons between ongoing orogeny in the circum-Pacific region and geological observations in the CAOB. We do not think that there is a single, coherent model to explain the evolution of the vast accretionary terrane of Central Asia, but this conference should lead to a clearer path of research and potential avenues of international collaboration.

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Program

Penrose Conference, 4-10 September 2011, Urumqi, China

4 September 2011:

19.00: Official opening of the Conference in the Mingyuan Newtimes Hotel, Urumqi, Chairman **Q. Wang**

Welcome address by **Academician Rixiang Zhu**, Director of the Institute of Geology and Geophysics, Chinese Academy of Sciences.

Short welcome address by **Baolin Wang**, Director of the National 305 Project Office, Xinjiang Uygur Autonomous Region of China.

Short introduction of conveners, short address of **A. Kröner** “Why do we have this conference?”

19.30-20.30: Introduction to field trip across Chinese Tianshan:

L. Shu: Tectonic evolution of the Chinese Tianshan – an overview

H. Hou: Fine crustal structure beneath the junction of the western part of the southwest Tianshan Mountains and Tarim Basin, NW China

W. Lin: Logistic arrangements for field trip and announcements.

20.30-21.30: Dinner, thereafter individual discussions over drinks.

5 September 2011:

09.00: Leave for field trip, arrive at hotel in Heshuo at ca. 21.00

21.30: Dinner

22.30: Short discussion on tectonic models for the Chinese Tianshan, Chairman **Q. Wang**

6 September 2011:

09.00: Leave for field trip, arrive at Jinxing (Golden Star) Hotel in Korla at ca. 19.30

20.00: Dinner

21.00: Presentation and discussion: **D.V. Alexeiev, G. Biske & A. Mikolaichuk**: Tectonic evolution of the Kyrgyz Tianshan.

Discussion on Kyrgyz and Chinese Tianshan, Chairman **A. Kröner**

7 September 2011:

09.00: Leave for return trip to Urumqi, arrive at ca. 21.00 at Mingyuan Newtimes Hotel

21.00: Dinner and free evening

8 September 2011:

Morning: Overview talks on accreetionary orogens of the Circum-Pacific. Chairmen **R. Seltmann, A. Kröner**

10.00-10.20 **O. Oncken**: Mountain building at ocean-continent margins - linking mass flux, mechanics, and earthquakes at the Andean margin

10.20-10.40 **J. Wakabayashi**: The rock record of long lived (>500 m.y.) orogenesis without continental collision in northern and central California

10.40-11.00 **T. Kusky**: The southern Alaska accretionary orogen: a review

11.00-11.20 **K. Wakita**: Tectonic features of the subduction - accretion orogeny in East Asia : Contribution to the correlation between two different types of orogenic belts in East Asia and Central Asia

11.20-11.40 Tea/Coffee break

11.40-12.00 **L. Teng**: Tectonic evolution of Taiwan and the Luzon Arc

12.00-12.20 **R. Hall:** The SE Asian Orogen: Will it resemble Central Asia after Australia-Asia collision is complete?

12.20-12.40 **D. Cluzel**: Geodynamic evolution of New Caledonia and New Zealand

12.40-13.00 **W.** J. **Collins**: A fundamental contrast between circum-Pacific orogenic belts and the Altaids, and other Eurasian orogens

13.00-13.20 **W. Mooney**: Accretionary orogens and the deep structure of western China from seismic methods

13.20-13.40: **R.J. Stern**: Intra-oceanic arc systems: Key petrotectonic indicators for understanding CAOB evolution

13.40-14.00 Discussion

14.00-15.00 Lunch

Afternoon: Overview talks on evolution of different parts of the CAOB. Chairmen **R.J. Stern, L. Zhang**

15.00-15.20 **D. P. Gladkochub**: The timing of Mongol-Okhotsk ocean crust subduction beneath the Siberian margin

15.20-15.40 **K. Schulmann**: Tectonic evolution of southern and central Mongolia

15.40-16.00 **W. Xiao:** Late Paleozoic to mid-Triassic multiple accretionary and collisional processes of the Beishan-Inner Mongolia orogenic collages

16.00-16.20 **S.R. Paterson:** Tectonic and magmatic evolution of three areas in the southern region of the Central Asian Orogenic Belt

16.20-16.40 Discussion

16.40-17.00 Tea/Coffee break

17.00-17.20 **S. Zhang**: Crustal structure revealed from a deep seismic reflection profile across the Solonker suture zone in Inner Mongolia, northern China

17.20-17.40 **I. Safonova**: The Russian-Kazakh Altai: An overview and main debatable issues

17.40-18.00 **D.V. Alexeiev**: Palaeozoic accretion of the Kazakhstan continent

18.00-18.20 **R. Seltmann**; Geodynamic control of ore deposits in the CAOB

18.20-20.00 Discussion

20.00-21.00 Dinner

21.00-22.30 Discussion and short contributions, **Chairman R. Hall**: Y. Tamura on Izu-Honshu collision, L. Shu on Bogda Shan, J. Mun on Uzbekistan

9 September 2011:

10.00-12.00 **Discussion Group on ophiolites and oceanic crust,** led and moderated by **J.W. Shervais and T. Kusky**. Overview talk by **J.W Shervais**: Supra-subduction zone (SSZ) ophiolites: the fore-arc connection and implications for orogenic belts

Discussion contributions: P. Jian, B. Wang

12.00-12.20 Tea/Coffee break

12.20-14.30 **Discussion Group on metamorphic rocks**, led and moderated by M. Brown and L. Zhang. Overview talk by **M. Brown**: Metamorphism in accretionary orogens

Discussion contributions: L. Zhang, Z. Lv, L. Gou, B. Wang

14.30-15.30 Lunch

15.30-17.40 **Discussion Group on magmatism, plumes and ore deposits**, led and moderated by **W. Collins and Y. Xu**. Overview talk by **A. Wurst**: Au-Cu porphyry deposits in accretionary orogens – comparing the Central Asian Orogenic Belt (CAOB) and modern examples

Discussion contributions: Y. Xu, B. Wan, A. Kröner, M. Ren, Y. Tong, Chao Yuan

17.40-18.00 Tea/Coffee break

18.00-20.00 **Discussion Group on structures, subduction kinematics**, **and geophysical data**, led and moderated by **K. Schulmann, W. Xiao and W. Mooney**. Overview talk by **A. D. Nugraha**: Seismic velocity structures of the subduction zones in western Japan and central Java, Indonesia, inferred from high-resolution tomography inversions

Discussion contributions: B. Wang, W. Lin

20.00-21.00 Dinner

21.00-22.30 Discussion and short contributions, **Chairman A. Kotov**: K. Cai, Y. Jiang, on Chinese Altai, D. Tumurhuu on Mongolian Trans-Altai, X. Long on East Junggar.

10 September 2011:

10.00-11.00 **Discussion Group on paleogeography and sedimentary basins**, led and moderated by Q. Wang and L. Teng. Overview talk by **Q. Wang**: The Carboniferous Junggar Basin in northwest China exemplifying basin evolution in the CAOB

Discussion contributions: D. He, L. Shu

11.00-14.30 **Discussion Group on isotopes and continental growth**, led and moderated by B.-M. Jahn and B.F. Windley.

11.00-11.20 **B.F. Windley**: What we have learnt (and not learnt) from the Central Asian Orogenic Belt since Sengör et al. (1993) ?

11.20-11.40 **B.-M. Jahn**: Distinct crustal development of SW and NE Japan – Sr-Nd isotopic evidence and tectonic implications

11.40-12.00 **E. Belousova**: Hf isotopes in zircons from the CAOB: Crustal evolution history and tectonic significance

12.00-12.20 Tea/Coffee break

12.20-14.30 Discussion contributions; S. Wilde, I. Sevastjano, K.-L. Wang, A. Kotov, V. Kovach, J. Gao

14.30-15.30 Lunch

15.30-17.40 Open session, chairman **W. Xiao**:

R. Armstrong; The CAOB: GIS-based reconstruction of a jigsaw puzzle in space and time

General discussion

17.40-18.00 Tea/Coffee break

18.00-20.00 General discussion: What have we learned from a comparison of the circum-Pacific with the CAOB and what are future strategies for research in the CAOB?

Discussion on publication of GSA volume. End of meeting.

21.15-23.00 Banquet in the Mingyuan Newtimes Hotel

Short discussion contributions

8 September

21.00-22.30: **General discussion on Circum-Pacific and CAOB**

Y. Tamura: Formation of continental crust at the Izu–Honshu collision zone

L. Shu et al.: Timing of initiation of extension in the Tianshan Belt: implication from structural, geochemical and geochronological analyses of bimodal volcanism and olistostrome in the Bogda Shan (NW China)

J. Mun et al.: Geodynamic-metallogenic settings of key deposits of the western Tien-Shan, Uzbekistan

9 September

10.00-12.00: **Ophiolites and oceanic crust**

P. Jian: Zircon dating of the northern and southern Tianshan mafic-ultramafic complexes

B. Wang: Tectonic significance of the ophiolitic melanges in the southern Chinese Tianshan.

12.20-14.30: **Metamorphic rocks**

L. Zhang: UHP metamorphic belt in Chinese Tianshan

Z. Lü: Coesite-bearing eclogitic rocks in western Tianshan, China

L. Gou: The syncollisional granitoid in the UHP metamorphic belt in Chinese Tianshan

B. Wang: Possible continental subduction of the Central-Middle Tianshan

15.30-17.40: **Magmatism, plumes and ore deposits**

Y. Xu: Effect of early Permian Tarim plumes on the CAOB

Y. Tong: Late Paleozoic post-collision granitoids in the Altai orogen

B. Wan: Iron mineralization associated with a major strike-slip shear zone: radiometric and oxygen isotope evidence from the Mengku deposit, NW China.

A. Kröner: Can we use geochemistry to infer tectinic settings of granitoids in the CAOB?

C. Yuan: Late Triassic NMORB-type terrestrial basalt in SW Chinese Altai: implication for lithospheric mantle of a juvenile continental block.

M. Ren: Cenozoic volcanic rocks on the northwest margin of the Junggar Basin

18.00-20.00 **Structures, subduction kinematics, and geophysical data**

B. Wang: Polyphase deformation and tectonic division of the southern part of the Tianshan

W. Lin: Tectonic evolution of the Chinese Tianshan: implications from new U-Pb age and Lu-Hf determinations of granites.

21.00-22.30 **General discussion, Chairman A. Kotov**

K. Cai: Magmatism and tectonic evolution of the Chinese Altai, NW China: insights from granites and mafic rocks in the Paleozoic.

Y. Jiang: What can we learn from the high-grade metamorphic rocks in the Altai Range?

D. Tumurhuu: Tectoniuc evolution of the Mongolian Trans-Altai

Xiaoping Long: Geochemistry and U-Pb detrital zircon dating of Paleozoic greywackes in East Junggar: Insights into subduction-accretion processes in the southern Central Asian Orogenic Belt.

X. Long: Geochemistry and U-Pb detrital zircon dating of Paleozoic greywackes in East Junggar: Insights into subduction-accretion processes in the southern Central Asian Orogenic Belt.

10 September

10.00-11.00 Palaeogeography and sedimentary basins

D. He, Q. Wang: Kinematic evolution of the Northwest margin of the Junggar Basin.

L. Shu: Implication of tectonic environment from early Permian stratigraphic sequence and sedimentary structures in the Northern Tianshan belt.

12.20-14.30 **Isotopes and continental growth**

S. Wilde: Tectonic evolution of the CAOB in NE China

I. Sevastjano, R. Hall: Detrital zircon Hf-isotope perspective on Permian-Triassic evolution of the Malay Peninsula and potential source areas for the Banda Arc sandstones

K.-L. Wang et al.: Finding microcontinents within the accretionary complexes of the Central Asia Orogenic Belt: in situ Re-Os perspectives

V. Kovach: Crust-forming events in the central part of the Central Asian Orogenic Belt

A. Kotov: Timing of the main crust-forming events in the eastern part of the Central Asian Orogenic Belt

J. **Gao**: Geochemical and geochronological studies of granitoid rocks from the Western Tianshan Orogen: implications for continental growth in the southwestern Central Asian Orogenic Belt.

Keynote Abstracts

Palaeozoic accretion of the Kazakhstan continent

Dmitriy V. Alexeiev, Geological Institute (GIN), Russian Academy of Sciences, 7 Pyzhevsky per., Moscow 119017, Russia (dvalexeiev@mail.ru)

Kazakhstan represented a major site of accretionary crustal growth during early Palaeozoic and was incorporated into Eurasia as a single continent after collisions with Siberia, Baltica and Tarim during the late Carboniferous and early Permian. The mechanism of this accretion and the geodynamic setting during different epochs are a major subject of current controversy. A synthesis of stratigraphic and structural data allows to identify allochthonous terranes, to reconstruct subduction systems and to restore a history of accretion and collisions through time.

