METAMORPHIC PETROLOGY

"Metamorphism of Basic rocks - metabasites"

MSc sem 2

Shekhar
Assistant Professor
Department of Geology
Patna Science College
Patna University
E-mail: sharan.srk@gmail.com

INTRODUCTION

- Primary mafic rocks in abundance belongs to igneous origin.
- Primary mafic igneous mineral assemblages are dominantly -

  - *Plagioclase, Amphiboles, Pyroxenes (mostly clinopyroxene; orthopyroxene in noritic rocks*

- Eskola (1914), classify metamorphic facies on the basis of mineral assemblages of metamorphic mafic igneous rocks.

- At very low grades, common to all types of P/T gradients will be the zeolite facies, where a host of zeolites and Ca-Al silicates are present in mafic bulk composition

Simplified petrogenetic grid showing univariant mineral reactions in the system CNMASH, applicable for metamorphism of mafic rocks.

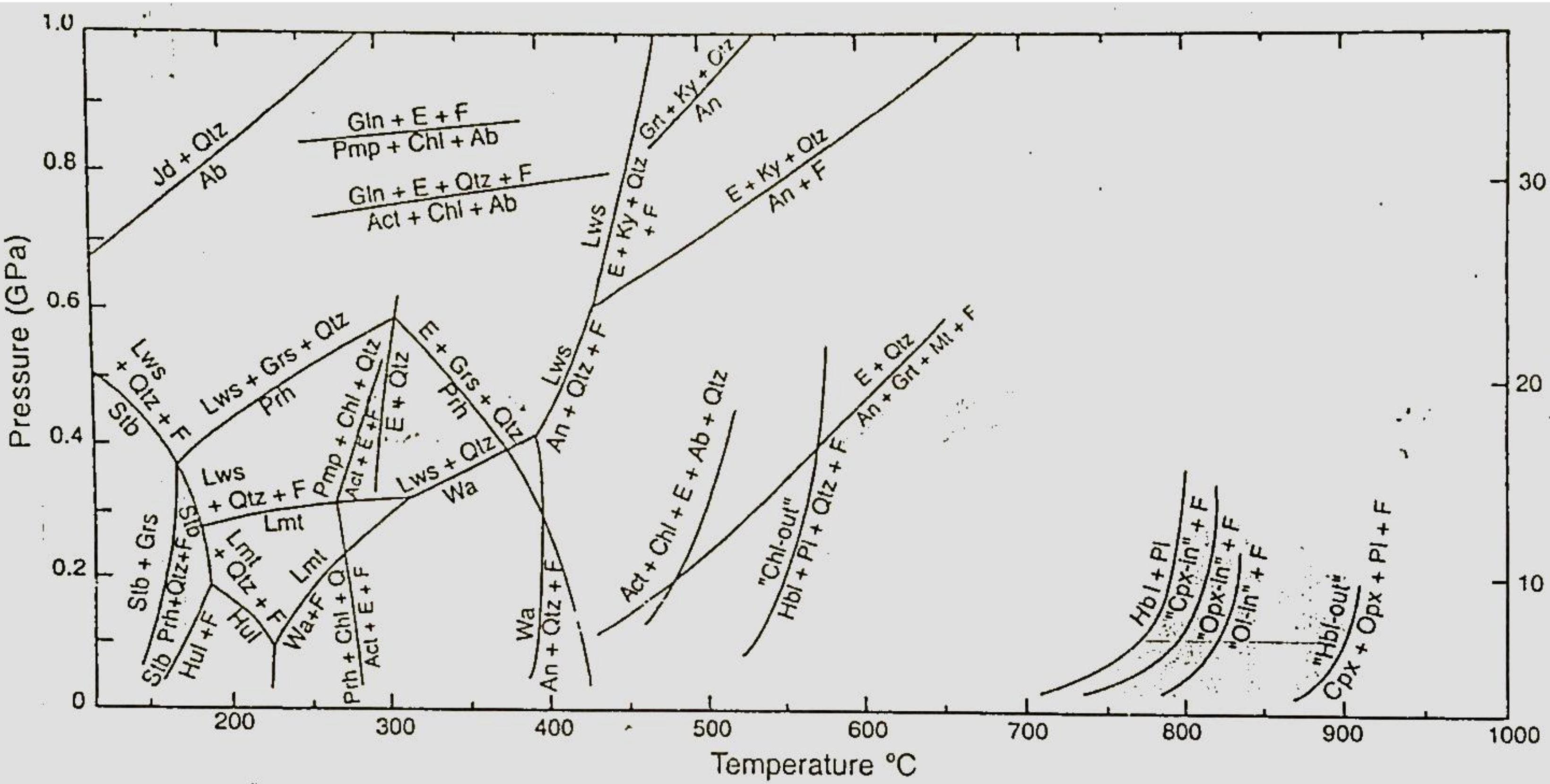


Figure 26–19 Simplified petrogenetic grid for metamorphosed mafic rocks showing the location of several determined univariant reactions in the CaO-MgO-Al_2O_3-SiO_2-H_2O-(Na_2O) system ("C(N)MASH"). Mineral abbreviations may be found in the inside cover (*F* = aqueous fluid, *E* = an epidote mineral: epidote, zoisite, or clinozoisite). Important continuous reactions are shaded (although most reactions are continuous with respect to Fe-Mg, Ca-Na, or some other components). Data from Liou (1970, 1971a,b,c), Liou et al. (1974), Cho et al. (1987), Liou et al. (1985, 1987), Maruyama and Liuo (1988), Maruyama et al. (1986), Newton and Smith (1967), Newton (1986), Newton and Kennedy (1963), Evans (1990), Massone (1989), Spear (1981), Bucher and Frey (1994).

Metabasites at Intermediate Pressures

Greenschist Facies

- comprises the *chlorite, biotite, and garnet zones* in spatially associated metamorphosed pelitic rocks.
- At lowest grades, calcite may be stabilized.

- At increasing *T*,

