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Author(s)	Hirajima, Takao; Banno, Shohei
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Schreinemakers' nets for Group B and C Eclogites in a Model 4-Component and 8-Phase System

By

Takao HIRAJIMA and Shohei BANNO

(Received October 14, 1988)

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 (glaucophane, 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 $N(NaAlO_2)$-CaO-$A(Al_2O_3+Fe_2O_3)$-MgO

The mineral assemblages of eclogitic rocks can generally be described in terms of a 6-component system, Na_2O-Al_2O_3-Fe_2O_3-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. Fe^{3+}-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 $N(NaAlO_2)$-CaO-$A(Al_2O_3+Fe_2O_3)$-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 $N(NaAlO_2)$-CaO-$A(Al_2O_3+Fe_2O_3)$-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

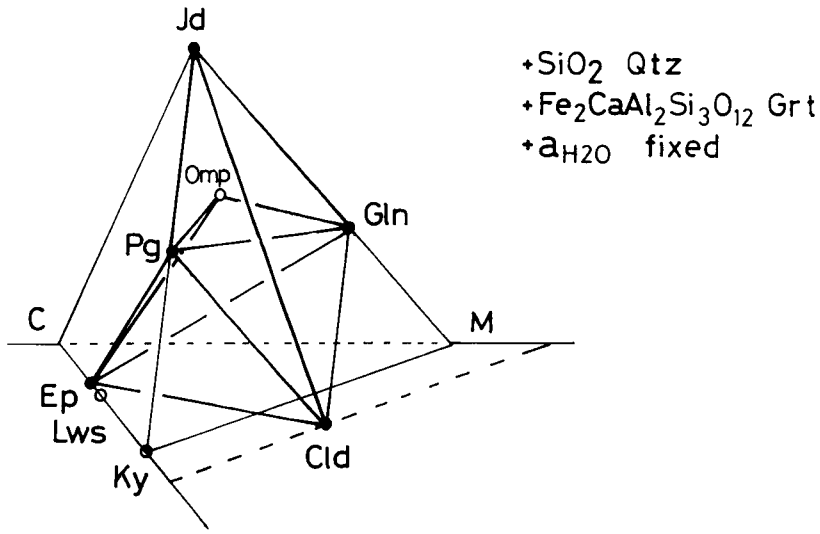


Fig. 1. Mineral paragenesis on the $N(NaAlO_2)$-CaO-$A(Al_2O_3+Fe_3O_2)$-M(MgO) tetrahedron projected from quartz, almandine and H_2O.

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=H_2O 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 HELGESON *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

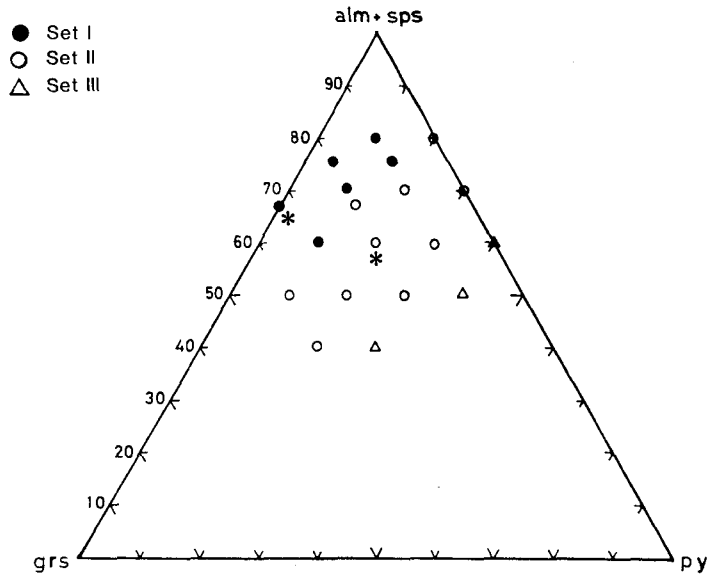


Fig. 2. Topology change of Schreinemakers' net correlated with projecting garnet compositions. The nets with marked garnet compositions (*) are shown in Figs. 3 and 4 as a representative for Sets I and II topologies, respectively.

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 $CaFe_2Al_2Si_3O_{12}$ garnet and Set II with $Ca_{0.6}Fe_{1.8}Mg_{0.6}Al_2Si_3O_{12}$ 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 invaiant 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:

$$\mathrm{Pg} = \mathrm{Jd} + \mathrm{Ky} \quad \cdots\cdots(1)$$

$$\mathrm{Lws} = \mathrm{Ep} + \mathrm{Ky} \quad \cdots\cdots(2)$$

$$\mathrm{Lws} + \mathrm{Jd} = \mathrm{Ep} + \mathrm{Pg}\,. \quad \cdots\cdots(3)$$

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 quatre-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.

