

Schreinemakers' nets for Group B and C Eclogites in a Model 4-Component and 8-Phase System

By

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Abstract

Petrogenetic grids for Group B and C eclogites, which were formed in the jadeite-quartz stability field, are constructed in a model 4-component and 8-phase system, with excess Fe-rich garnet. 8 geometrically independent nets are derived from this model system which treats univariant curves as straight lines. Varying the composition of the excess garnet causes topological changes in the nets and three topologically similar groups can be distinguished: Set I with the most Fe-rich garnet, Set II with intermediate garnet composition, and Set III with garnet richer in Mg than usual group C eclogites. All possible nets for Sets I and II will be presented and the most plausible net will be chosen by comparing them with petrographic and synthetic evidence.

1. Introduction

Eclogites are composed essentially of two minerals, omphacitic clinopyroxene and garnet. Although some eclogites are mantle derived exotic blocks, such as included in basalt, kimberlite and solid intrusion of ultramafic rocks, some eclogites were metamorphosed at the same physical conditions as the enclosing schists and gneisses (REINSCH, 1979; KROGH, 1980). Recent petrographic work has revealed that these eclogites are stably associated with amphiboles (glaucophanes, winchite, barroisite and hornblende), micas (muscovite, biotite and paragonite in particular), hydrous Ca-Al silicates (lawsonite, epidote and zoisite), hydrous Mg-Al silicates (magnesian staurolite and Mg-Fe chloritoid), talc and kyanite. It is now possible to classify eclogites not only on the basis of partition coefficients, but also on mineral assemblages.

We have constructed petrogenetic grids for Group B and C eclogites, in the sense of COLEMAN (1965), on the basis of mineral assemblages of the Spitsbergen eclogites. Our discussion was based on a 4-component and 8-phase model system with excess Fe-rich garnet and we derived 8 geometrically independent nets. Only the most plausible one has been described in another paper (HIRAJIMA *et al.*, 1988). In this paper we will present all the possible nets. Petrogenetic discussion based on these nets is given in HIRAJIMA *et al.* (1988).

2. The system $N(\text{NaAlO}_2)\text{-CaO-A}(\text{Al}_2\text{O}_3+\text{Fe}_2\text{O}_3)\text{-MgO}$

The mineral assemblages of eclogitic rocks can generally be described in terms of a 6-component system, $\text{Na}_2\text{O-Al}_2\text{O}_3\text{-Fe}_2\text{O}_3\text{-FeO-MgO-CaO}$, with excesses of quartz, phengite and H_2O . However, we are still far from being able to deal quantitatively with such a complex system. $\text{Fe}^{3+}\text{-Al}$ substitution is not essential in eclogite paragenesis, and Fe-rich garnet is common in the Group B and C eclogites. Hence, we may describe them in terms of the paragenesis of a 4-component $N(\text{NaAlO}_2)\text{-CaO-A}(\text{Al}_2\text{O}_3+\text{Fe}_2\text{O}_3)\text{-MgO}$ with excesses of quartz, Fe-rich garnet and water. The Motalafjella eclogites in Spitsbergen (HIRAJIMA *et al.*, 1988) and other high pressure eclogites, such as Tauern Window (HOLLAND, 1979a), Sesia-Lanzo (REINSCH, 1979) and Corsica (CARON & PEQUIGNOT, 1986), mainly consist of following 8 phases; lawsonite, epidote, paragonite, Mg-rich chloritoid, jadeite, omphacite, glaucophane and kyanite. Although Ca-amphiboles and magnesite are also stable in the eclogites mentioned above, they are ignored in this study. Idealized compositions for these 8 phases, mainly based on the data of Motalafjella, are given in Table 1 and their projection onto the $N(\text{NaAlO}_2)\text{-CaO-A}(\text{Al}_2\text{O}_3+\text{Fe}_2\text{O}_3)\text{-MgO}$ tetrahedron from quartz, phengite, almandine and H_2O is shown in Figure 1, respectively. In describing the mineral assemblages, the abbreviations proposed by KRETZ (1983) will be mostly used (Table 2).

In the model system, we have only adopted garnet-forming reactions which involve the decomposition of Mg-rich chloritoid. Other garnet-forming reactions are not

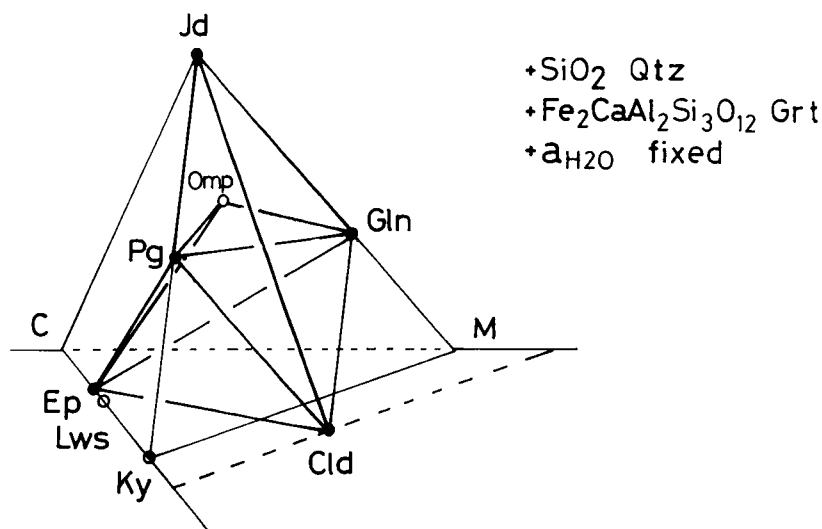


Fig. 1. Mineral paragenesis on the $N(\text{NaAlO}_2)\text{-CaO-A}(\text{Al}_2\text{O}_3+\text{Fe}_2\text{O}_3)\text{-M}(\text{MgO})$ tetrahedron projected from quartz, almandine and H_2O .

Table 1. Mineral formulae and molar volumes for the Schreinemakers' analysis.

	Omp	Gln	Ep	Cld	Pg	Jd	Ky	Lws	Grt	Qtz	W
Na	1	2	0	0	2	1	0	0	0	0	0
Ca	1	0	2	0	0	0	0	1	0 -1.2	0	0
Fe	0	0	0	0.5	0	0	0	0	1.2-2.4	0	0
Mg	1	3	0	0.5	0	0	0	0	0 -1.2	0	0
Al	1	2	3	2	6	1	2	2	2	0	0
Si	4	8	3	1	6	2	1	2	3	1	0
H	0	2	1	2	4	0	0	4	0	0	2

Omp=126.5(1), Gln=258.5(1), Ep=136.4(2), Cld=69.2(3), Pg=264(4), Jd=60.4(1),
Ky=44.1(1), Lws=101.3(1), Grt=114.7-118.8(5), Qtz=22.7(1), W=H₂O at 15 kbar,
550°C=16.73(5)

(1) Robie & Waldbaum (1968), (2) Myer (1966), (3) Chopin & Monie (1984),
(4) Holland (1979b), (5) Halbach & Chatterjee (1982)

Table 2. Abbreviations of representative minerals and end-members.

<Phases>			
Gln : glaucophane	Wnc : winchite	Phg : phengite	Pg : paragonite
Jd : jadeite	Omp : omphacite	Cld : chloritoid	Grt : garnet
Ep : epidote	Hbl : hornblende	Lws : lawsonite	Ky : kyanite
<End-members>			
alm : almandine	grs : grossular	jd : jadeite	acm : acmite
di : diopside	hd : hedenbergite	cat : Ca-tschermakite component	

used in the model system, mainly because they have large transitional loops and cannot be approximated by model univariant reactions. It follows that the extension of the nets to the P-T field, where chlorite is stable in metabasites, is not warranted. Pressure and temperature estimates of the eclogite occurrences mentioned above indicate that they were formed in the stability field of jadeite+quartz assemblage, and the following discussion is only applicable to the region where jadeite+quartz is stable.

3. Schreinemakers' analysis

As we do not have enough quantitative thermodynamic data to apply the method of PERKINS *et al.* (1986) of calculating the stable Schreinemakers' net, we choose a different way of obtaining the petrogenetic grid for the eclogitic rocks in question, i.e., we calculated all possible geometries of Schreinemakers' nets of the model system, giving only the slope of the univariant curves. In calculating the nets, we used

a program written by TANABE *et al.* (1988), which can find out all possible nets of invariant points for the systems, treating univariant curves as straight lines. For 4-component and 8-phase model system, we obtain 8 possible nets, the invariant points of which are listed in Table 3. We then choose the most plausible ones by comparing them with petrographic and synthetic evidence. The slopes of the univariant curves were calculated assuming a constant dehydration entropy of 14 cal/deg.