  calcite + chlorite → *epidote + actinolite +* H_2O-CO_2

- The middle greenschist facies assemblage characterising metabasite:

  epidote + chlorite + actinolite + albite ± quartz ± calcite ± titanite ± Fe–Ti oxides

- Breakdown of Fe–Al-rich chlorite might produce almandine garnet,

  Fe-rich chlorite + albite + epidote + quartz → *almandine + Mg-rich chlorite + hornblende +* H_2O

Metabasites at Intermediate Pressures

Greenschist Facies (contd..)

Yardley (1989) suggests two model reactions responsible for production of end-member hornblendes

- $NaAlSi_3O8 + Ca_2(Mg,Fe)_5Si8O_{22}(OH)_2 \rightarrow NaCa_2(Mg,Fe)_5AlSi_7O_{22}(OH)_2 + 4SiO_2$
  (albite) (actinolite) (hornblende) (quartz)

- $Ca_2(Mg,Fe)_5Si8O_{22}(OH)_2$ +
  (actinolite)
  $7(Mg,Fe)_3Al_4Si_6O_{20}(OH)_{16}$ + $\rightarrow$ $25Ca_2(Mg,Fe)_3Al_4Si_6O_{22}(OH)_2 + 44H_2O$
  (chlorite) (hornblende)
  $4Ca_2Al_3Si_3O_{12}(OH)_2 + 28SiO_2$
  (epidote)

Metabasites at Intermediate Pressures

Amphibolite facies:

- epidote and chlorite decrease in abundance and eventually disappear,
- hornblende, almandine-rich garnet, and plagioclase increase.

Yardley (1989), these changes are the result from continuous reactions involving solid solutions, possibly of the form

$$3(Mg,Fe)_{10}Al_4Si_6O_{20}(OH)_{16} + \rightarrow 10Ca_2(Mg,Fe)_3Al_4Si_6O_{22}(OH)_2$$

(chlorite) *(hornblende)*

$$12Ca_2Al_3Si_3O_{12}(OH)_2 + \quad + 4CaAl_2Si_2O_8 + 2H_2O$$

(epidote) *(anorthite)*

$$4SiO_2$$

(quartz)

**The anorthite produced in this reaction combines with existing albite to yield oligoclase.*

Metabasites at Intermediate Pressures

Amphibolite facies (contd..):

- Minor amounts of almandine-rich garnet may appear in some amphibolites and, transition into the granulite facies.
- Relatively calcic basaltic protoliths will contain a minor amount of clinopyroxene formed by initial breakdown of hornblende.

