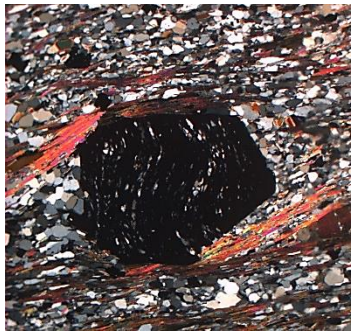
Metamorphic Facies Series

M.Sc. Semester II



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

Facies Series

- A metamorphic facies series is a sequence of facies that occurs across a metamorphic terrane due to differences in pressure and temperature (P/T) conditions.
- Variations in P/T conditions are related to both space and time.
- In order to describe a sequence of changing metamorphic conditions, geologists refer to pressure – temperature – time (P - T - t) relations in which the history of pressure and temperature changes over some period of time are inferred from the rock record.
- Each facies series is characterized by the development of a particular sequence of individual facies, with each facies stable at a specific range of temperature and pressure conditions.

Why is the concept of a facies series so important?

- Facies series provide key information concerning the progressive P - T - t conditions as well as the tectonic setting in which metamorphism occurred.

- Metamorphic facies series were defined (Miyashiro, 1994) on the basis of pressure and temperature gradients, both of which are related to the conditions of metamorphism and tectonic setting.

Metamorphic facies series known so far

- Five metamorphic facies series, assigned to three major groups, are recognized.

❖1. Low P/T series group: two low pressure and high temperature facies series are recognized:

a) the very low P/T contact facies series, and

b) the somewhat higher P/T Buchan or Abukuma facies series.

❖2. Moderate P/T series group: moderate P/T gradients characterize the Barrovian facies series.

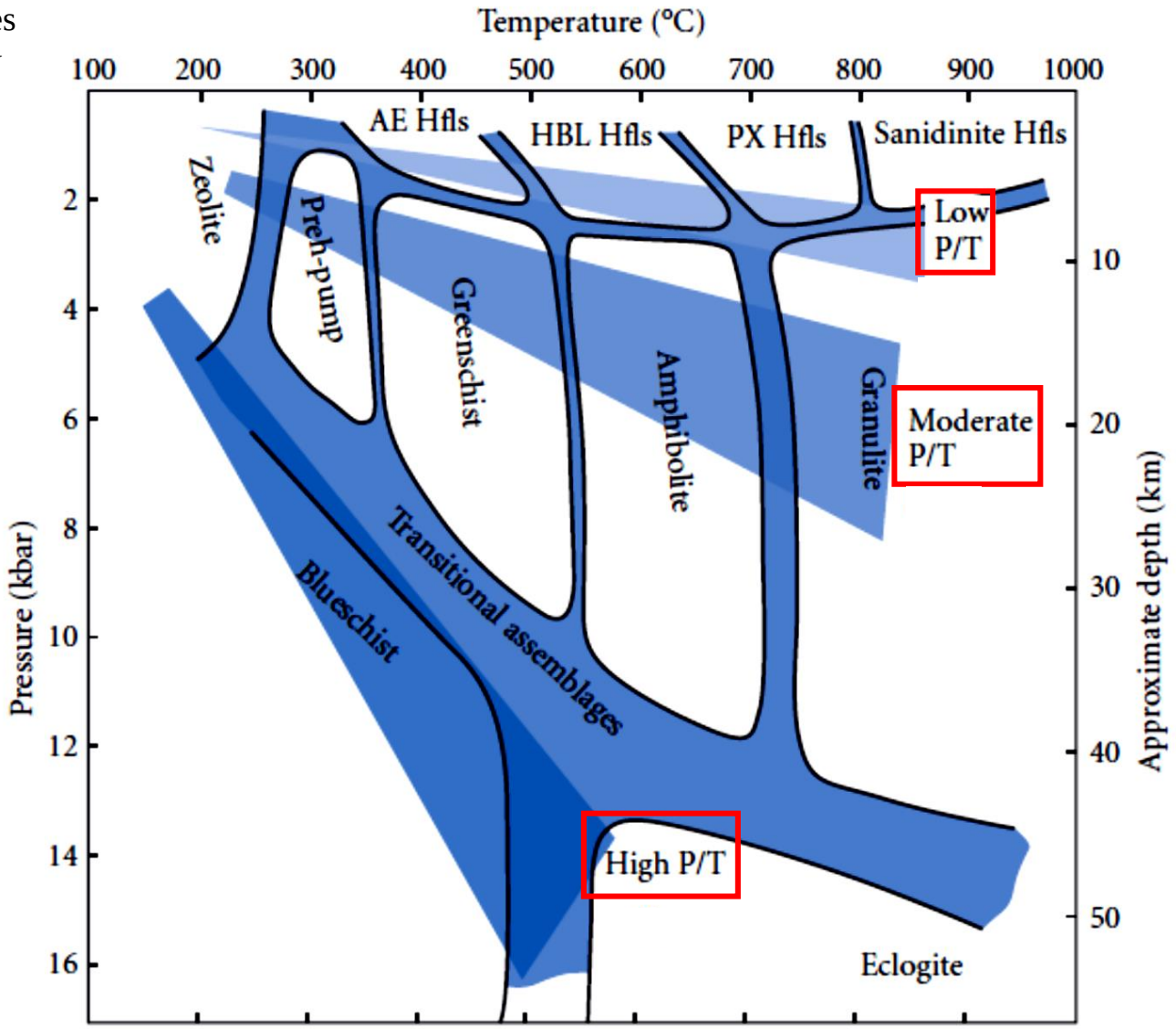
❖3. High P/T series group: the high P/T group includes the