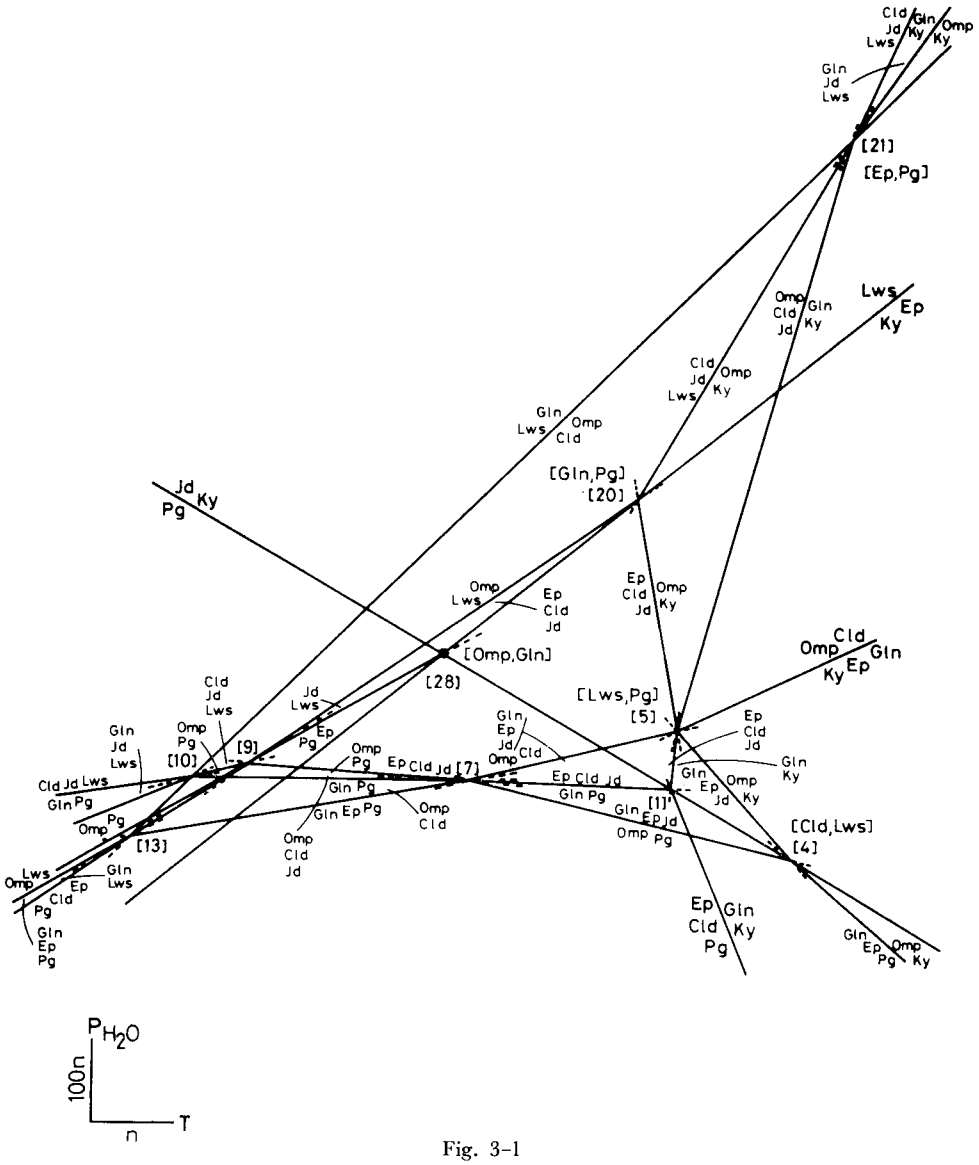
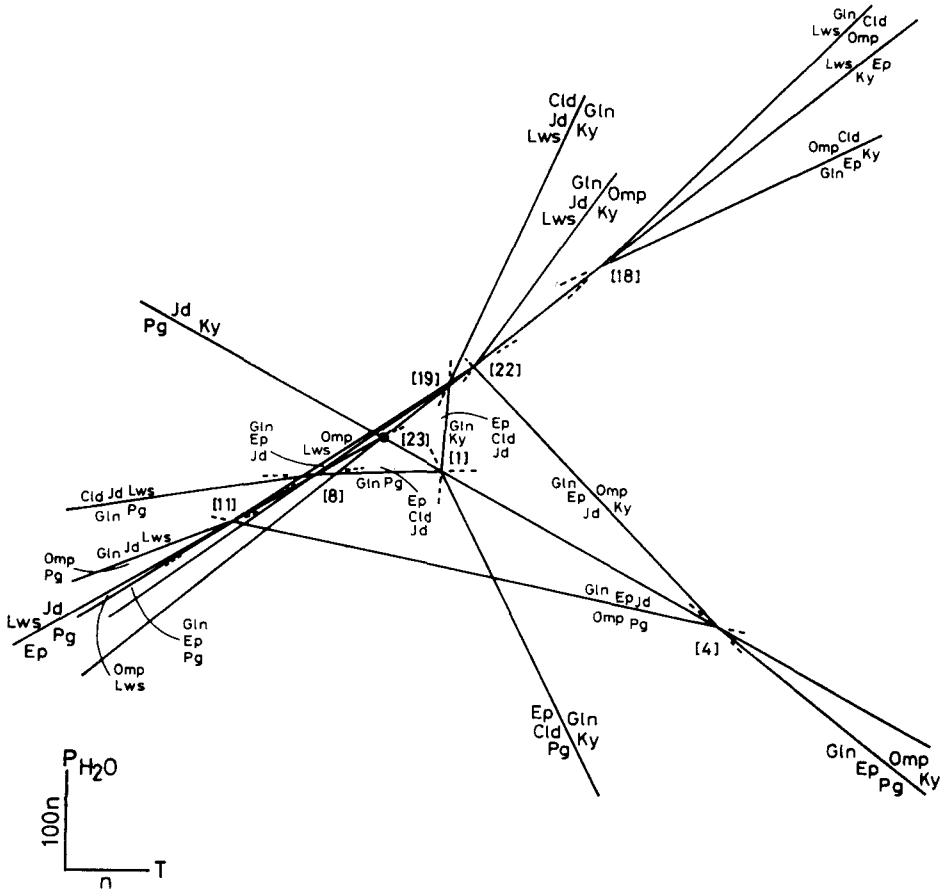