Table 3. Eight independent nets of invariant points for three sets of combinations of invariant points with compositional change of excess garnet. The abbreviations of invariant points constituting each net are tabulated.

Eight independent nets of invariant points for Set I. The abbreviation number of the net and that of invariant point constituting each net are tabulated.	
Net 1	[1] [Omp, Lws], [4] [Cld, Lws], [5] [Pg, Lws], [7] [Ky, Lws], [9] [Gln, Ky], [10] [Ep, Ky], [13] [Jd, Ky], [20] [Gln, Pg], [21] [Ep, Pg], [28] [Omp, Gln]
Net 2	[1] [Omp, Lws], [4] [Cld, Lws], [8] [Omp, Ky], [11] [Cld, Ky], [18] [Pg, Jd], [19] [Omp, Pg], [22] [Cld, Pg], [28] [Omp, Gln]
Net 3	[2] [Gln, Lws], [3] [Ep, Lws], [6] [Jd, Lws], [9] [Gln, Ky], [10] [Ep, Ky], [13] [Jd, Ky], [20] [Gln, Pg], [21] [Ep, Pg], [28] [Omp, Gln]
Net 4	[1] [Omp, Lws], [4] [Cld, Lws], [5] [Pg, Lws], [8] [Omp, Ky], [11] [Cld, Ky], [12] [Pg, Ky], [20] [Gln, Pg], [21] [Ep, Pg], [28] [Omp, Gln]
Net 5	[6] [Jd, Lws], [13] [Jd, Ky], [15] [Gln, Jd], [16] [Ep, Jd], [24] [Gln, Cld], [25] [Ep, Cld], [26] [Omp, Ep]
Net 6	[14] [Omp, Jd], [17] [Cld, Jd], [18] [Pg, Jd], [24] [Gln, Cld], [25] [Ep, Cld], [26] [Omp, Ep]
Net 7	[3] [Ep, Lws], [6] [Jd, Lws], [10] [Ep, Ky], [13] [Jd, Ky], [15] [Gln, Jd], [21] [Ep, Pg], [24] [Gln, Cld], [27] [Gln, Ep]
Net 8	[4] [Cld, Lws], [11] [Cld, Ky], [14] [Omp, Jd], [18] [Pg, Jd], [22] [Cld, Pg], [23] [Omp, Cld], [26] [Omp, Ep]
Eight independent nets of invariant points for Set II.	
Net 1	[1], [4], [5], [7], [9], [10], [13], [18], [20], [21], [28]
Net 2	[1], [4], [8], [11], [19], [22], [28]
Net 3	[2], [3], [6], [9], [10], [13], [18], [20], [21], [28]
Net 4	[1], [4], [5], [8], [11], [12], [18], [20], [21], [28]
Net 5	[6], [13], [15], [16], [18], [24], [25], [26]
Net 6	[14], [17], [24], [25], [26]
Net 7	[3], [6], [10], [13], [15], [18], [21], [24], [27]
Net 8	[4], [11], [14], [22], [23], [26]
Eight independent nets of invariant points for Set III.	
Set 2	[1], [4], [7], [9], [10], [12], [13], [19], [22], [28]
Other sets are same as Type II.	

Because of degeneracy, invariant points [23], [24] and [28] are the same.

mol (FYFE *et al.*, 1958; ALBEE, 1965; HIRAJIMA, 1983). The chemical compositions and volumes of the relevant phases are summarized in Table 1, which also gives the data sources. The slopes of the curves calculated using the data of HELGE-SON *et al.* (1978) are slightly higher than ours, but both methods result in similar net-topology.

4. Effect of garnet compositional change to the Schreinemakers' net

This Schreinemakers' analysis of model system is very convenient for constructing a petrogenetic grid when we do not have sufficient thermodynamic data. However, because this model essentially deals with discontinuous reactions, discrepancies necessarily appear when considering real reactions. Actually, the geometry of the nets varies according to the assumptions of the chemistry of the phases involved. In general, garnet compositions in Group B and C eclogites change depending on the mineral assemblages and P-T conditions, these range from nearly pure almandine to $X_{Mg}=0.5$ garnet with a variable amount of CaO.

We have examined how the topology of nets changes according to the composition of excess garnet by using the compositions shown in Figure 2. As compositions

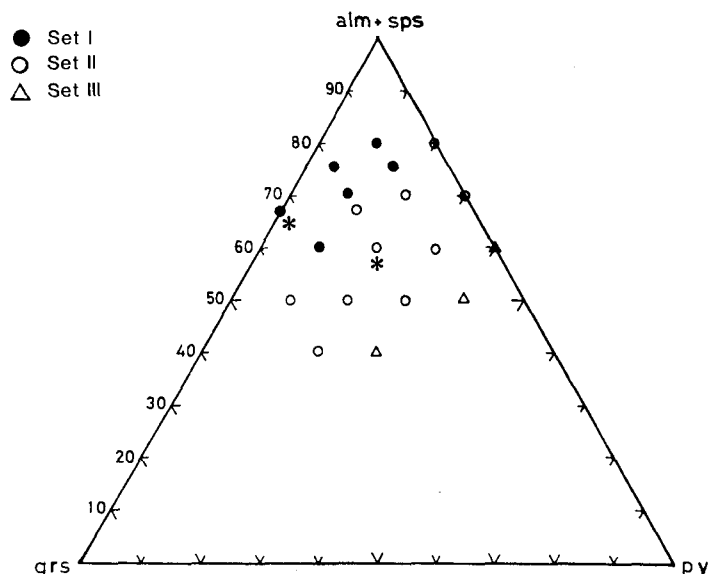


Fig. 2. Topology change of Schreinemakers' net correlated with projecting garnet compositions. The nets with marked garnet compositions (*) are shown in Figs. 3 and 4 as a representative for Sets I and II topologies, respectively.

of other ferromagnesian phases are fixed to those in Table 1, only the reactions involving chloritoid are affected by the composition of excess garnet. Therefore, the topology of 8 nets, as determined by the combination of the various invariant points for the nets, changes with the excess garnet composition. We define the combination of invariant points for 8 nets which give the same topology as a "set" (Fig. 2). We obtained three sets for the compositional grid of Figure 2; Set I corresponds to the most Fe-rich garnet (solid circle in Figure 1), Set II to intermediate garnet (open circle) and Set III to garnet richer in Mg than usual Group C eclogites (triangle). The combination of invariant points for each of the three sets is shown in Table 3.

5. Geometry of possible nets

Eight possible nets for Set I with $\text{CaFe}_2\text{Al}_2\text{Si}_3\text{O}_{12}$ garnet and Set II with $\text{Ca}_{0.6}\text{Fe}_{1.8}\text{Mg}_{0.6}\text{Al}_2\text{Si}_3\text{O}_{12}$ garnet are shown in Figures 3 and 4, respectively. As the combination of invariant points for Set III resembles that of Set II, it is omitted here. A 4-component and 8-phase system generally contains 28 invariant points. Because 3 of them are degenerated for the model system of this study, 26 independent invariant points are derived. Degenerated invariant points are Nos. [23], [24] and [28], for which P-T values are given by HOLLAND (1979b) as 650°C and 24 kbar determined by synthetic experiments. The following three univariant lines radiate from these degenerated invariant points:



Although the slopes calculated in this study are slightly different from those determined by synthetic experiments, the topology around the degenerated invariant points is the same as that given by HOLLAND (1979b). Because all the possible nets contain the degenerated invariant points, all petrogenetic grids are framed by the three univariant lines mentioned above.

Reactant and product mineral assemblages are written on both sides of univariant lines of the petrogenetic grids (Figs. 3 and 4). Therefore, stability fields of tri- and quate-variant assemblages are easily identified in these nets. The following mineral assemblages have similar stability fields in the all nets: Omp-Ky assemblage at high temperature, Gln-Ep-Pg assemblage at the lowest pressure and Jd-Lws and Omp-Lws assemblages at low temperature. However, the stability field of Omp-Cld assemblage varies considerably between the different nets. In the even numbered nets of each set, the Omp-Cld stability field is either restricted to the paragonite-metastable field, that is the high pressure side of the reaction (1), or absent.