$$NaCa_2(Mg,Fe)_5AlSi_7O_{22}(OH)_2 + \rightarrow 5Ca(Mg,Fe)Si_2O_6 + NaAlSi_3O_8 +$$

(hornblende) *(diopside)* *(albite)*

$$6SiO_2 + 3CaCO_3 \qquad H_2O + 5CO_2$$

Metabasites at Intermediate Pressures

Granulite Facies:

- Hornblende and locally *biotite persist into the lower part of the granulite facies*, whereas only anhydrous mafic phases are stable with rise in temperature
- *Hornblende* could be possibly consume as -

➢ $NaCa_2(Mg,Fe)_5AlSi_7O_{22}(OH)_2$ (hornblende) + $3SiO_2$ (quartz) → $NaAlSi_3O_8$ (albite) + $2Ca(Mg,Fe)Si_2O_6$ (diopside) + $3(Mg,Fe)SiO_3$ (hypersthene) + H_2O

➢ $Ca_2(Mg,Fe)_3Al_4Si_6O_{22}(OH)_2$ (hornblende) → $Ca(Mg,Fe)_2Al_2Si_3O_{12}$ (garnet) + $CaAl_2Si_2O_8$ (anorthite) + $(Mg,Fe)SiO_3$ (hypersthene) + H_2O

Metabasites at Intermediate Pressures

Granulite Facies (contd...):

- In more mafic rocks, *anthophyllite* breaks down

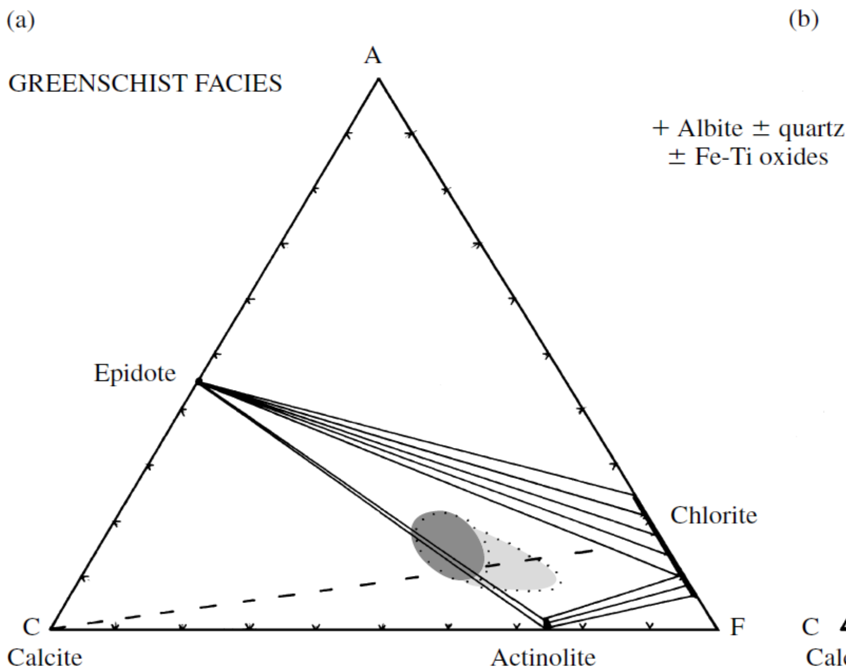
$$(Mg,Fe)_7Si_8O_{22}(OH)_2 \rightarrow 7(Mg,Fe)SiO_3 + SiO_2 + H_2O$$

(orthopyroxene)