Fig. 3-1

Fg. 3. 8-possible nets of invariant points for Set I, projected from $CaFe_2Al_2Si_3O_{12}$ 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).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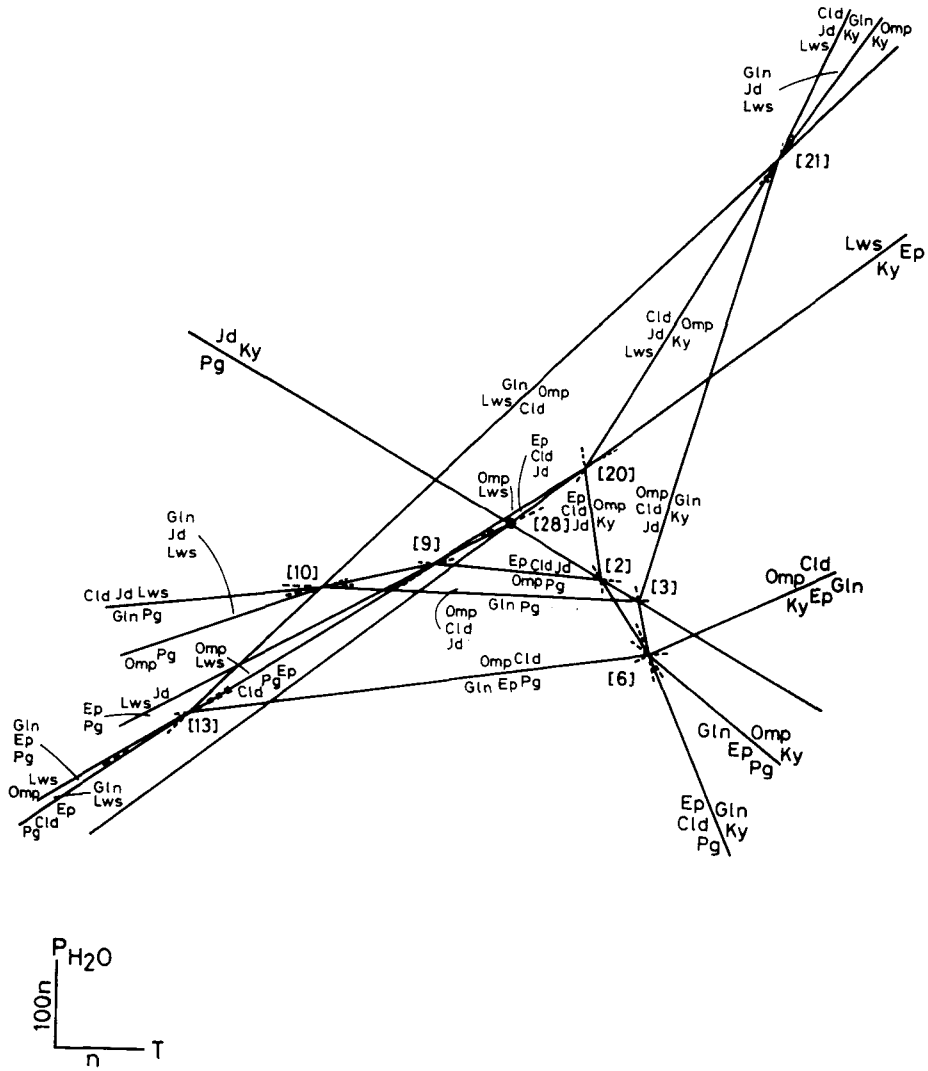
Cld Jd Gln Lws Ky
Omp Cld Ep Ky Gln
Gln Jd Omp Lws Ky
[18]
Jd Pg Ky
[19]
[22]
Gln Ep Jd
Omp Lws
[23]
Gln Ky
Ep Cld Jd
[1]
Cld Jd Lws Gln Pg
[11]
[8]
Gln Pg
Ep Cld Jd
Gln Ep Omp Jd Ky
Omp Pg
Gln Jd Lws
Gln Ep Jd Omp Pg
[4]
Lws Jd Pg Ep
Gln Ep Pg
Omp Lws
Ep Cld Pg Ky
Gln Ep Pg Omp Ky
P H2O
100n
n
T

Fig. 3-2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Gln Ky
Omp Ky
Gln Jd Lws
[21]
Lws Ep Ky
Jd Ky Pg
Cld Jd Lws
Omp Ky
Gln Lws Omp Cld
Ep Cld Jd
[20]
Omp Lws
Ep Cld Jd
Omp Ky
[28]
Omp Cld Jd
Gln Ky
Gln Jd Lws
[9]
[10]
Ep Cld Jd
Omp Pg
[2]
[3]
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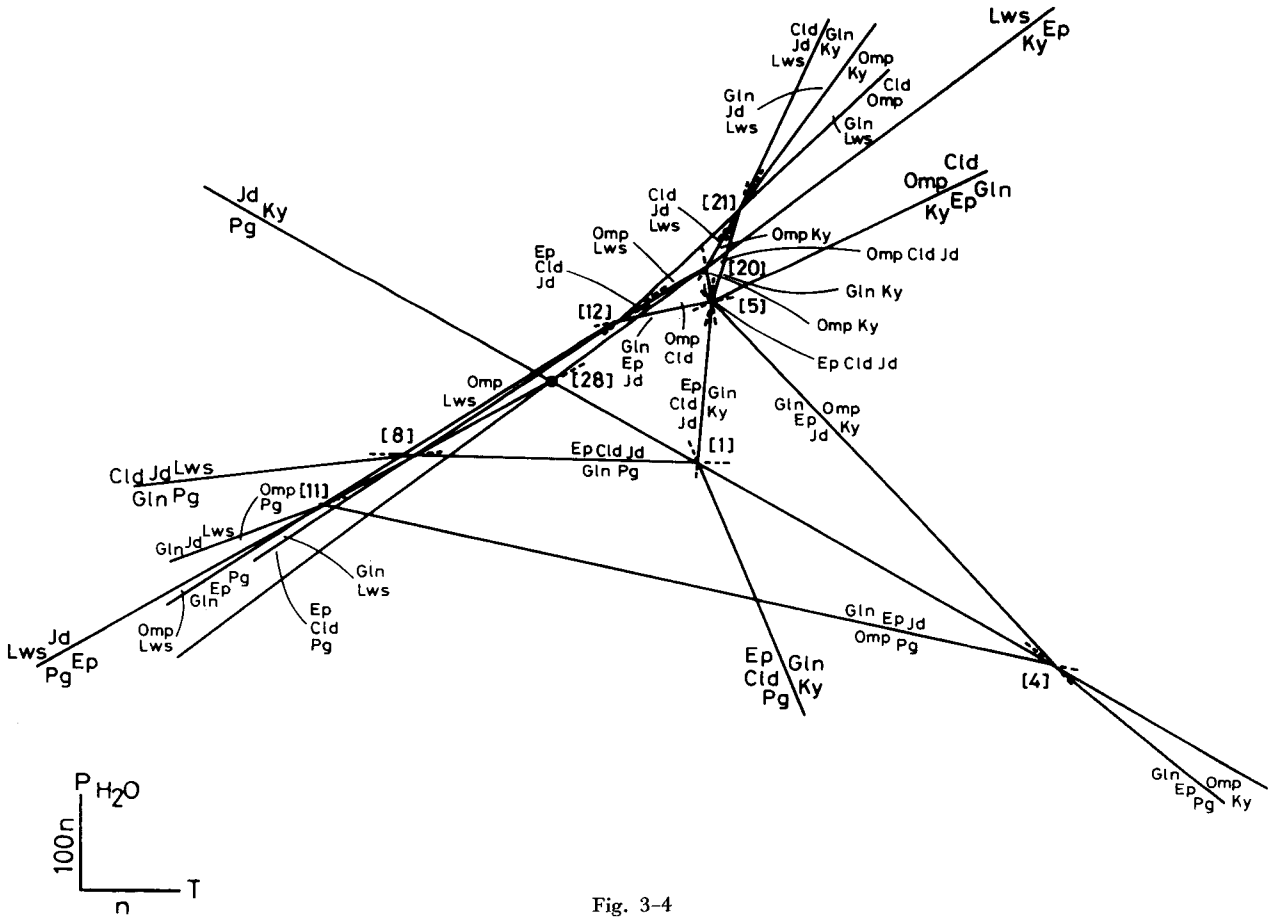
Gln Pg
Omp Cld Jd
Gln Pg
Omp Cld Ky Ep Gln
Omp Pg
Omp Lws
Cld Pg Ep
Omp Cld
Gln Ep Pg
[6]
Ep Pg
Lws Jd
[13]
Gln Ep Pg
Lws
Omp
Gln Lws
Ep
Cld Pg
Gln Omp Ep Pg Ky
Ep Cld Pg
Gln Ky
P H2O
100n
n
T