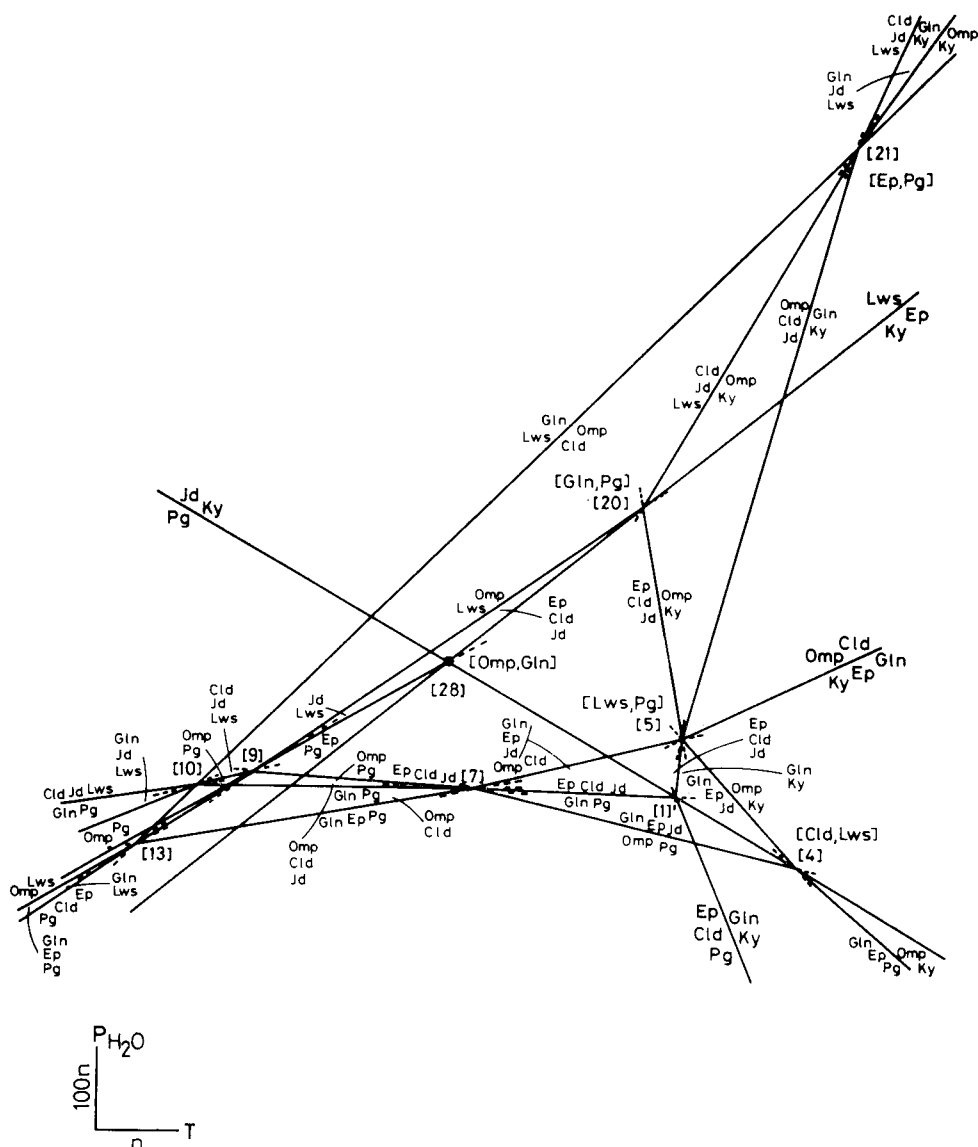


Fig. 3-1

Fig. 3. 8-possible nets of invariant points for Set I, projected from $\text{CaFe}_2\text{Al}_2\text{Si}_3\text{O}_{12}$ garnet. Net No. 5 (Fig. 3-5) is most plausible in this system and stability fields of several eclogites are shown by abbreviations; **M**: Motalafjella eclogite (HIRAJIMA *et al.*, 1988), **T**: Tauern Window (HOLLAND, 1979a), **S**: Sesia-Lanzo zone (REINSCH, 1979), **C**: Corsica (CARON & PEQUIGNOT, 1986).