1. *Allochthonous terranes* (arcs and microcontinents) are defined as major blocks with coherent internal lithologies and specific individual geological histories, separated from each other by ophiolite-decorated sutures. The occurrence of ophiolite fragments in these sutures implies that the terranes were previously separated by oceanic crust. 2. *Subduction systems* are reconstructed as ternary belts where a) calc-alkaline magmatism (arc) b) sedimentary basins (forearc) and c) turbidite and mélange complexes (accretionary wedge) developed synchronously within parallel domains. The relative position of the above three units suggests arc polarity. 3. *Accretionary and collisional events* are indicated by cessation of deep marine sedimentation within suture zones and cessation of volcanism in adjacent arcs, followed by formation of regional unconformities, by emplacement of granitoid batholiths and jumps of subduction-related magmatic belts. The time of suturing is also constrained by the age of overlap assemblages and stitching plutons.

An analysis of the above features for Kazakhstan and the western Tianshan Mountains allows to restore their amalgamation history during the Palaeozoic. Numerous allochthonous blocks with distinctly different histories, short-lived arcs, and non-synchronous multiple sutures all argue against a single arc evolution and support a model of numerous terranes which were welded together in an oceanic setting, similar to the present-day Indonesian archipelago.

During the earliest phases, from Cambrian to early Ordovician (535-475 Ma), tectonic accretion occurred within the Kokchetav-Kyrgyz North Tianshan belt, which represents a complex amalgamation of Precambrian microcontinental blocks, arc-related, ophiolitic and metamorphic rocks, including HP and UHP complexes, which were welded together by the end of the early Ordovician. In the middle Ordovician the east-facing Stepnyak – North Tianshan (SNT) continental arc evolved on the margin of this amalgamated domain. Collisions of the SNT arc with the Aktau-Junggar microcontinent, the Boschekul-Chingiz arc (Cm_2-O_2) and the Baidaulet-Akbastau arc (O_{1-3}) in the beginning of late Ordovician led to formation of a large, stable continental domain known as Kazakhstan continent. From the late Silurian to late Carboniferous the evolution of the eastern margin of the Kazakhstan continent around the Junggar Balkhash area was dominated by an east-facing continental arc. In the west and southwest, continental arcs evolved in the early to middle Devonian (~415-390 Ma) and in the later Carboniferous (335-300 Ma), whereas the area constituted a passive margin from the Givetian to Bashkirian. Collision of Kazakhstan with Siberia, Baltica and Tarim began at ~320 Ma, ~315 Ma, and ~300 Ma respectively.

The eastern part of Kazakhstan represents a giant orocline which was formed mainly during the late Carboniferous and early Permian as a result of the opposing movements of Siberia and Tarim, which squeezed Kazakhstan during the latest stage of collision. Structural unconformities between Devonian and early Palaeozoic structures in NE Kazakhstan as well as palaeomagnetic data indicate that some clockwise rotation along the northern limb of the orocline also took place in pre-Devonian time.

Hf isotopes in zircons from the CAOB: Crustal evolution history and tectonic significance

Elena Belousova[1], Reimar Seltmann[2], William L. Griffin[1] and Suzanne Y. O'Reilly[1]
[1]GEMOC National Key Centre, Department of Earth and Planetary Sciences, Macquarie University, Sydney, NSW 2109, Australia (elena-belousova@mq.edu.au)
[2]Center for Russian and Central EurAsian Mineral Studies (CERCAMS), Department of Mineralogy, Natural History Museum, London SW7 5BD, UK

Most mineral exploration models require an understanding of the geological evolution of the crust in the area of interest; critical information includes the timing of magmatic events and the types and sources of the magmas. In this study we combine SHRIMP U-Pb age data and Hf-isotopic information collected on individual zircon grains recovered from granitoid rocks of the Central Asian Orogenic Belt (CAOB). Hf isotopes provide information on the source of the magmatic rock from which each zircon crystallised; they tell whether the magmatism involved a juvenile source (e.g., melting of the depleted mantle, or of young mantle-derived rocks), or if only pre-existing crust was involved (i.e., crustal reworking), or if there is a combination of these processes.

The Hf-isotope data clearly define different types of terranes reflecting the nature and origin of the middle to deep crust where the younger magmas were generated. The relative homogeneity of data from some terranes, and the scatter in others, may also reflect different magmatic processes and different degrees of juvenile input.

A major period of crustal growth (juvenile input) occurred in the region from Ordovician to Triassic time (ca 470 - 220 Ma). The granitoids with evolved/crustal signatures are restricted to the southern part of the CAOB, where model ages and inherited zircon grains indicate involvement of pre-existing Proterozoic crust as old as 2.0 Ga.

The range of Hf-isotope compositions that is particularly large in the granites from the Kokchetav-Tienshan superterrane could be due to: (1) mixing between juvenile magmas and older crustal rocks, (2) dipping (non-vertical) terrane boundaries, or (3) complexity of the terranes, requiring further subdivision. Moreover, this superterrane shows an apparent transition between the juvenile Sayan-Balkhash and older crustal Tarim superterranes. The combination of geological and Hf-isotope information suggests that the juvenile Sayan-Balkhash Superterrane dips to the south or southwest.

The outcomes of this study indicate that Hf-isotope data allow "mapping" of the underlying source area, which does not always correlate with surface geology and thus provides a key to recognising different terranes at depth. This is important information in terms of exploration models that regard lithospheric boundaries as foci for mass transfer and, hence, important target areas.

Metamorphism in accretionary orogens

Michael Brown, University of Maryland, College Park, MD 20742, USA (mbrown@umd.edu)

Regional metamorphism occurs in plate boundary zones where one-sided subduction creates tectonic environments with distinctive thermal, chemical and physical characteristics. Lower thermal gradients are associated with the subducting slab whereas higher thermal gradients are characteristic of backarcs/orogenic hinterlands, which is reflected in a duality of metamorphic belts with contrasting apparent thermal gradients in the geological record. Apparent thermal gradients derived from inversion of age-constrained metamorphic *P–T* data may be used to identify tectonic settings of ancient metamorphism, to evaluate the age distribution of metamorphism in the rock record and to consider how this relates to the supercontinent cycle and the process of terrane export and accretion. Breaches in the subducting plate may occur due to subduction of a spreading ridge, thermal erosion or tearing of the slab, affecting mantle flow patterns and the characteristics of the overlying plate. In turn, this results in changes to magmatism and heat flow, and leads to extensional or transcurrent faulting. High-temperature (HT) metamorphism involving melting (upper amphibolite and granulite facies) requires a large quantity of energy because the latent heat of fusion of silicates is high (~320 kJ kg^{-1}). The heat production of granites derived by crustal melting (back calculated from the K, Th and U (HPE) content) and the bulk D for the HPE requires they be derived from sources elevated in HPE, which in turn suggests that radiogenic heat plays the key role in high-grade metamorphism and crustal melting. Ridge subduction or thickening of thin lithosphere (e.g. in backarcs) or addition of mantle derived magma, each of which has been invoked as the enabler of HT metamorphism and crustal melting, in the absence of elevated HPE, cannot provide the energy necessary to achieve regional scale granulite facies metamorphism and associated granite magmatism.

Accretionary orogenic systems may exhibit retreating trench–advancing trench cycles, associated with high (>750 ˚C/GPa) thermal gradient type of metamorphism, or advancing trench–retreating trench cycles, associated with low (<350 ˚C/GPa) to intermediate (350-750 ˚C/GPa) thermal gradient types of metamorphism, and they may involve suturing of allochthonous and/or para-autochthonous elements to continental margins at trenches. Paired metamorphic belts in which an inboard high d*T*/d*P* metamorphic belt (high *P–T* type) is juxtaposed against an outboard low d*T*/d*P* metamorphic belt (low *P–T* type) along a tectonic contact—such as the Ryoke and Sanbagawa belts in Japan—are found in Phanerozoic accretionary orogens of the circum-Pacific. Generally, they appear to result from juxtaposition of terranes with different metamorphic facies series that may or may not be exactly contemporaneous and that may or may not be far-traveled. This is an consequence of the difference between globally-continuous subduction, generating a low-to-intermediate d*T*/d*P* environment in the subduction zone and a high d*T*/d*P* environment in the arc–backarc system, and metamorphic imprints in the geological record that represent discrete ‘events’ due to changes in plate kinematics or subduction boundary dynamics, or as a result of collision of ridges, arcs, blocks/terranes, or continents with the upper plate at the trench. The concept of ‘paired’ metamorphic belts may be generalized and extended more widely than in the original proposition to terminal subduction-to-collision orogenic systems where the suture and lower plate materials will register the imprint of low-to-intermediate d*T*/d*P* and the upper plate will register penecontemporaneous high d*T*/d*P* metamorphism commonly manifested at shallow crustal levels by the occurrence of granites in the rock record.

Geodynamic evolution of New Caledonia and New Zealand

Dominique Clouzel, University of New Caledonia, Nouméa Cedex, New Caledonia (dominique.clouzel@univ-nc.nc)

New Caledonia and New Zealand represent the emerged parts of large submarine continental fragments of the Permian-Mesozoic South Gondwana margin; as such, they differ from the ridges and islands located in the eastern part of the Southwest Pacific, which mainly represent extinct or active volcanic arcs. The two islands share many geological features and especially Mesozoic endemism; however, in detail, their geological history differs by some points.

Both are located within a complex set of marginal basins that opened continuously from the Late Cretaceous to Present. The persistence of actively spreading marginal (or back-arc) basins through time is probably due to repeated subduction reversals; however, the reason why the Gondwana margin was rifted and fragmented during the Cretaceous and its fragments eventually drifted 1000’s of kilometres away from their original location remains conjectural. A back-arc origin is generally advocated, but this interpretation is questionable in view of the eastward propagation of rifting events from 120 to 89 Ma and geochemistry of the associated magmatic rock, which are consistent with the rifting of an ancient active margin.

Present New Zealand comes from the welding of the Campbell-South Island and Challenger-North Island plateaus that separated from Antarctica in Campanian time (ca. 89 Ma) and obliquely collided during the Miocene to Present, forming the Southern Alps. New Zealand is formed of two classes of terranes; Western Province terranes represent the older continental active margin of Gondwana, they consist of a fragment of Antarctica and a Permian continent-based volcanic arc (Brooke Street Terrane) that extends northward into the Lord Howe Rise and eastern Australia. The Eastern Province terranes are formed of several volcanogenic deep sea fans tectonically accreted to the Mesozoic margin before the Late Cretaceous. In between, the Median Batholith and Dun Mountain-Maitai Terrane mark the suture of one (or several) marginal basin(s). The provenance of detrital zircons in the Mesozoic accreted terranes suggests derivation from several mixed (volcanogenic and continental) sources that may be identified in Eastern Australia.

In contrast, New Caledonia’s Mesozoic terranes are mainly composed of volcaniclastic turbidites (Teremba and Central terranes), coming from an intra-oceanic arc, and an accretionnary complex (Boghen Terrane), metamorphosed into the blueschist-facies. The lack of continental components in turbidites and the geochemistry of associated volcanic rocks suggest that New Caledonia’s Mesozoic terranes formed in a fore-arc located on the eastern side of an arc-marginal basin system, in which New Zealand deep sea fans accumulated. To account for the Australian (northern) provenance of New Zealand’s terranes, an oblique closure of the marginal basin is advocated. The tectonic amalgamation was completed in mid-Cretaceous time.

In New Zealand and in New Caledonia as well, Mesozoic terranes are overlain unconformably by terrigenous sandstone that accumulated in a near-shore environment within tilted block basins. Thereafter, pelagic siliceous then carbonated sediments accumulated during Paleocene and Early Eocene thermal subsidence. In the Late Paleocene (ca. 58 Ma), a new northeast-dipping subduction appeared to the northeast of New Caledonia. This probably started near, or at a spreading ridge and generated MORB-like amphibolites (56 Ma, Ar-Ar) and a variety of dykes that formed from slab-derived and supra-subduction melts (55-50 Ma, U-Pb) and are now found in the sole and within the Peridotite Nappe of New Caledonia respectively. This Eocene subduction generated the Loyalty Arc that runs more or less parallel to the main island of New Caledonia. In the fore-arc region, the upper oceanic crust of the shallow-dipping lower plate was scrapped off and accumulated to form the Poya Terrane, whilst the same kind of mafic material was subducted to form eclogite-serpentinite mélange (Pouebo Terrane). The steepening and rollback of the slab provoked the south-westward migration of the trench that eventually reached the tip of the Norfolk-New Caledonia Ridge in the late Early Eocene. The involvement of New Caledonia in the fore-arc bulge and thereafter in the trench resulted in the formation of foreland imbricate thrusts and syntectonic basins in which detritus coming from allochthonous units accumulated. No peridotite or ultramafic mineral clast is present at that time. Meanwhile, eclogite exhumation began at 44 Ma (U-Pb zircon) and was completed at the Eocene-Oligocene boundary (34±4 Ma, apatite fiss. tracks). Finally, New Caledonia was subducted at shallow depth and exhumed rapidly, giving birth to the Peridotite Nappe.