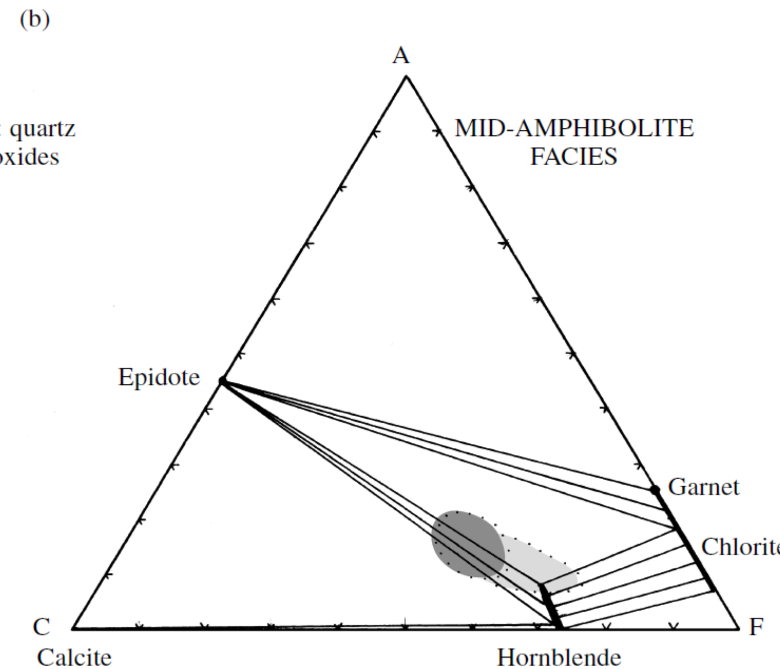
- *Orthopyroxene is stable with clinopyroxene* and also compatible with *andesine or labradorite*.

**At higher pressures in the granulite facies, this compatibility is broken and is replaced by garnet + clinopyroxene.*

ACF diagrams for metabasites in intermediate-*P* facies associated with Barrovian pelite zones