Fig. 3-3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Ep Cld Jd
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Gln Ep Jd Omp Pg
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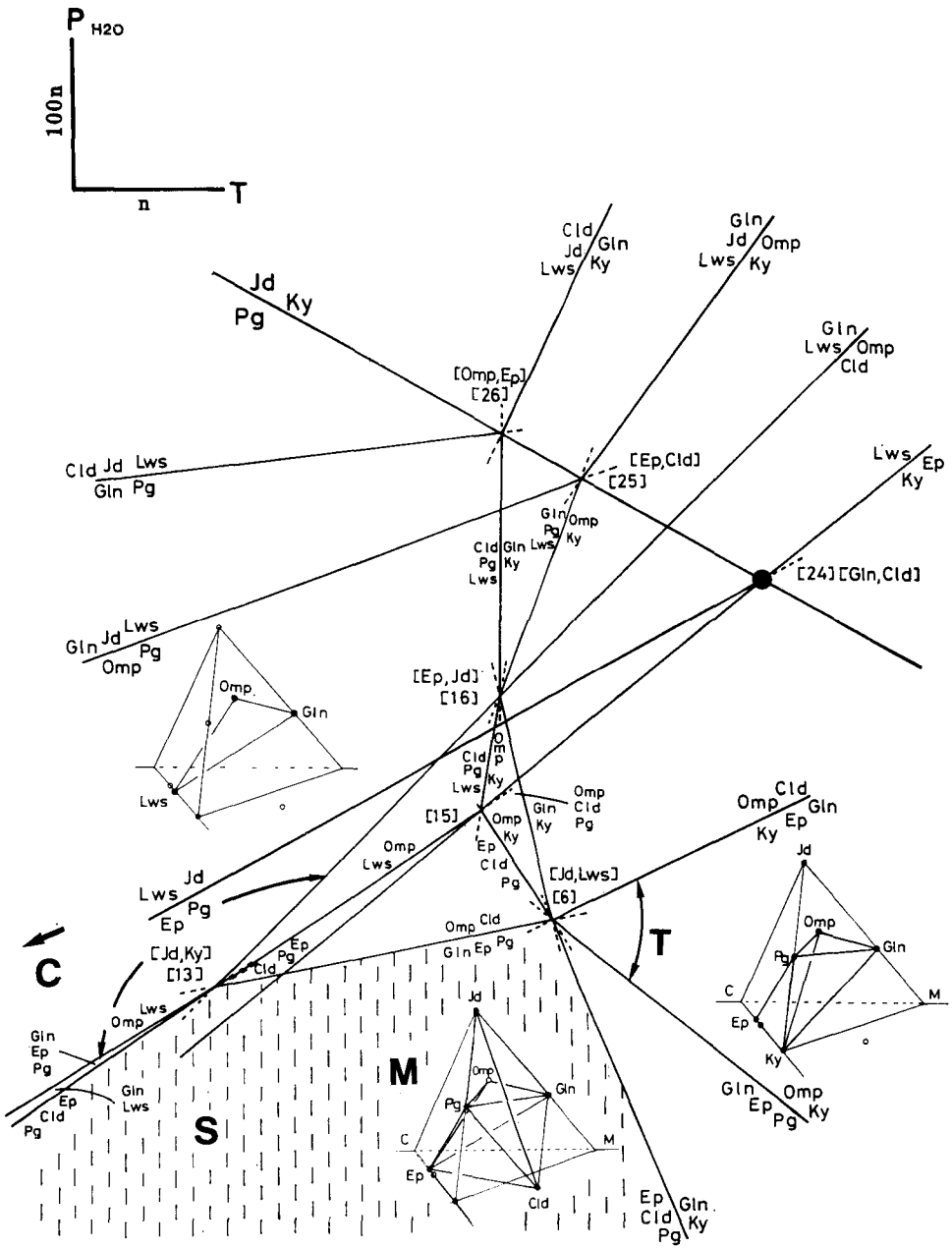
P H2O
100n
n
T