Subduction did not stop after obduction and propagated southwards, it reached the eastern Three Kings Ridge in Oligocene time (31 Ma) and finally the northern part of North Island of New Zealand and provoked the Miocene obduction of Northland and East Cape mafic allochthons. Meanwhile, the west- or southwest-dipping Vitiaz-Fiji-Tonga subduction that had been (re)activated at ca. 45 Ma relayed the blocked east-dipping subduction and progressively reached its present location. Again, at ca. 10 Ma, the northern branch of the Vitiaz-Fiji-Tonga subduction collided with the Ontong Java Plateau, and north-dipping subduction gave birth to the New Hebrides (Vanuatu) volcanic arc. At present, the Eocene Loyalty Ridge and the Late Miocene to Recent New Hebrides Arc (Vanuatu) are close to a collision that would probably result in a major tectonic event in the next two or three million years.

A fundamental contrast between circum-Pacific orogenic belts and the Altaids, and other Eurasian orogens

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One of the defining features of the Altaids, along with many Eurasian orogens, is the intermittent arrival of continental fragments, mostly Gondwanan derived, into the orogenic system. This not only provides a major driver for collisional processes and the completion of Wilson Cycles, but it highlights the contrast with the circum-Pacific orogenic system. In the latter, continental fragments are rare and usually small, so the Wilson Cycle style of tectonics rarely occurs, and orogenic contraction and crustal thickening is probably driven by arrival at the active convergent margin, of buoyant oceanic anomalies (such as oceanic plateaus, aseismic ridges, seamount chains) located on the subducting oceanic plate. This is a fundamental contrast between the Eurasian and circumPacific orogenic systems, causing the former to be ultimately located within the interior of continents, and the latter along the continent periphery. Accordingly, Eurasian orogens like the Altaids are grouped as the internal orogenic system, whereas the circumPacific orogens are grouped as the external orogenic system. In the case of the circumPacific system, it began some 550 Ma ago and continues today as the Pacific “Ring of Fire”.

This fundamental contrast between the two orogenic systems can be observed from Hf isotopes in zircon (Collins et al., 2011, Nature Geos. 4, p.333-337). A global compilation of Hf isotope analyses (>3200 datapoints) shows that the internal (Eurasian) orogenic system describes a “fanning” Hf isotopic evolutionary array dominated by mixing between ancient (Proterozoic) crustal and depleted mantle end-members throughout the Phanerozoic. By contrast, the external orogenic system describes a “narrowing” Hf isotopic evolutionary array over the last 550 Ma.

The Hf isotope arrays for both orogenic systems are caused by global-scale differences in subduction symmetry, which controls the nature of the lower plate, potential magma sources, and orogen dynamics. Because the circumPacific subduction system is symmetrical, with general W-dipping subduction in the western Pacific and E-dipping subduction in the eastern Pacific, oceanic crust continuously generated at the East Pacific Rise is continuously subducted at opposed active plate margins on either side of the Pacific Ocean, usually without incorporation of continental fragments on that plate. As a result, ancient lower crust and subcontinental lithospheric mantle (SCLM) are progressively removed or isolated along the active margins, primarily by thermal erosion or subduction retreat (a common process), and replaced with juvenile oceanic crust. By contrast, within the internal (including Altaid and Alpine-Himalayan) system, lower crust and SCLM beneath the arcs are replaced by ancient crust and SCLM from the lower plate, usually similar (ie., Gondwanan) to that already removed during the earlier phase of ocean closure.

Similar long-term (billion year) Hf isotopic patterns can be identified for some Precambrian orogens, suggesting that these global-scale, geodynamic processes can be identified on the ancient Earth.

The timing of Mongol-Okhotsk ocean crust subduction beneath the Siberian margin

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A synthesis of geological, geochronological and geochemical data of the late Palaeozoic – Mesozoic intrusions, lavas and sediments located northward from the Mongol-Okhotsk suture allow us to conclude that subduction of the Mongol-Okhotsk oceanic crust beneath the Siberian continental margin occurred continuously since the Devonian until the early Jurassic according to the following scenario:

(1) Initially (in the Devonian), gentle subduction of oceanic lithosphere led to slab stagnation in the upper mantle zone and a decrease in the subduction rate. It caused dispersed extension and accelerated the collapse of the early Palaeozoic orogen and formation of the Tocher trough of Transbaikalia. Slab stagnation in the upper mantle resulted in an increase in density and the angle of slab dip and led to a change in the extension regime to compression.

(2) Early Carboniferous was characterized by delamination of continental lithosphere, continental subduction (A-subduction), closure of the Tocher trough and thickening of continental crust. Mantle input into the lower crust caused melting of the metamorphic protoliths and produced autochthonous biotite granites of the Angara-Vitim batholith.

(3) The late Carboniferous – early Permian phase was related to destruction of the subducted slab, roll-back towards the ocean, and formation of slab-windows. This caused extension of the continental lithosphere and magmatic mantle input into the continental crust. Moreover, early Permian subduction-related basaltoids occur in the southern part of the Siberian craton, demonstrating the long-distance influence of subduction on the Siberian continent.

(4) In the latest Permian – middle Triassic normal-angle subduction occurred close to the trench of the Mongol-Okhots ocean and low-angle subduction (with slab-window) farther from the trench, where alkaline granitoids and bimodal lavas were generated. Similar spartial relationships of igneous complexes are typical of Andean-type active continental margins.

(5) During the late Triassic normal-angle subduction continued near the trench, and low-angle subduction existed farther away. The distribution of the late Triassic igneous and volcanic complexes testifies to the beginning of Mongol-Okhotsk ocean closure in its western part where the Siberian continent collided with the Amurian continental block.

(6) In the Jurassic, a significant decrease in igneous activity occurred in Transbaikalia, northern and central Mongolia. We relate this to the end of Mongol-Okhotsk oceanic crust subduction beneath Siberia in this region. Closure of this ocean in its western part occurred between the early and middle Jurassic (Zorin, 1999) or in the late Jurassic to Early Cretaceous (Kravchinsky et al., 2002; Cogné et al., 2005).

(7) Complete closure of the Mongol-Okhotsk ocean occurred in the Early Cretaceous (Kravchinsky et al., 2002; Cogné et al., 2005). Since then all mafic intrusions of Transbaikalia demonstrate chemical features of within-plate basalts.

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The SE Asian Orogen: Will it resemble Central Asia after Australia-Asia collision is complete?

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SE Asia is a geologically complex region currently at the edge of the Eurasian continent, mainly within Indonesia. The continental margin is an active orogenic belt characterised by intense seismicity and volcanic activity. Collision with Australia began in the Early Miocene and at some stage in the distant future is likely to lead to an orogenic belt within a large continental region between Asia and Australia that may resemble the much older orogenic belt of Central Asia. I will try to describe what this orogenic belt may look like in several tens of millions of years from now so that that those who know central Asia can judge if SE Asia really is a suitable analogue for the CAOB.

SE Asia can be described in terms of small plates and multiple suture zones although the many crustal fragments may not be true plates. Subduction has been the long-term driver of tectonics. The region has a composite continental core composed of blocks rifted from Gondwana. The region was surrounded by subduction zones for much of the Mesozoic and Cenozoic and has many features of Pacific margin orogens: there has been transfer of material at subduction and strike-slip boundaries; development of back-arc basins; collision of oceanic buoyant objects, arcs, and continental fragments; and abundant magmatism. Continental growth occurred in an episodic way, related primarily to arrival of fragments at subduction margins.

I imagine that the final orogen will be composed largely of continental fragments with subordinate proportions of accreted oceanic lithosphere and arc magmatic products. Despite a long magmatic history there will be relatively little ‘new’ crust. Arcs are particularly vulnerable to destruction and disappearance. In eastern Indonesia the wide plate boundary zone includes several sutures but they may well be difficult to separate in the future. Rollback has produced major extension within the collision zone, but future contraction will eliminate most of the evidence for it.

Fine crustal structure beneath the junction of the western part of the southwest Tianshan Mountains and Tarim Basin, NW China

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As one of the most spectacular and active intra-continental mountain ranges in the world caused by the convergence of the continents, the Tianshan Mountain has complex geologic and tectonic setting. Since the Paleozoic, it has undergone a long tectonic evolution, especially reactivation in the Cenozoic. It has been taken as an object of a classical intra-continental orogeny to understand and explain the geodynamics of the mountain building process. Today, GPS velocity field results indicate that horizontal tectonic deformation of the Tianshan area occurs through the northward push-compression action of the Indian plate, and the Tianshan's crustal shortening decreases gradually from south to north. The rigid Tarim Basin plays an important role through the transformation of compressive forces from the south. However, the crustal structure of the southwestern Tianshan Mountain relative to the Tarim Basin is unclear. In order to investigate the fine crustal structure as well as the deep to shallow tectonic relations beneath the basin-range in the junction belt of the western part of the South Tianshan Mountain and Tarim basin, a deep and 121 km long ismic reflection profile was completed in 2007. This nearly S-N profile is located in the transition zone between the Tianshan Mountain and the Tarim Basin in the east of Kashi. The profile shows that the crust beneath the investigated area is divided into upper and lower crust by a strong reflective zone including 4 reflective layers within 5-7s TWT under the basin. From south to north, for upper crustal structures observed from the profile are the undeformed Kashi sedimentary basin with 10-12 km thick deposits; to the south of the junction area the Atushi anticline reveals more compression than the Kashi anticline; to the north of the junction area the South Tianshan Mountain is thrust from north to south. For the lower part of the crust, the northern margin of the Tarim Basin wedges to the north. A flat Moho reflection appears at 17s TWT with about 1s (~53-61 km from the migrated profile) variation through the S-N profile. Deformation of the Cenozoic sedimentary rocks is deeper from south to north. In the northern part of the profile, compared with continuous reflection of the Tarim basin, a discontinuous reflection of the middle and shallow crust beneath the Tianshan Mountain is weak and distorted and indicates that strong deformation occurred in this region.We explain the broad scale of north-dipping reflectors beneath the crystalline basement within the lower crust as northward-wedging of the middle and lower crust of the Tarim basin under the Tianshan Mountain. The tapered Tarim basin ends beneath the Kashi anticline. This imaged reflection fabric records the subduction polarity from the Tarim basin to the South Tianshan. Especially northward subduction in the area of the Moho is very clear. The lithosphere image of the deep structure displays a coupling relationship between the Tarim Basin and the Tianshan Mountain at lithospheric scale and reflects the process of continent-continent collision.

Distinct crustal development of SW and NE Japan – Sr-Nd isotopic evidence and tectonic implications

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The Japanese Islands represent a Phanerozoic subduction-accretion orogen developed along the western Pacific convergent margin. The formation of the Japanese Islands, particularly SW Japan, has been taken as a classic model of accretionary orogeny. According to Maruyama (1997), the most important cause of the orogeny is the subduction of an oceanic ridge, by which the continental mass increases through the transfer of granitic melt from the subducting oceanic crust to the orogenic belt. Sengör and Natal'in (1996) named the orogenic complex the "Nipponides", consisting predominantly of Permian to Recent subduction-accretion complexes with very few fragments of older continental crust. These authors pointed out the resemblance in orogenic style between SW Japan and the Altaids or Central Asian Orogenic Belt (CAOB). However, the granitoids from SW Japan have high initial $^{87}Sr/^{86}Sr$ ratios (0.705-0.713), negative $\varepsilon_{Nd}(T)$ values and Proterozoic Sm-Nd model ages (1000-2000 Ma). These data are in strong contrast with those of two celebrated accretionary orogens, the CAOB and Arabian-Nubian Shield (ANS), but are comparable with those observed in SE China and Taiwan, or in classical collisional orogens in the European Hercynides and Caledonides. Despite the well-documented subduction-accretion complexes in Japan, the isotopic data dictate that the granitoids were mainly produced by remelting of Proterozoic rocks, overlain by the accretionary complexes in SW Japan. However, the isotopic data support the idea of Isozaki (1996) and Maruyama et al. (1997) that the proto-Japan (SW Japan) was initially developed along the southeastern margin of the South China Block.

On the other hand, the crustal and tectonic development of NE Japan (and Hokkaido) appears to be highly distinct from SW Japan as inferred from the highly contrasting Sr-Nd isotopic characteristics of granitoids. The low $^{87}Sr/^{86}Sr$ ratios (<0.705), positive $\varepsilon_{Nd}(T)$ values and young model ages (400-1000 Ma) in the granitoids of NE Japan indicate that its bulk crust is much more "juvenile" than that of SW Japan. The granitoids from NE Japan are mainly of TTG (tonalite-trondjemite-granodiorite) or adakitic composition. The broad similarity in the age distribution (Cretaceous-Paleogene) of felsic magmatism, the occurrence of Jurassic accretionary complexes and the presence of local Paleozoic continental fragments (S. Kitakami) in NE Japan and the Sikhota-Alin belt suggests a possible link between them. In this scenario, NE Japan was not related to SW Japan in the initial development of proto-Japan. It is speculated that NE Japan and the Sikhota-Alin belt constituted the same tectonic unit from the Jurassic to Paleogene.

