Exotic terranes

• How do we know they are “exotic”
• Where have they been?
• When and how did they arrive?
Reminder of this suggestion of a connection of the outboard terranes to Sonomia being tied to more exotic stuff. Colprin and Nelson connect allochthons in lower Shoo Fly with northern BC based on the older TIMS detrital zircon work. Here we compare with newer stuff, and maybe OK. Lang-Duncan Peak-Culbertson
Figure 1. The Canadian Cordillera showing terranes studied here. Rectangles denote sampling regions: 1—southeastern British Columbia for Cache Creek, Quesnel, and Kootenay samples (KO = Kootenay terrane proper); 2—Wells-Barkerville region for Quesnel, Slide Mountain and Kootenay/Cassiar-equivalent samples; 3—Neatlin assemblage at Little Salmon Lake, Yukon.

Patchett and Gehrels, J. Geol. 1998
Most terrane maps focus on Canada; map at right extends this into US.
First, how do we know they are exotic? First big clue (well, maybe second) was very different geologic histories. While many terranes are relatively young, the Alexander terrane has a history going into the pC. Not a WUS history....
from rocks that are not currently part of the proportion of Precambrian grains derived likely that most of the clastic detritus in the between the detrital zircon ages and UEPb ZIRCONS PROVENANCE OF DETRITAL analyses are of fairly poor precision due to a 5I appear to be analytically concordant 5IO that Klakaszage thrusts are apparently southwest vergentE whereas Karheen strata were shed from source areas to the south or southweste rocks during the Middle Silurian–earliest Devonian Klakas orogenye The Karheen Formation is interpreted to be a clastic wedge shed from this orogen. The unusual geometry of elastic strata accumulating in the hinterland of the thrust system derives from the observations that Klakas-age thrusts are apparently southwest vergent, whereas Karheen strata were shed from source areas to the south or southwest. Gehrels et al., GSA Bull 1996 Butler et al., GSA Bull 1997

Figure 5. Schematic diagram showing the interpreted juxtaposition of the Alexander terrane with continental or continental-margin rocks during the Middle Silurian–earliest Devonian Klakas orogeny. The Karheen Formation is interpreted to be a clastic wedge shed from this orogen. The unusual geometry of elastic strata accumulating in the hinterland of the thrust system derives from the observations that Klakas-age thrusts are apparently southwest vergent, whereas Karheen strata were shed from source areas to the south or southwest. Gehrels et al., GSA Bull 1996 Butler et al., GSA Bull 1997
Second clue fauna--lots of stuff looks wrong
Fig. 2. Stratigraphic column of the Alexander terrane in the southern part of southeast Alaska after Gehrels and Saleeby (1987). Filled circles indicate the horizons sampled for paleomagnetic study.

Butler et al., GSA Bull 1997
Third clue paleomag—often messed up relative to NAM
A more recent approach is our old friend detrital zircons. Here we see a lousy fit to NAM, and not great to Australia (other areas in Aus better).
Newer work has focused on Baltica and the northern Calidonides.
We can also look at other isotopic systems. So here measurements on detrital zircons of E-Nd show that stuff in the Karheen allochthon still don’t look North American [which is actually an interesting problem beyond our scope]
Actually quite a range in Alexander Terrane—some very immature stuff in SE Alaska
The available U-Pb and Hf isotopic data values, and epsilon Hf trends through time values, and grains in strata (Karheen Formation and equivalents) of early Paleozoic configuration of the Alexander terrane, especially when combined with geologic relations and paleomagnetic data. As summarized by Gehrels and Saleeby (1987), this orogenic highland. Rocks of the Saint Elias Mountains region were interpreted by Gehrels et al., 2010). Second is the interpretation of Tertiary dextral offset (Hudson et al., 1981; Karl et al., 2010). This arrow would point north if the terrane was located in the Northern Hemisphere (Bazard et al., 1995; Butler et al., 1997). This arrow would point north if the terrane was located in the Northern Hemisphere (Bazard et al., 1995; Butler et al., 1997). But also shown on panel D of this figure represent borders between Alaska–Yukon–British Columbia to the north and between Alaska and British Columbia to the south. Note that thin dashed lines within the Alexander terrane in each figure.