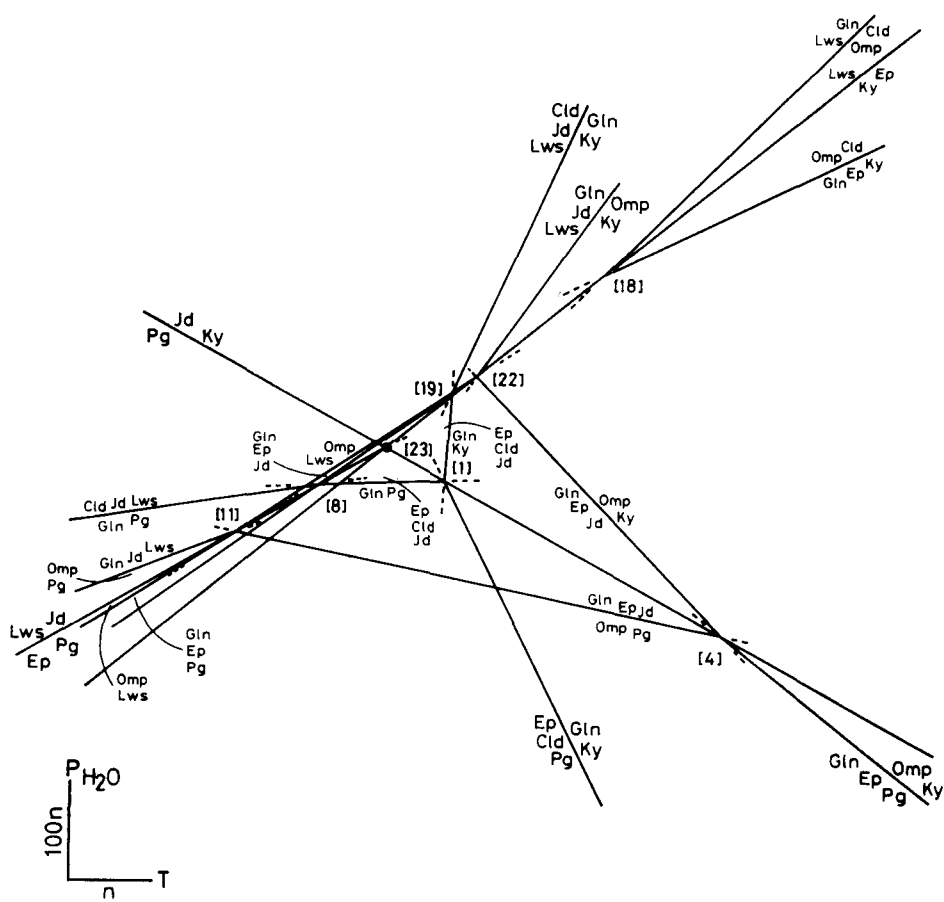


Fig. 3-2

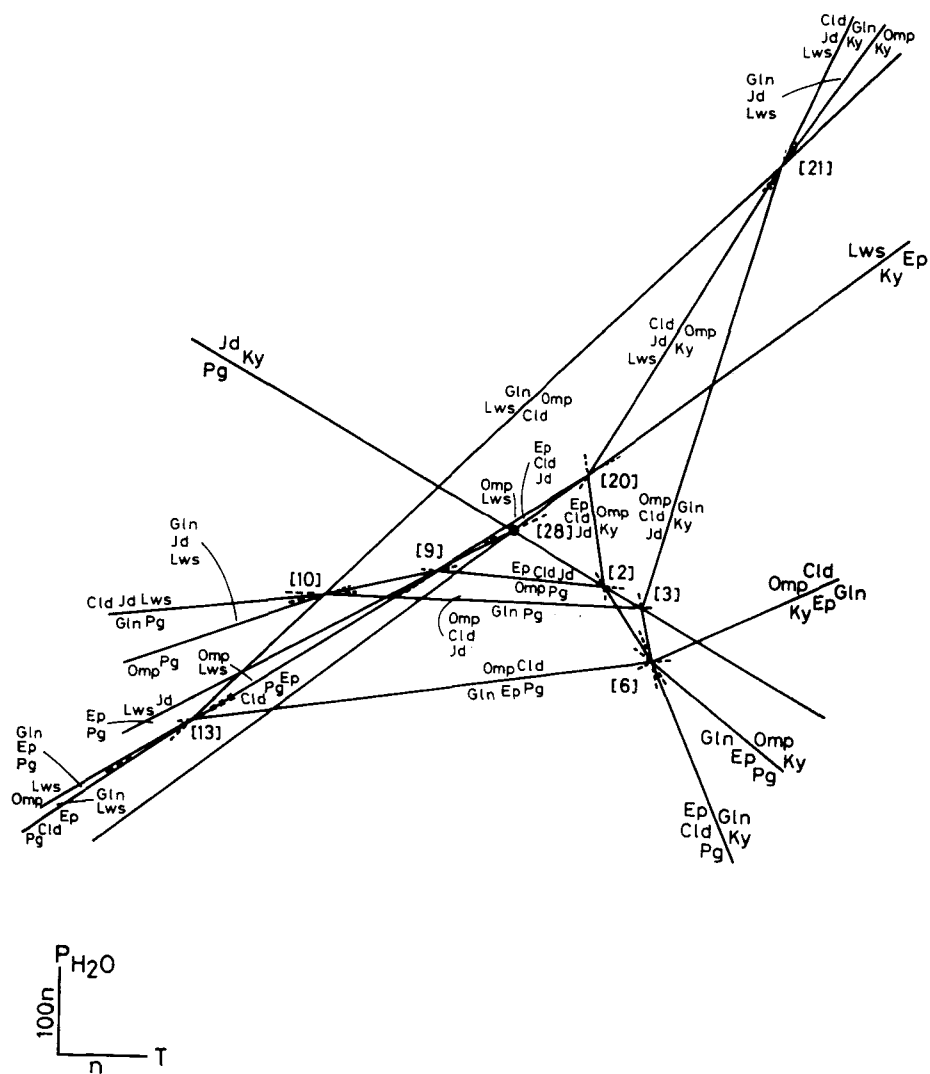


Fig. 3-3

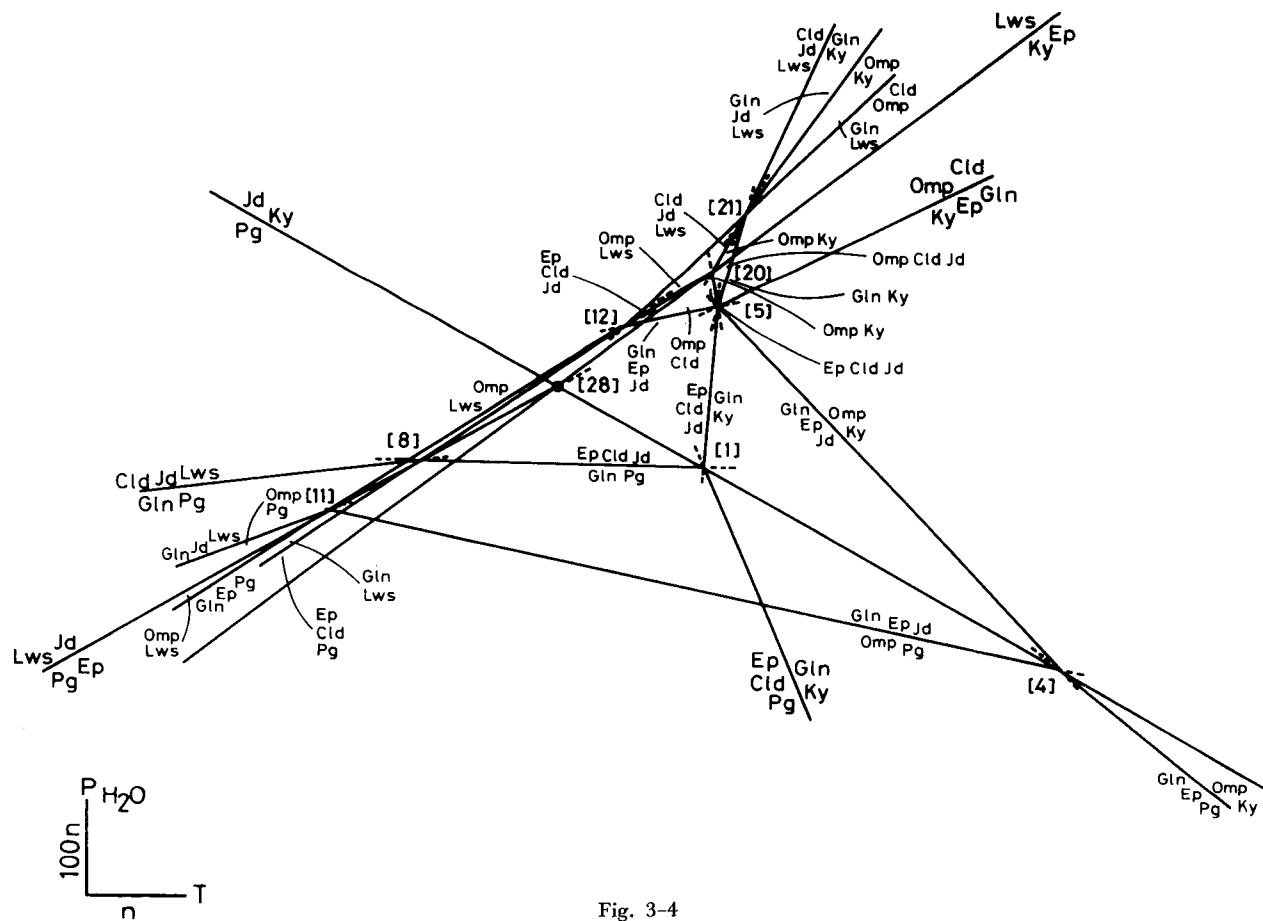


Fig. 3-4