The southern Alaska accretionary orogen: a review

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Southern Alaska is a convergent margin accretionary orogen underlain by a complex collage of accreted terranes, including the Wrangellia superterrane (consisting of the Peninsular, Wrangellia, and Alexander Terranes), and farther outboard, the Chugach-Prince William superterrane. During much of the Mesozoic, the two superterranes formed a magmatic arc and accretionary wedge, respectively, above a circum-Pacific subduction zone. The Border Ranges fault forms the boundary between the Wrangellia and Chugach-Prince William superterranes; it initiated as a subduction thrust but has been reactivated in various places as a strike-slip or normal fault. On the Kenai Peninsula the Chugach terrane contains two major units. Farther inboard lies the McHugh complex, composed mainly of basalt, chert, argillite and greywacke mélange, as well as several large circa 227-228 Ma ultramafic/mafic massifs interpreted as remnants of the offscraped subducting oceanic plate or as forearc ophiolites representing the initiation of subduction. Fossil radiolarians from McHugh cherts throughout south-central Alaska range in age from Middle Triassic to mid-Cretaceous. The interval during which the McHugh complex formed by subduction and offscraping / accretion is not well known, but probably spanned most of the Jurassic and Cretaceous. The McHugh has been thrust seaward on the Eagle River/Chugach Bay fault over a relatively coherent tract of trench-fill turbidites, assigned to the Upper Cretaceous Valdez Group. There is a significant change in structural style between mélanges of the McHugh Complex, and coherent accreted tracts of flysch of the Valdez Group, likely related to initial offscraping from a poorly-sedimented oceanic plate (McHugh Complex), to a thickly sedimented oceanic plate (Valdez Group), after collision, uplift, and erosion of the Wrangellia terrane after it collided with North America in the Upper Cretaceous. Accretion continued through the Cenozoic with the growth of the Prince William “terrane” outboard of the elusive Contact fault, forming extensive tracks of greywacke turbidites known as the Orca Group. The modern accretionary wedge continues to grow in the submarine realm above the Aleutian trench. After the protracted episode of subduction-accretion that built the Chugach terrane, the accretionary wedge was cut by a series of granititod rocks that formed unusually close to the trench. These near-trench intrusive rocks, assigned to the Sanak-Baranof plutonic belt, are probably related to ridge subduction where a mid-ocean ridge system interacted with the trench-forearc system.

Accretionary orogens such as the Southern Alaska margin and the Central Asian Orogenic Belt (CAOB) are characterized by alternating belts of structurally complex turbidites, mélange, ophiolites, exotic blocks, gneiss, and suites of mafic-felsic magmatic rocks of uncertain significance. Some of these magmatic belts may be remnants of arcs that intruded the wedge during progradation of the wedge, and characterized by magmatic fronts that are virtually the same age everywhere along strike. Some other magmatic belts may be accreted oceanic arc sequences. Still other magmatic belts may be induced by passage of a ridge triple junction like in southern Alaska, with magma intruding the forearc as a result of magmas from the slab window melting and mixing with shallow level accretionary prism material. These magmatic belts are characterized by diachronous migration of many features, including active magmatism, anomalous structural deformation, heating, mineralization, sedimentation, and a possible change in kinematics of the wedge before and after ridge subduction, as different plates with different plate convergence vectors are interacting before and after ridge subduction. Ridge subduction is recognized as an important process in the generation of the Sanak-Baranof belt in Alaska, and several belts in the CAOB. Recognition of other belts as ridge-subduction related could dramatically change the tectonic models for the evolution of these orogens.

Accretionary orogens and the deep structure of western China from seismic methods

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The deep crustal structure of western China provides insights into the evolution of accretionary orogens. Western China has been investigated in the past several decades with multiple geophysical techniques, including gravity, magnetic, magnetotellurics, seismic surface waves and receiver functions, seismic reflection profiles, and seismic refraction/wide-angle reflection profiles. Here we review new results obtained by the latter technique, compare with previous results, and discuss the implications for the tectonic evolution of western China.

Northern Margin of the Tibetan Plateau

The northern margin of the plateau has been examined with a seismic refraction/wide-angle reflection profile across the Altyn Tagh Range and its adjacent basins. We find that the crustal velocity structure and its compositional interpretation sharply change beneath the Cherchen fault, i.e. ~100 km north of the northern margin of the Tibetan plateau. North of the Cherchen fault, beneath the Tarim basin, a platform-type crust is evident. In contrast, south the Cherchen fault the crust is characterized by a missing high-velocity lower-crustal layer. The high topography (~3 km) of the Altyn Tagh Range is supported by a wedge-shaped region of 7.6-7.8 km/s that we interpret as a zone of crust-mantle mix.

The central Qaidam basin, the largest basin within the Qinghai-Tibetan plateau, has been investigated with a detailed seismic wide-angle reflection/refraction profile. The 350-km- long profile extends from the northern margin of the East-Kunlun Shan to the southern margin of the Qilian Shan. The P- and S-wave velocity structure and Poisson’s ratio data provide constraints on composition. The crust here consists of a near-surface sedimentary layer and a four-layered crystalline crust having several significant features. (1) The sedimentary fill of the Qaidam basin reaches a maximum thickness of 8 km, and the basin shape mirrors the uplifted Moho. (2) Low-velocity zones with a 3-5% reduction in seismic velocity are detected in the lower half of the crust beneath the Qaidam basin and its transition to the Qilian Shan.

The Northeastern Tibetan Plateau (Tarim Basin to Sichuan Basin)

\We have obtained a deep crustal section across the northeastern Tibetan plateau based on active-source seismic data. Our profile was recorded along a 1600-km-long profile crossing the southern Tarim basin, the western flank of the South-Qilian Shan, the northeastern margin of Qaidam basin, East-Kunlun Shan, Songpan-Ganzi terrane, and Sichuan basin. The crustal P- and S-wave velocity structure and Poisson’s ratio outline the seismic characteristics of the crust and provide constraints on the crustal composition. The derived crustal cross section shows several significant features. The crustal thickness varies considerably along this profile. North of the Kunlun fault variations in crustal thickness and topography correlate well. The crust thickens from 48 km below the Tarim basin to 70 km beneath the northeastern margin of the Qaidam basin, and then thins to about 56 km beneath the eastern flank of the Qaidam basin. The crust thickens to 70 km beneath the East-Kunlun Shan. Across the Songpan-Ganzi terrane, the crust steadily thins from 70 km just south of the Kunlun fault to 48 km beneath the Sichuan basin, despite the fact the topography remains constant across the Songpan-Ganzi terrane and then abruptly drops by 3.5 km from the elevated Longmen Shan into the low lying Sichuan basin. We discuss these results in terms of the evolution of accretionary orogens.

Seismic velocity structures of the subduction zones in western Japan and central Java, Indonesia, inferred from high-resolution tomography inversions

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Japan and Indonesia are located in high seismicity and active tectonic zones. Understanding the seismic structure beneath these two places is very important for earthquake hazard mitigation purposes. In this study, we used high-resolution tomography inversions to determine P- and S-wave velocity structures in the western part of Japan and in central Java of Indonesia in order to investigate subduction zone structures and geological features in relationship to shallow seismicity and arc-volcanism in the region.

For the western part of Japan, our tomography results clearly depict the high velocities associated with the subducting Philippine Sea plate from local velocity increases of ~10-15 %. We also found a high Vp/Vs ratio parallel to, and may be above, the slab with a thickness of ~10-20 km that may correspond to high pore fluids that are released from the dehydration process within the slab. The high Vp/Vs characteristics are also clearly imaged beneath active volcanic regions in eastern Kyushu at a depth of ~20-30 km. This is interpreted as being associated with hot material or fluid-like material.

In central Java, our high resolution tomography results show a high velocity subducting slab beneath the region. A low velocity anomaly and a high Vp/Vs value of about 1.9 are observed under the active volcanic area and are interpreted to be associated with the path of partial melting migration resulting from the subduction processes.

Mountain building at ocean-continent margins – linking mass flux, mechanics, and earthquakes at the Andean margin

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Long-term accumulation of deformation at convergent plate margins is known to be dominated by the principal style of mass flux: accretionary versus erosive. While the general mechanisms controlling these mass flux styles are gradually emerging from global research on plate margins, the relation to the much shorter term processes of seismic cycle deformation – the most obvious manifestation of active subduction in forearc systems – remains intriguing, but poorly understood. In the global forearc system, deformation is recently identified to be highly discontinuous and transient in nature: silent slip events, non-volcanic tremors, afterslip, fault coupling and complex response patterns of the upper plate during a single event as well as across several seismic cycles have all been observed in various settings and combinations. Segments of convergent plate margins with high recurrence rates and at different stages of the rupture cycle like the Chilean margin offer an exceptional opportunity to study these features and their interaction resolving behaviour during the seismic cycle, over repeated cycles and over millions of years. A past (TIPTEQ) and an active international initiative (IPOC; Integrated Plate Boundary Observatory Chile) address these goals with research groups from IPG Paris, Seismological Survey of Chile, Free University Berlin, Potsdam University, Hamburg University, IFM-GEOMAR Kiel, GFZ Potsdam, and Caltech (USA) employing an integrated plate boundary observatory and associated projects.

We focus on the south Central Chilean convergent margin and the North Chilean margin as natural laboratories for an accretionary versus an erosive margin under nearly identical plate kinematic conditions – hence allowing to identify crucial intrinsic driving mechanisms. Here, major recent seismic events have occurred (south Central Chile: 1960, Mw = 9.5; 2010, Mw = 8.8; North Chile: 1995, Mw = 8; 2001, Mw = 8,7; 2007; Mw: 7,8) or are expected in the very near future (Iquique, last ruptured 1877, Mw = 8,8) allowing observation at critical time windows of the seismic cycle. Seismic imaging and seismological data have allowed us to relocate major rupture hypocentres and to locate the geometry and properties of the locked zone in both areas. The reflection seismic data exhibit well defined changes of reflectivity and Vp/Vs ratio along the plate interface that can be correlated with different parts of the coupling zone as well as with changes during the seismic cycle. Moreover, some aspects of short term properties may be related with the long-term mass flux processes. Geophysical and geodetic observations suggest an important role of the hydraulic system, and of lateral variation of locking on subsequent rupture and aftershock distribution as evidenced by the recent Maule earthquake.

Neogene surface deformation in Chile has been complex exhibiting tectonically uplifting areas along the coast driven by interseismically active reverse faulting. In addition, we observe coseismically subsiding domains along other parts of the coast. Moreover, the coseismic and interseismic vertical displacement identified is not coincident with long-term vertical motion that probably is superseded by slow basal underplating (southern Chile) or tectonic erosion (northern Chile) occurring at the downdip parts of the seismogenic zone causing discontinuous uplift. Our reconstruction clearly indicates that the Central Andean trench has always been underfilled with less than 500 m of sediment. In southern Chile, in contrast, our data illustrate a similar trend during most of the Cenozoic with a shift around some 6-7 Ma to substantial sediment influx resulting from glaciation of the Patagonian part of the Andean Cordillera. As a consequence, backarc shortening slowed or stopped at this latitude, while shortening velocity in the Central Andes was still accelerating. Analogue and numerical modelling lend additional support to the kinematic patterns linking slip at the seismogenic coupling zone and upper plate response in forearc systems. Finally, we note that the characteristic peninsulas along the South American margin constitute stable rupture boundaries and appear to have done so for a protracted time as evidenced by their long-term uplift history since at least the Late Pliocene that points to anomalous properties of the plate interface affecting the mode of strain accumulation and plate interface rupture. In summary, the climatically-controlled sediment flux into the trench and the subduction channel as well as the associated hydraulic properties of the latter and the overlying upper plate appear to be the dominating parameters affecting mass flux patterns and the response styles of the overlying plate.

Tectonic and magmatic evolution of three areas in the southern region of the Central Asian Orogenic Belt

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Below we summarize research conducted in three areas, separated by >2000 km along the southern margin of the Central Asian Orogenic Belt (CAOB), which from more “inboard” to more “outboard” include: 1. The northern margin of the North China craton (NCC) near Siziwangqi, China; (2) the Gobi-Tienshan Intrusive Complex, southwest Mongolia; and (3) marine sediments and volcanic rocks in the Ulanhot area, China.