The configuration of early Paleozoic tectonic elements portrayed in Figure 7 suggests that the Alexander terrane consists of an oblique margin system and latest Silurian–Early Cretaceous structures (Monger et al., 2016). This arrow would point north if the terrane was located in the Northern Hemisphere (Bazard et al., 1995; Butler et al., 1997). This arrow would point north if the terrane was located in the Northern Hemisphere (Bazard et al., 1995; Butler et al., 1997). Also shown is the direction toward the geomagnetic pole (53° west of south) interpreted from paleomagnetic analysis of Lower Devonian red beds on Prince of Wales Island (Bazard et al., 1995; Butler et al., 1997). Also shown in Figure 7 is an attempt to reconstruct the Early Devonian orogen and clastic wedge preserved within SE Alaska. (Hudson et al., 1981; Karl et al., 2010). (C) Restoration of ~1000 km of left-lateral offset on Kitkatla shear zone (and related faults). Early Devonian orogenic and clastic wedge. (E) Proposed configuration of the Ordovician–Silurian arc system preserved within the Alexander terrane, especially when combined with geologic relations and paleomagnetic data. As summarized by Gehrels and Saleeby (1987), this orogenic highland. Rocks of the Saint Elias Mountains region were interpreted by Gehrels et al., 2010). Second is the interpretation of Tertiary dextral offset (Hudson et al., 1981; Karl et al., 2010). This arrow would point north if the terrane was located in the Northern Hemisphere (Bazard et al., 1995; Butler et al., 1997). This arrow would point north if the terrane was located in the Northern Hemisphere (Bazard et al., 1995; Butler et al., 1997). Also shown on panel D of this figure.
So early part of history of Alexander Terrane seems to be coming into focus...
Does this all agree with the paleomag (which we will talk more about next time)?
Yes, it does.
Can start to see when departed. Argue that the big change in epsilon Hf from lower Dev to Mid Dev is departure from scandinavian margin and creation of arc—think this agrees well with Scandinavia [unfortunately this pub lacks a good comparison figure]. Ice field is in St. Elias area.
Argue that the big change in epsilon Hf from lower Dev to Mid Dev is departure from scandinavian margin and creation of arc--think this agrees well with Scandanavia [unfortunately this pub lacks a good comparison figure]
Argue that the big change in epsilon Hf from lower Dev to Mid Dev is departure from scandinavian margin and creation of arc--think this agrees well with Scandanavia [unfortunately this pub lacks a good comparison figure]
792

ca. 500-650 Ma

Verkoyansk

Taimyr

1.49–1.62 Ga

059/1 (75)

Russia

ca. 500-650 Ma

USA

8°

Lomonosov

70°

N. ALASKA

SL. LADOGA REGION,

Middle Ordovician

Upper Devonian

Lower Carboniferous

Paleo-Pacific Ocean

slab rollback

Baltica

Laurentia

Siberia

Gondwana

Gabbro

Baltic Shield

Ordovician (Fig. 2), while the interior part of the Baltic Shield (B); AAC—Arctic Alaska–Chukotka; AAC

North Annyui zone. Arrows in Arctic Ocean and

Baltic Shield (B); AAC—Arctic Alaska–Chukotka; AAC

South Annyui zone. Arrows in Arctic Ocean and

Baltic Shield (B); AAC—Arctic Alaska–Chukotka; AAC

Middle Cambrian strata near the St. Petersburg

Upper Ordovician

Lower Silurian

Cordillera

Upper Cambrian

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of 58 Ma and probably less (time scale of Gradstein et al. 2004). In this case average motion would need to be about 5 cm a$^{-1}$, comparable with rates of advance of short modern arc segments such as the Scotia and New Hebrides arcs (Schellart et al. 2007).