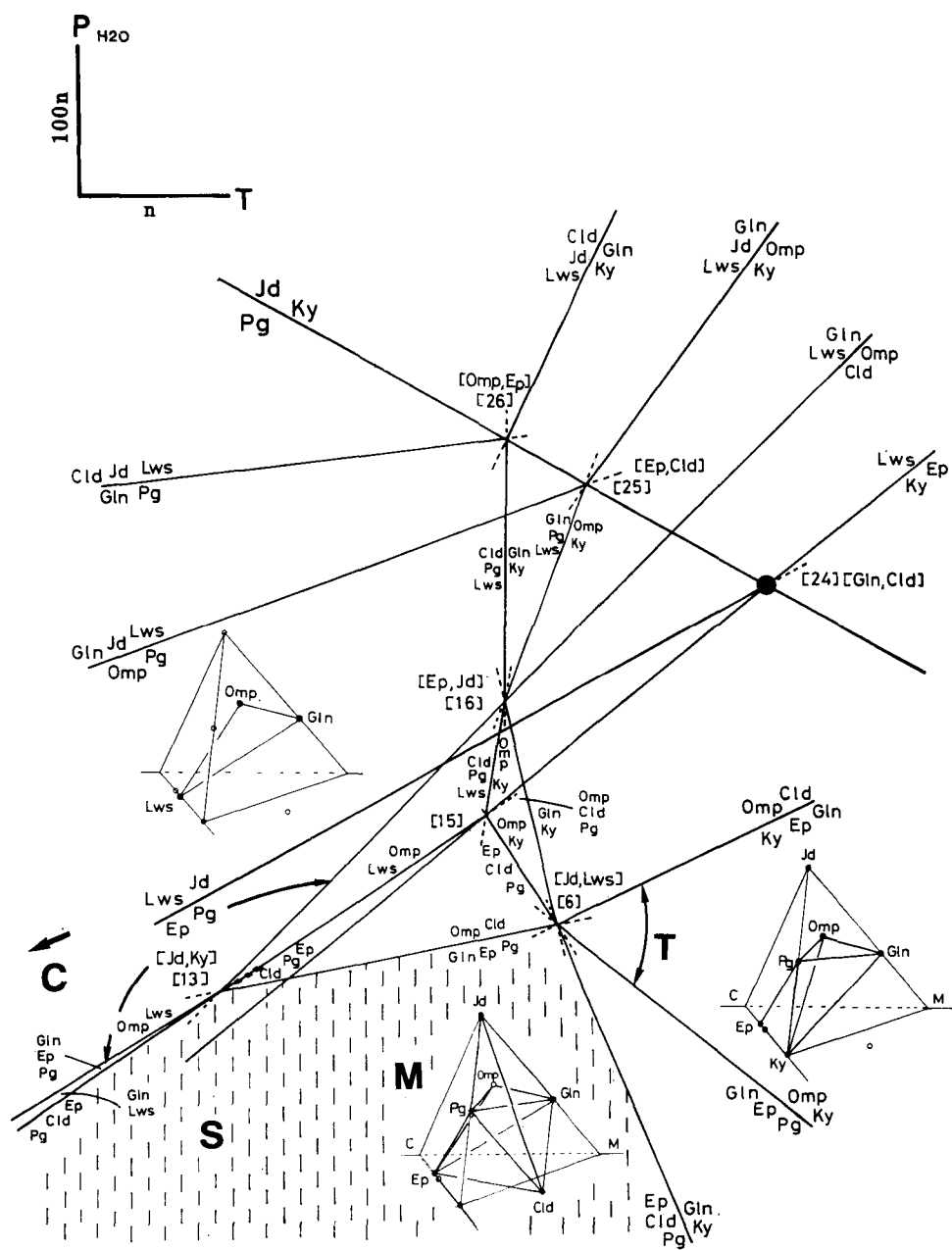


Fig. 3-5

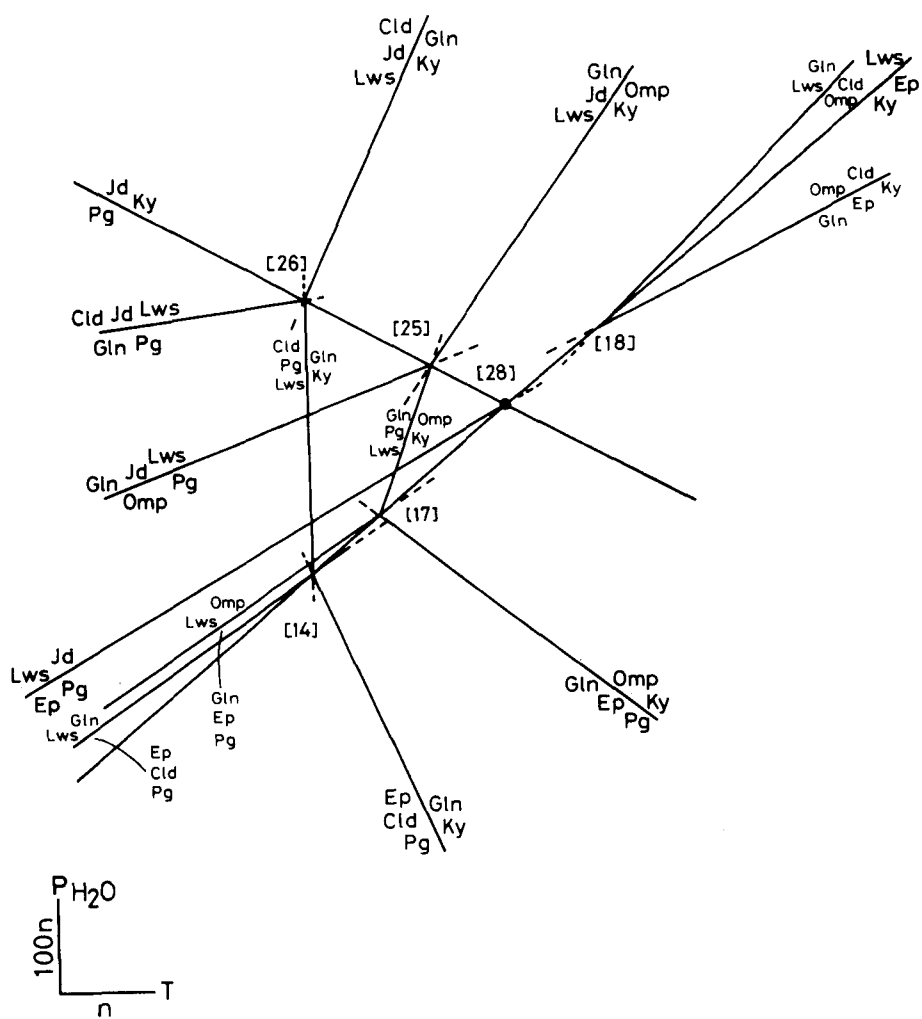


Fig. 3-6

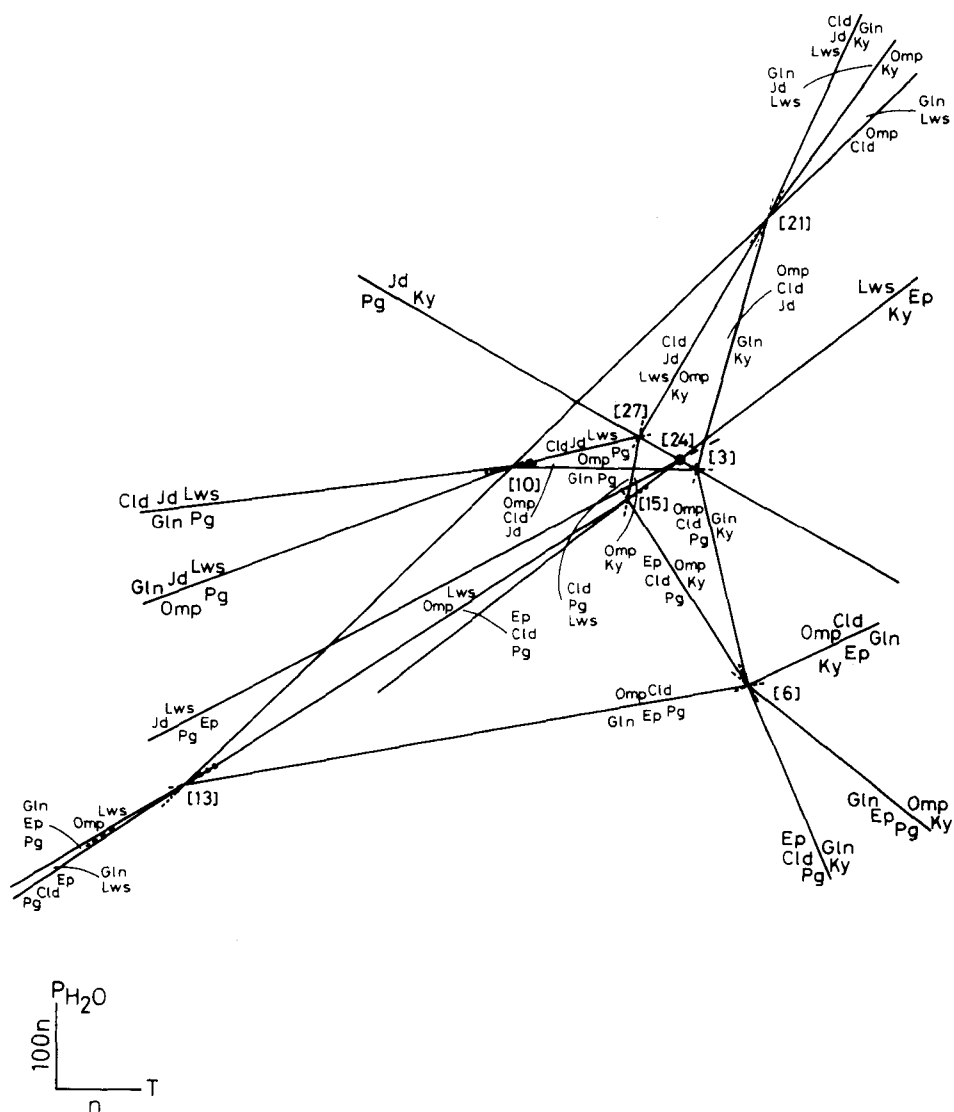
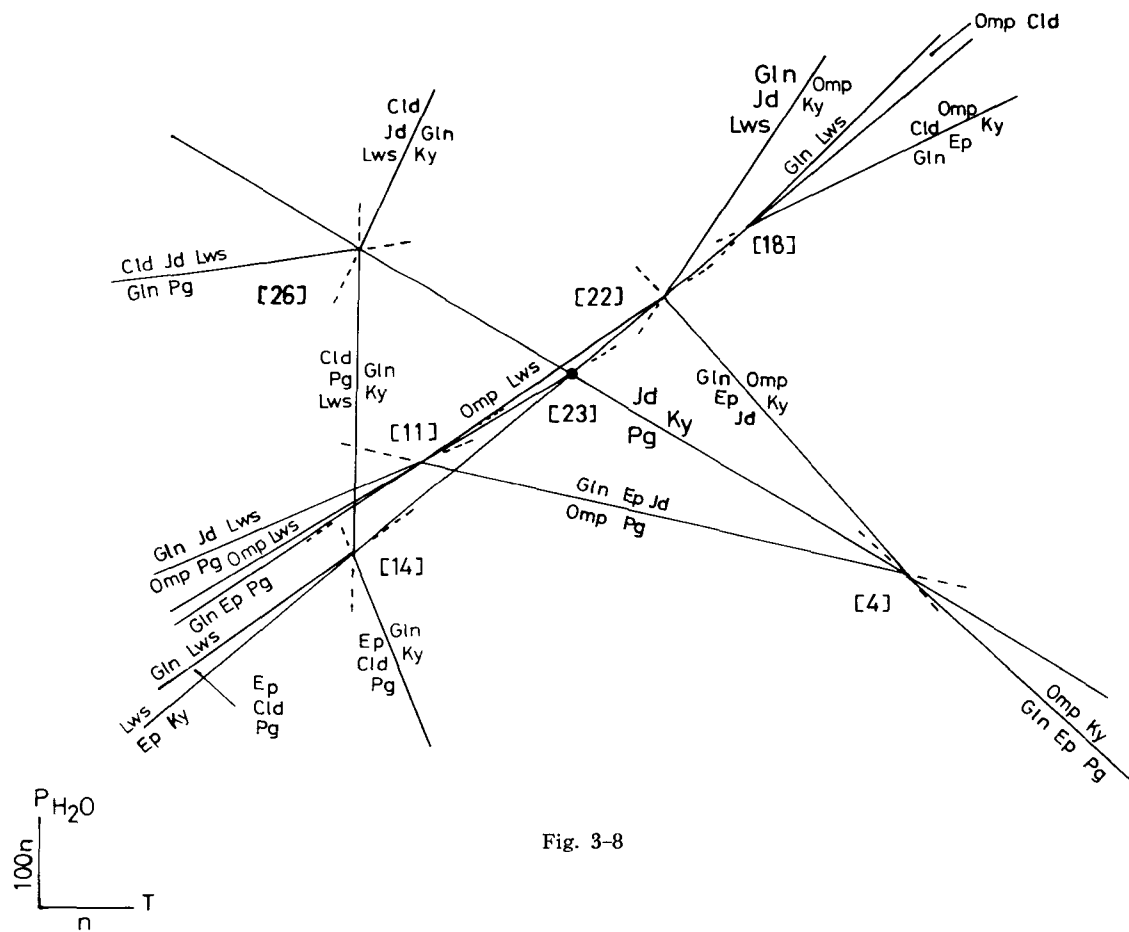