Calcite + chlorite →
epidote + actinolite + H_2O-CO_2 fluid

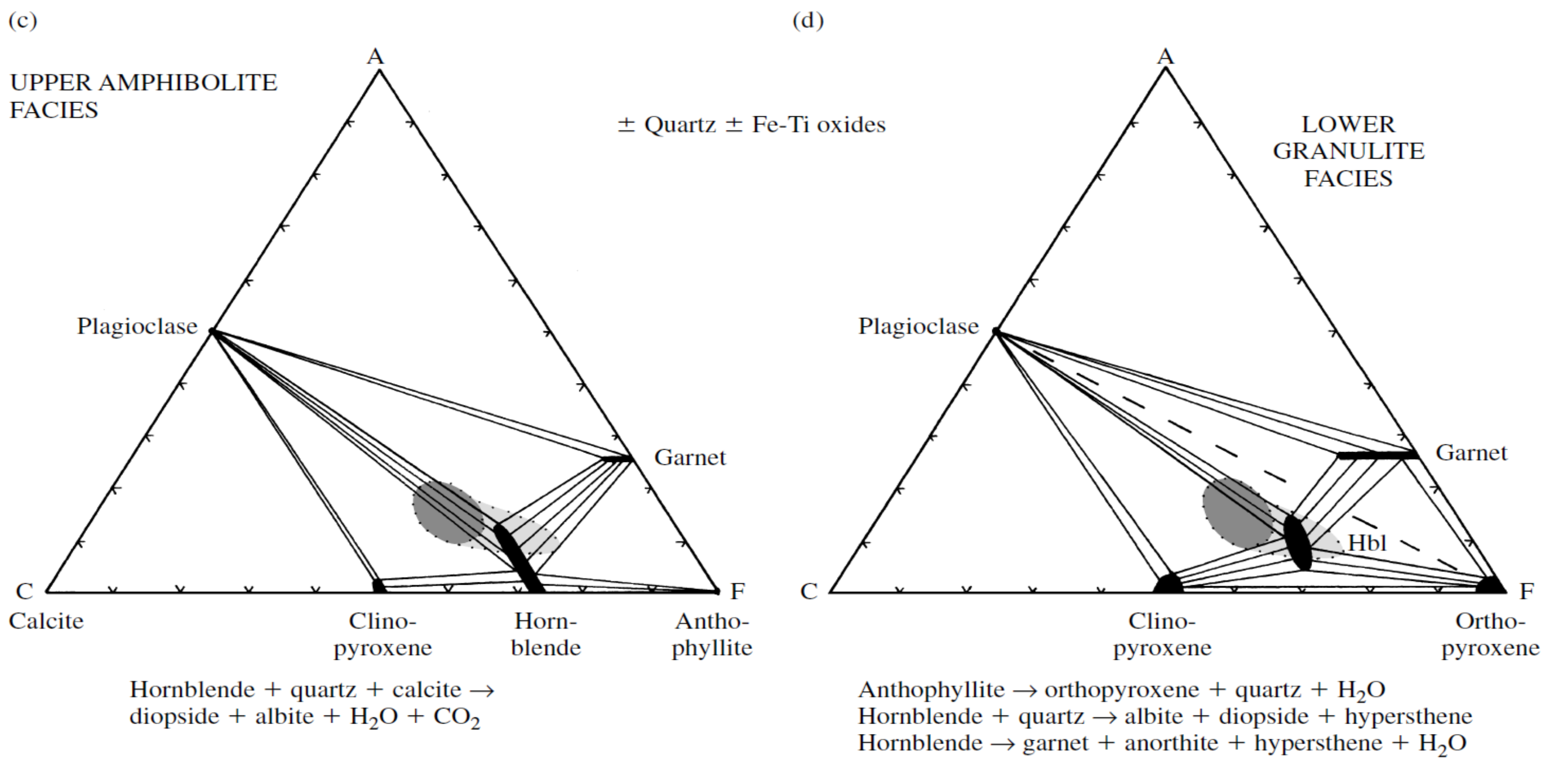


Albite + actinolite → hornblende + quartz
Actinolite + chlorite + epidote + quartz → hornblende + H_2O
Chlorite + albite + epidote + quartz → almandine + hornblende + H_2O

Tie-line switching between Calcite - Chlorite compatibility at lower grade (dashed line) and Epidote - Actinolite at higher grade.

Compatibility of Hornblende with epidote and possibly either calcite or chlorite (or perhaps almandine garnet)

ACF diagrams for metabasites in intermediate-*P* facies associated with Barrovian pelite zones



- *In the upper higher grade part, hornblende disappears completely,*
  - *allowing compatibility of Orthopyroxene - plagioclase (dashed line).*
  - *Anthophyllite is replaced by orthopyroxene,*
  - *mineral assemblages of the upper granulite facies are entirely anhydrous.*

Metabasites at Low Pressures

Metamorphism of mafic rocks along a low P/T gradient will produce a series of metamorphic facies:

- ***albite epidote-hornfels*** (roughly equivalent to albite-epidote amphibolite facies in Barrovian facies series),
- ***hornblende hornfels*** (equivalent to amphibolite facies)
- ***pyroxene hornfels*** (equivalent to granulite facies)
- ***sanidinite*** (equivalent to ultrahigh temperature granulite facies)

**Mineralogy of metabasites along the low P/T series does not differ significantly from that in the medium P/T series, but for less abundance of garnet and earlier conversion of albite to calcic plagioclase with respect to the change in amphibole, as noted earlier.*

Metabasites at High Pressures

Blueschist Facies:

- Metabasites contain characteristic sodic (Na–Mg–Fe–Al) amphibole glaucophane – lawsonite as the diagnostic assemblage, also locally Fe-rich garnet, plagioclase and paragonite.

- In metabasite, lawsonite crystallize directly from magmatic plagioclase

$$CaAl_2Si_2O_8 \cdot NaAlSi_3O_8 + 2H_2O \rightarrow CaAl_2Si_2O_7(OH)_2 \cdot H_2O + NaAlSi_3O_8$$

(plagioclase) (lawsonite) (albite)

Metabasites at High Pressures

Blueschist Facies (contd...):

- Other diagnostic minerals include *aragonite and jadeitic clinopyroxene*.
- Because of relatively low temperatures, *biotite does not occur, although stilpnomelane is widespread*.
- Depending on bulk rock composition *chlorite*, *titanite*, *pumpellyite*, *Ca–Mg–Fe–Mn garnet*, *and phengitic white mica* are also found.
- Evans and Brown (1987), shows the stability of amphibole and epidote

