Paired Metamorphic Belts

M.Sc. Semester II

M. K. Yadav
Assistant Professor
Department of Geology
Lucknow University-226007
Email: mkyadav.geo@gmail.com

Paired Metamorphic Belts

- Paired metamorphic belts are sets of parallel elongate rock units that display contrasting metamorphic mineral assemblages.

- Each pair consists of two belts: a high Pressure-low Temperature belt and a low P-high T belt.

- These paired belts develop along convergent plate boundaries where subduction is active.

Historical background

- Japanese geologist Akiho Miyashiro (1961) was the first to theorize the concept of paired metamorphic belts.
- He noted the existence of paired metamorphic belts, consisting of high P/T terranes adjacent to low P/T terranes, in young mountains of Japan and other regions within the circum-Pacific region. The question arose as to why young paired metamorphic belts exist in the circum-Pacific, Caribbean, Scotia and eastern Indian Ocean region and not elsewhere?
- Miyashiro's observation was particularly timely as 1960s research revolutionized our knowledge of Earth's dynamic nature.
- Within a few years, the paired metamorphic belts that encircle the Pacific Ocean were recognized as subduction zone (outer metamorphic belt) and magmatic arc (inner metamorphic belt) assemblages that developed in response to lithospheric plate convergence and subduction.

The **paired metamorphic belts** correspond with the two major components of convergent margins:

1) The outer metamorphic belt occurs on the ocean or trench side and consists of Sanbagawa or Franciscan facies series rocks, characterized lower thermal gradients and high P/T to very high P/T mineral assemblages.

- Rapid, steep subduction favors the development of very high P/T ratios that characterize the Franciscan facies series, whereas slower, shallower subduction favors the development of the moderate to high P/T ratios that characterize the Sanbagawa facies series.

- The outer metamorphic belt also contains hornfels facies, zeolite facies and prehnite-pumpellyite facies metamorphism from early ocean ridge alteration.

- However, these rocks are commonly overprinted by more recent greenschist facies and high pressure assemblages such as blueschist and eclogite facies rocks due to burial in the subduction zone.

- Notably, the assemblages of the amphibolite and granulite facies are absent. (These are high T metamorphic facies', do you remember??)

- The outer metamorphic belt is exposed in subduction zone complexes, accretionary wedges and mélanges.

2) The inner metamorphic belt occurs on the continent or arc side and consists of Buchan or Barrovian facies series rocks, characterized by moderate to high temperature gradients and by moderate P/T to low P/T mineral assemblages.

- The inner metamorphic belt is marked by the occurrence of hornfels facies, zeolite facies, prehnite-pumpellyite facies, greenschist facies, amphibolite facies and granulite facies produced by arc magmatism and compressive stresses.

- Notably, assemblages of the blueschist and eclogite facies are absent. (These are high P metamorphic facies', do you remember??)

- The inner metamorphic belt occurs along the magmatic arc complex.