Fig. 3-4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n
T
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[Ep,Cld] [25]
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Cld Jd Lws Gln Pg
Gln Omp Pg Ky
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[24] [Gln,Cld]
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S
M
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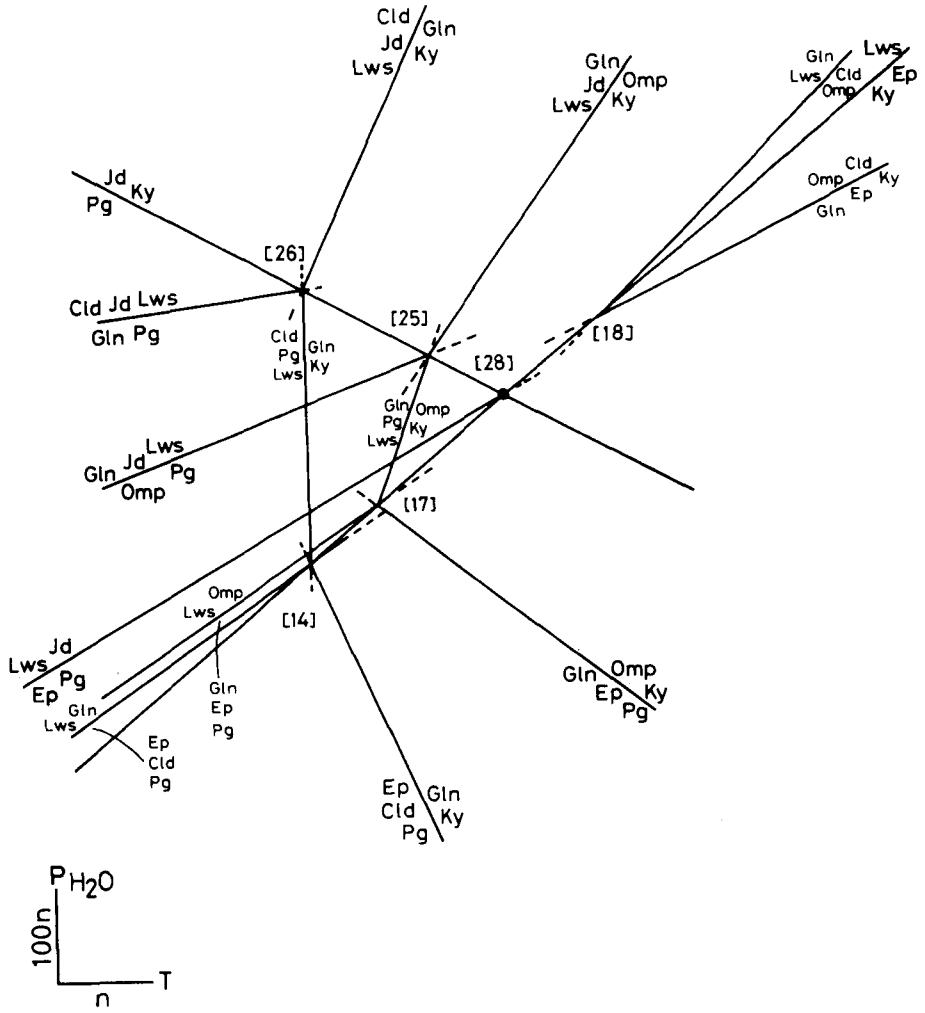
Gln Ep Pg Omp Ky
Ep Cld Pg Gln Ky

Fig. 3–5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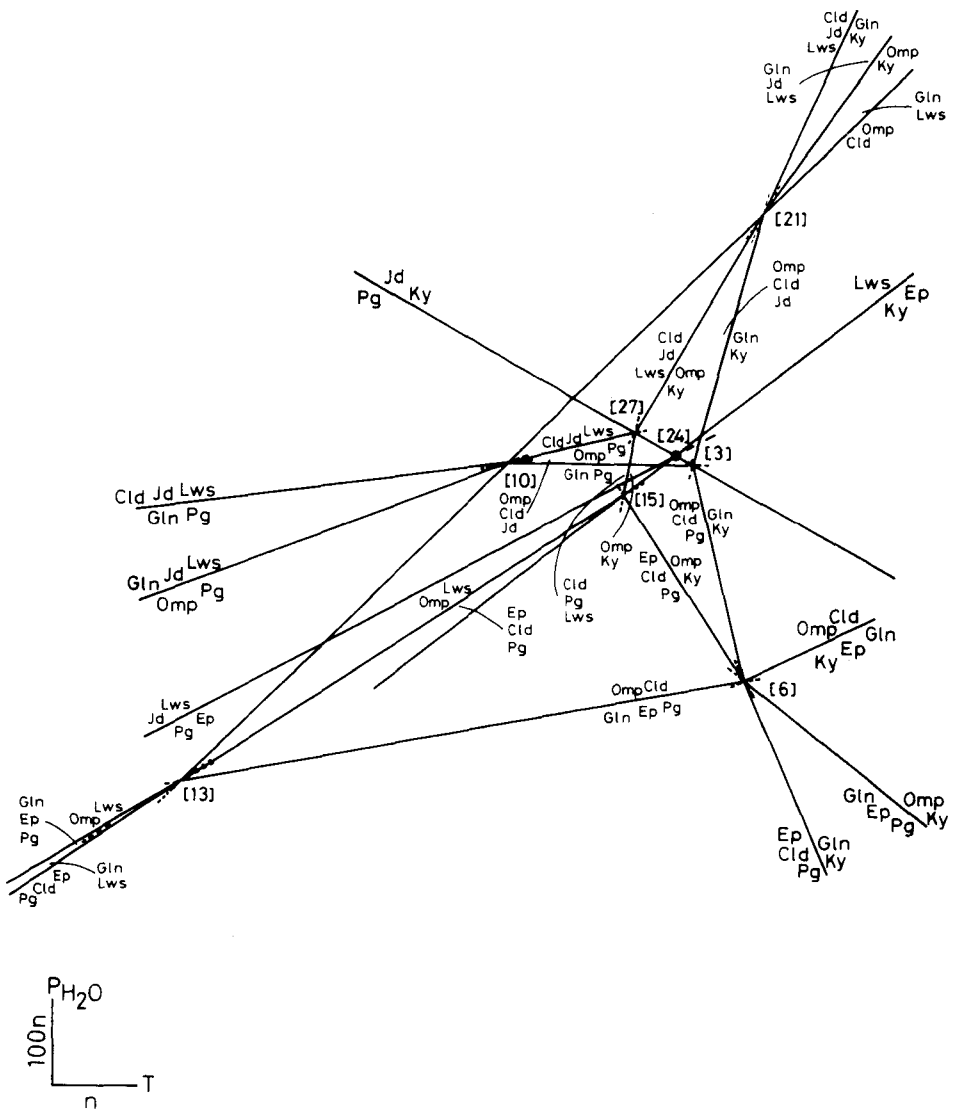
Pg
P H2O
100n
T
n