Fig. 3-7



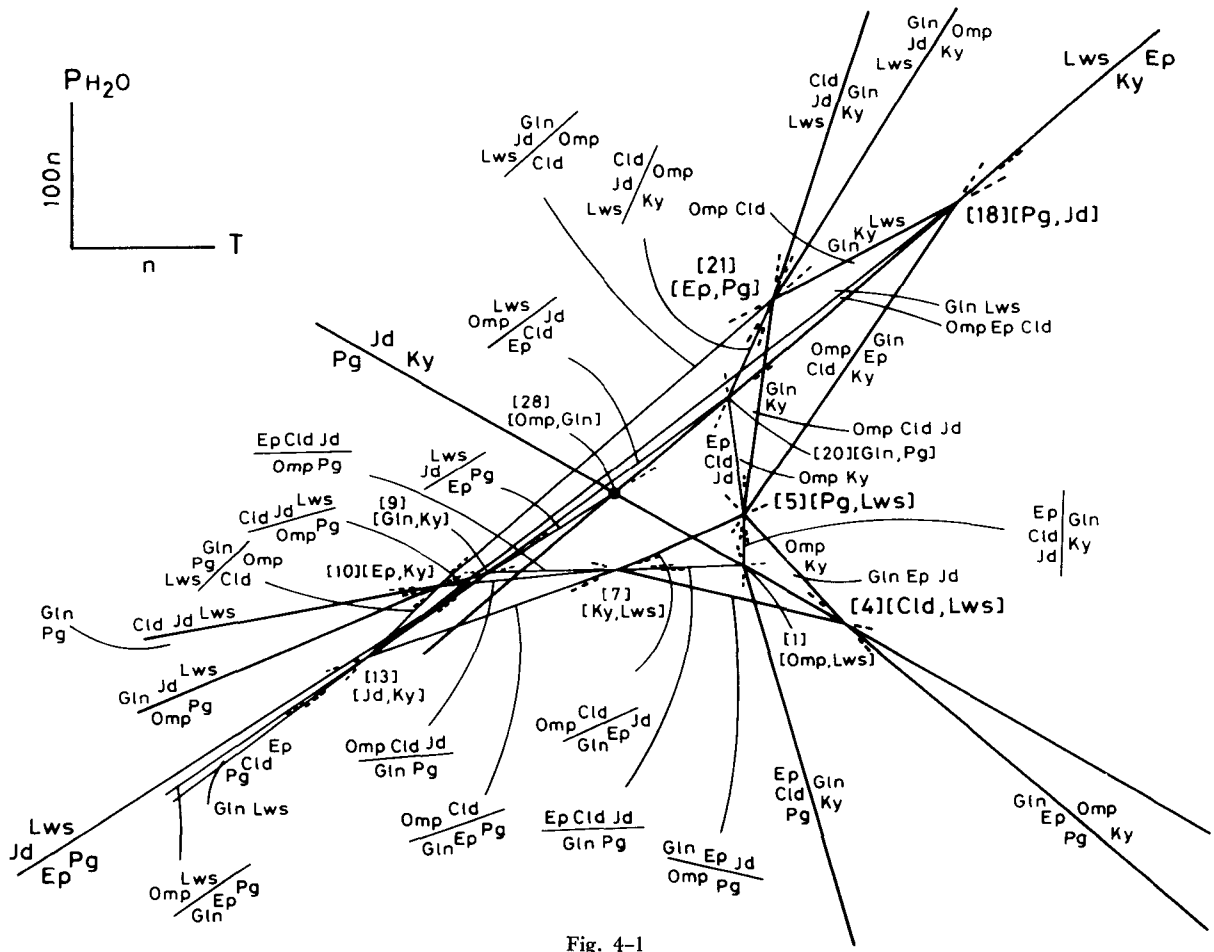
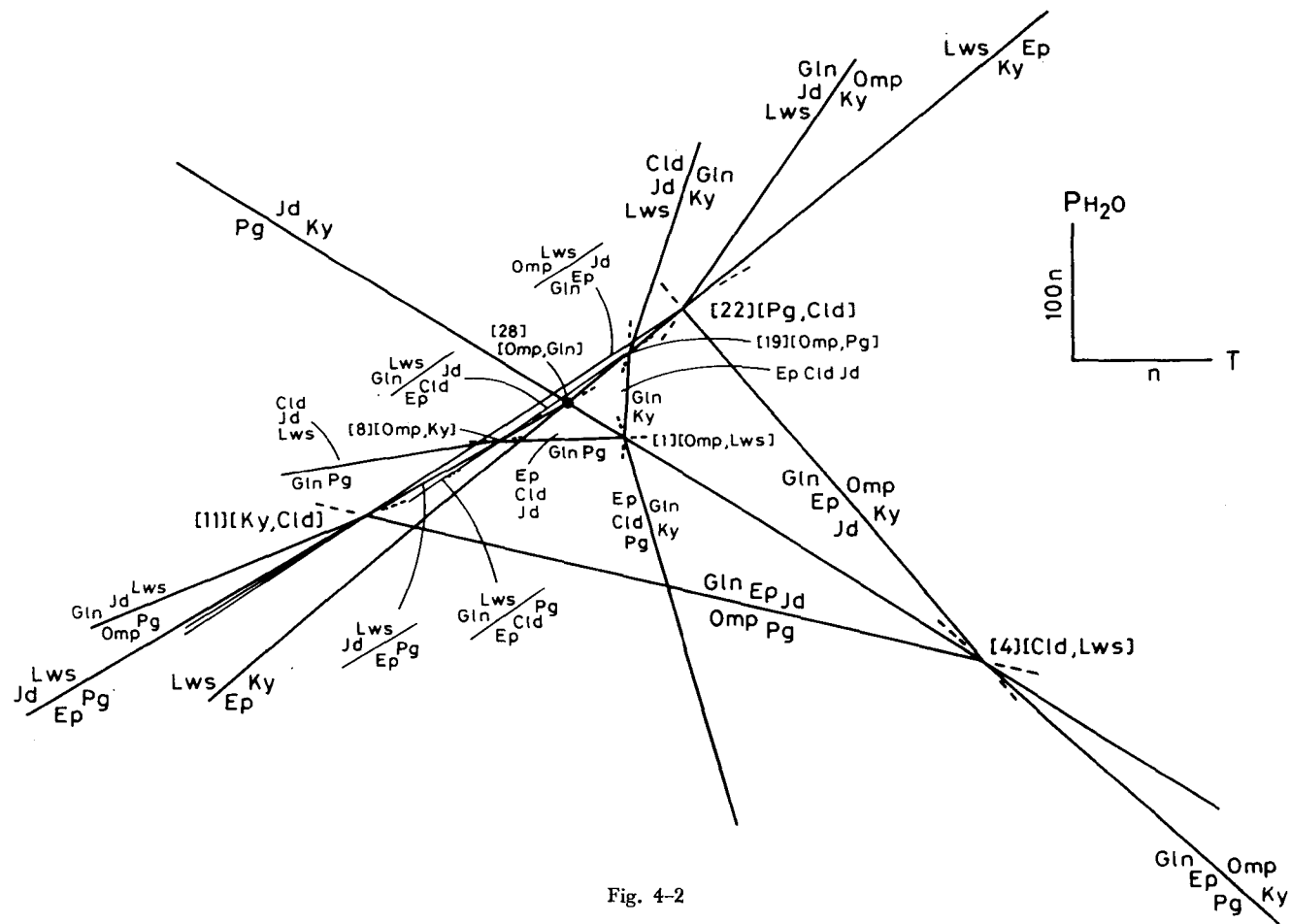


Fig. 4-1

Fig. 4. 8-possible nets of invariant points for Set II projected from $Ca_{0.6}Fe_{1.8}Mg_{0.6}Al_2Si_3O_{12}$ garnet. Net No. 5 (Fig. 4-5) is most plausible to explain the Group B and C eclogites. Abbreviations are same as Fig. 3.