Paired Metamorphic Belts of Japan

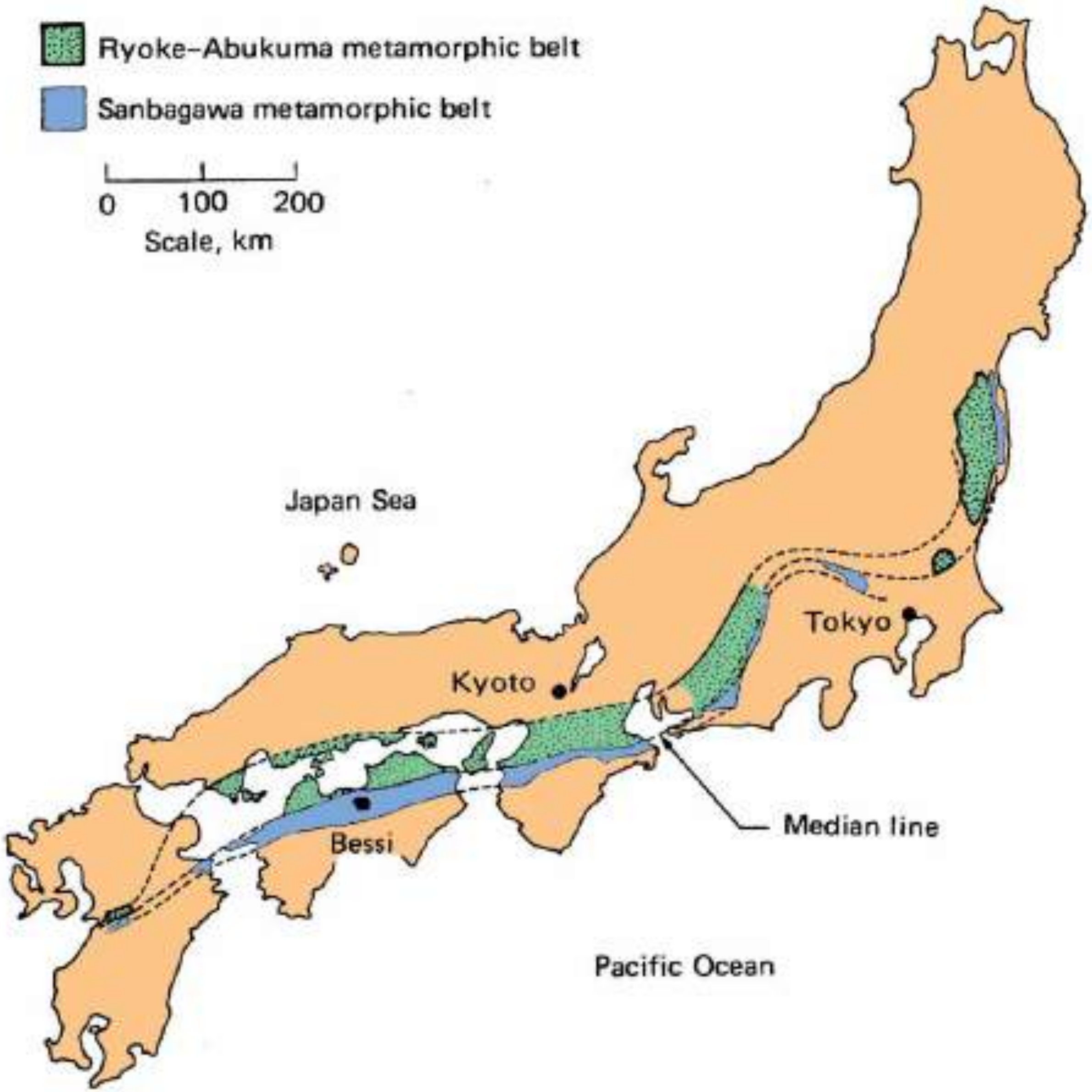


Figure. The Sanbagawa and Ryoke metamorphic belts of Japan. From Turner (1981) *Metamorphic Petrology: Mineralogical, Field, and Tectonic Aspects.* McGraw-Hill and Miyashiro (1994) *Metamorphic Petrology*. Oxford University Press.

Shikoku and Honshu in Japan: a pair of parallel metamorphic belts are exposed along a NE-SW axis parallel to the active subduction zone

These belts are of the **same age**, suggesting that they **developed together**

- The NW belt ("**inner**" belt, inward, or away from the trench) is the **Ryoke** (or **Abukuma**) Belt
  - **Low P/T** **Buchan-type** of regional orogenic metamorphism
  - Dominant meta-pelitic sediments, and isograds **up to the sillimanite zone** have been mapped
  - A **high-temperature-low-pressure** belt, and **granitic plutons** are common
- **Outer** belt, called the **Sanbagawa** Belt
- It is of a **high-pressure-low-temperature** nature
  - Only reaches the **garnet zone** in the pelitic rocks
  - Basic rocks are more common than in the Ryoke belt, however, and in these **glaucophane** is developed (giving way to hornblende at higher grades)
  - Rocks are commonly called **blueschists**
- Two belts are in contact along their whole length across a **major fault zone** (the Median Line)
- **Ryoke-Abukuma** lithologies are similar to **seds** derived from a relatively mature **volcanic arc**
- **Sanbagawa** lithologies more akin to the **oceanward** **accretionary wedge** where distal arc-derived sediments and volcanics mix with oceanic crust and marine sediment