Fig. 3-6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Gln Ep Pg Lws Omp
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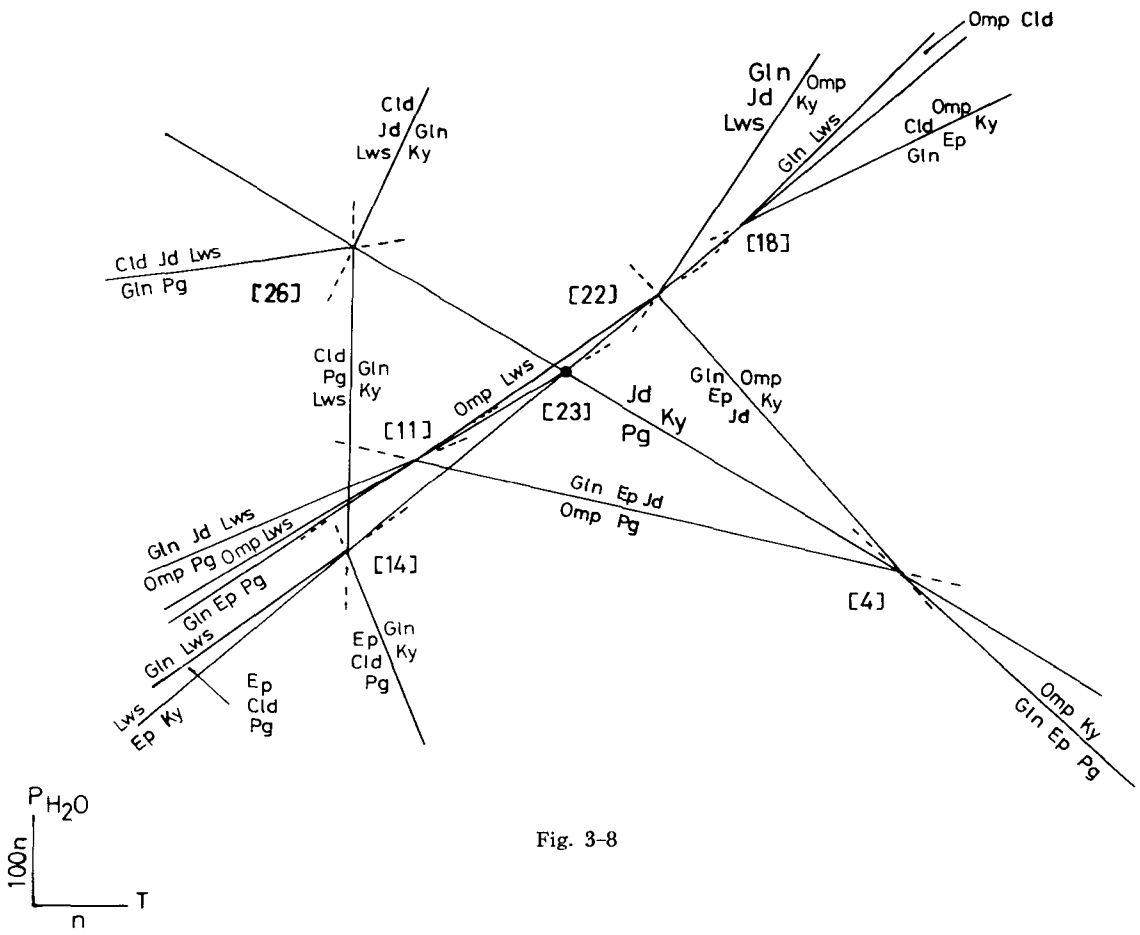
P_{H_2O}
100n
T
n

Fig. 3-7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P H2O
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T
n