**Palaeogeographical implications**

The evidence summarized above clearly points to common, non-western Laurentian origins for a number of western Cordilleran terranes, as has been previously argued by many of the workers we cite. Much of the geological history (Ordovician–Silurian arcs, Cambrian–Ordovician and Silurian–Devonian deformational events) and detrital zircons from the Alexander terrane suggest early Palaeozoic interactions with the Appalachian–Caledonian orogen and a source region dominated by Mesoproterozoic and late Palaeoproterozoic igneous rocks, including significant contributions from Grenvillian (1.0–1.3 Ga) and 1.49–1.61 Ga sources (Figs 2 and 7; Wright & Wyld 2006; Grove et al. 2008). The occurrence of Ediacaran arc-related rocks at the base of the Alexander terrane contrasts, however, with the Neoproterozoic history of either eastern Laurentia or western Baltica, each of which was characterized by rifting and development of a passive continental margin at that time (e.g. Cawood et al. 2001). Wright & Wyld (2006) proposed an early affinity with Avalonia and other peri-Gondwanan terranes. But when considering Silurian–Devonian palaeomagnetic, faunal and detrital zircon data together, a position near northern Baltica, adjacent to the north end of the Caledonides, seems to provide a better fit (Fig. 11; Bazard et al. 1995; Soja & Antoshkina 1997; Pedder 2006; Soja & Krutikov 2008).

Neoproterozoic arc magmatism (c. 600–550 Ma) and tectonism characterize the Timanide orogen, which extends along eastern Baltica from the southern Urals northward to the Barents–Kara Sea region, where it is locally overprinted by the Caledonian deformation front (Gee & Pease 2004; Gee et al. 2006). The North Kara terrane is inferred to underlie much of the Barents–Kara Shelf.
overcome by either gravity or compression, unless it has been previously weakened (Stern 2004). Propagation of a sinistral transform fault that apparently nucleated out of the Northwest Passage in Devonian time could have provided the weakness along which the oceanic lithosphere collapsed and subduction propagated southward (Figs 13 and 14). Onset of subduction and its southward propagation is recorded by magmatism of 380–400 Ma in the Arctic Alaska terrane, 380–390 Ma in the Yukon–Tanana terrane of the Coast Mountains (which probably restored near present-day Alaska in Palaeozoic time; Mihalynuk et al. 1994), 360–370 Ma in the parautochthonous continental margin of eastern Alaska and Yukon, and c. 360 Ma along the entire margin of western Laurentia (Nelson et al. 2006). These events were probably the result of a global plate reorganization that followed the Middle Devonian Acadian orogeny in the Appalachians and continued with the Carboniferous collision of Gondwana (Fig. 14). A narrow subduction zone that propagated westward through the Northwest Passage in Silurian–Devonian time could have provided the seed point from which subduction was initiated along western Laurentia (Figs 11–14).

Along northern Laurentia, this change in plate motion led to a collision with an enigmatic crustal block, the mythical Crocker Land of Arctic explorers, and development of the Late Devonian–Early Mississippian Ellesmerian orogeny as Laurentia apparently tracked north during collision with Gondwana (Fig. 14). Crocker Land was possibly one of the Caledonian crustal fragments associated with the Alexander and other terranes (Fig. 5). It apparently supplied sediments intermittently to the Sverdrup basin to the south until mid-Mesozoic time (Davies & Nassichuk 1991) and was probably removed during Jurassic–Cretaceous opening of the Arctic Ocean. Future provenance studies will provide more information about the nature and origins of Crocker Land (Omma et al. 2007).

Shortly after initiation of subduction along western Laurentia, slab rollback is thought to have caused extension in the back-arc region, which led to rifting of parts of the distal continental margin, such as the Snowcap assemblage (basement to Fig. 12.