Along the northern margin of the NCC, we mapped a north-vergent fold and thrust belt with local sheath folds in passive margin quartzites, thin phyllites and rare marbles overlying Precambrian crystalline basement. The quartzites have detrital zircon ages > 1.2 Ga, with a large peak at 1.6-1.8 Ga and a smaller peak at 2.45 Ga. These passive margin units are thrust northward over the ~448 Ma Bainaimiao arc (Liu, 2010). Here the arc consists of a variety of volcaniclastic and flow units of basaltic to rhyolitic compositions and associated with marine sediments. These rock types plus the variable chemistries and xenocrystic zircons reported by Liu (2010) indicate that this was a fringing oceanic arc that received continental detritus during arc formation. All arc units experienced greenschist-facies metamorphism and deformation, resulting in steeply dipping structures that formed between ~440 and 270 Ma, presumably prior to and during final amalgamation with the NCC. The craton margin is intruded by Carboniferous (305-354 Ma), calc-alkaline and Permo-Triassic (285 to 235 Ma), late tectonic, high-K, two-mica ± garnet plutons. SE-dipping magmatic to local subsolidus fabrics occur in the latter plutons and are consistent with N-directed thrusting, indicating that late thrusting during final closure occurred around 250 Ma. Molasse basins to the south have detrital zircon populations with minimum ages of 271 Ma, a broad age spectrum from 271-418 Ma, no zircons with ages between 418 Ma to 1.9 Ga, and older zircons defining age peaks at 1.9 and 2.45 Ga. These data are compatible with (a) formation of a passive margin sequence derived from a NCC source, (b) N-vergent thrusting of this sequence during collision of a fringing oceanic arc with the NCC (~250 to > 300 Ma) during subduction, and (c) ~15 km of exhumation of the Carboniferous arc (Shuan-Hong Zhang et al., 2009) with erosional material deposited in nearby molasse-filled basins during which widespread high-K plutons were emplaced.

Based on our new field mapping, zircon U-Pb geochronology and isotope data, the Gobi-Tienshan Intrusive Complex (GTIC) in southwestern Mongolia is a 295-290 Ma, voluminous batholith of intermediate composition generated by subduction (Economos et al., in press). It was subsequently tilted and now exposes a largely intact arc crustal section consisting of, from shallow to deep, surface volcanic rocks, large hypabyssal felsic plutons, large enclave-bearing granodiorites and midcrustal (~15 km) plutons with variable sizes, shapes and degrees of mingling. Steeply dipping mafic dikes occur at all crustal levels and throughout the magmatic history. Structural studies of the host rocks are in their infancy: magmatic structures change from early steep-sided plutons, steep NE-SW fabrics and steep dikes to shallowly dipping granite sheets and magmatic fabrics supporting a change from NW-SE shortening and NE-SW extension to vertical shortening. Vergence is not well constrained. Final amalgamation is thought to have occurred ~290-300 Ma. In the GTIC, as well as Carboniferous and Permian plutons across the Tianshan, isotopic signatures remain constantly primitive. Permian plutons show an increase in radiogenic Sr with no concurrent decrease in radiogenic Nd, which may be due to the influence of subducted continental sediment in the early Permian.

In the Ulanhot area, deformed quartzites and phyllite and arc volcanic rocks define a north-vergent fold-and-thrust belt that is intruded by weakly deformed 240-252 Ma plutons and unconformably overlain by weakly deformed Mesozoic volcanic rocks (135 Ma at unconformity) and local sediments. Strain intensities increase dramatically towards the base of ductile thrusts where strains increase to >600 % lineation-parallel extension and 85 % foliation-perpendicular shortening. A deformed rhyolite involved in the thrusting gave an age of 288 Ma. Permian sediments, also involved in the thrusting, have detrital zircon ages ranging from 270 to 390 Ma and some scattered single zircons between 0.4-2.8 Ga. Weakly deformed Cretaceous sediments above the unconformity have a broad detrital zircon age peak from 140-340 Ma and scattered zircon ages between 0.4-2.67 Ga. A 132 Ma granite dike cuts one thrust fault and is interpreted to be a feeder to the overlying rhyolitic units in the volcanic rocks. Our studies to date indicate that this region consists of marine sediments and an oceanic arc that underwent north-vergent thrusting between ~280-240 Ma and was then intruded by late to post-thrusting, high-K plutons at ~250 Ma. Uplift and erosion followed. Subsequently, Mesozoic volcanism ensued, resulting in an unconformity with an ~105 m.y. age gap. Minor deformation, including some extensional faulting, affected these Mesozoic units.

All three regions share evidence for large-scale Permian shortening, often in north-vergent systems resulting in amalgamation of both continental and oceanic materials to the northern edge of the NCC. Final amalgamation (>300 to ~250 Ma) was associated with both subduction-related magmatism (GTIC and NCC) and late- to post-amalgamation high-K magmatism (all three areas). Detrital zircon ages are consistent with sediments being derived from NCC sources and from exhumation and nearby redeposition of 270 to 440 Ma arc materials.

The Russian-Kazakh Altai: An overview and main debatable issues

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The Russian-Kazakh Altai is part of the Central Asian Orogenic Belt (CAOB), located between Kazakhstan and Siberia. It is a collage of oceanic, accretionary, fore-arc, island-arc, and continental margin terranes of different ages, separated by strike-slip faults and thrusts. The three major tectonic components of the Russian-Kazakh Altai are: (1) Altai-Mongolian terrane (AMT); (2) Subduction-accretionary (Rudny Altai, Gorny Altai) and collisional (Kalba-Narym) terranes; (3) Kurai, Charysh-Terekta, North-East, Irtysh and Char suture-shear zones (SSZ). The AMT begins between the Gorny Altai and Rudny Altai terranes and extends to the Chinese and Mongolian Altai. It is dominated by late Neoproterozoic metasediments such as rhythmically bedded quartz-feldspar and polymictic sandstones as well as siliceous and phyllitic shales (Dergunov, 1989). The rocks are isoclinally folded and overlapped by Ordovician-early Silurian grey marine sediments and Early Devonian island-arc units. The Gorny Altai terrane is located between the Charysh-Terekta and Kurai SSZs and consists of late Neoproterozoic to Cambrian oceanic, island-arc, accretionary wedge (with OPS, ophiolites, eclogites), fore-arc, and back-arc units, overlain by Ordovician-Early Devonian passive margin and Devonian to early Carboniferous active margin units. The Rudny Altai terrane is situated between the Irtysh and North−East SSZs and consists of (i) pre-Devonian metamorphic schists and metasediments; (ii) Middle Paleozoic (?) oceanic crust overlain by early Emsian fore-arc sediments; iii) Devonian island-arc units including volcanic and terrigeneous rocks and reef limestones. The Kalba-Narym terrane is located between the Char and Irtysh SSZs and consists of Late Devonian–early Carboniferous passive margin sediments intruded by early Permian granitoids. The Charysh-Terekta SSZ of middle Paleozoic age separates the AMT and Gorny Altai. It includes late Cambrian-Early Ordovician oceanic crust (Safonova et al., 2004) and island-arc units of the Paleo-Asian Ocean (PAO), early Paleozoic accretionary complexes, turbidites and HP rocks. Most tectonic reconstructions on the CAOB consider its oceanic units as fragments of the PAO. The Altai tectonic collage formed during four major phases: (i) Late Neoproterozoic to early Paleozoic subduction-accretion; (ii) Ordovician-Silurian passive margin; (iii) Devonian-Carboniferous active margin; (iv) late Paleozoic closure of the PAO and collision of the Kazakhstan and Siberian continents, accompanied by strike-slip faulting and deformation (Buslov et al., 2001).

The age and nature of the basement of the Russian-Kazakh Altai is still under debate. Precambrian metamorphic rocks in the Kazakh Altai were mentioned by Yakubchuk (1997). Buslov et al. (2001) suggested several Gondwana-derived microcontinents in the western CAOB, including the Altai-Mongolian microcontinent (AMT). U-Pb zircon ages of 1450 Ma in the Kurchum block (Rudny Altai) and of 1500 and 1800 Ma in the Irtysh SSZ (Kazakh Altai) were reported by Bespaev et al. (1997). Kruk et al. (2011) discussed whole-rock Nd isotopic data and model ages for Neoproterozoic-middle Paleozoic rocks of the Russian Altai, suggesting 70-75 % of juvenile crust. Glorie et al. (2011) reported U-Pb zircon ages for the Russian Altai which are mostly late Neoproterozoic-early Paleozoic. For the Chinese Altai, Hu et al. (2002) discussed Precambrian ages of metamorphic rocks, but pointed out that many zircon ages and Nd model ages are dubious. Later, Chinese scientists (e.g., Sun et al., 2008; Long et al., 2010) reported many U-Pb ages and Hf isotope data for the Chinese Altai, which disprove a Precambrian microcontinent and suggest a large amount of juvenile crust. It is obvious that the existence of Precambrian Gondwana-derived terranes and proportion of juvenile versus recycled crust in the Altai is still under discussion and require more U-Pb, Sm-Nd and Lu-Hf isotopic studies.

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Geodynamic control of ore deposits in the Central Asian Orogenic Belt

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An overview is given on the geodynamic and metallogenic evolution of past and present accretionary orogens of the CAOB that have a large endowment of different types of mineral deposits. The diversity in style and timing of mineralization appears to be a direct consequence of different lithosphere-asthenosphere processes during the evolution of accretionary orogens where differences in arc architecture affect the mineral endowment. Over the last decade increasing specialization has caused the knowledge gap between lithospheric processes versus asthenospheric processes to widen, and interdisciplinary research has missed to bridge it adequately and to keep pace. The necessary holistic view of crustal growth processes, mantle dynamics and crust-mantle interaction has suffered in the literature from some decoupling of plate tectonic processes (rifting – spreading - subduction – accretion – collision cycles) from (post-collisional) anorogenic (within-plate) or plume tectonics (Xiao et al., 2008, Pirajno et al., 2009). Too little attention has been paid to interconnect such studies, facts and processes, and some concepts developed two-three decades ago hinder mineral exploration rather than help successful exploration targeting for a variety of deposit types. For example, some mineral deposits classified as “orogenic” actually qualify much better as non-orogenic and related to trans-crustal shear zones and dilational jogs controlled by processes of the subcrustal lithospheric mantle. The close temporal and spatial relationship (contemporaneous development) of giant intrusion-related gold deposits in the Southern Tienshan (Muruntau, Zarmitan) with diamondiferous lamproites and carbonatites (Karashokho, Chagatai) are evidence for post-collisional crustal extension folowing orogenic collapse. High-heat flow (thermal aureoles) and noble gas data indicate mantle input. Giant on a first glance arc-related ore districts such as Oyu Tolgoi in Mongolia, Aktogai in Kazakhstan or Almalyk in Uzbekistan are controlled by tectonic elements that cross-cut the hosting arc. Aktogai and Muruntau are reportedly located above zones of seismic transparency, interpreted to indicate heat-matter flux from the mantle and causing the generation of giant, though crustal-dominated magma-ore systems. In consequence, supergiant mineral deposits appear to be controlled by atypical orogenic processes (Seltmann & Porter, 2005). Addressing these relationships properly and to catalyse a paradigm change requires to take into account an inventory of robust facts using modern micro-analytical, thermochronology, noble gas and isotope studies as well as geophysical data.

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Supra-subduction zone (SSZ) ophiolites: the fore-arc connection and implications for orogenic belts

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Ophiolites are distinct assemblages of submarine volcanic and plutonic rocks that include cumulate dunite, wehrlite, and gabbro, as well as isotropic gabbro and diorite, and peridotite tectonite, representing the underlying refractory mantle. They were originally thought to represent oceanic crust formed at mid-oceanic spreading centers, but their connection with island arcs has become increasingly apparent ever since it was proposed by Miyaashiro (1973). Recognition that ophiolites are not normal arc assemblages, but form during unique, transient episodes of arc formation, has led to the concept of supra-subduction zone (SSZ) ophiolite (Pearce et al., 1984; Pearce, 2003). SSZ ophiolites display a consistent development history from birth through death that implies a common origin and evolution in response to systematic, non-random processes (Shervais, 2001).

A review of modern volcanic rocks formed at mid-ocean ridges and back-arc basins shows that they have a limited range in major element compositions and trace element systematics that range from depleted ("normal") to enriched MORB, in which ratios of fluid-mobile LFS elements to fluid-immobile HFS elements are relatively constant. In contrast, volcanic rocks formed within regionally-extended fore-arcs (which may also form the basement of later arc complexes) have a wider range in major element compositions and trace element systematics that are depleted in the HFS elements and enriched in fluid-mobile LFS elements (Metcalf and Shervais, 2008).

Most ophiolite volcanic suites are dominated by major and trace element systematics that are identical to those displayed by fore-arc volcanic suites, including the occurrence of boninites, which are only found within forearc settings. These systematics are consistent with fluid-enrichment of the mantle source region that had seen a prior extreme melt depletion event. Some ophiolites display more complex relations, with both SSZ and MORB or BAB-like compositions, but the SSZ components are generally dominant ((Metcalf and Shervais, 2008; Whattam and Stern, 2011)

These observations of volcanic rock chemistry are reinforced by recent studies of mantle peridotite tectonites that underlie ophiolites. These studies show that ophiolite tectonites are strongly depleted in HFS and rare earth elements, requiring extensive melt extraction, and enriched in fluid-mobile elements, requiring a significant fluid flux that can only be sustained in a supra-subduction zone setting (Choi et al., 2008a; Jean et al., 2010). This conclusion is enforced by isotopic studies, which document subduction-enriched isotopic compositions of Sr and Pb in SSZ ophiolites (Choi et al. 2008b). We conclude that ophiolites provide an analogue to modern fore-arc settings, and that their position in the upper plate of a subduction zone leads to their preferential emplacement by obduction onto passive continental margins, or by accretionary uplift along continually active margins.