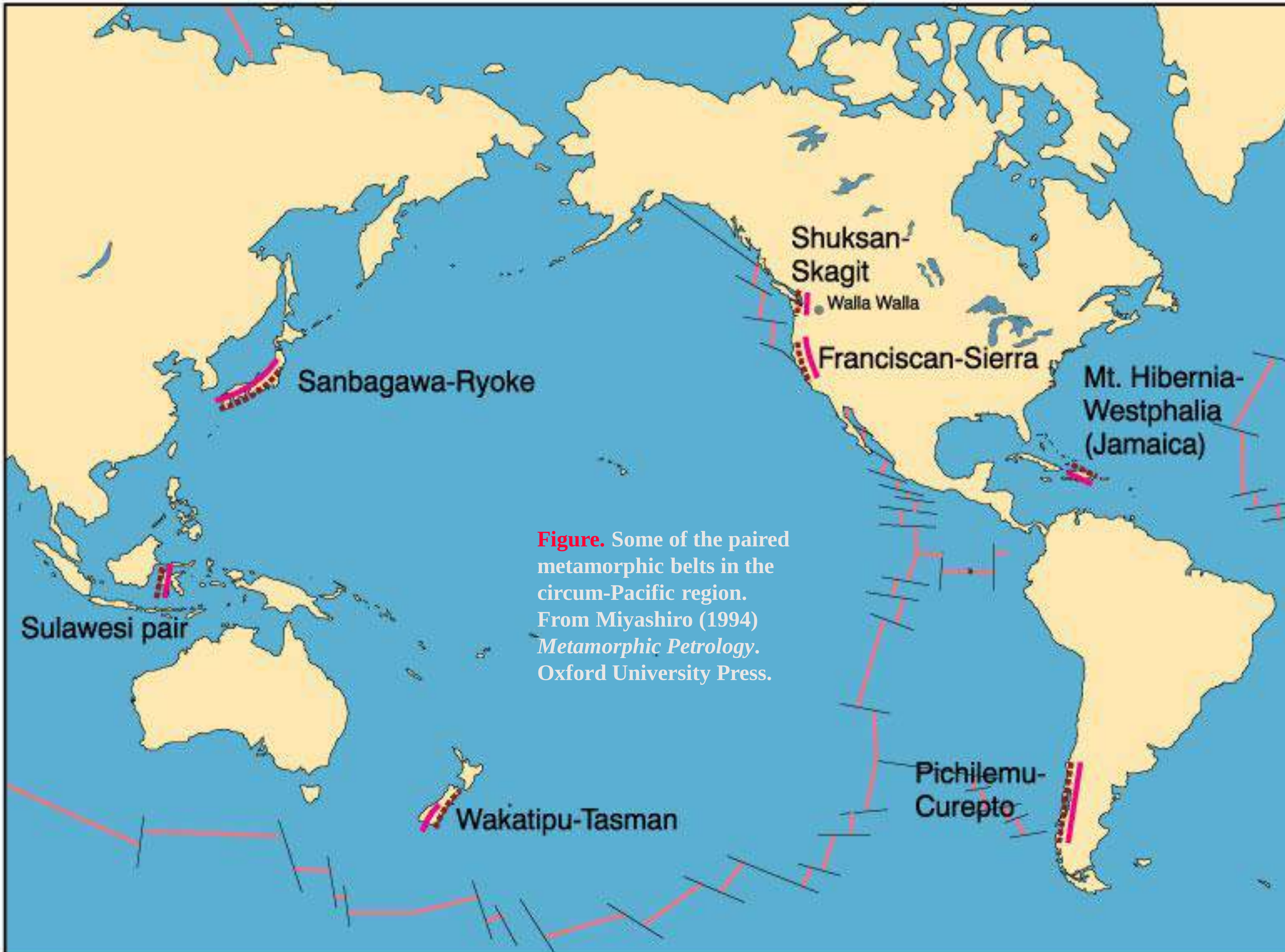


Figure. Some of the paired metamorphic belts in the circum-Pacific region. From Miyashiro (1994) *Metamorphic Petrology*. Oxford University Press.

Miyashiro (1961, 1973) noted the paired nature of the Ryoke-Sanbagawa belts, and suggested …

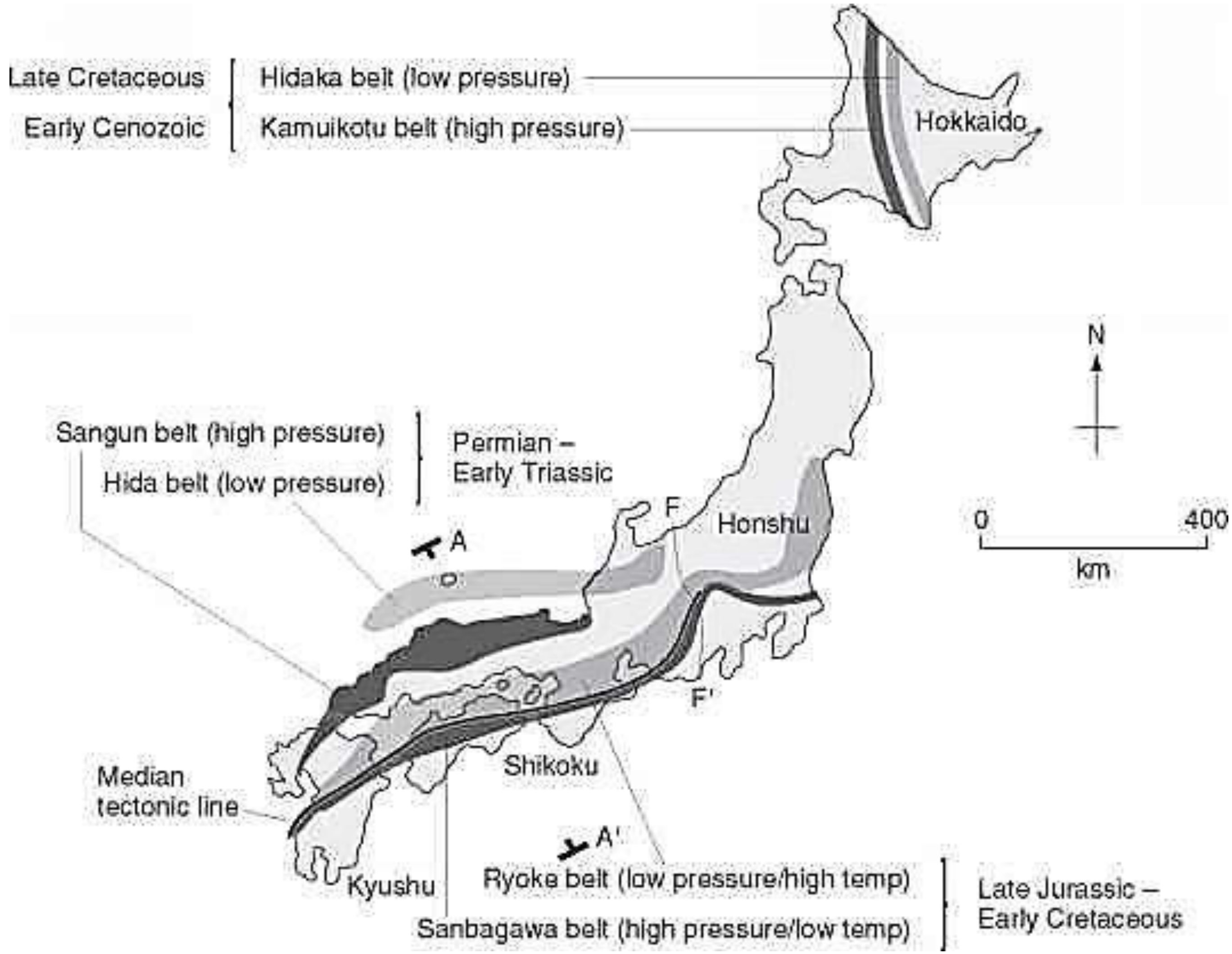
- Coeval (nearly of same age) metamorphic belts, an outer, high-P/T belt, and an inner, lower-P/T belt ought to be a common
- Called these **paired metamorphic belts**
- May be separated by 100-200 km of less metamorphosed and deformed material ("**arc-trench gap**") or closely juxtaposed (Ryoke-Sanbagawa)