Fig. 3-8

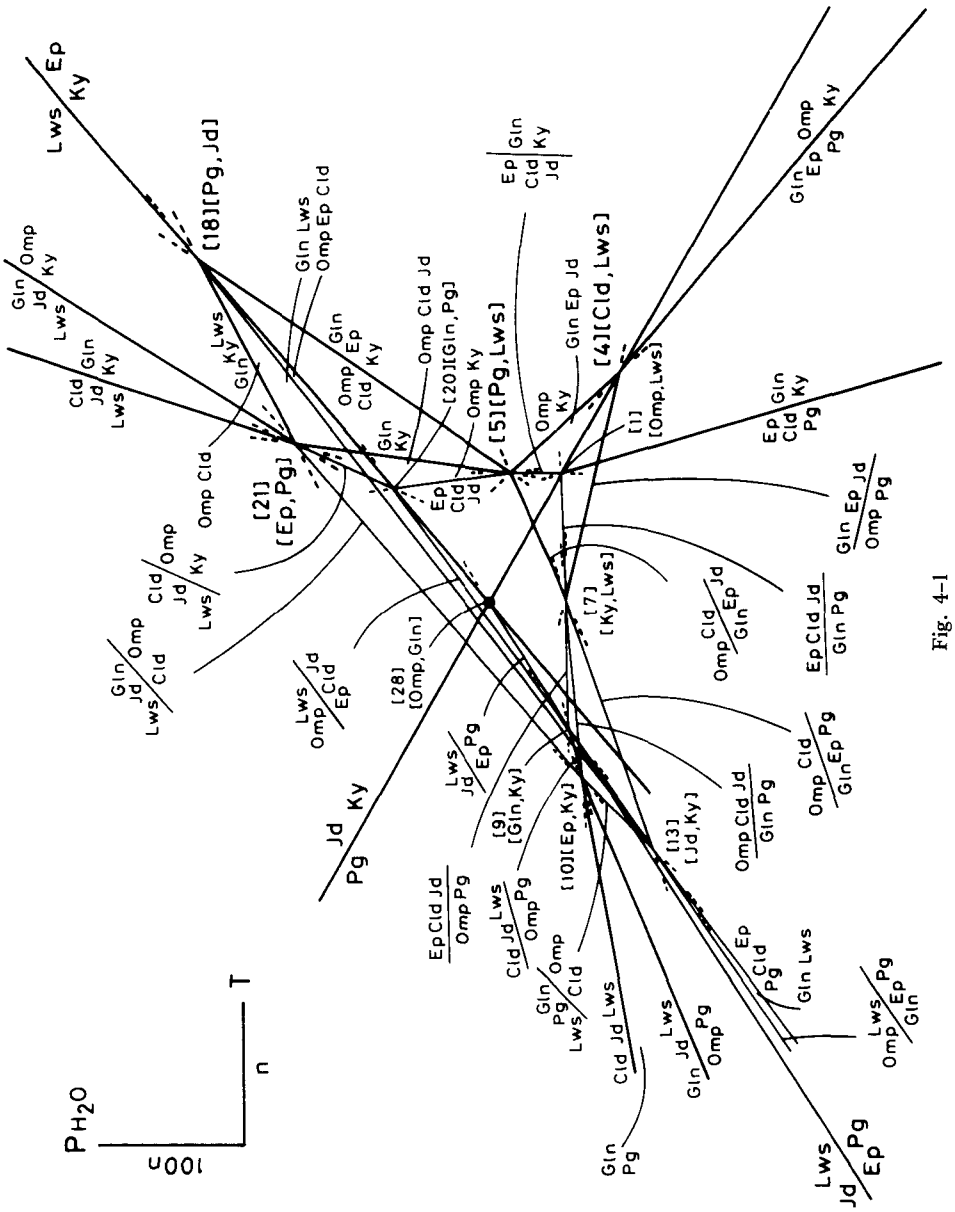

Fig. 4–1

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.

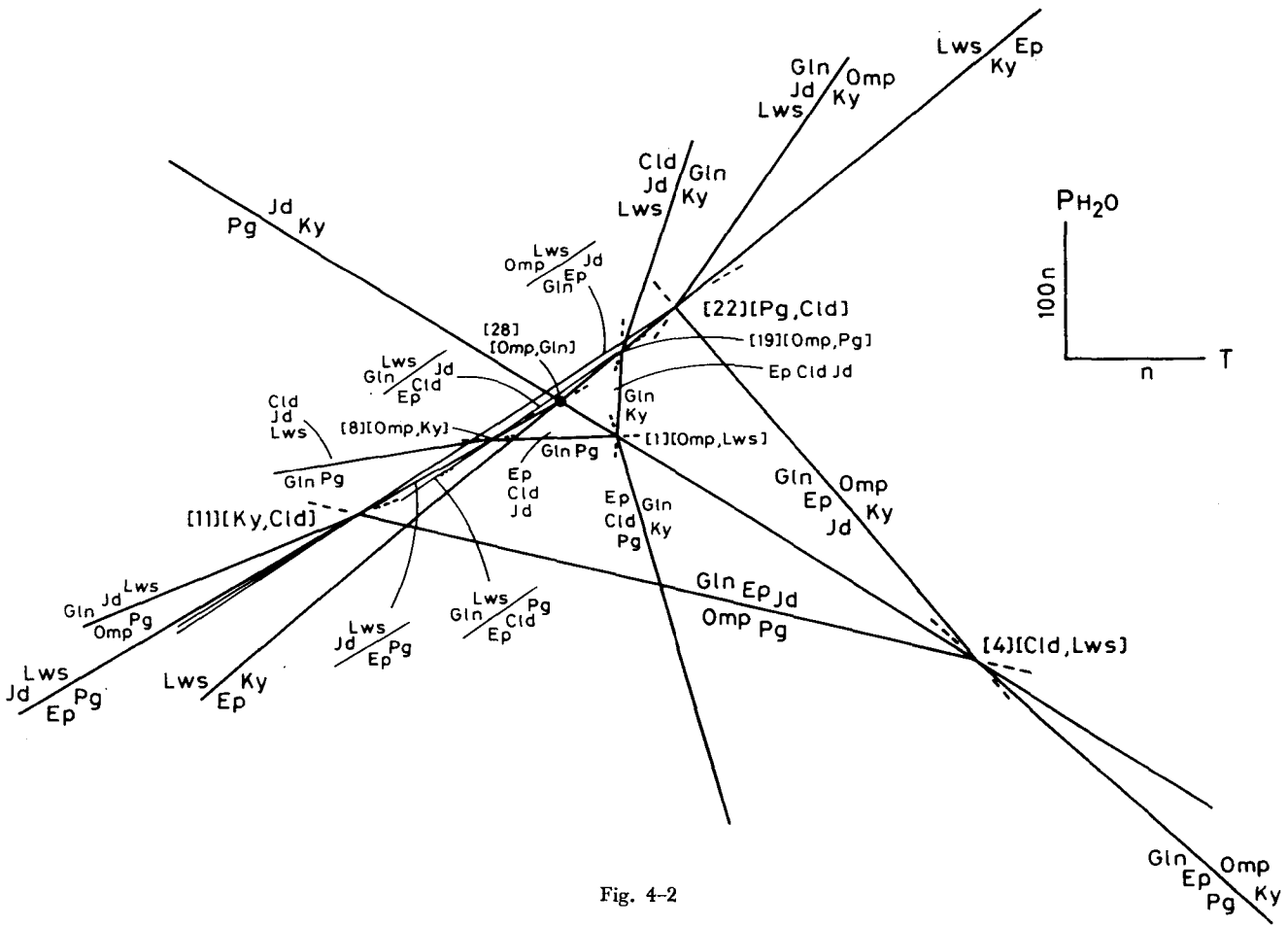
Jd Pg Ky
Lws Omp Ep Gln
Cld Jd Gln Lws Ky
Gln Jd Lws Omp Ky
Lws Ep Ky
[22][Pg,Cld]
[28] [Omp,Gln]
[19][Omp,Pg]
Ep Cld Jd
Gln Ky
[1][Omp,Lws]
Lws Gln Jd Cld Ep
Cld Jd Lws
[8][Omp,Ky]
Gln Pg
Ep Cld Jd
Ep Cld Pg Gln Ky
Gln Ep Jd Omp Ky
[11][Ky,Cld]
Gln Jd Lws Omp Pg
Lws Jd Ep Pg
Lws Ep Ky
Lws Jd Ep Pg
Lws Gln Pg Ep Cld
Gln Ep Jd Omp Pg
[4][Cld,Lws]
Gln Ep Omp Pg Ky
PH2O
100n
n
T