Emplacement may occur when the extended fore-arc over-rides a passive continental margin (*obduction*) or in response to the formation of a subduction accretionary complex. In the former case, the ophiolite may overlie an *obduction mélange* of imbricate thrust sheets composed of passive margin sedimentary rocks and rift-related volcanics (e.g., ocean island alkali basalts, fringing limestone reef complexes). Examples include the Hawasina Formation nappes and Haybi mélange (Oman) and the Mamonia Complex (Cyprus). Pericollisional ophiolites are a subset of obducted ophiolites in which the subduction zone encounters a promontory or salient first, pinning that sector of the subduction zone in place, and allowing rapid extension of the fore-arc crust into the re-entrant. In the latter case (subduction accretion), the ophiolite will overlie a *subduction mélange* composed of trench sediments and off-scraped oceanic crust. The classic example of this setting is the Coast Range ophiolite/Franciscan mélange complex in California (Shervais et al., 2004; 2005; 2011).

In both the emplacement scenarios discussed above, significant deformation may occur that predates, and is unrelated to, any continent-continent collision that may occur later. This has significant implications for understanding the tectonic history of an orogenic belt, which may include a number of discrete orogenic deformations that are unrelated to one another in space or time. In addition, the occurrence of an SSZ ophiolite within an orogenic belt implies the former existence of an ocean basin and subduction zone, but the ages of the rocks involved may predate collisional orogeny and document a complex pre-collisional history.

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Tectonic evolution of the Chinese Tianshan — An overview

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The sub-E-W-trending Chinese Tianshan belt (TS in short), situated between the Siberian and Tarim blocks, occupies an important position in the CAOB and is a key to understand Paleozoic tectonic evolution of Central Asia even if several controversial evolutionary models still exist. Tectonically, the Chinese TS can be divided into three sub-belts: Southern, Central and Northern TS by the TS Main fault and the Heiyingshan-Wuwamen-Hongliuhe fault; the NE-trending Urumqi-Korla fault divides this belt into the gentle eastern and the steep western segments, namely, Western TS and Eastern TS. In the Western TS, the wedge-shaped Yili block occurs between C-TS and N-TS. Pre-Triassic sequences are widely developed in the entire TS.

Permian rocks consists of conglomerates, muddy-sandy sediments and bimodal volcanic rocks, intruded by granitoids and mafic dike swarms; the Carboniferous is composed of arc-volcanic rocks dated at 310-340 Ma in the Yili-N-TS and muddy-sandy sediments and carbonates in the C-TS and S-TS; Devonian rocks consists of muddy-sandy sediments and carbonates in the C-, S-TS and, locally, volcanic rocks in the Yili-N-TS; Silurian rocks consist of slaty turbidites or muddy-sandy flysch sequences in the C-S-TS and locally volcanic rocks in the Yili block; Ordovician deposits consists of a basalt-andesite suite dated at about 470 Ma; locally mafic-ultramafic rocks are dated at 470-480 Ma in the C-TS, whereas only muddy-sandy sediments and carbonates occur in the N-TS; the Cambrian is represented by a carbonate- muddy-sandy sedimentary assemblage in the entire TS. Precambrian rocks are very complex and consist of various phyllites, schists as well as para- and ortho-gneisses derived from muddy-sandy rocks and igneous rocks dated at 2.5 to ～0.7 Ga.

Four distinct angular unconformities indicate polyphase tectono-thermal events that are marked by (1) a D3-C1 red molasse sequence in the C-TS and S-TS, (2) P1 or P2 red and thick molasse in the entire TS, (3) T3 coarse-grained detrital rocks in the entire TS and (4) Neogene red beds and coarse-grained detrital rocks. Locally A K1 unconformity occurs locally around the Tarim basin.

Six key petrotectonic indicators suggesting polyphase tectono-magmatic events can be observed in the Chinese TS, including (1) several zones (N-, S- and Main TS zones) of ophiolitic mélanges, (2) two episodes of arc-magmatism, (3) two zones of HP metamorphic rocks, (4) three zones of distinct ductile shearing, (5) post-collisional rift-type volcanic rocks and (6) two episodes of post-orogenic granitoids.

Geochemically and geochronologically, the N-zone (Kelamaili zone) of ophiolitic mélanges shows N-MORB type features for mafic-ultramafic rocks with a radiolarian age of D3-C1. Mafic rocks of the Main TS zone display N-MORB patterns and contain abundant fossils dated at O-S in the Mishigou ophiolitic section. The ophiolitic rocks in the S-zone (Hongliuhe-Kumux-Heiyingshan) were dated at 425±8 and 392±5 Ma (U-Pb) and D3-C1 (radiolarians in chert). Also, there exist several ophiolitic zones not related to subduction, i.e., the inter-arc Alaskan-type Huangshan zone in Hami City and the intra-oceanic MORB- or OIB-type Darbut Zone in the western Junggar basin.

There were two episodes of arc-magmatism. The older episode is characterized by Ordovi-cian-Silurian arc-volcanic rocks and granites in the C-TS dated (U-Pb zircon ages) at 481±17, 477±18, 466±10, and 428±10 Ma. The younger episode is represented by Carboniferous arc-volcanic rocks and granites in the N-TS, dated (U-Pb zircon ages) at 341±6, 338±8, 313±4, 334±2, 345±3, and 325±7 Ma .

Two zones of HP metamorphic rocks are shown by (1) the Yushugou granulite with protolith zircon ages of 390±11 and 392±7 Ma, and a peak metamorphic Ar-Ar age of 368±5 Ma, and (2) the Kaerkeshan Carboniferous eclogite-blueschist with Ar-Ar ages on muscovite of 310, 323±1 and 316±2 Ma.

Four zones of ductile shearing in schists as well as para- and orthogneisses are widely distributed and show a dominant strike-slip and, locally, previous thrust deformation. They are (1) the Erqishi sinistral strike-slip zone dated at 290-250 Ma (Ar-Ar) in the southern Altay belt, (2) the N-TS shear zone that contains a north-vergent thrust (320-305 Ma) and dextral strike-slip shearing (255-235 Ma), (3) the Main TS dextral strike-slip zone (280-245 Ma), and (4) the S-TS zone with a distinct north-vergent thrust (370-355 Ma) in the Eastern TS.

Post-collisional rift-type bimodal volcanic rocks dated as early Permian (296±3 Ma to 272±4 Ma) are well developed in the entire Chinese TS, especially in the southern Bogda Mts. of N-TS. Furthermore, two episodes of post-orogenic granitoid emplacement (D3, P1) were recently identified. For example, a peraluminous granite intruding O-S volcanic rocks in the C-TS yielded a zircon age of 368±9 Ma, whereas peraluminous granitoids intruding the C2 basalt-andesite series in the N-TS were dated at 294±7, 280±5, 272±6 and 266±6 Ma.

From the aforementioned geological facts, we propose the following preliminary geodynamic model for the evolution of the Chinese TS. The Precambrian basement consists of various schists, paragneisses, and orthogneisses dated at 2.5 to～0.7 Ga and provide a solid foundation for the Phanerozoic evolution of the Chinese TS. Since the late Neoproterozoic break-up of the Tarim continental block, a stable sedimentary sequence was deposited on the northern margin of Tarim, consisting of muddy-sandy flysch, carbonates intercalated with tillites, and thin basalts dated at 820-570 Ma.

Subduction began in the late Cambrian, forming an Ordovician-Silurian magmatic arc and a Silurian-Devonian flysch basin, followed by collision between the C-TS and the Tarim block in the middle-Late Devonian, producing HP granulites, blueschist and K-granites. Uplift and erosion were widespread in the early Carboniferous in the C-TS and S-TS, producing a thick, red accumulation of molasse. During the late Devonian or early Carboniferous, an active continent margin formed in the N-TS region that is characterized by ophiolitic rocks dated at D3-C1 (radiolarian chert in the Kelamaili zone), ophiolitic mélanges dated at 340-320 Ma (U-Pb and Ar-Ar at Bayingou), arc-volcanic and granitoid rocks with ages of 340-310 Ma in the Yili-N-TS, thrust- and sheari-zones dated at 320-305 Ma in the C-TS and Yili-N-TS, and strike slip shear-zones with Ar-Ar ages of 290-235 Ma in the entire Chinese TS. They suggest that subduction probably began in the Devonian, forming a Carboniferous magmatic arc. Collision between the N-TS and the Siberian block occurred in the late Carboniferous-early Permian, producing HP eclogite, blueschist as well as thrust- and shear-zones and ending the oceanic history of the Chinese TS. Widespread late Permian red and thick molasse deposits and a regional-scale angular unconformity indicate uplift and erosion. We suggest that post-collisional extension and strike-slip deformation began in the early Permian and lasted into the Early Triassic. This is marked by rift-type magmatism and strike-slip shearing, including olistostromes, bimodal volcanic rocks and granites (295-270 Ma) and large-scale shear-zones (290-235 Ma), forming the basic framework of the Chinese TS.

After the late Paleozoic orogeny, the Chinese TS was subjected to multi-stage reworking during both early Mesozoic and late Cenozoic events, that is characterized by (1) a T3 unconformity and T3 coarse-grained clastic sediments in the entire Chinese TS belt and some peraluminous and alkaline granites dated at 250-220 Ma in the C-TS and Yili-N-TS, and (2) a Neogene angular unconformity followed by strong folding, thrusting and uplift in the entire Chinese TS. Peak apatite fission track ages are in the interval 22 to 5 Ma, and finally Quaternary Xiyu Formation conglomerates covered the entire TS.

Several open questions were recently discussed, in particular (1) was the N-TS an arc or intracontinental rift during the Carboniferous? (2) was the tectonic setting during the Permian an active continental margin, or an intracontinental rift, or post-collisional? and (3) was subduction during the early Paleozoic southward beneath the Tarim craton or northward beneath the Central TS basement?

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Intra-oceanic arc systems: Key petrotectonic indicators for understanding CAOB evolution

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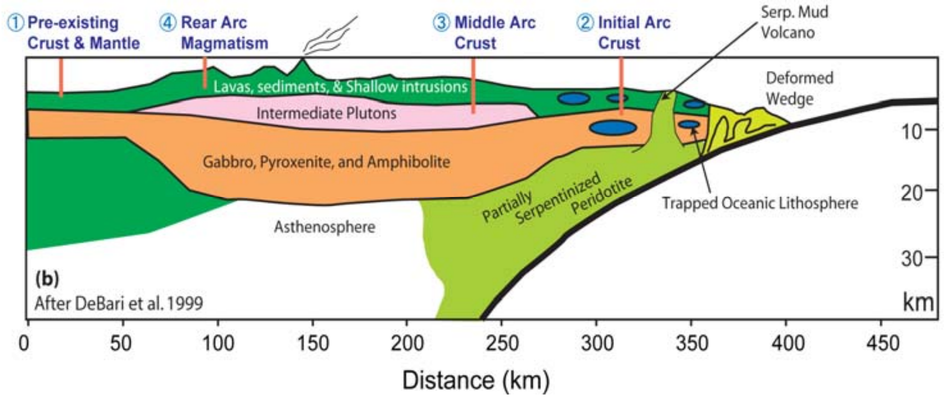
Intra-oceanic Arc Systems (IOAS's) represent the oceanic endmember of arc-trench systems and are likely to be important if highly fragmented components of the CAOB. Active IOAS's mostly lie below sealevel but are often associated with chains of small islands known as "island arcs", defined by the tops of the largest arc volcanoes and forearc structural ridges. Modern IOAS's are mostly found in the Western Pacific, where they subduct old, dense oceanic lithosphere produced by a very wide ocean and so tend to be extensional. IOAS crustal profiles are wedge-shaped, with crust that is 20-35 km thick beneath the magmatic arc, tapering to ophiolitic crust that is a few km thick near the trench. IOAS's typically comprise a >200 km-wide zone along the leading edge of the overriding plate, consisting of 4 parallel components: trench, forearc, volcanic/magmatic front, and backarc. These components form as a result of hydrous melting of the mantle and reflect the strongly asymmetric nature of subduction processes. 1) Forearc: Most ophiolites are fossil IOAS forearcs that formed when subduction began and consist of a diagnostic succession of MORB-like basalts at the base succeeded by arc-like lavas and sometimes boninite. Early IOAS evolution begins with ~10 m.y. of evolving mantle circulation, from early upwelling and seafloor spreading to later downwelling and retreat of magmatic focus to volcanic/magmatic front, ~150 km from trench. 2) Magmatic front: Igneous rocks from IOAS magmatic/volcanic front are dominantly fractionated basalts and basaltic andesites of low-K and medium-K suites. Felsic igneous rocks are also common, and IOAS igneous assemblages may be bimodal in silica. IOAS arc magmatic rocks can be distinguished from those of continental arcs by lower Nb/Yb and OIB-like radiogenic isotopic compositions. Erosion of accreted IOAS's in orogenic belts like CAOB often removes the arc volcanic carapace, revealing batholithic roots beneath the volcanic/magmatic front. 3) Backarc: Mature IOAS's often have minor rear-arc volcanism and seafloor spreading often forms back-arc basins that remain active for ~20 m.y. 4) IOAS mantle: Sub-IOAS mantle composition is asymmetric, with serpentinized harzburgite beneath the forearc, pyroxene-rich, low-Vp mantle beneath the magmatic front, and lherzolite/harzburgite beneath back-arc basins. Because most IOAS's are far-removed from continents, they subduct oceanic lithosphere with thin sediments and rarely are associated with accretionary sedimentary prisms; Arc terranes associated with accretionary prisms are probably continental margin arcs. Instead IOAS's typically have naked forearcs subject to tectonic erosion. Accreted IOAS's are highly disrupted in orogenic belts such as CAOB but their great thickness, width, and length in tandem with their distinctive asymmetries and evolution makes it likely that they will be identified by careful field and laboratory studies.