  In the latter cases the contact is commonly a major fault

RECENT STUDIES suggest that Most of these belts are quite complex, and are not always coeval

- On the Japanese islands of Hokkaido, Honshu, and Shikoku (see fig. on next page), Miyashiro identified three pairs of metamorphic belts of different age that approximately parallel the trend of the modern Japanese subduction zone. Each of these belts consists of an outer zone of high pressure/low temperature blueschist and an inner belt of low pressure/ high temperature rock. This spatial relationship and the similar age of each outer and inner belt led him to conclude that the belts formed together as a pair. After the introduction of plate tectonics, these paired belts were interpreted to be the result of underthrusting of oceanic crust beneath an island arc or continental crust (Uyeda & Miyashiro, 1974). The outer metamorphic belt was interpreted to develop near the trench due to the low geothermal gradient caused by subduction. The inner belt was interpreted to form in the arc, some 100-250 km away, where geothermal gradients are high.

- The application of the paired metamorphic belt model to Japan has allowed some investigators to infer the direction of subduction and plate motions at various times in the past. At present, Pacific lithosphere is subducted in a northwesterly direction beneath the Japan arc. The metamorphic polarity of the Sangun/Hida and Ryoke/Sanbagawa paired belts suggests that they were formed similarly, by underthrusting in a northwesterly direction. The Hidaka/Kamuikotu paired belt shows the opposite metamorphic polarity, and therefore may have formed during a different phase of plate movements when the direction of subduction was from the west of Japan.



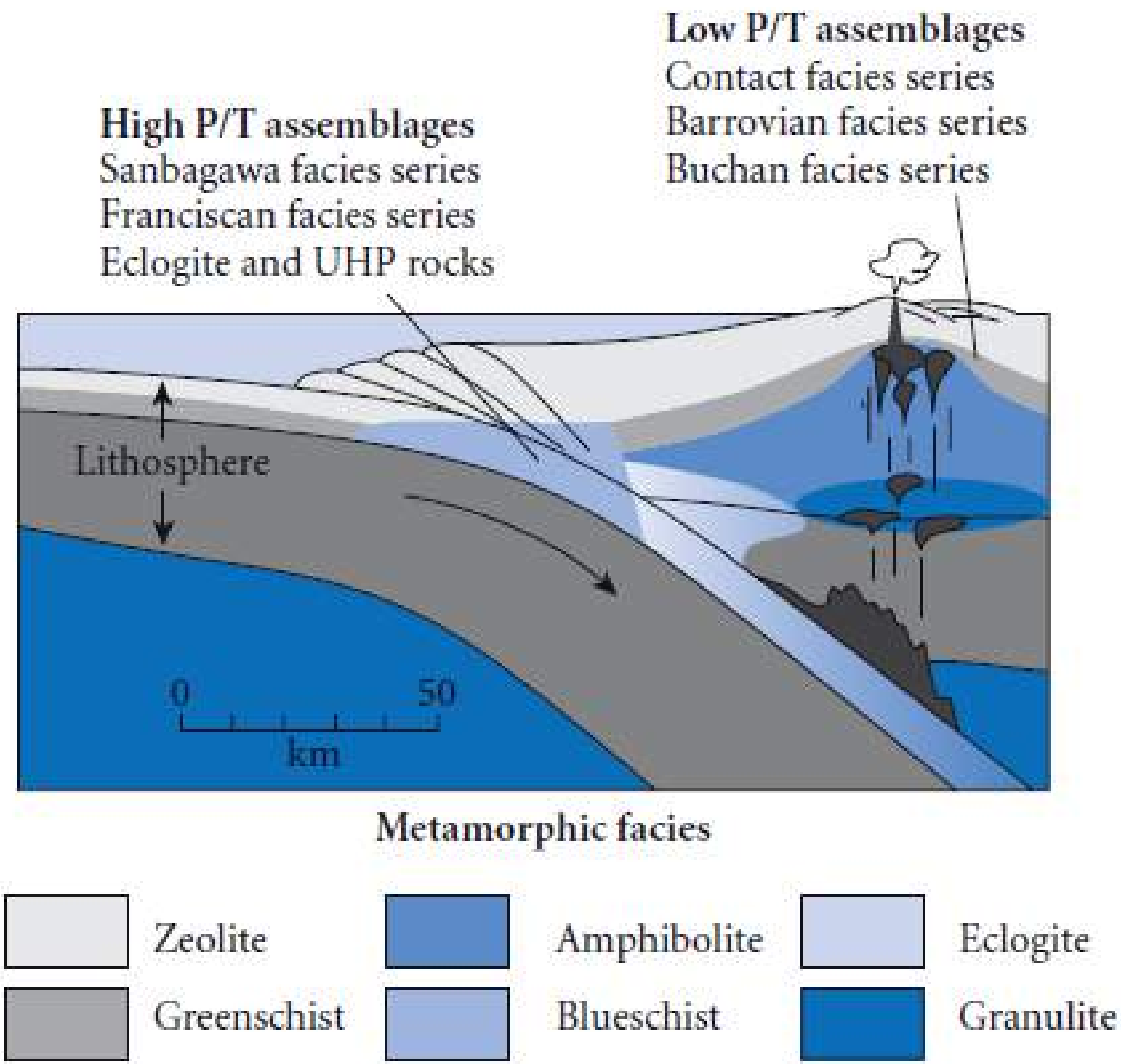
- Ryoke belt is also known as Ryoke-Abukuma belt