a) Sanbagawa facies series and

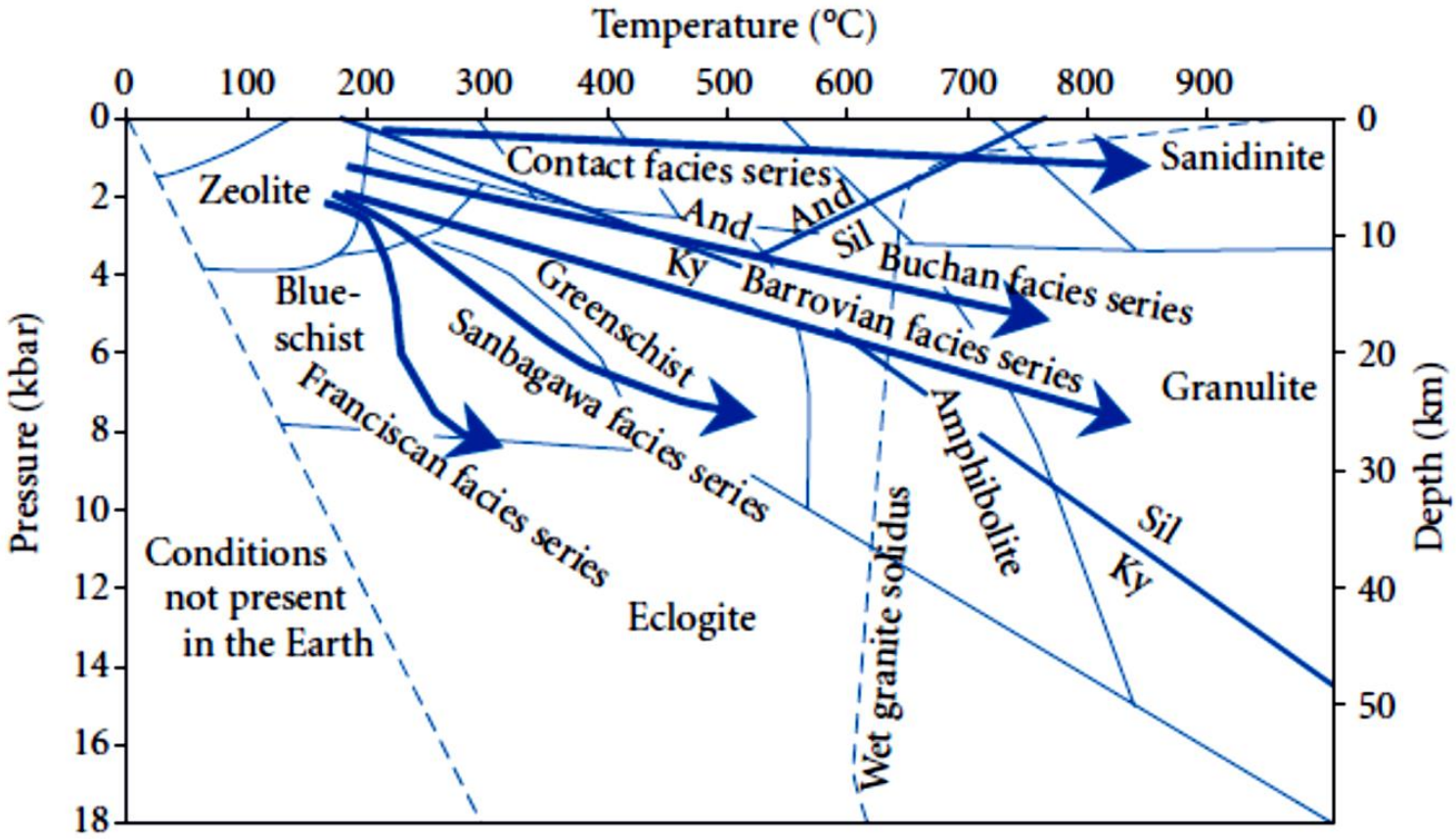
b) Franciscan facies series.

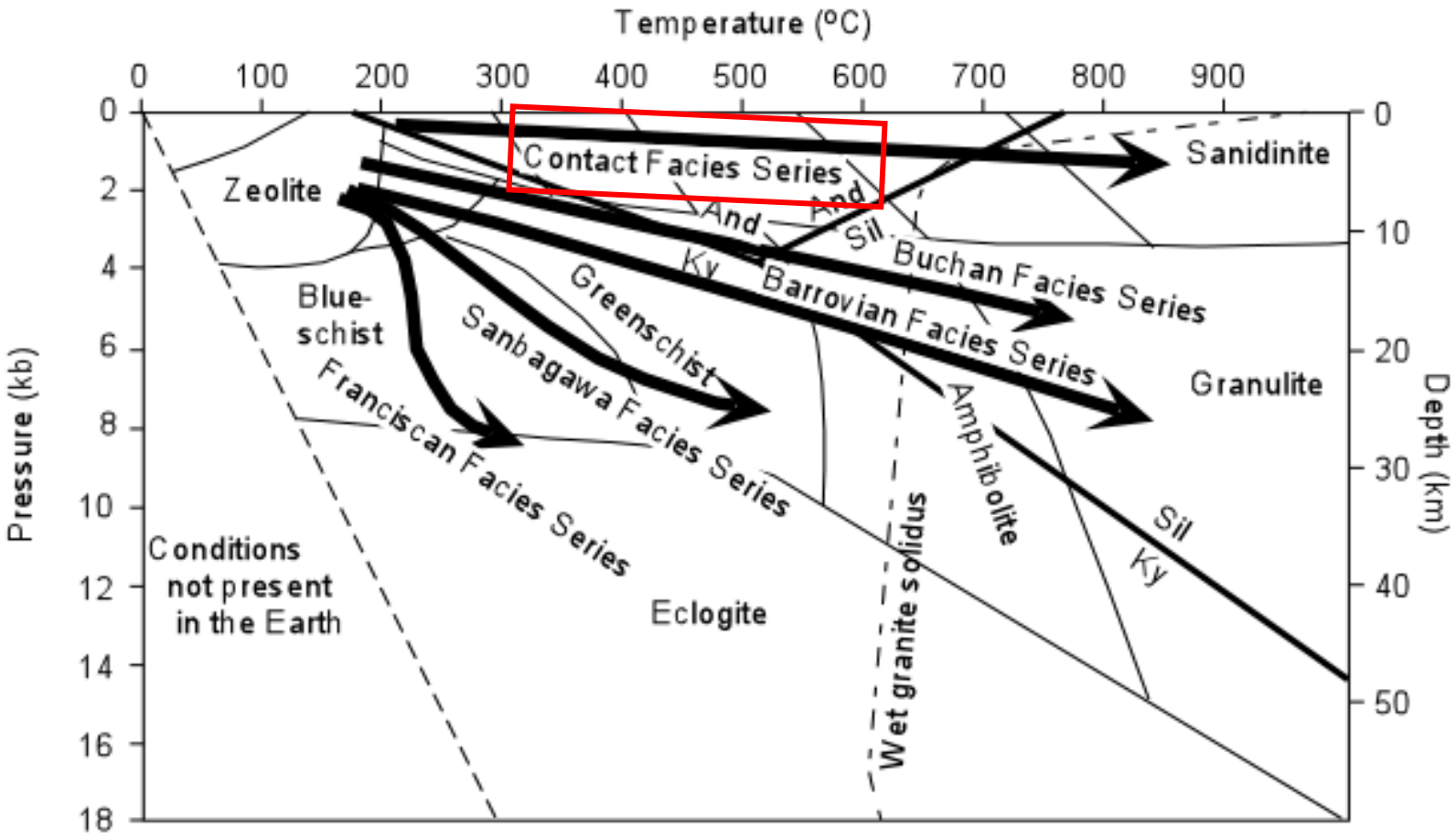
Metamorphic series trends

Fig. Temperature-pressure diagram showing the three major types of metamorphic facies series proposed by Miyashiro (1973, 1994).