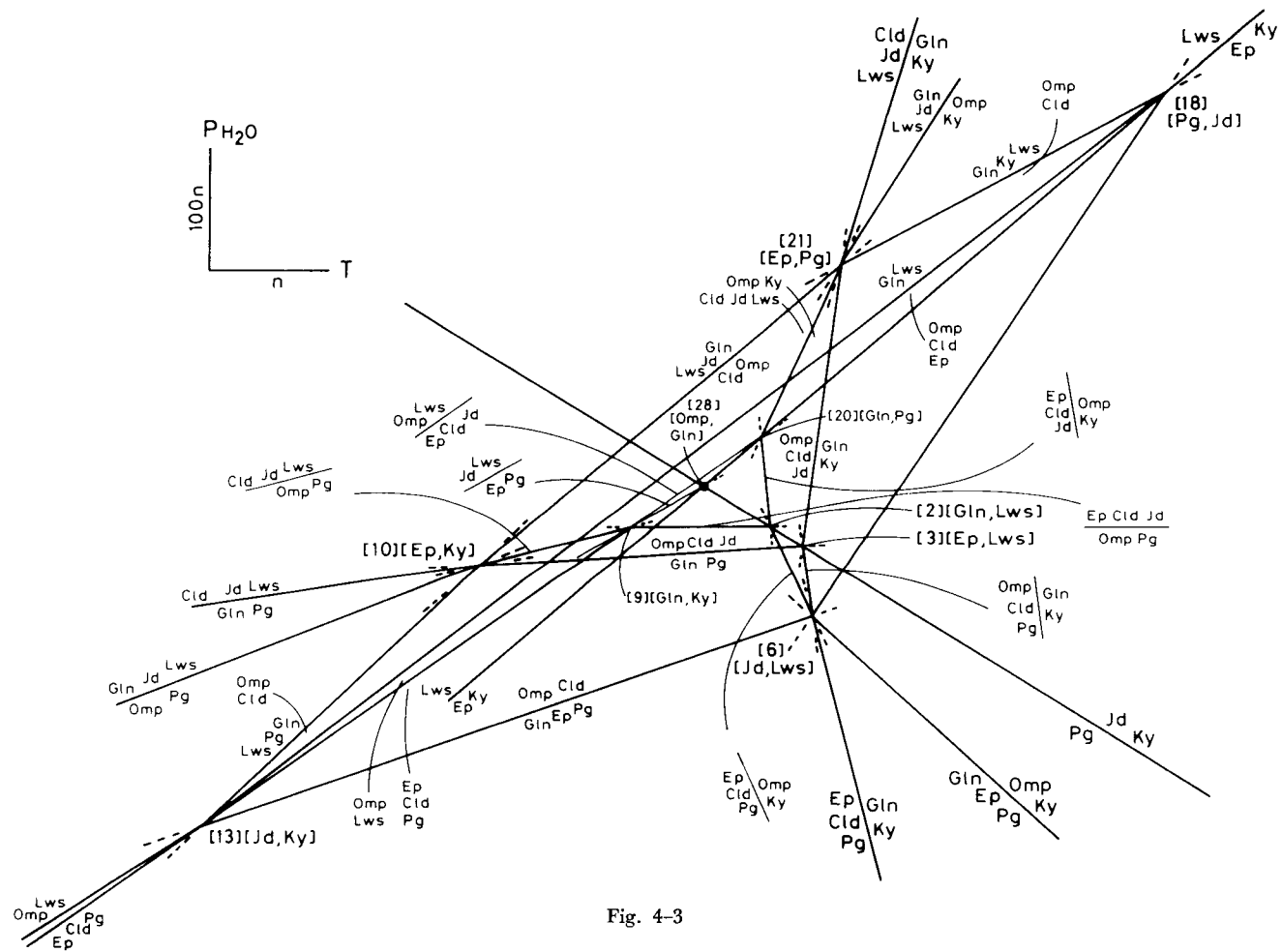


Fig. 4-3

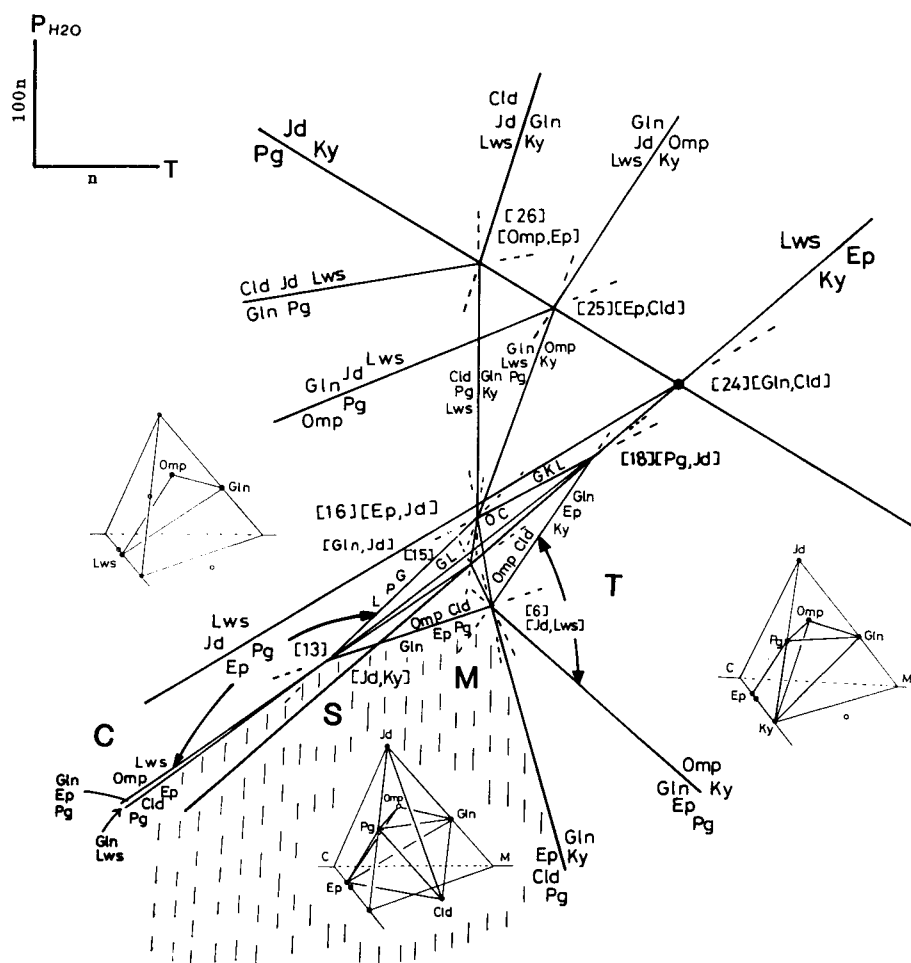


Fig. 4-5

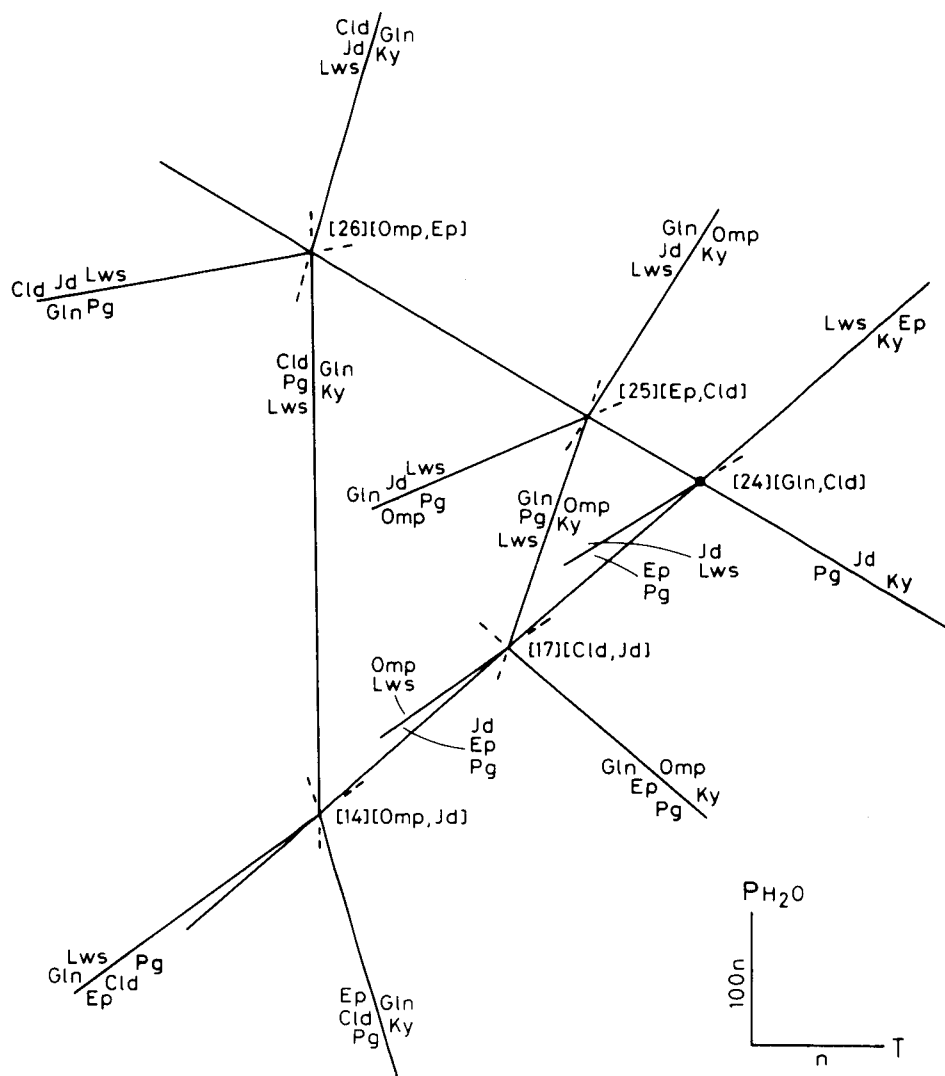


Fig. 4-6

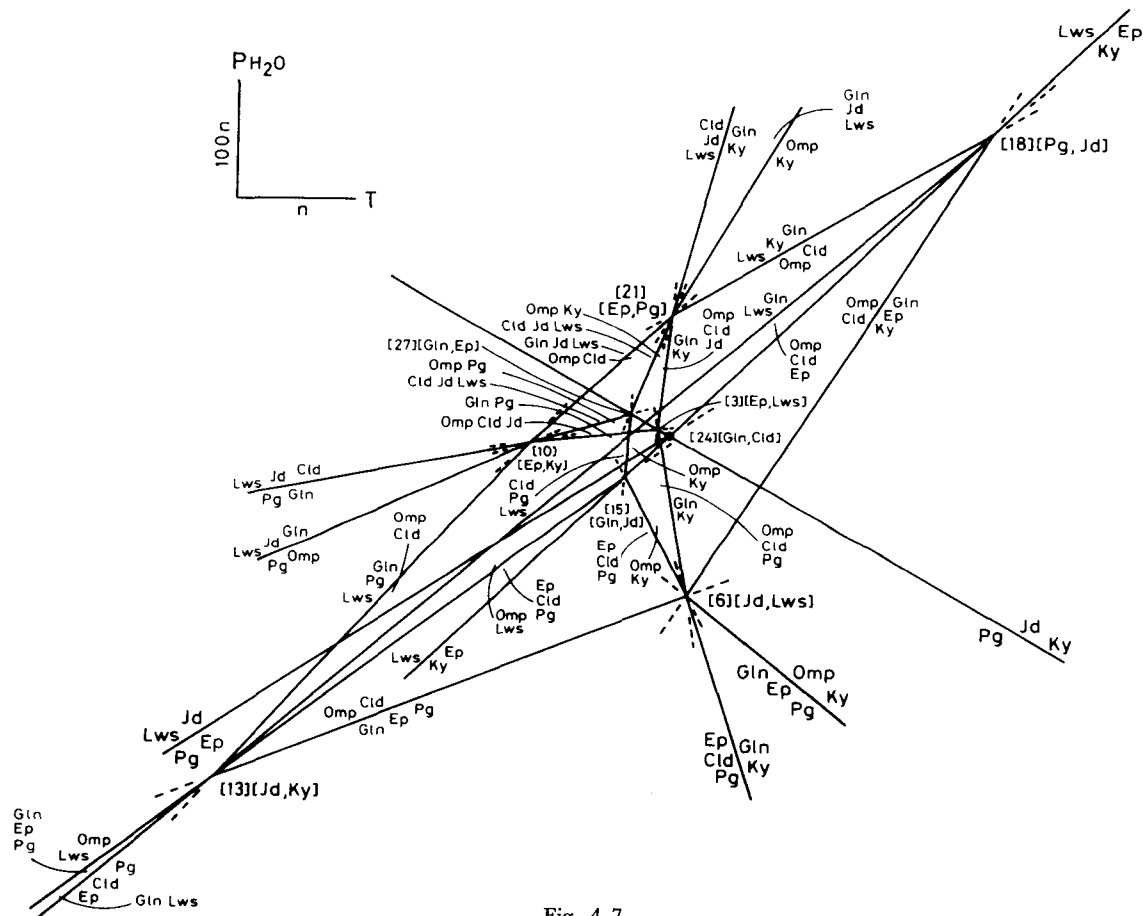


Fig. 4-7

In the odd numbered nets of each set, Omp-Cld assemblage is stable on both sides of reaction (1) or restricted to the low pressure side of it.

6. Discrimination of plausible and implausible nets

For the model system of this study, there is only one synthesized invariant point, that is degenerated invariant points, Nos. [23], [24] and [28] mentioned in the previous section. Because the degenerated invariant point is contained in all the nets, we must use natural mineral assemblages for selecting a plausible net. As OBERHANSLI (1986) reported an example of Omp-Cld-Pg paragenesis in the eclogites from the Zermatt-Saas Fee zone, we can choose the 4 odd numbered nets of each set as more plausible than the others.

The naturally occurring assemblages do not allow a simple choice to be made between the remaining 4 nets (Nos. 1, 3, 5 and 7), but we consider that the stability relationships of the Omp-Ky and Ep-Cld-Pg assemblages made net No. 5 of both sets the most plausible to represent naturally occurring eclogites. HOLLAND (1979a) has described Omp-Ky assemblage from the Tauern eclogites, for which the calibration of RÄHEIM and GREEN (1974) for the Fe-Mg partitioning between omphacite and garnet gives $620 \pm 30^\circ\text{C}$ at 19.5 kbar. The Ep-Cld-Pg assemblage is incompatible with the Omp-Ky assemblage in the model system, and has been reported from metapelites associated with eclogites in Spitsbergen (HIRAJIMA *et al.*, 1988) and Sesia-Lanzo zone (REINSCH, 1979). The estimated conditions of formation temperatures are $610 \pm 30^\circ\text{C}$ at 18–24 kbar for the Spitsbergen eclogites by the calibration of ELLIS and GREEN (1979) and about 500–600°C at 15 kbar for the Sesia-Lanzo eclogites by that of RÄHEIM and GREEN (1974). Although RÄHEIM and GREEN's calibration gives a lower temperature than ELLIS and GREEN's the stability boundary should be located between RÄHEIM-GREEN's 500–600°C and $620 \pm 30^\circ\text{C}$ at 15–20 kbar.