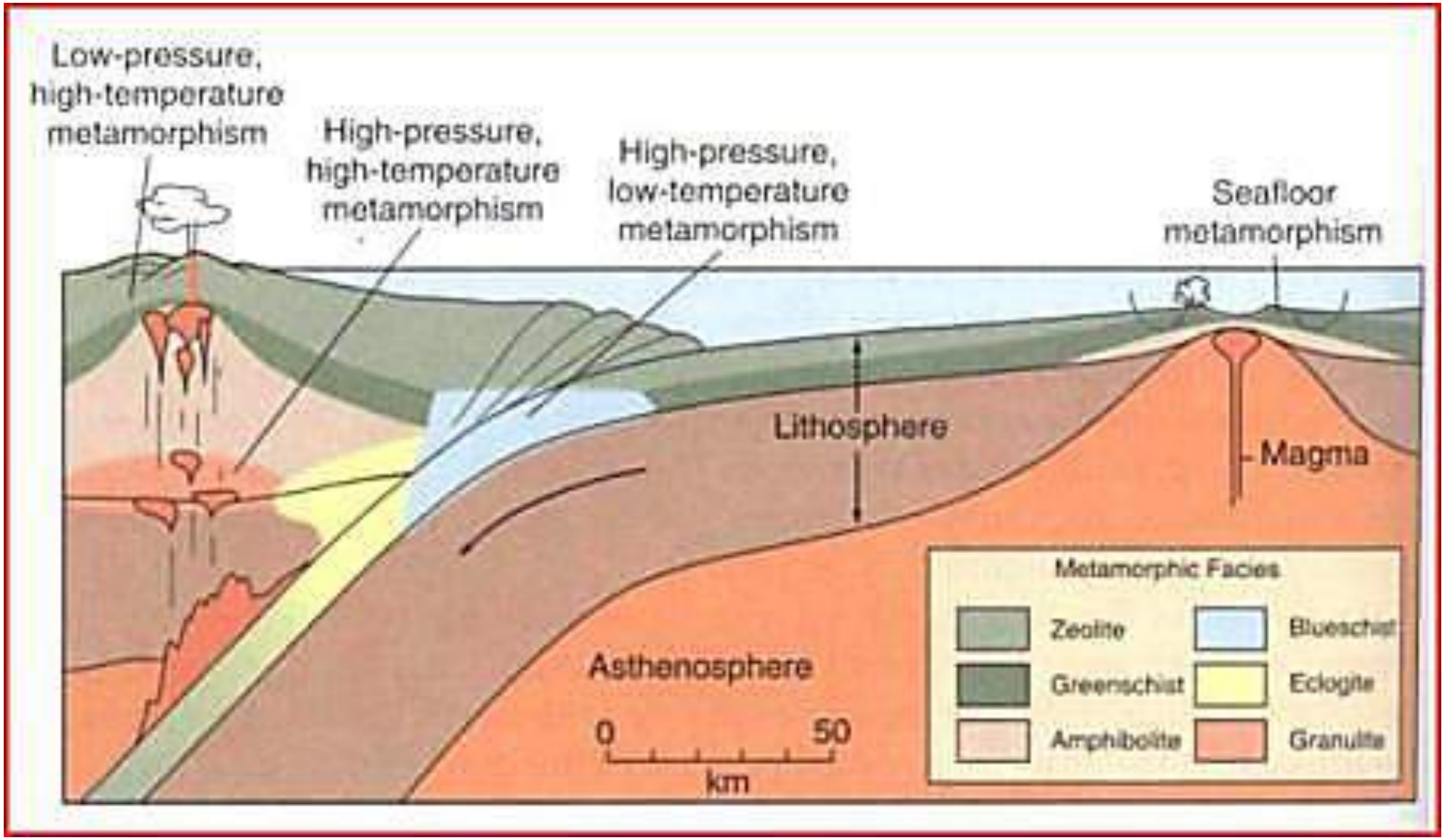
- Sanbagawa facies series progresses from (1) zeolite, (2) prehnite-pumpellyite, (3) blueschist facies (4) greenschist to (5) amphibolite facies.

- Franciscan facies series progresses from (1) zeolite, (2) prehnite-pumpellyite, (3) blueschist to (4) the eclogite facies.

- Buchan facies series progresses from (1) zeolite (2) prehnite-pumpellyite, (3) greenschist (4) amphibolite to (5) the high temperature, moderate pressure granulite facies.

- Barrovian facies series progresses from (1) zeolite (2) prehnite-pumpellyite, (3) greenschist (4) amphibolite to (5) the high temperature, moderate to high pressure granulite facies.