Metamorphic facies series




Temperature (ºC)
0
100
200
300
400
500
600
700
800
900
Pressure (kb)
0
2
4
6
8
10
12
14
16
18
Depth (km)
0
10
20
30
40
50
Contact Facies Series
Sanidinite
Zeolite
And
And
Sil
Buchan Facies Series
Ky
Barrovian Facies Series
Blue-
schist
Greenschist
Sanbagawa Facies Series
Granulite
Franciscan Facies Series
Amphibolite
Sil
Ky
Conditions
not present
in the Earth
Eclogite
Wet granite solidus

Contact facies series

- Contact facies series consists of relatively low pressure (< 2.5 kbar ≈ 8 km depth) but moderate to high temperature mineral assemblages.
- The geothermal gradient for the contact facies series is > 80 ° /km, implying a significantly higher than average heat input due to magmatic activity.
- This facies series develops by contact metamorphism in aureoles adjacent to igneous intrusions.
- While contact metamorphism commonly occurs at shallow depths, it may also develop in moderate pressure conditions of the lower crust.
- Low pressure contact metamorphism produces hornfelsic and/or granoblastic rather than foliated textures.
- However, the rocks may display (1) relict foliated fabrics due to deformation that preceded contact metamorphism, or (2) overprinted foliated fabrics from deformation that occur after contact metamorphism.

Contact facies series

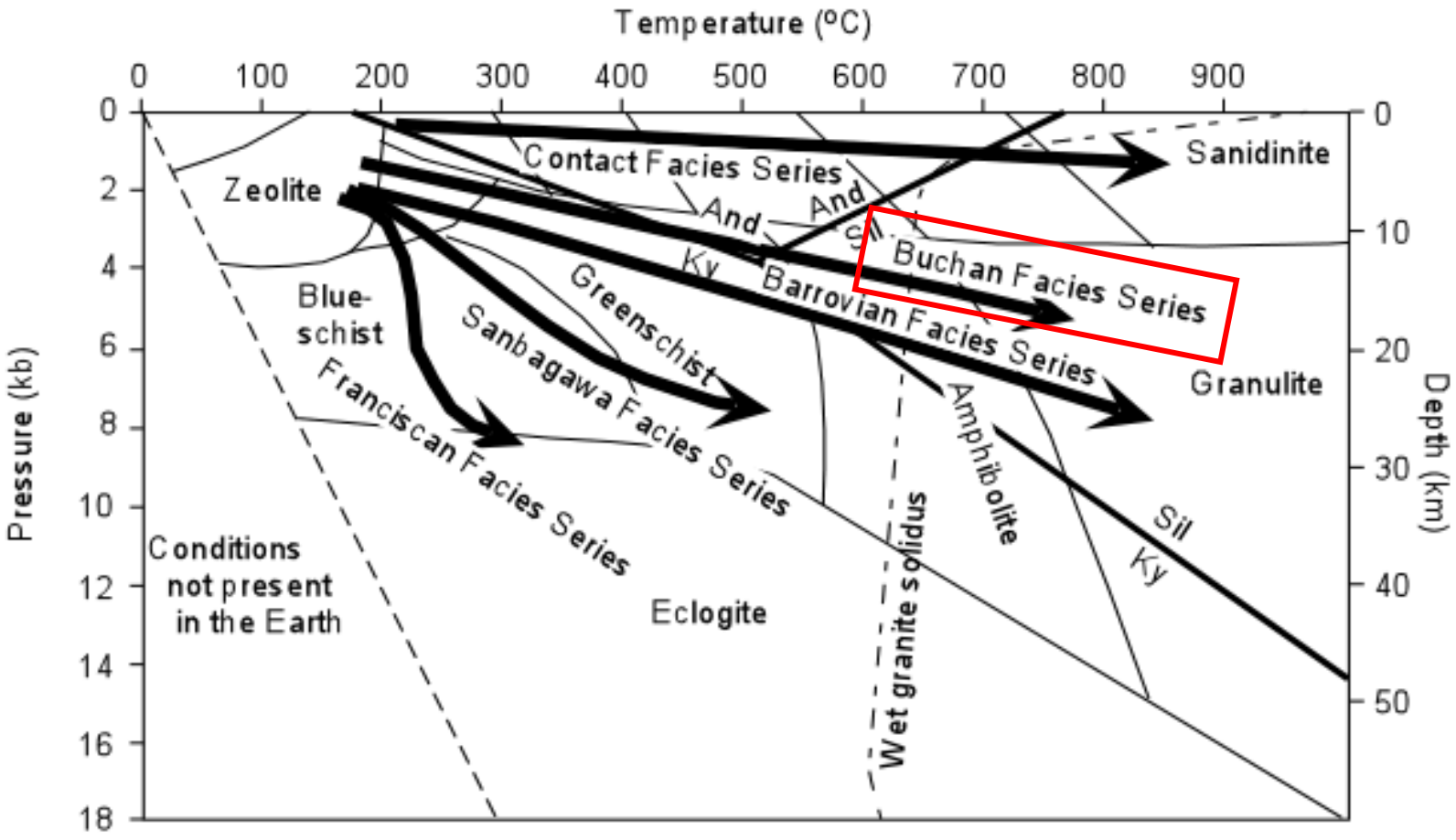
- Contact facies series metamorphism is recorded by the series of hornfels facies; each of the individual facies is defined based on a low pressure assemblage of minerals stable at specific temperature.
- For example, pelitic rocks commonly contain the low temperature polymorph andalusite in low temperature contact facies and the high temperature polymorph sillimanite in high temperature contact facies. The high pressure aluminum silicate polymorph kyanite does not occur.

Contact facies series

- With increasing temperature the contact facies series progresses through the sequence (1) zeolite facies, (2) albite - epidote hornfels facies, (3) hornblende hornfels facies, (4) the rarer pyroxene hornfels facies, and (5) at very high temperatures, sanidinite hornfels facies.
- On a temperature – pressure diagram, a line marking the trajectory of progressive contact metamorphism has a gentle slope, which reflects the progressive increase in temperature.

Contact facies series

- Higher temperature facies occur in close proximity to the intrusion with progressively lower temperature facies toward the outer margins of the contact metamorphic aureole.
- The contact facies series can occur anywhere hot plutons intrude rock, such as at convergent margins, ocean spreading ridges, hotspots and localized aureoles around intrusions.
- In contrast, the Buchan, Barrovian, Sanbagawa and Franciscan facies series are associated with orogenic belts at convergent plate boundaries.