Crustal structure of a typical intra-oceanic arc, based on the Izu arc. Vertical exaggeration ~3x.

Tectonic Evolution of Taiwan and the Luzon Arc

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The Taiwan Island, located at the convergent boundary between the Eurasian and Philippine Sea plates, comprises an active orogen formed by the collision between the Luzon Arc and the China continent. Having moved north to northwestward with the underlying Philippine Sea plate since the early Cenozoic, the northern segment of the Luzon Arc collided with the China margin in late Miocene time and, thus, initiated the collisional orogeny of Taiwan. The accreted segment of the Luzon Arc, exposed in the Coastal Range of eastern Taiwan, has recorded in its forearc basin deposits an orogenic history showing a rising mountain belt that emerged above sealevel around 5 Ma and later grew to a high mountain range at about 3 Ma. This orogenic history is corroborated with the sedimentary records of the western Taiwan foreland basin as well as the exhumation history of the Central Range. Though part of the northern Taiwan orogen has collapsed as a result of flipping of subduction, the collisional orogeny is still active in south-central Taiwan.

In contrast to the general acceptance of the late Cenozoic arc-continent collision, the pre-collisional tectonics of both the Luzon Arc and the China continental margin remain contentious. The volcanic record of eastern Taiwan shows that the Luzon Arc did not begin to develop until Early to Middle Miocene (22-16 Ma), but comparable records of the Luzon Island seem to show that the Luzon Arc might have formed as early as the Cretaceous and have since gone through multiple stages of subduction, obduction, and flipping of subduction. The pre-collisional continental margin around Taiwan, usually interpreted as part of the passive South China Sea margin, might also have involved multiple subduction and collision events before its final collision with the Luzon Arc. All these arguments indicate that the early Cenozoic tectonic history of either Taiwan or the Luzon Arc is far from well understood and awaits more investigations.

The rock record of long lived (>500 m.y.) orogenesis without continental collision in northern and central California

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Active plate margin tectonics without continental collision have dominated the geologic history of of much of California from the early Paleozoic, or perhaps earlier, to the present. Little agreement exists on many basic aspects of large-scale tectonic models for the assembly of this orogenic belt, with models ranging from those advocating one protracted east-dipping subduction event to those suggesting at least seven discrete subduction events with multiple subduction polarity changes. Researchers disagree on the relative importance of transform margin versus subduction tectonics, but all agree on the lack of involvement of continental/microcontinent collision; this is an oceanic orogenic belt whose assembly spanned some 500+ million years.

I believe that the orogen includes multiple subduction sutures, based on the presence of spatially and temporally distinct high-pressure, low-temperature (HP-LT) units, ophiolite sheets, and associated metamorphic soles. Metamorphic soles, thin sheets of highly-strained, dominantly mafic, HP-HT metamorphic rocks, structurally underlie ophiolite sheets and may record separate intraoceanic subduction initiation events. A single zone of mafic-ultramafic rocks, the Feather River ultramafic belt, appears to record two such events at 340 Ma and 240 Ma, suggesting that a single ophiolitic belt within the composite orogen may itself mark the location of multiple subduction sutures. Dates have not been obtained from all of the metamorphic soles, but some are likely older than 400 Ma and the youngest, represented by high-grade rocks of the Franciscan Complex, is about 160-169 Ma.

Only the youngest HP-LT rocks, those of the Franciscan subduction complex, have sufficient geochronologic data to demonstrate the duration of subduction-accretion events. Franciscan HP-LT rocks were metamorphosed from about 160 Ma to 85 Ma, with a youngest protolith of about 85 Ma and the oldest metamorphic age of about 160 Ma. Existing data suggests that the Franciscan records the longest period of HP-LT metamorphism of the various belts. The oldest HP-LT unit, the Skookum Gulch schist of the Klamath Mountains has yielded an age of about 450 Ma.

Spatially limited HP-HT metamorphic soles and more common HP-LT rocks give important insight into tectonic process, but much of the orogen, including interpreted subduction complexes, comprises greenschist facies and lower grade rocks; the presence of HP-LT rocks reflects exhumation and preservation processes as well as subduction. Collisional metamorphic signatures with moderate to high-grade metamorphism have not been identified to date. The Feather River ultramafic belt may record a ridge subduction event with LP-HT metamorphism locally overprinting HP-HT metamorphic sole rocks. Ridge subduction marked the transition from subduction to transform tectonics at ca. 25 Ma, and is recorded mainly by volcanic rocks; exhumation has since then has been less than 5 km, so the metamorphic and plutonic levels of this transition have not been exposed.

The general architecture of the orogenic belt comprises folded, fault-bounded nappes of mélange and coherent units, perhaps best preserved in the youngest of the accreted units, the Franciscan. The Klamath Mountains display older nappe structures, but in the Sierra Nevada, deformation postdating terrane amalgamation severely overprinted and deformed the major unit contacts resulting in high-angle fabrics dips.

Sedimentary/metasedimentary units comprise mostly clastic rocks (mostly sandstone, shale) with lesser amounts of pelagic sedimentary rocks (chert and less common limestone) and these units make up parts of subduction complexes, as well as forearc and possibly backarc basin fill. Mafic-ultramafic rocks comprise both ophiolite sheets, that marked the upper plate of subduction zones (the largest ophiolitic units) and formed in a supra subduction zone environment prior to arc development, and smaller pieces of mid-ocean ridge and oceanic island origin, scraped off subducting plates and incorporated into subduction complexes. Volcanic and plutonic rocks associated with island arc construction are common, but California lacks a large island arc remnant such as the Kohistan arc. The last subduction episode resulted in the evolution of an island arc to continental margin arc with the roots of the latter represented as the Sierra Nevada batholith.

Block-in-matrix mélange units are most common in subduction complex settings, but also occur in upper plate settings such as within forearc basin deposits. Recent work in the Franciscan shows that mélanges there preserve sedimentary origins of the block-in-matrix fabric in the form of sedimentary breccia and conglomerate with the full suite of exotic components. Even mélanges between coherent nappes, that apparently accommodated large (paleomegathrust) displacement between them, locally preserve these sedimentary structures, although tectonic strain has obscured these structures in most outcrops. Field relationships suggest that most displacement within subduction complexes such as the Franciscan was accommodated on the upper contact of the mélanges rather than within them. Franciscan mélanges and clastic sedimentary rocks include a significant amount of material reincorporated after exhumation and erosion of the subduction complex; this record may include up to three subduction-exhumation cycles to HP conditions. Franciscan clastic detritus also includes blocks and finer sediment sourced from the upper plate.

Researchers commonly evaluate orogenic belt history as one of amalgamation and accretion, but the rock record also reflects non-accretion and subduction erosion. Geochronology of the Franciscan has revealed episodic versus continuous accretion, with long periods of non accretion, including 40-60 million years of non-accretion following subduction initiation, varying along strike.

Tectonic features of the subduction - accretion orogeny in East Asia: Contribution to the correlation between two different types of orogenic belts in East Asia and Central Asia

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The aim of this presentation is to review the processes of subduction and accretion in East Asia in order to understand the actual configuration of the Central Asian terranes. These areas include various evidences of geological history from continental break-up to continent-continent collision, via an important history of supra-subduction history. During the accretion stage, subduction was responsible for extension and sea-floor spreading in the back-arc region and, later, subduction perturbation was responsible for shortening of these basins. The geological record on the ocean development is referred to as “Ocean Plate Stratigraphy” that consists of pillow basalt, limestone, chert, siliceous shale, and detrital turbidite in ascending order. It implies the travel history of an oceanic plate from its "birth" at a mid-oceanic ridge to its "death" at a trench. Sediment accretion and tectonic erosion are commonly recognized along the convergent margins of the present Pacific. The Japanese Islands yield five major accretionary complexes, which are mélanges of Ocean Plate Stratigraphy origin and their metamorphic affinities but also relicts of continental crust material. Tectonic erosion is also detected along many convergent margins and removes material by underscrapping the lower part of the upper plate. Examples of arc-arc collision are also observed between the Japanese Islands and the Izu-Bonnin arc, or between the Japanese Islands and the Chishima-Kuril arc. Minor collision tectonics occurred in the form of arc-arc, arc-microcontinent, and arc-continent collision in East Asia. All geological records of East Asia help to understand the geologic and tectonic history of the Central Asian collages.

The Carboniferous Junggar Basin in northwest China exemplifying basin evolution in the CAOB

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The Central Asian Orogenic Belt (CAOB) is one of the largest accretionary orogens on Earth and has evolved from the Neoproterozoic through the late Paleozoic by subduction and accretion of juvenile material and microcontinental fragments. The Paleo-Asian Ocean finally closed at the end of the Paleozoic. During the evolution of the CAOB, various sedimentary basins developed, some being destroyed and others preserved. The Carboniferous Junggar Basin in northwest China exemplifies such a scene of basin evolution.

The reconstructed paleogeography of the Carboniferous Junggar Basin is characterized by an archipelago geomorphological structure, just like the present Southwest Pacific Ocean. Many islands and small basins scattered in the vast Paleo-Asian Ocean. Some basins were connected with each other, whereas others were separated and even isolated. Such a paleogeography resulted in a variety of basin deposits. Chert were deposited in the deep sea where no terrigenous material was available. Turbidite and pyroclastic rocks accummulated in arc-related basins. Carbonate rocks and carbonaceous shale could develop on top of accretionary wedges.

Tectonically, the Carboniferous Junggar Basin is characterized by weak extension and strong compression. Small basins in the Paleo-Asian Ocean experienced various fates. During closure of arc-related basins, the basin sediments were deformed and mixed together chaotically. However, basins sitting on top of accretionary wedges may be preserved together with remnant accretionary wedges.

Continuing subduction of oceanic crust cooled the paleo-geothermal gradient in the arc-related basins. Potentially, some carbonaceous shale could be preserved as good hydrocarbon source rocks for oil and gas. This is a special type oil-gas basin in the CAOB.

What we have learnt (and not learnt) from the Central Asian Orogenic Belt since Sengör et al. (1993) ?

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The classic paper by Sengör et al. 1993 (modified by e.g. Yakubchuk, 2002) advanced the novel concept that the CAOB evolved from a single, long-lived arc. Much work since then was undertaken to constrain this model. Many important papers have been published from every sector of the CAOB particularly on geochronology and geochemistry. So we now know, for example, that: the oldest ophiolite is c. 1.0 Ga in Siberia (Khain et al., 2002), Sr/Nd data of ubiquitous granitic rocks indicate the CAOB evolved largely by juvenile accretion (Jahn, 2004); in N. Mongolia continental arcs (silicic lavas and granites) are prominent (Kröner et al., 2007); some Precambrian micro-continents are actually the roots of Neoproterozoic arcs (Salnikova et al., 2010), ocean plate stratigraphy rocks are widespread (Safonova, 2009; Kurihara et al. 2009; Sennikov et al. 2004), as are oceanic seamounts and plume-generated oceanic island basalts (Safonova et al. 2011), an island arc system of Izu-Bonin-Mariana type is in the Gorny Altai (Buslov et al., 2002; Ota et al., 2007), the Oka belt of Siberia is like the Japanese Shimanto belt (Kuzmichev et al. 2007), at Bayankhongor in Mongolia a minor Neoproterozoic ophiolite is juxtaposed against a major Triassic ophiolite (Jian et al., 2010), HP metamorphism of eclogites in Kyrgyzstan took place in the Late Carboniferous (Hegner et al., 2010), the Beishan accretionary collage developed in the Permo-Triassic at the termination of the CAOB (Xiao et al., 2010), Cambrian eclogites in SW Mongolia (Stípská et al., 2010) are part of an accretionary complex with remnants of island arcs, ophiolites and a passive margin (Lehmann et al., 2010), and major post-collisional strike-slip faults are widespread (Buslov, 2011). And finally, we now have a new tectonic synthesis of the CAOB by Caroline Wilhem (unpublished). Apologies here to the very many unquoted authors and papers. However, few papers published since 1993 have provided detailed information on the field and structural relations of this vast orogen. Thus it is fair to say that by 2011 we still do not understand in detail the tectonic evolution. We know that in Phanerozoic subduction-accretion complexes worldwide as much crust has been subducted as has been accreted (e.g. Scholl and von Huene, 2009; Stern and Scholl, 2010). In Japan whole arcs have disappeared (Isozaki et al., 2010). In the CAOB narrow, only kilometre-scale slivers of arcs, ophiolites, and accretionary complexes are juxtaposed, which means that the bulk (>70-90%) of much of the crust is missing; we see today only remnant, imbricated, inter-thrusted slivers. Only extensive field mapping at say 1:5000-1: 20000 scale and structural analysis of the imbricated slices will enable the tectonic evolution to be worked out satisfactorily. Geochemistry and geochronology can provide important constraints, but could not unravel such complex structural inter-relations that indicate how the crust was accreted and built up. So, great prospects for the younger generation interested in long periods of fieldwork. And it is now widely accepted that the CAOB evolved by multi-subduction zone/arc interactions, as in Mesozoic-Cenozoic Indonesia, Japan and Alaska.