Low P/T assemblages
Contact facies series
Barrovian facies series
Buchan facies series
High P/T assemblages
Sanbagawa facies series
Franciscan facies series
Eclogite and UHP rocks
Lithosphere
0
50
km
Metamorphic facies
Zeolite
Amphibolite
Eclogite
Greenschist
Blueschist
Granulite

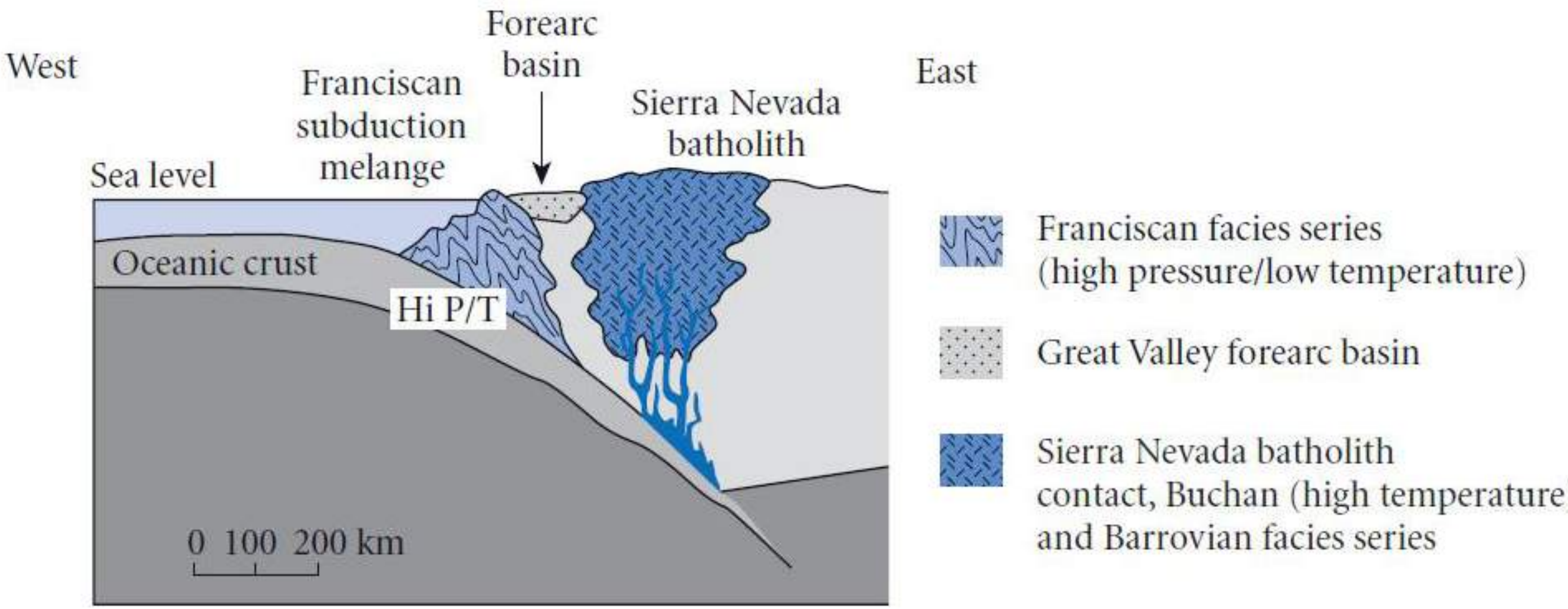


Same figure as on previous page, just more coloured for better understanding

- Two popular examples of paired metamorphic belts are: (1) Sanbagawa-Ryoke pair, (2) Franciscan- Sierra Nevada belt.

- In Japan, where the Sanbagawa Belt represents the high-pressure/low-temperature belt, and the adjacent Ryoke-Abukuma Belt, representing the low-pressure/high-temperature belt. The Ryoke-Abukuma belt consists of Barrovian- and Buchan-facies series metamorphic rocks. The other example is represented by the western U.S., where the Franciscan complex contains rocks metamorphosed at high pressure and low temperature, whereas rocks exposed in the Klamath Mountains and Sierra Nevada Mountains expose remnants of Barrovian- and Buchan-facies series metamorphic rocks.

- The occurrences of paired belts have since been recognized throughout the world and include areas in New Zealand, Indonesia, Washington State in the U.S., Chile, Jamaica., the Alps of central Europe and the northern coast of South America.



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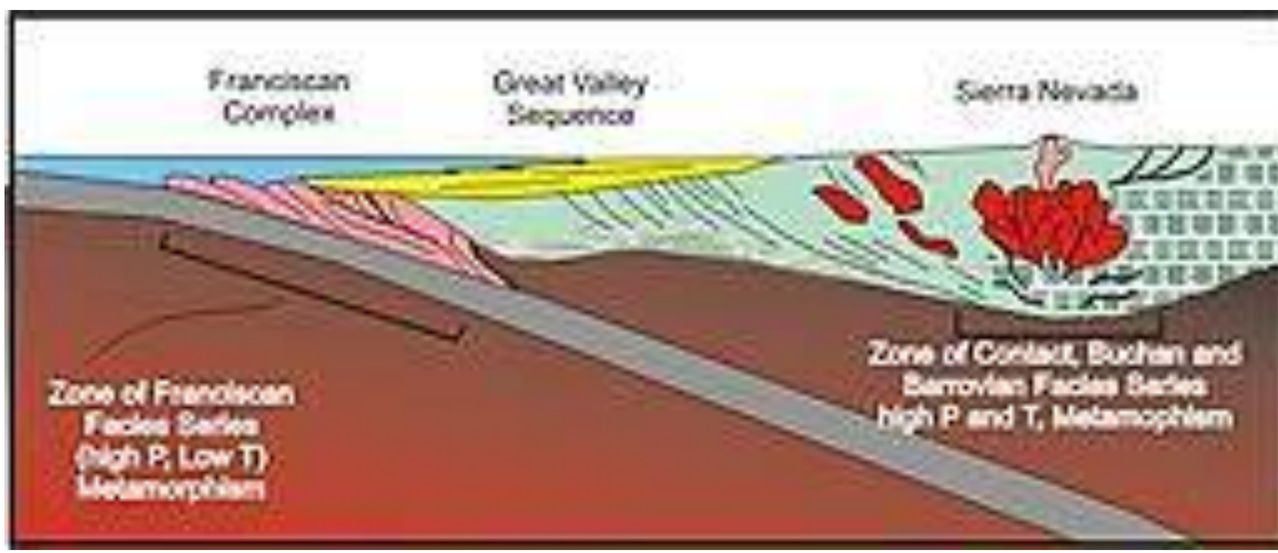