Temperature (ºC)
0
100
200
300
400
500
600
700
800
900
Pressure (kb)
0
2
4
6
8
10
12
14
16
18
Depth (km)
0
10
20
30
40
50
Zeolite
Blue-
schist
Franciscan Facies Series
Greenschist
Sanbagawa Facies Series
Contact Facies Series
And
And
Sil
Ky
Buchan Facies Series
Barrovian Facies Series
Sanidinite
Granulite
Amphibolite
Sil
Ky
Conditions
not present
in the Earth
Eclogite
Wet granite solidus

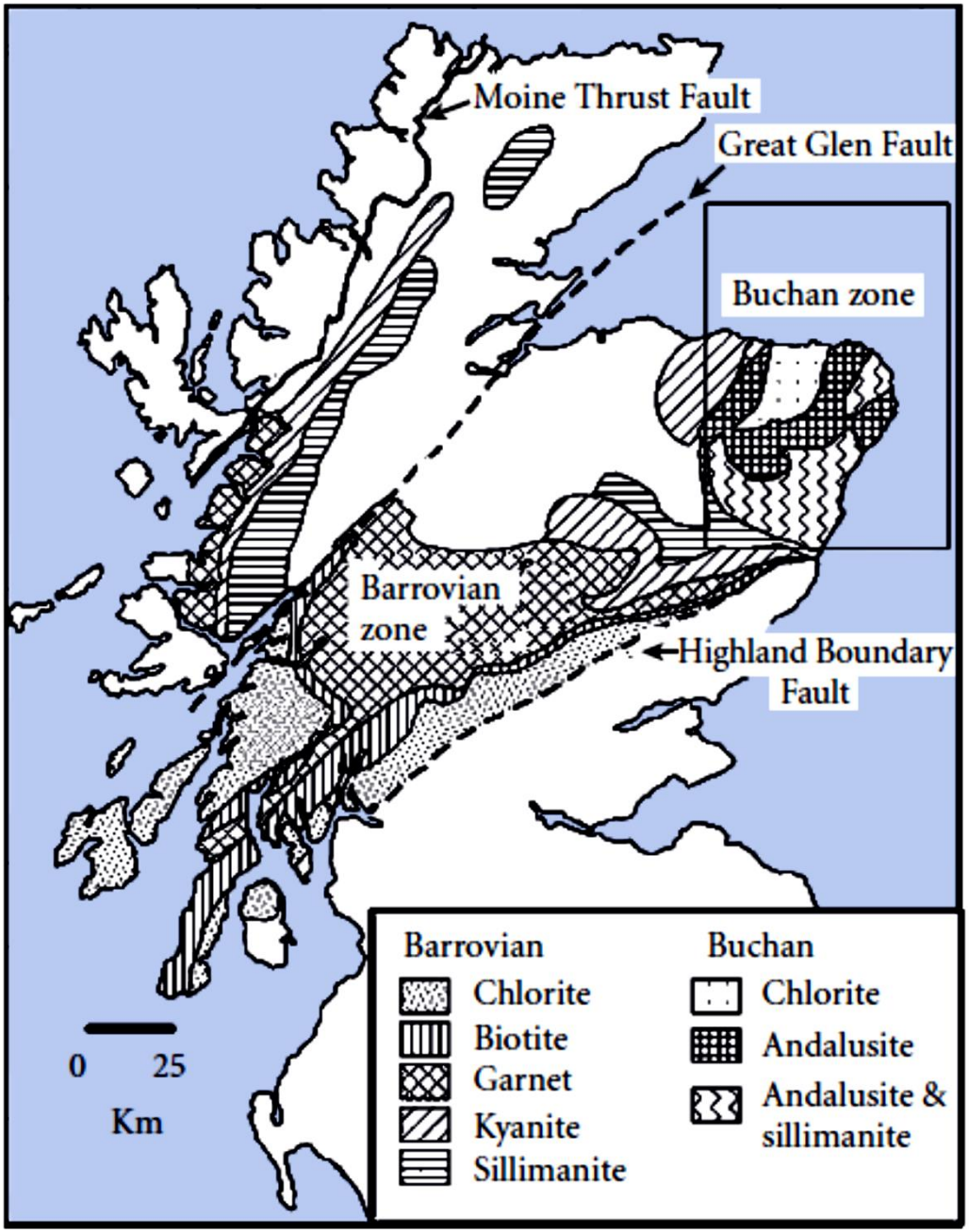


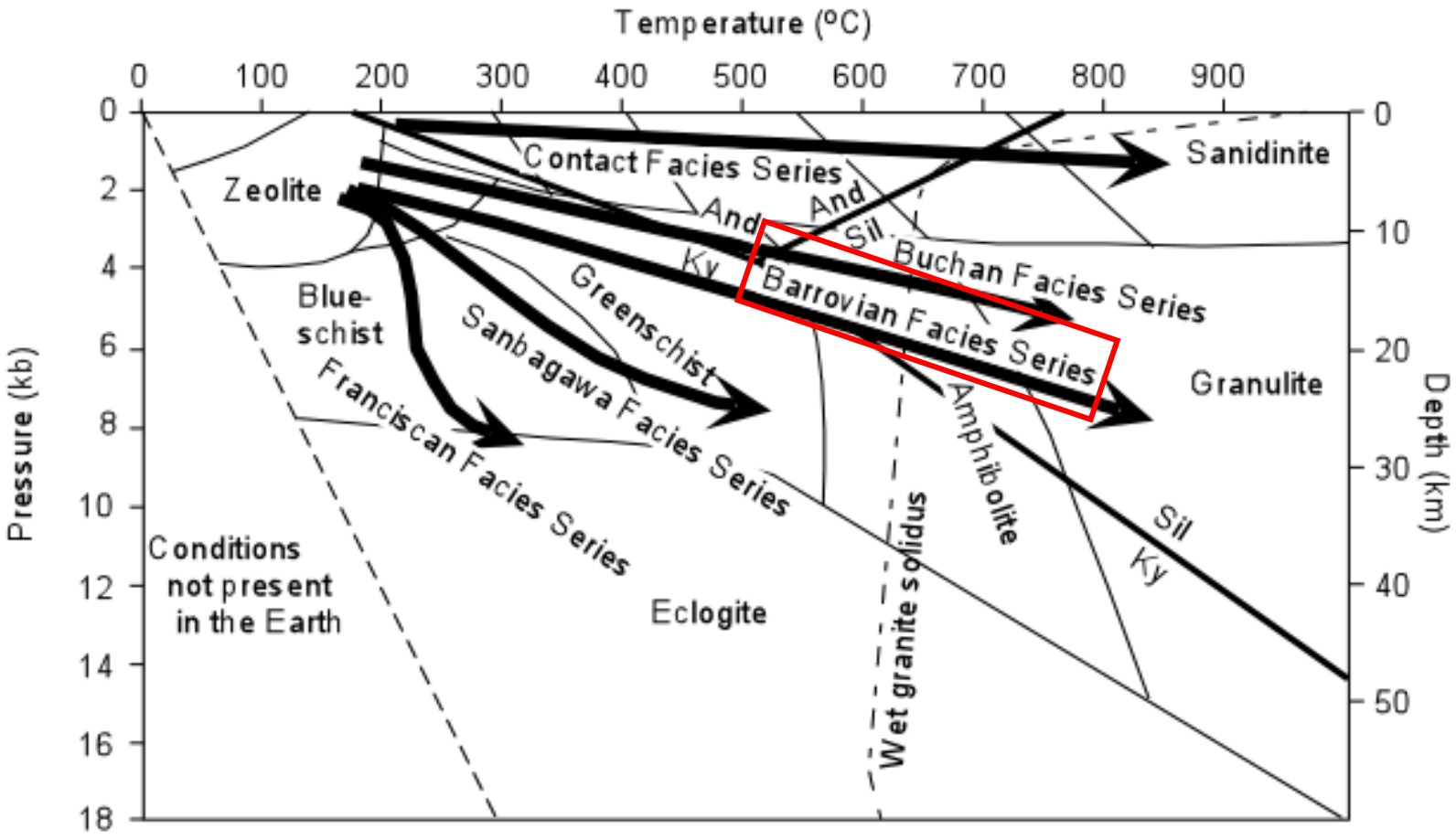
Fig. Generalized geological map of northern Scotland showing the Barrovian and Buchan zones (after Miyashiro, 1961).