Fig. 12. Early Devonian palaeogeography and development of the Northwest Passage between Laurentia–Baltica and Siberia. Light grey terrane with dashed outline represents possible additional crustal fragments now submerged in the Arctic Ocean. ARB, Arabia; IND, India; MEX, Mexico; SEU, southern Europe. Other abbreviations as in Figure 11.
Yukon–Tanana) and possibly the Shoo Fly Complex (basement to the Northern Sierra terrane; Fig. 14). This rifting culminated in opening of the Slide Mountain ocean in Early Mississippian time and hence migration of the late Palaeozoic peri-Laurentian arcs away from the continental margin (Figs 14 and 15). The Yukon–Tanana terrane shares Late Devonian to earliest Mississippian (370–355 Ma) magmatism with the Laurentian margin, but younger Carboniferous to Permian arc magmatism is unique to the terrane (Nelson et al. 2006). The western Kootenay terrane (Eagle Bay assemblage; Fig. 3) of southern British Columbia appears to be a portion of the Late Devonian–earliest Mississippian remnant arc that remained stranded on the Laurentian margin after opening of the Slide Mountain ocean. The exact distribution of the Slide Mountain terrane in southern British Columbia has been obscured by the penetrative Mesozoic deformation and severe early Cenozoic extension that affected this region. However, the occurrence of upper Palaeozoic arc sequences with McCloud faunal elements overlying parts of the Okanagan terrane (Harper Ranch and Attwood groups, Mt. Roberts Formation; Figs 2 and 3) requires a more southerly palaeolatitude in Early Permian time (Belasky et al. 2002). The Havallah and Schoonover basinal sequences in the Golconda allochthon are probably the southern extension of the Slide Mountain ocean (Figs 1 and 10; Miller et al. 1984; Harwood & Murchey 1990).

The Slide Mountain ocean apparently reached its maximum width in Early Permian time (Fig. 15; Nelson et al. 2006). Differences between the McCloud and western Laurentian faunas, based on statistical analysis, suggest that the McCloud belt probably lay 2000–3000 km west of the continental margin (Belasky et al. 2002), providing a maximum estimate for the width of the Slide Mountain ocean. By Middle Permian time (c. 270 Ma), subduction polarity was reversed and the Slide Mountain lithosphere was being subducted beneath the Yukon–Tanana and related terranes. This is recorded in the belt of high-pressure rocks that lies along the eastern edge of the Yukon–Tanana terrane and Middle to Late Permian magmatic rocks of the Klondike arc (Fig. 2). By Triassic time, the Slide Mountain ocean had closed and the
Late Palaeozoic peri-Laurentian arcs were accreted to western Laurentia, by then a part of Pangaea, during the Sonoma orogeny (Fig. 16; Dickinson 2004). Triassic synorogenic clastic rocks overlying the Yukon–Tanana and Slide Mountain terranes, as well as the Laurentian continental margin, and amphibolite-facies metamorphism in the Yukon–Tanana terrane provide records of the Sonoman event in the northern Cordillera (Beranek & Mortensen 2007; Berman et al. 2007).

The Alexander terrane is inferred to have migrated out of the Northwest Passage during Carboniferous time (Fig. 14). By Pennsylvanian time, it had joined Wrangellia in northern Panthalassa, where they apparently evolved in an isolated intra-oceanic setting until their Middle Jurassic accretion (Figs 15 and 16).

The Farewell terrane is thought to have originated from the northern margin of the Northwest Passage, where it originally evolved as part of the Siberian Platform until at least Early Permian time, when it was deformed during the c. 285 Ma Browns Fork orogeny, an event related to development of the Uralian and Taimyr fold belts (Figs 11–15; Bradley et al. 2003). Details of its Mesozoic history are sparse. The Farewell terrane may have been expelled from its site of origin during or following Uralian tectonism (Figs 15 and 16).

By Middle to Late Triassic time, east-dipping subduction was re-established along the entire western margin of Laurentia (now part of Pangaea; Fig. 16), giving rise to voluminous Triassic–Jurassic arc magmatism of Stikinia, Quesnellia and related terranes of the western USA, which were in part built upon Palaeozoic basements of the Yukon–Tanana, Okanagan, Eastern Klamath and Northern Sierra terranes (Fig. 2). This more stable, wide-slab geometry (Schellart et al. 2007) apparently persisted more or less in its original form along western North America until at least early Cenozoic time.

Convergence between the North American plate and the various oceanic plates that succeeded Panthalassa (e.g. Farallon, Kula and Pacific) began with the Jurassic opening of the North Atlantic.
Ocean and the westward drift of North America over its western subduction zone (Monger & Price 2002). It is possible that another Caribbean- or Scotia-style subduction system developed between southern Laurentia and Gondwana (Wright & Wyld 2006) and coexisted with the Northwest Passage in Silurian–Devonian time (Figs 11–13), much like the modern Caribbean and Scotia systems developed at either end of South America. However, our review of the geological evidence leads us to conclude that Cordilleran terranes of inferred Caledonian and Siberian affinities were more probably introduced into eastern Panthalassa via the Northwest Passage rather than its southern equivalent.