- Most of these areas show evidence of having been associated with convergent plate margins, where subduction has occurred. It appears that subduction is necessary to produce the low geothermal gradient necessary to form the belt of high pressure and low temperature. Such belts are quite rarely preserved in the geologic record due to the presence of hydrous minerals during blueschist-facies metamorphism. An exception takes place when these rocks are uplifted and exposed at the surface relatively fast after subduction ceases so that these rock units are able to escape being overprinted by facies of a normal geothermal gradient, as there would be still fluids available to form the greenschist- and amphibolite-facies mineral assemblages.

- The high-pressure, high-temperature belts are expected to form in areas beneath the island arc or continental margin volcanic arc. During emplacement of the arc, these areas are subject to higher-than-normal geothermal gradients that could produce Buchan-facies series metamorphic rocks. Furthermore, emplacement of batholiths and isostatic adjustment after magmatism has ceased due to the fact that these belts of high-T, high-P metamorphism were uplifted and exposed at the surface.

- In the case of the Japanese paired belts, the two belts are adjacent to one another likely because subduction has moved farther off the coast. Compressional tectonics between the Pacific and Eurasian Plate has accreted the island arc and trench complex to Japan at the end of the Mesozoic.

- In the case of the western U.S., the paired belts are separated from one another. This is because the oceanic ridge that existed off the western coast of North America was subducted, and the margin changed from dominated by compression and subduction to a transform-fault margin dominated by strike-slip faulting. Isostatic rebound of the highly deformed Franciscan Complex has resulted in its exposure at the surface.

Significance of Paired metamorphic belts

- Paired metamorphic belts permit the inference of subduction directions and relative plate motions at various points in the past.

- For example, the Ryoke/Sanbagawa paired metamorphic belt in eastern Japan displays a metamorphic sequence indicating a north-west subduction direction. Whereas the Hidaka/Kamuikotu paired metamorphic belt on the western coast of Japan exhibits opposite orientation, indicating a different subduction direction. Furthermore, by dating paired metamorphic belts, the origin of present-day tectonic subduction mechanisms (asymmetric subduction) can be inferred.

Geothermal Gradient

- Metamorphic belts are a consequence of thermal perturbations, due to low temperature with respect to pressure ratios (dT/dP) in oceanic trenches and high temperature with respect to pressure ratios (dT/dP) in arcs.
- Paired metamorphic belts are the product of subducted colder crustal rocks, which are taken to depth, metamorphosed and then exhumed. However, if the rock unit is not exhumed relatively quickly after subduction ceases, the rock unit will re-equilibrate to the standard geothermal gradient and the geological record will be lost.
- Recently, it has been established that a metamorphic belt no longer could be considered characterized by a single geothermal gradient (it is opposite to what Miyashiro had suggested), because the thermal history must record evolution across a range of geotherms with time.

Recent discoveries

- In recent years, greater knowledge of processes along convergent plate boundaries has caused skepticism about this simplistic model. Observations indicate convergent boundaries typically display oblique motion. The implications of such observations demonstrate the possibility that metamorphic belts could have formed in different sectors of the same subduction margin and became juxtaposed afterwards. Furthermore, accreting allochthonous terrains along subduction zones as a mechanism, encourages the skepticism. The contrasting metamorphic assemblages may have been produced from remote environments. Moreover, the realization that most metamorphic belts are not the product of a single geothermal gradient indicates a more complex mechanism.