Buchan or Abukuma facies series

- The Buchan facies series record high geothermal gradients ranging from 40 to 80 ° C/km.
- This facies series is named after the Buchan area of northeastern Scotland.
- The Buchan facies series is also known as the Abukuma facies series, named after the Abukuma region in Japan (Miyashiro, 1961).
- The individual facies within the Buchan facies series are defined by low to moderate P/T mineral assemblages.
- As with the contact facies series, pelitic rocks may contain the low temperature polymorph andalusite or the high temperature polymorph sillimanite; the high pressure polymorph mineral kyanite is commonly absent.
- However, because of its higher P/T ratio, the trajectory of progressive metamorphism followed by the Buchan series on a P/T diagram is somewhat steeper than that of the contact facies series.

Buchan facies series

- The Buchan facies series progresses, with increasing temperature and pressure, through (1) zeolite, (2) prehnite - pumpellyite, (3) greenschist, (4) amphibolite, to (5) the high temperature, moderate pressure granulite facies.
- Buchan facies series metamorphism reflects higher temperatures, but only moderate increases in pressure.
- Buchan facies series develop by regional metamorphism and magmatic arc activity at convergent margins.
- Because of the non - uniform stress states produced in orogenic belts, rocks of the Buchan facies series are commonly, but not always, foliated.
- Non - foliated Buchan facies series rocks can occur in regions that experience crustal thinning and heating, which causes low to moderate P/T ratio metamorphism.
- Higher P/T ratios result in the development of Barrovian facies series assemblages.


Temperature (ºC)
0
100
200
300
400
500
600
700
800
900
Pressure (kb)
0
2
4
6
8
10
12
14
16
18
Depth (km)
0
10
20
30
40
50
Zeolite
Blue-
schist
Contact Facies Series
And
And
Sil
Ky
Buchan Facies Series
Barrovian Facies Series
Greenschist
Sanbagawa Facies Series
Franciscan Facies Series
Sanidinite
Granulite
Amphibolite
Sil
Ky
Conditions
not present
in the Earth
Eclogite
Wet granite solidus

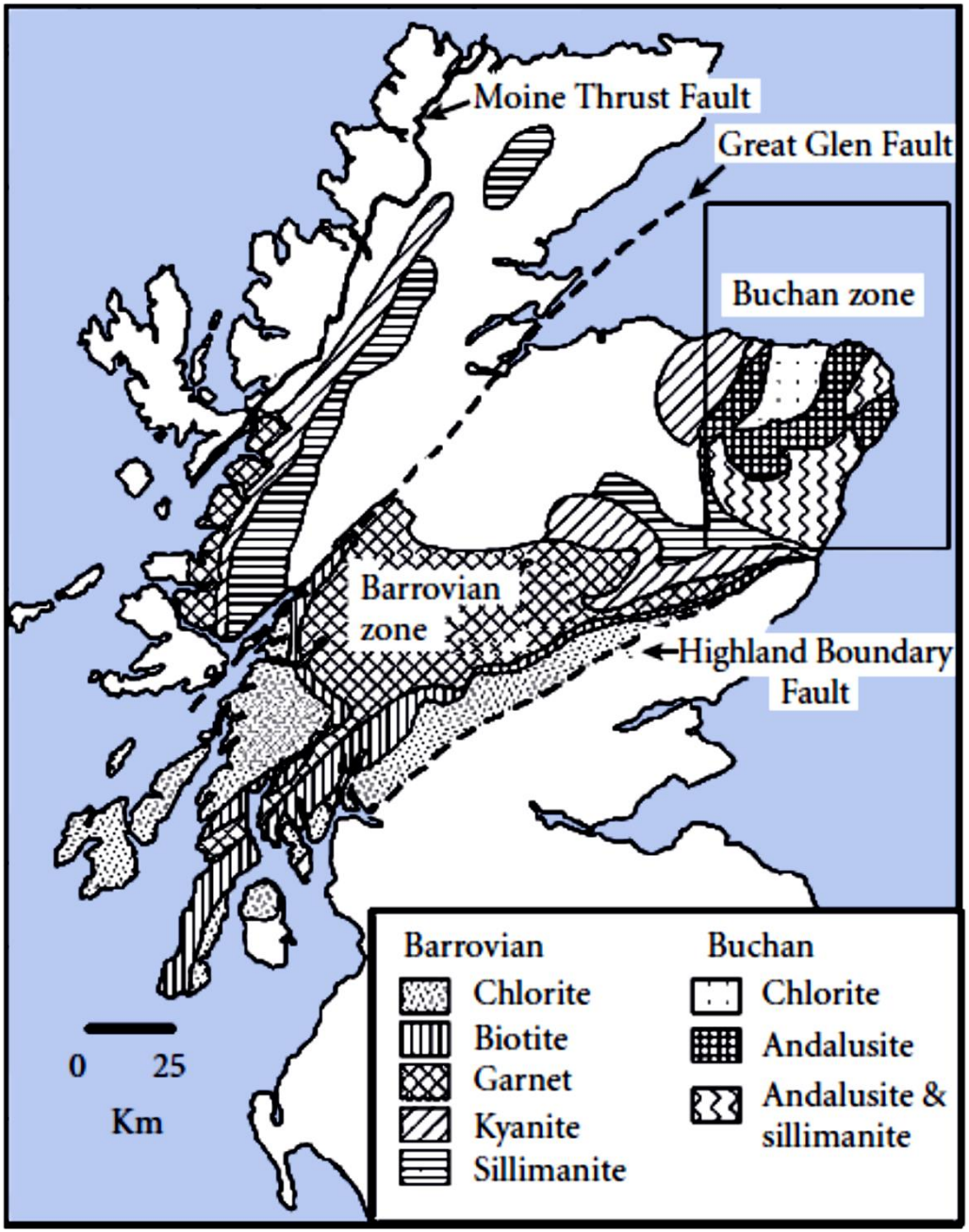


Fig. Generalized geological map of northern Scotland showing the Barrovian and Buchan zones (after Miyashiro, 1961).