The boundary of these incompatible assemblages is defined by the following two reactions (Figs. 3 and 4);

assemblages of **Spitsbergen** = assemblages of **Tauern window**



These reactions occur at higher-temperature than the degenerated invariant point, which HOLLAND (1979b) gives at 650°C and 24 kbar, in the nets Nos. 1, 3 and 7 of each set. However, these reactions are stable at lower-temperature than 650°C at 15–20 kbar in the net No. 5 for each set. Therefore, only the net No. 5 gives a reasonable temperature for the formation of the Tauern eclogites.

In the net No. 5 of Sets I and II (Figs. 3–5 and 4–5, respectively), stability fields of several eclogite occurrences are shown by abbreviations (**T**: Tauern Window, HOLLAND (1979a), **M**: Motalafjella in Spitsbergen, HIRAJIMA *et al.* (1988), **S**: Sesia-Lanzo, REINSCH (1979), **C**: Corsica, CARON & PEGUIGNOT (1986)). Their mineral parageneses are also shown on the $N(\text{NaAlO}_2)\text{-CaO-A}(\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3)\text{-MgO}$ tetrahedron (Figs. 3–5 and 4–5). In both the nets, their stability fields are compatible with the estimated P-T values from the literature. The major difference between the two nets is the stability field of Omp-Cld assemblage. It is stable on both sides of the reaction $(1)\text{--Pg}=\text{Jd}+\text{Ky}\text{--}$ in the net No. 5 of Set I, although its stability field is restricted to the low pressure side of the reaction (1) in the net No. 5 of Set II. We have insufficient knowledge about the stability of the Omp-Cld assemblage to be able to determine which of the two nets is more plausible. However, we suggest that net No. 5 of Set II is the more favorable candidate, because its garnet has a composition representative of Spitsbergen eclogites as well as the other Group C eclogite occurrences.

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