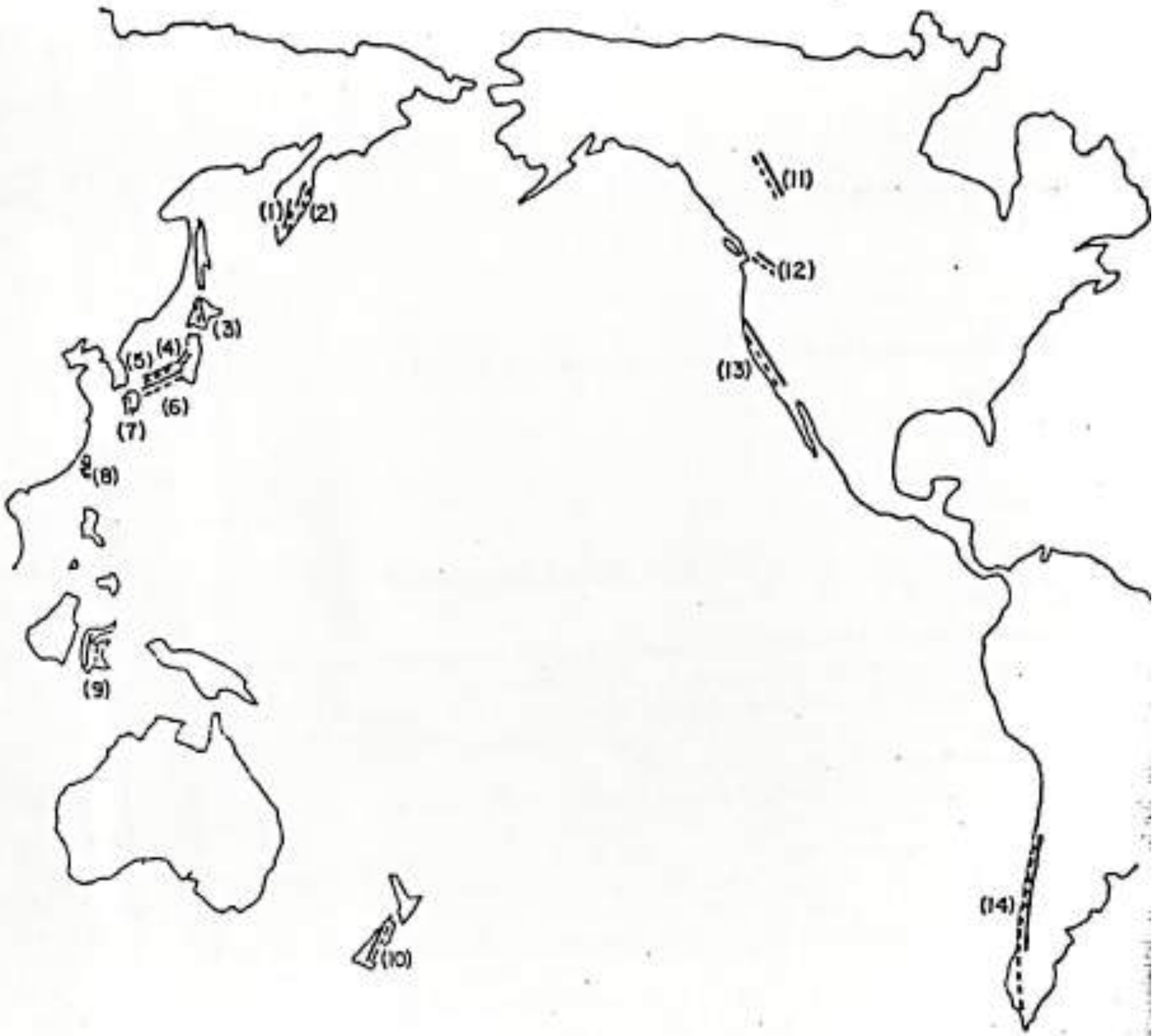

Fig. 1. Paired metamorphic belts in the circum-Pacific regions. Thick broken lines represent high-pressure metamorphic belts, and thick full lines low-pressure metamorphic belts. The deformation by faulting after their formation is ignored for simplicity. The names and geologic ages of these belts are shown in Table I.

TABLE I

Paired metamorphic belts in the circum-Pacific regions

Number	Region	High-pressure belt	Low-pressure belt	Age of metamorphism	References
1	Kamchatka	Ganalsky	Sredinny	Early Mesozoic (?)	Lebedev et al. (1967), Dobretsov and Kuroda (1969)
2	Kamchatka	Karaginsko-Kronotskaya	(Central Kamchatka)	Late Mesozoic (?)	Lebedev et al. (1967), Dobretsov and Kuroda (1969)
3	Hokkaido	Kamuikotan	Hidaka	Cretaceous–Tertiary	Miyashiro (1961, 1967)
4	Central Japan	Circum-Hida (Omi)	Hida (partly)	Carboniferous	–
5	Southwest Japan	Sangun	Hida (partly)	Permian–Jurassic	Miyashiro (1961, 1967)
6	Southwest Japan	Sanbagawa	Ryoke	Jurassic–Cretaceous	Miyashiro (1961, 1967)
7	Westernmost Kyushu	Nishisonogi (Nagasaki)	Ai-no-shima	Cretaceous	Miyashiro (1965), Karakida et al. (1969)
8	Taiwan	Yüli	Tailuko	Late Mesozoic (?)	Yen (1963)
9	Celebes	–	–	–	Miyashiro (1961)
10	New Zealand	Wakatipu	Tasman	Jurassic–Cretaceous	Landis and Coombs (1967)
11	Canada	–	Cassia-Omineca-Columbia	Mesozoic	Monger and Hutchison (1970)
12	Washington State	Shuksan	Skagit	Permian (?)	Misch (1966)
13	California	Franciscan	Sierra Nevada	Jurassic–Cretaceous	Hamilton (1969), Suppe (1970)
14	Chile	Pichilemu (Western)	Curepto (Eastern)	Late Paleozoic	Gonzalez-Bonorino (1971), Aguirre (1972)

Note: The numbers of regions in this table are shown in Fig. 1.

Indian Example

- The Indus Suture Zone in Eastern Ladakh shows two metamorphic belts, a northern low pressure belt and the southern high pressure belt. The two belts to be referred to as Pongong and Zildat-Sumdo metamorphic belts respectively are now separated by the Ladakh batholith and post-batholith Indus flyschoidal sediments. Postmetamorphic thrusting has narrowed the width of the two belts though they can be traced for over 100km in the Indian territory before they extend into Tibet. The Pongong belt shows andalusite-kyanite-sillimanite type metamorphism accompanied by andesitic and rhyolitic volcanism and granitic activity. The Zildat-Sumdo belt is characterized by glaucophanitic metamorphism accompanied by abundant basites and ultra-basites. The two belts do not differ much in age though the high-pressure belt may be slightly younger.

Thank You

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