Barrovian facies series

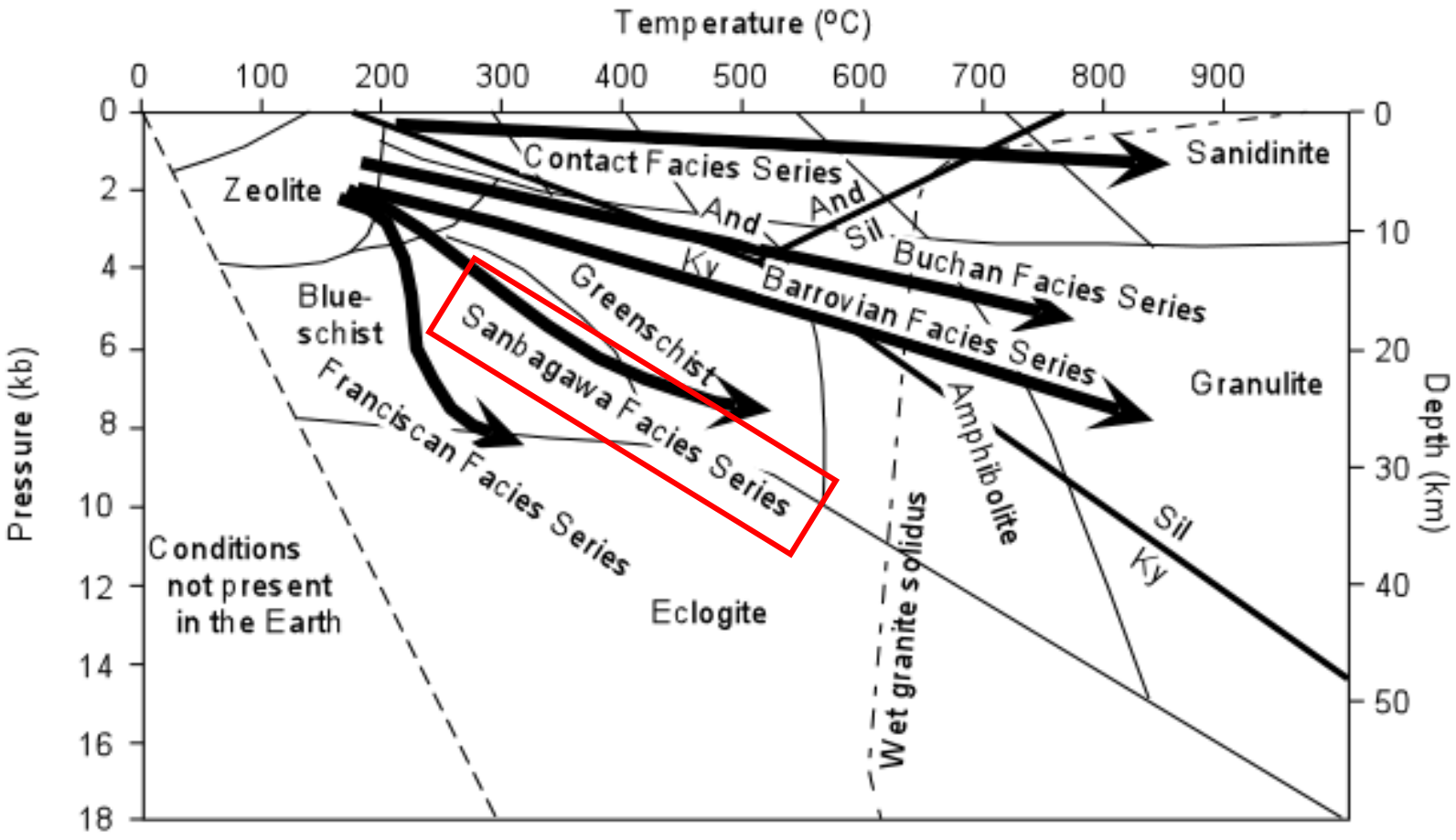
- The Barrovian facies series develop in response to geothermal gradients of ~ 20 – 40 ° C/km, reflecting the progressive increase in both temperature and pressure during regional metamorphism.
- The Barrovian facies series is named for George Barrow, the geologist who first mapped isograd zones in the Scottish highlands.
- With increasing temperature, the Barrovian facies series progresses through the same facies sequence as the Buchan facies series, from (1) zeolite, (2) prehnite - pumpellyite, (3) greenschist, (4) amphibolite, to (5) the high temperature, moderate to high pressure granulite facies.

Barrovian facies series

- Because of its higher P/T ratio, the trajectory of progressive metamorphism followed by Barrovian series metamorphism on a P/T diagram is somewhat steeper than that of the Buchan series.
- However, the equilibrium mineral assemblage differs from the Buchan system because of the higher P/T ratios during metamorphism.
- For example, pelitic rocks may contain not only the low temperature polymorph andalusite and the high temperature polymorph sillimanite, but also the high pressure polymorph kyanite.

Barrovian facies series

- The Barrovian facies series develops in response to increasing temperature and pressure in thickening orogenic belts at convergent plate boundaries, especially collisional orogens.
- As a result, Barrovian facies series rocks commonly display foliated textures as a result of non - uniform stresses.


Temperature (ºC)
0
100
200
300
400
500
600
700
800
900
Pressure (kb)
0
2
4
6
8
10
12
14
16
18
Depth (km)
0
10
20
30
40
50
Zeolite
Blue-
schist
Franciscan Facies Series
Contact Facies Series
And
And
Sil
Ky
Buchan Facies Series
Barrovian Facies Series
Greenschist
Sanbagawa Facies Series
Sanidinite
Granulite
Amphibolite
Sil
Ky
Eclogite
Wet granite solidus
Conditions
not present
in the Earth

Sanbagawa facies series

- The Sanbagawa facies series are produced under geothermal gradients in the range of 10 to 20 ° C/km.
- Miyashiro named this facies after the Sanbagawa belt of Japan. The Sanbagawa facies series progression includes (1) zeolite, (2) prehnite - pumpellyite, (3) blueschist facies, followed in some cases by (4) greenschist, and/or (5) amphibolite facies.
- Sanbagawa facies series metamorphism reflects the rapid increase of pressure relative to temperature during progressive regional metamorphism at convergent plate boundaries.