Conclusions

Palaeozoic to early Mesozoic terranes of the North American Cordillera are proposed to have originated from three major regions in Palaeozoic time: (1) the western peri-Laurentian margin; (2) western Panthalassa in proximity to the Palaeo-Tethys realm; (3) in proximity to the northern Caledonides, occupying an intermediate position between NE Laurentia, Baltica and Siberia (Figs 1 and 11). Dispersion of the Caledonian–Siberian terranes and their westward migration into eastern Panthalassa is interpreted to result from development of a Caribbean- or Scotia-type subduction system between northern Laurentia–Baltica and Siberia in mid-Palaeozoic time: the Northwest Passage. This system was probably driven by upper mantle outflow from the closing Iapetus–Rheic oceans along eastern Laurentia, as Pangaea was being amalgamated (Figs 11–14). The rapid westward migration of a narrow subduction zone through the Northwest Passage entrained Caledonian and Siberian terranes into eastern Panthalassa and provided a seed point for propagation of subduction along western Laurentia in...

Fig. 15. Pennsylvanian to Early Permian palaeogeography. By this time, the Slide Mountain ocean had reached its maximum width and volcanic arcs of the McCloud belt (late Palaeozoic sequences of Stikinia (ST), Quesnellia (QN), Eastern Klamaths (EK) and Northern Sierra (NS) terranes) were developing on top of pericratonic mid-Palaeozoic and older fragments of Yukon–Tanana (YT), Yreka–Trinity and Shoo Fly terranes. Onset of Uralian tectonism along northern Baltica, Kazakhstania and Siberia, and inferred expulsion of the Farewell terrane (FW) from the Siberian margin. OM, Omulevka ridge; WR, Wrangellia. Other abbreviations as in Figures 11–14.
Late Devonian–Early Mississippian time. Subduction along western Laurentia is inferred to have been initiated as a result of a global plate reorganization related to Devonian convergence in the Appalachian orogen of eastern Laurentia and Carboniferous collision with Gondwana. By early Mesozoic time, this subduction system had evolved to a stable, wide-slab geometry that persisted along western North America at least until early Cenozoic time.

This paper, as indeed our entire learning experience in the Cordillera, has been shaped by the observations and inferences of many others. As well as citing their papers, we highlight here some principal influences on our grasp of the Caledonian–Siberian terranes: P. Belasky, D. Bradley, J. Dumoulin, G. Gehrels, D. Harwood, E. Katvala, L. Lane, N. Lindsley-Griffin, W. McClelland, M. Mihalynuk, E. Miller, M. Miller, J. Monger, T. Moore, B. Murchey, and C. Soja; it is hoped that their ideas appear here in forms that are true to the originals. In particular, we wish to acknowledge recent conversations with J. Wright, whose innovative solution to some problems of Cordilleran terrane origin was the spark for the present endeavour. Thanks to P. Cawood for encouraging us to submit a western Laurentian story to this volume. We are grateful to N. Lindsley-Griffin for her careful corrections to the section on the eastern Klamaths. Formal reviews by D. Bradley, G. Gehrels and C. van Staal have helped to clarify our arguments. This is Yukon Geological Survey Contribution YGS2008-001.

References


OK< now where were things?
One clue is stuff separating the really exotic from the not-so-exotic. Black terranes are juvenile oceanic terranes. In contrast, stuff to east shows signs of looking like NAM.