  Na-amphibole + epidote = albite + chlorite + actinolite + Fe-oxide

Mineral assemblage for metabasite in Blueschist facies

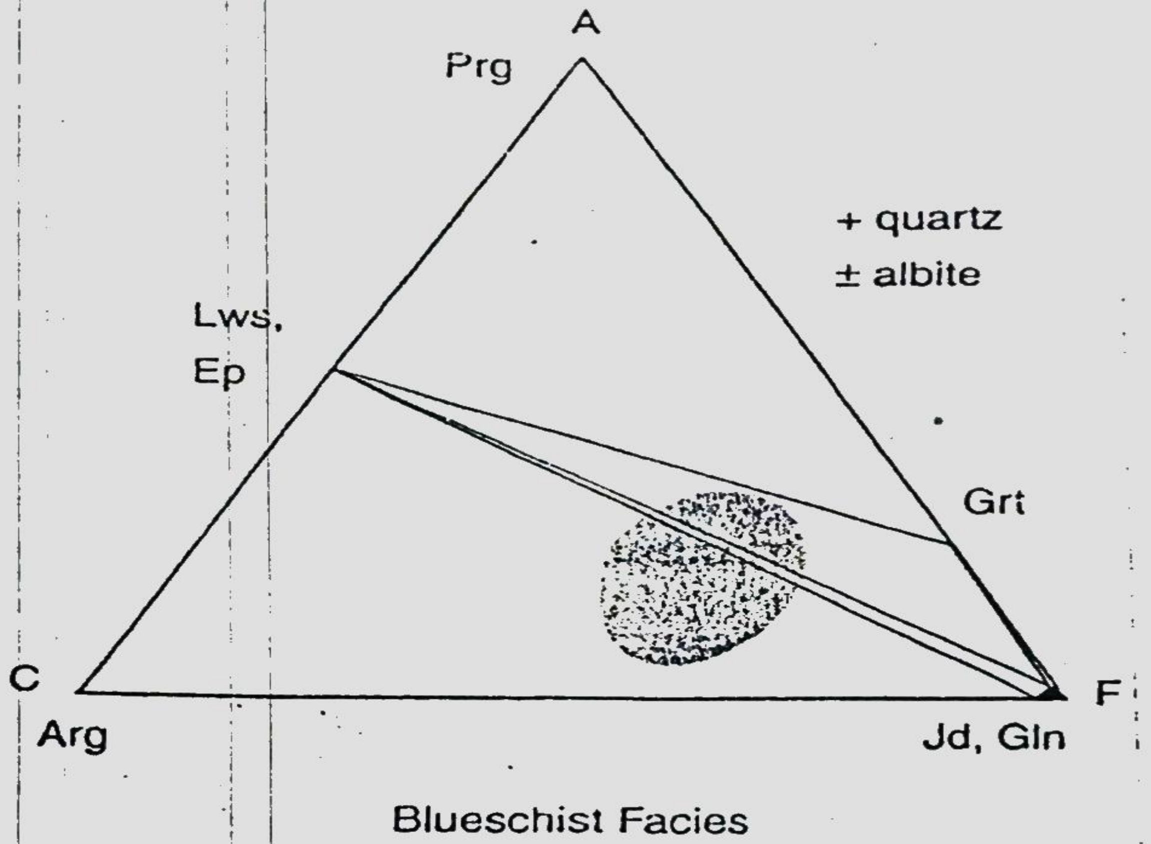


Figure 25–10 *ACF* diagram illustrating representative mineral assemblages for metabasites in the blueschist facies. The composition range of common mafic rocks is shaded.

Metabasites at High Pressures

Eclogite Facies:

- Eclogite is a rock with high density and conversion of oceanic basalt to eclogite will occur during subduction.
- they equilibrate over a wide range of *T*, from the 1000°C of mantle-derived xenoliths to the 500°C of convergent plate associations.
- characteristic assemblage is *omphacitic clinopyroxene and pyrope-grossular rich garnet.*
- Albite component in plagioclase breaks down by the reaction

$$\textit{Albite} \rightarrow \textit{jadeite} + \textit{quartz}$$

Metabasites at High Pressures

Eclogite Facies (contd...):

- Omphacite forms through complex mineral reaction involving glaucophane and paragonite.

- The grossular component in garnet and kyanite can appear through the breakdown of Ca-plagioclase