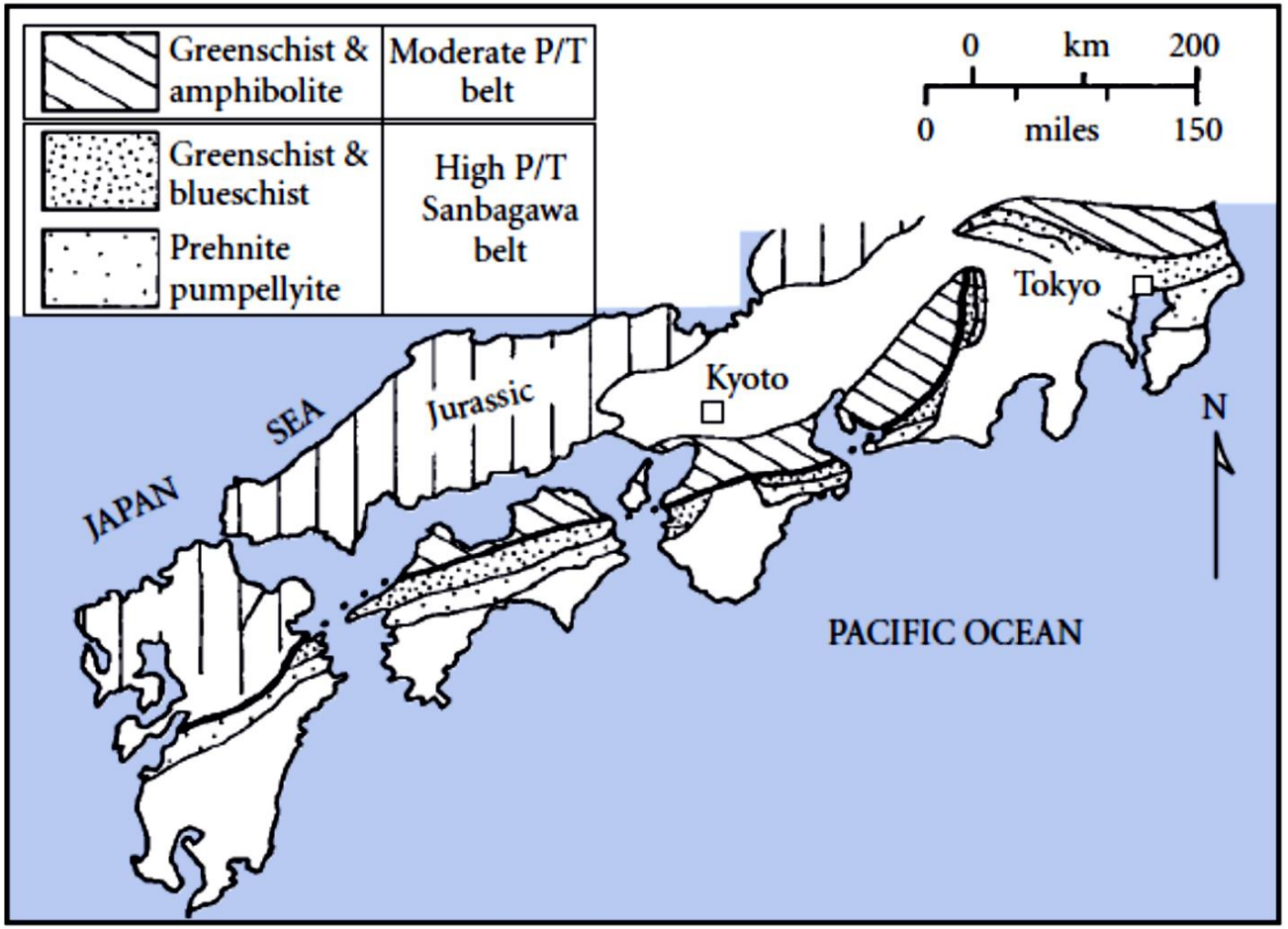
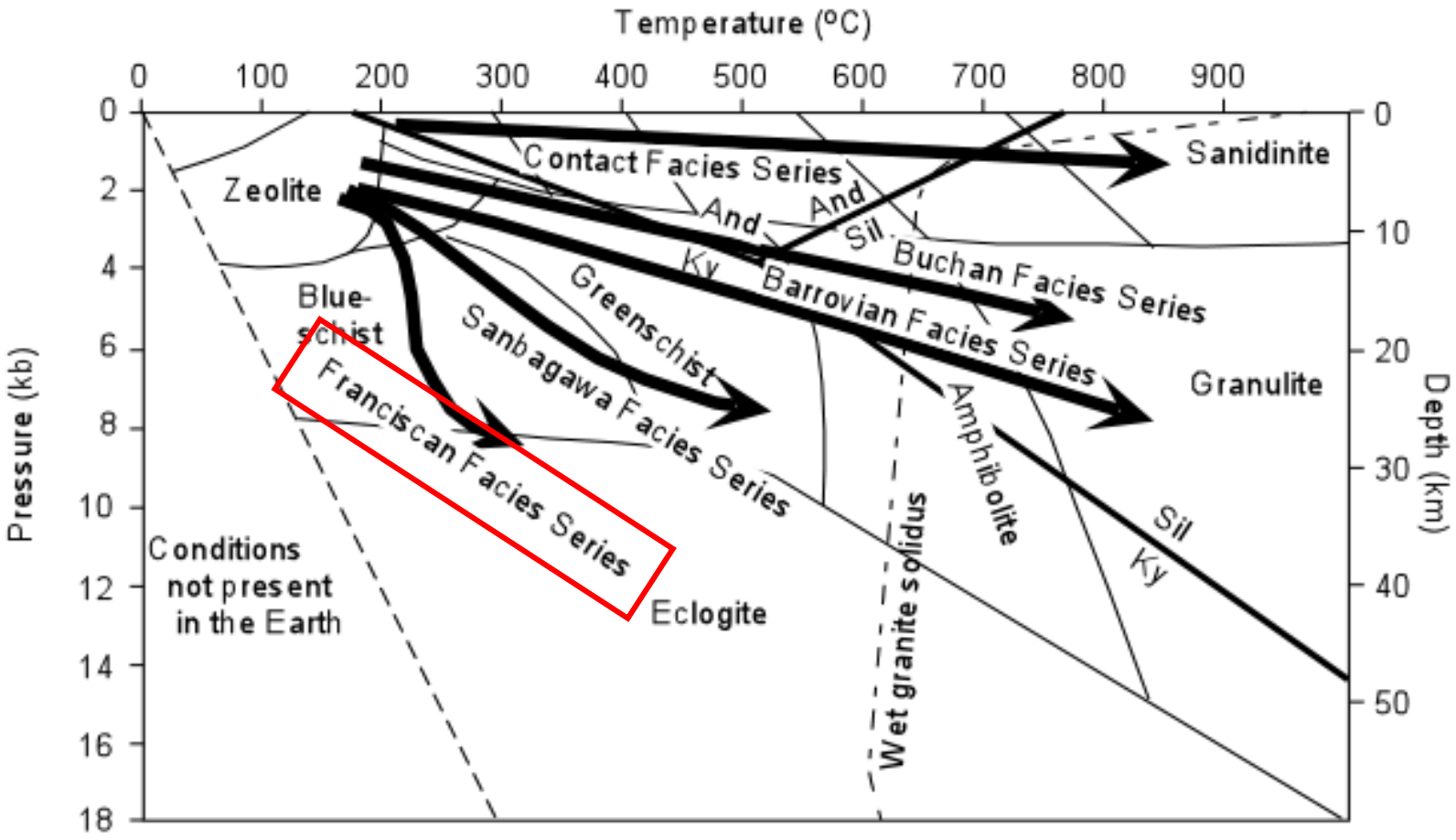