Figure 4. Evolution of the Canadian Cordilleran mios- genetic in Alberta. (Dawson et al. 1990) compared to the sedimentary samples of this study having negative εNd values. Five northern Cache Creek samples are from Jackson (1992). Nusetan assemblage samples, with poorly constrained sedimentation age, have been omitted.
Most terrane maps focus on Canada; map at right extends this into US
Fauna work here too...
Paleomag often used. Here is K from a compilation a few years back.
Figure 1. Cretaceous offsets. The table and map illustrate the displacement field across the Cordillera. Coarse points indicate the relative displacement of the Omineca and Interior terranes, and fine points indicate the relative displacement of the Coast and Interior terranes. The table shows the differential displacement in the Northward direction. The map shows the relative displacement of the Omineca and Interior terranes. The table includes symbols for no tilt correction, tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt 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of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the tilt correction of the ti...
We can in theory combine pmag and compare with NAM to see N–S motions…. (this is based on a strongly revised NAM paleolatitude analysis)
Of course longitude is unclear...
OK, when did stuff arrive? Here is where controversy arises. Overlap or stitching plutons usually what is used...
By geologic measures, might think Intermontane terrane docked in J and Insular (Alex + Wrang) in early K.
...and this is the cartoon interpretation.
but recall this pmag. Suggests not docked in early K. This is heart of trouble...
Cowan et al., Am J. Sci., 1997
Attention focused on one pluton for what could be wrong in pmag...
Fig. 3. Equal-area projection on the lower hemisphere, showing site-mean directions of magnetism for the Mt. Stuart batholith. Symbols are keyed to Fig. 4: eastern sites are shown by triangles, western sites by circles. The solid square represents the Cretaceous expected direction at the present latitude and longitude of the Mt. Stuart rocks, calculated from Mankinen [19].

Beck et al., EPSL, 1981
could translate or tilt....
Figure 10. Depth contours computed from the best-fit paleosurface by determining the intersection of the present topography with surfaces of constant crystallization depth (cf. text and Fig. 2A).

Ague & Brandon, GSA Bull, 1996
So suggestion that detrital zircons should be the answer....
Note small numbers of zircons in this analysis
not so fast say Housen and Beck--look at all these 1.2–1.7 Ga zircons… [but remember where the magmatic gap was? Do these look Baltica?]
Even more extreme is the “yo-yo” model where Baja BC is close and then moves way south and then north again...
5.1. Upsection Trends in Provenance as a Proxy for Mesozoic Exhumation

Existing biostratigraphic age constraint and new maximum depositional ages from the Kahiltna assemblage allow us to examine changes in provenance during individual stages of sedimentation and evolution of the Kahiltna basin (Figure 7). The oldest stratigraphic interval in the Kahiltna assemblage that was sampled for this study is located in the easternmost part of the Alaska Range suture zone (Figures 2 and 3) and is interpreted here to represent the lowermost, basal stratigraphy in the Kahiltna basin (Figure 7). Detrital zircon age populations from this stratigraphic interval reveal that 100% of zircon grains are Mesozoic in age and fall between an age range of 140–180 Ma (Figures 5, 6, and 7). Possible sources for this detritus include the Talkeetna, Chitina, Chisana arcs of the Wrangellia composite terrane in southern Alaska as well as age-equivalent magmatic source areas of the Yukon–Tanana, Quesnellia–Slide Mountain, Cache Creek, and Stikinia terranes of the Intermontane belt (Figure 1). It could be argued that the occurrence of 100% Mesozoic age zircons at this stratigraphic interval represents the initial exhumation of Mesozoic source areas both inboard and outboard of the Kahiltna basin. However, given the multiphase history of exhumation in the North American Cordillera throughout the Phanerozoic it seems unlikely that regions inboard of the Kahiltna basin have not undergone extensive phases of exhumation and hence, would have been exhumed to much deeper levels to expose Paleozoic and Precambrian age sources by Late Jurassic–Early Cretaceous time. This argument together with the lack of Paleozoic and Precambrian age detrital zircons in the basal parts of the Kahiltna assemblage as compared to younger stratigraphic intervals leads us to infer that detritus at this stage represents an initial exhumation of Mesozoic source areas both inboard and outboard of the Kahiltna basin.

These are from Wrangellia-affinity rocks (Kahiltna assemblage). They don’t exactly land on either side but do argue this records suturing of Wrangellia to Intermontane terrane.
Figure 8. A three-stage conceptual model for sedimentary basin evolution associated with the accretion of the Wrangellia composite terrane to the Intermontane belt and North American Cordillera during Jurassic–Cretaceous time. The tectonic configurations of two parallel, north dipping subduction zones are based on reconstructions of Trop and Ridgway [2007].

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