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Au-Cu Porphyry Deposits in Accretionary Orogens – Comparing the Central Asian Orogenic Belt (CAOB) and Modern Examples

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Gold-rich porphyry copper deposits are important contributors to global gold and copper reserves and resources (Kessler, 1973; Sillitoe, 1997, 2000; Richards, 2003, Cooke et al., 2005). Individual porphyry deposits normally contain several hundred tonnes of gold, however some "super-giant porphyry systems" contain greater than 1200 tonnes of gold (e.g., Grasberg, Irian Jaya; Oyu Tolgoi, Mongolia; Kalmakyr-Dalnee, Uzbekistan; Cadia District, Australia: Singer, 1995; Cooke et al., 2005). Average grades are generally low at 0.5 g/t Au but can reach values greater than 2.0 g/t Au. Low grades are offset economically by the ability to mine these deposits by bulk tonnage mining methods.

Au-Cu porphyry deposits are generally more abundant in the modern geologic record (post Mesozoic) and are commonly situated around recently active volcanic arcs in the South American and the SW Pacific portions of the "rim of fire". However, several of the biggest examples of Au-Cu porphyry deposits are associated within arcs of pre-Mesozoic age (here termed "Ancient Porphyries") and occur in ancient accreted terranes of the North American Cordillera, the Lachlan Fold Belt (LFB) of Australia and the Central Asian Orogenic Belt (CAOB) (Wurst, 2010). Many Au-Cu porphyry deposits are located in the CAOB which extends for over 4500 km from the Urals in Russia to the west through central Eurasia and into northeastern China and range in age from Silurian to Jurassic (Seltmann and Porter, 2005). The largest examples include the Devonian Oyu Tolgoi Cu-Au super-giant porphyry in Mongolia (>2.3 Gt @ 1.16% Cu and, 0.35 g/t, Au) and the Carboniferous Kalmakyr-Dalnee Cu-Au super-giant porphyry in Uzbekistan (>5 Gt @ 0.5% Cu and 0.4 g/t, Au: Seltmann and Porter, 2005).

When ancient and modern settings for Au-Cu porphyry deposits are compared it is apparent that the processes linking formation and preservation are crucial in convergent arc and accretionary settings. In particular, stress regime, depth and age of emplacement, and climate are all important fundamental controls on Cu-Au porphyry preservation (Wurst, 2010).

Cu-Au porphyries commonly form in compressive regimes which also have high uplift, exhumation, and erosion rates, which ultimately lead to their loss from the geologic record (Tosdal and Richards, 2001; McInnes, 2005). Porphyry deposits can be preserved in localised extensional environments which promote subsidence and burial, whereas continued compression enhances preservation by tectonic burial during accretion. Cu-Mo porphyries have a greater chance of preservation due to a greater depth of emplacement, while Au-Cu porphyries are less likely to be preserved due to a shallower emplacement level. Porphyry deposits formed in temperate and arctic environments are less likely to be preserved than those formed in arid environments. The abundance of Au-Cu porphyries in the recent geological record appears in-part due to their decreased erosion opportunity and loss from the geologic record (Wurst, 2010).

The stability and tectonics of particular sections of the CAOB since the late Mesozoic appear to have provided unique temporal and spatial windows fitting the above criteria for the formation and preservation of super-giant Cu-Au porphyry systems.

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Late Paleozoic to mid-Triassic multiple accretionary and collisional processes of the Beishan-Inner Mongolia orogenic collages

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The Beishan-Inner Mongolia orogenic collages and suture in the southern Altaids connect the Southern Tien Shan suture with the suture at the eastern end of the Altaids (Şengör et al., 1993; Jahn et al., 2004; Xiao et al., 2003; 2010). This abstract reviews the tectonic units of these collages, which along a north-south traverse consist of several E-W-trending arcs and ophiolitic mélanges (Zuo et al., 1990; Wu et al., 1998; Mao et al., 2011; Xiao et al., 2010). The late Paleozoic collages are characterized by three units interpreted as active continental margins or arcs that are separated by two major ophiolitic mélanges, which are branches of the Paleo-Asian Ocean (Xiao et al., 2003; 2010; Mao et al., 2011; Guo et al., 2011) (Fig. 1).

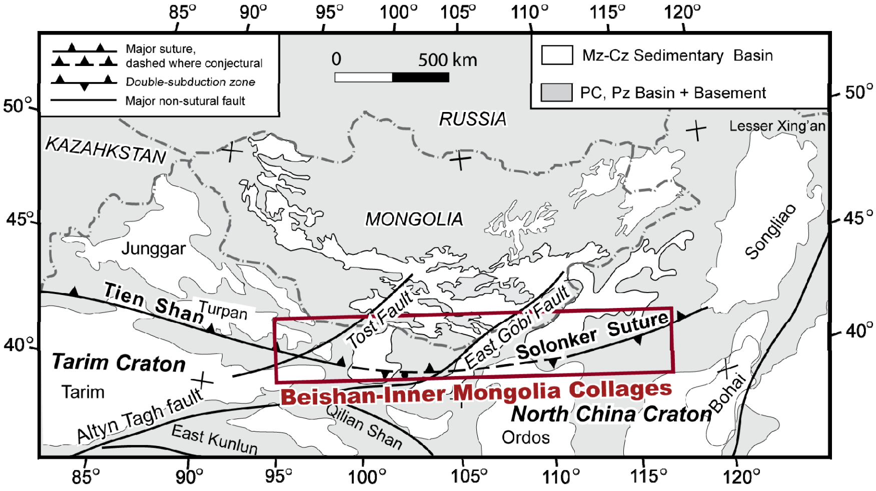

Fig. 1. Schematic map showing the tectonic position of the Beishan-Inner Mongolia collages in the southern Altaids (modified from Xiao et al., 2010).

The northernmost unit is represented by the Queershan-Uliastai active margin, which may have lasted until the Permian. The Shibanshan-Yabulai-Bainaimiao unit is the southernmost subduction- related continental arc along the northern margin of the Dunhuang block and the North China Craton. The middle unit is a composite arc (Gongpoquan-Shalazhashan in the west) or an island arc (Baolidao in the east) (Wu et al., 1998; Xiao et al., 2003; 2010; Mao et al., 2011; Guo et al., 2011). The northern ophiolitic mélange (Hongshishan-Engerwusu-Hegenshan) represents a northern branch of the Paleo- Asian Ocean, which was mainly subducted to the north, whereas the southern mélange (Liuyuan-Chaganchulu-Solonker) represents a southern branch of the Paleo-Asian Ocean that was characterized by double-subduction zones (Xiao et al., 2003; 2010; Jian et al., 2008; Guo et al., 2011; Mao et al., 2011) (Fig. 2).

These tectonic units were thrust-imbricated and overprinted by strike-slip faulting during Permian- Triassic times, and the youngest strata involved in the deformation are fossiliferous and Permian. Stitching plutons have late Permian to Triassic magmatic ages (Xiao et al., 2003; 2010; Mao et al., 2011). Peaks of magmatic- metamorphic-tectonic activity as well as paleomagnetic and paleogeographic data indicate that the Beishan-Inner Mongolia orogenic collages evolved by development of several, late Paleozoic to Permian arcs in different parts of the Paleoasian ocean (Xiao et al., 2003; 2010; Mao et al., 2011; Guo et al., 2011).

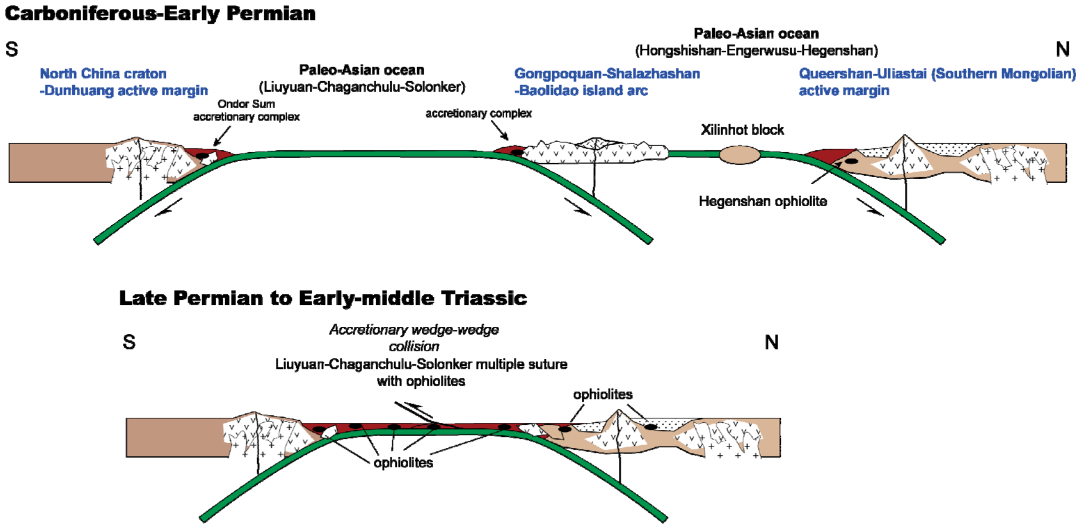

Fig. 2. Schematic dagrams showing the tectonic evolution of the Beishan-Inner Mongolia collages of the southern Altaids (modified from Xiao et al., 2003; 2010; Mao et al., 2011).

In the late Permian to mid-Triassic the northern active margins of the Dunhuang block and the North China Craton probably collided with the middle unit and the northern active continental margin, generating the complicated subduction-accretion orogenic collages. Comprehensive data suggest these orogenic phases were the last in the development of the long-lived Altaid accretionary orogen. This new model for the orogen bridges the gap between the western and eastern ends of the southern Altaids. The modern Circum-Pacific subduction zones with surrounding arcs are appropriate analogs for the southern Altaids in the late Permian to Middle Triassic.

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Crustal structure revealed from a deep seismic reflection profile across the Solonker suture zone in North China: a preliminary interpretation

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The Solonker suture zone represents an important tectonic boundary between the North China Craton (NCC) and the Mongolia composite terrane. It has been considered as the final collision suture formed in the late Paleozoic, after a long accretionary history in both its southern and northern sides. However, existing models related to the tectonic framework and evolution of this suture zone are highly variable. The newly completed deep seismic reflection profile, SinoProbe-02, spanning ca. 480 km from Erenhot to Beijing, provides a new look into this orogenic belt.

The seismic reflection profile can be divided into three segments. The southern segment is about 120 km long, covering the Yanshan fold and thrust belt on the southern side of the Shangyi-Chongli-Gubeikou-Pingquan Fault zone (SCGP). Except for one small Mesozoic basin and its boundary faults, a transparent image with minor discontinuous reflections dominates the deep structure of the crystalline basement area of the NCC.

The middle segment of the profile covers the region between the SCGP and Sonid Youqi that is located in the center of the Solonker suture zone. This segment is characterized by northward-dipping reflection structures in the lower crust and transparent granite bodies in the upper crust. The northward-dipping reflectors may represent accretionary wedges formed along the northern margin of the NCC during the Paleozoic. At some localities these structures are truncated by transparent columnar bodies that often connect with the granite outcrops. The middle segment passes through the Ondor Sum ophiolite mélange, but no structure is observed in the mantle to suggest possible subduction. Together with geological data, we speculate that this area had experienced considerable crustal thickening, uplift and lithosphere delamination, and acquired a new Moho. The SCGP zone may represent the tectonic transition from the NCC to its northern accreted marginal region. The compressional structures which have likely formed during the collision stage (latest Paleozoic to early Mesozoic) can be traced from the wedge-shaped crustal block of the NCC inserting the lower crust of the SCGP zone. This deep structural feature is also common in the transitional zones from rigid block to mobile belt in western China.

The northern segment covers ca. 120 km of the profile from Sonid Youqi to Erenhot, and shows a more complex deep structure. The eastward extending Solonker suture is superimposed by Mesozoic extensional structures. A few reflection structures dip southwards, whereas others dip northwards. Some transparent bodies along the boundary faults of the Mesozoic basins may represent magma chambers. The major boundaries revealed by the seismic profile so far are in first-order agreement with the geological observations.