Fig. Generalized map indicating the location of Japan's Sanbagawa belt (after Miyashiro, 1994).

Sanbagawa facies series

- As a result of non - uniform stress, rocks within this facies series commonly are commonly foliated and highly deformed.
- Because of its higher P/T ratio, the trajectory of progressive metamorphism during Sanbagawa series metamorphism on a temperature– pressure diagram is somewhat steeper than that of the Barrovian series.
- Compared to the high pressure/very low temperature Franciscan facies series, the Sanbagawa facies series is characterized by slightly higher temperatures.
- This may result from (1) slower subduction giving the rocks more time to heat up as pressures increase, or (2) higher geothermal gradients during subduction.


Temperature (ºC)
0
100
200
300
400
500
600
700
800
900
Pressure (kb)
0
2
4
6
8
10
12
14
16
18
Depth (km)
0
10
20
30
40
50
Zeolite
Blue-schist
Franciscan Facies Series
Greenschist
Sanbagawa Facies Series
Contact Facies Series
And
And
Sil
Ky
Buchan Facies Series
Barrovian Facies Series
Sanidinite
Granulite
Amphibolite
Sil
Ky
Eclogite
Conditions not present in the Earth
Wet granite solidus

Franciscan facies series

- The Franciscan facies series develop where geothermal gradients are < 10 ° C/km.
- Franciscan facies rocks are characterized by unusually high P/T ratios during progressive metamorphism.
- Because of its very high P/T ratio, the trajectory of progressive metamorphism during Franciscan series metamorphism on a temperature – pressure diagram is very steep.
- Miyashiro named this facies series after the Franciscan Complex of California (USA).
- The Franciscan facies series progresses from (1) zeolite, (2) prehnite - pumpellyite, (3) blueschist, possibly to (4) the eclogite facies.

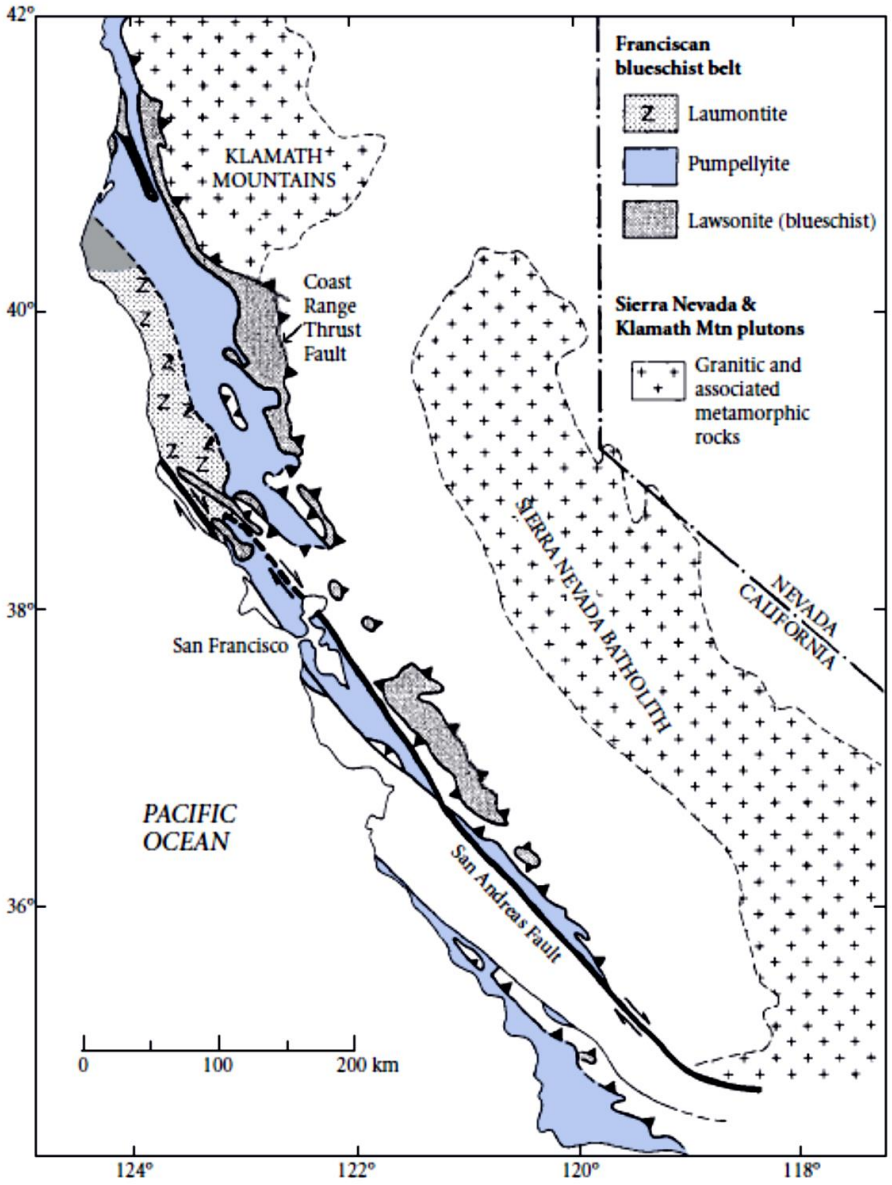


Fig. Generalized map of the Franciscan belt (after Ernst, 1975 ; Miyashiro, 1994).

Franciscan facies series

- Franciscan series metamorphism reflects the progressive rapid increase in pressure relative to slow increases in temperature during regional metamorphism as rocks are rapidly dragged downward in subduction zones.
- The high pressure minerals jadeite, glaucophane and lawsonite are particularly important indicators of the high pressure, low temperature conditions.
- Kyanite, the high pressure polymorph of aluminum silicate, and phengite are common in pelitic rocks.
- Franciscan facies series rocks are commonly highly deformed and foliated.