Anorthite → grossular + kyanite + quartz

* *Mafic rocks at high pressures are notably orthopyroxene-free*

Mineral assemblage for metabasite in Eclogite facies

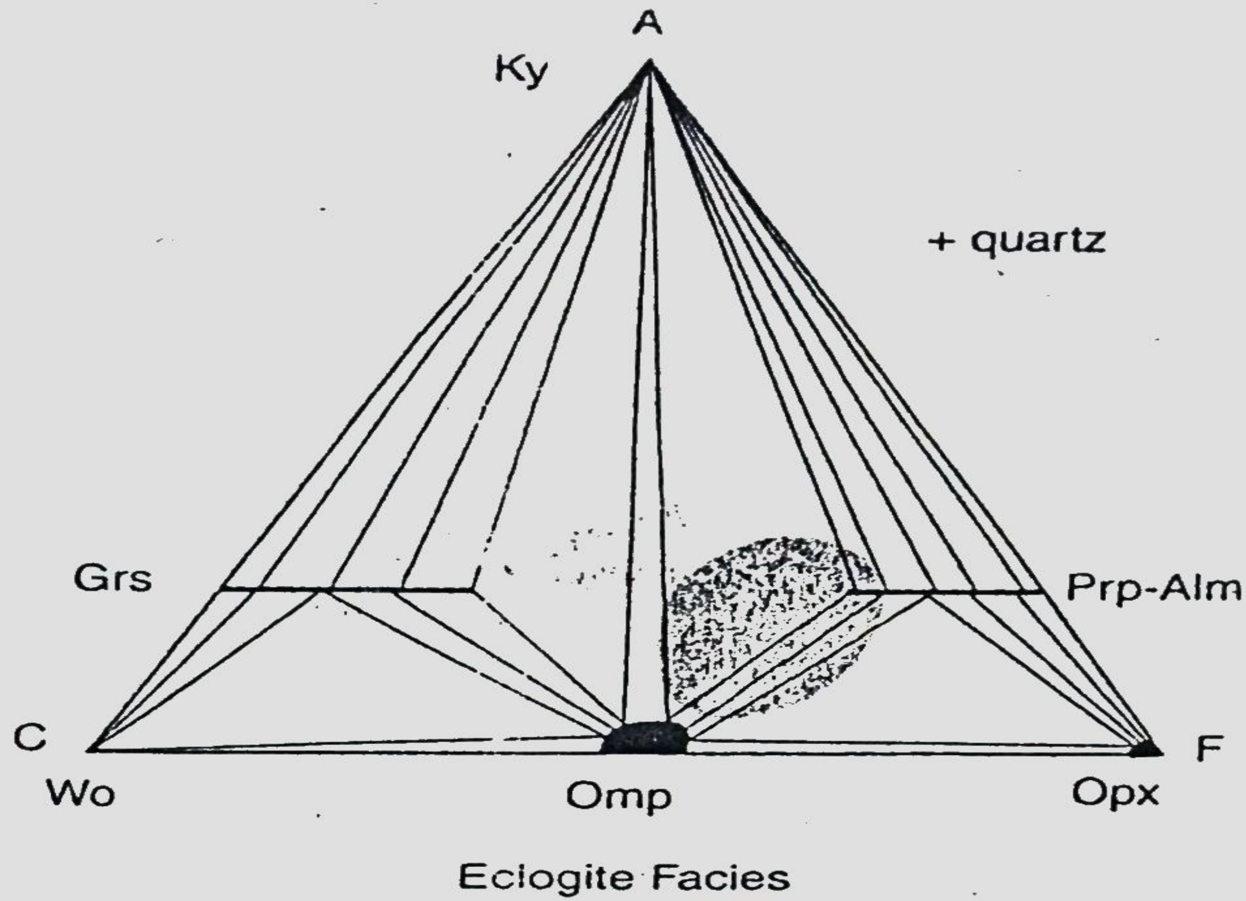


Figure 25–11 *ACF* diagram illustrating representative mineral assemblages for metabasites in the eclogite facies. The composition range of common mafic rocks is shaded.

References & for Further studies

- *Best, M. G. (2003). Igneous and Metamorphic Petrology. Blackwell Publishing*
- *Miyashiro, A. (1961). Evolution of metamorphic belts. J. Petrol., 2*
- *Spear, F. S. (1993). Metamorphic Phase Equilibria and Pressure Temperature-Time Paths. Mineral. Soc. Amer. Monograph 1. MSA, Washington, D.C.*
- *Winter, John D. (2001). An Introduction to Igneous and Metamorphic Petrology, 1st Edn. Prentice-Hall Inc., New Jersey. ISBN: 0132403420, 978-0132403429.*
- *Yardley BWD. 1981. Effect of cooling on the water content and mechanical behaviour of metamorphosed rocks. Geology 9: 405–408.*
- *Yardley BWD. 1989. An introduction to metamorphic petrology. New York, John Wiley and Sons.*