Fig. 4-2

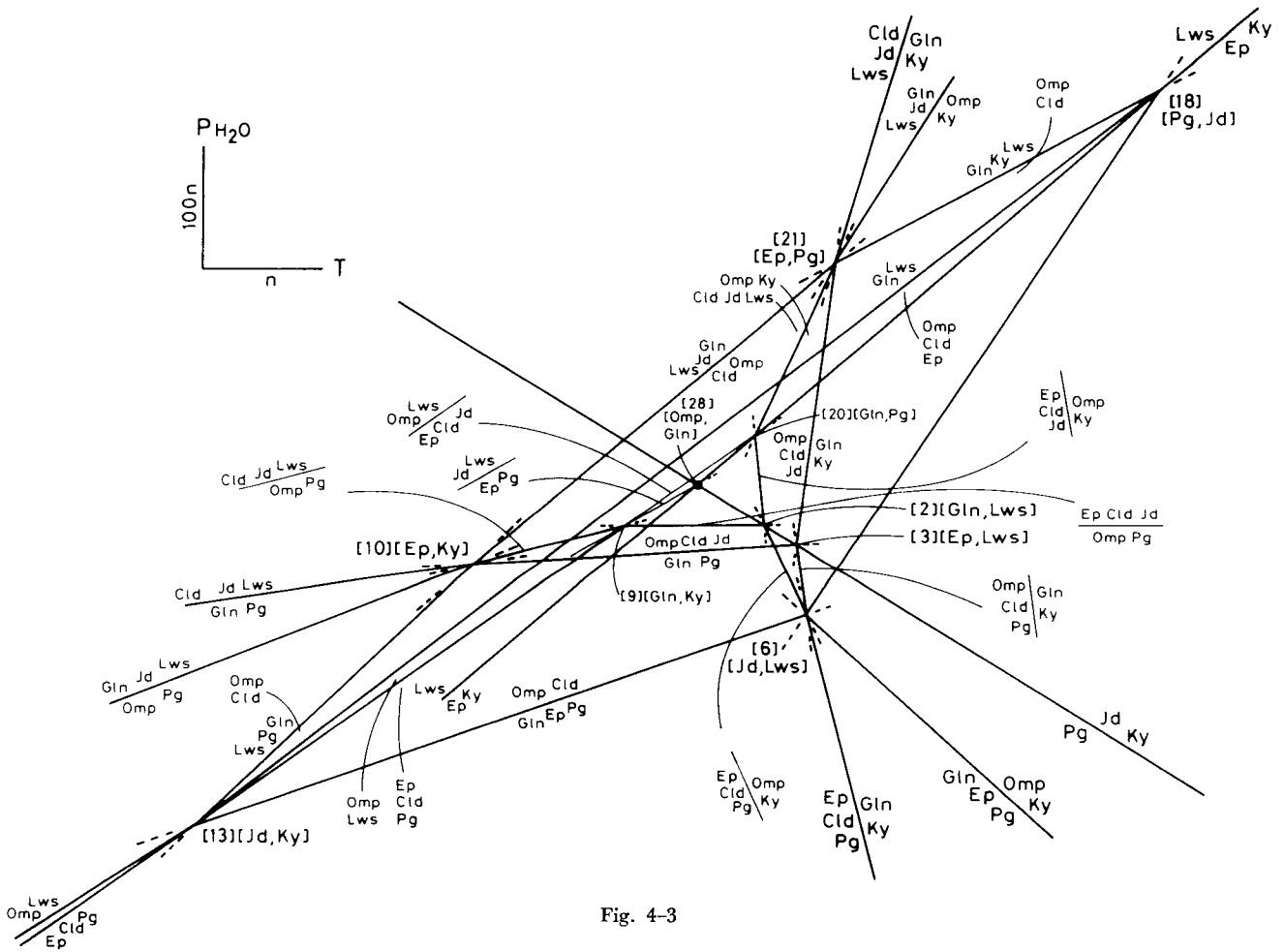
P H2O
100n
n
T
[18] [Pg, Jd]
[21] [Ep, Pg]
[28] [Omp, Gln]
[20][Gln, Pg]
[2][Gln, Lws]
[3][Ep, Lws]
[10][Ep, Ky]
[9][Gln, Ky]
[6] [Jd, Lws]
[13][Jd, Ky]
Cld Jd Ky Lws
Gln Jd Ky Lws
Omp Cld Gln Ky
Lws Ky Ep
Omp Cld
Gln Ky Lws
Omp Ky Cld Jd Lws
Gln Lws Jd Omp Cld
Lws Gln
Omp Cld Ep
Lws Omp Jd Cld Ep
Lws Jd Ep Pg
Cld Jd Lws Omp Pg
Omp Cld Jd Gln Ky
Ep Cld Jd Omp Ky
Ep Cld Jd Omp Pg
Omp Cld Jd Gln Pg
Cld Jd Lws Gln Pg
Gln Jd Lws Omp Pg
Omp Cld Gln Pg Lws
Lws Ep Ky
Omp Cld Gln Ep Pg
Omp Lws
Ep Cld Pg
Omp Cld Pg Gln Ky
Jd Pg Ky
Ep Cld Pg Omp Ky
Ep Cld Pg Gln Ky
Gln Ep Pg Omp Ky
Lws Omp Cld Ep Pg

Fig. 4–3

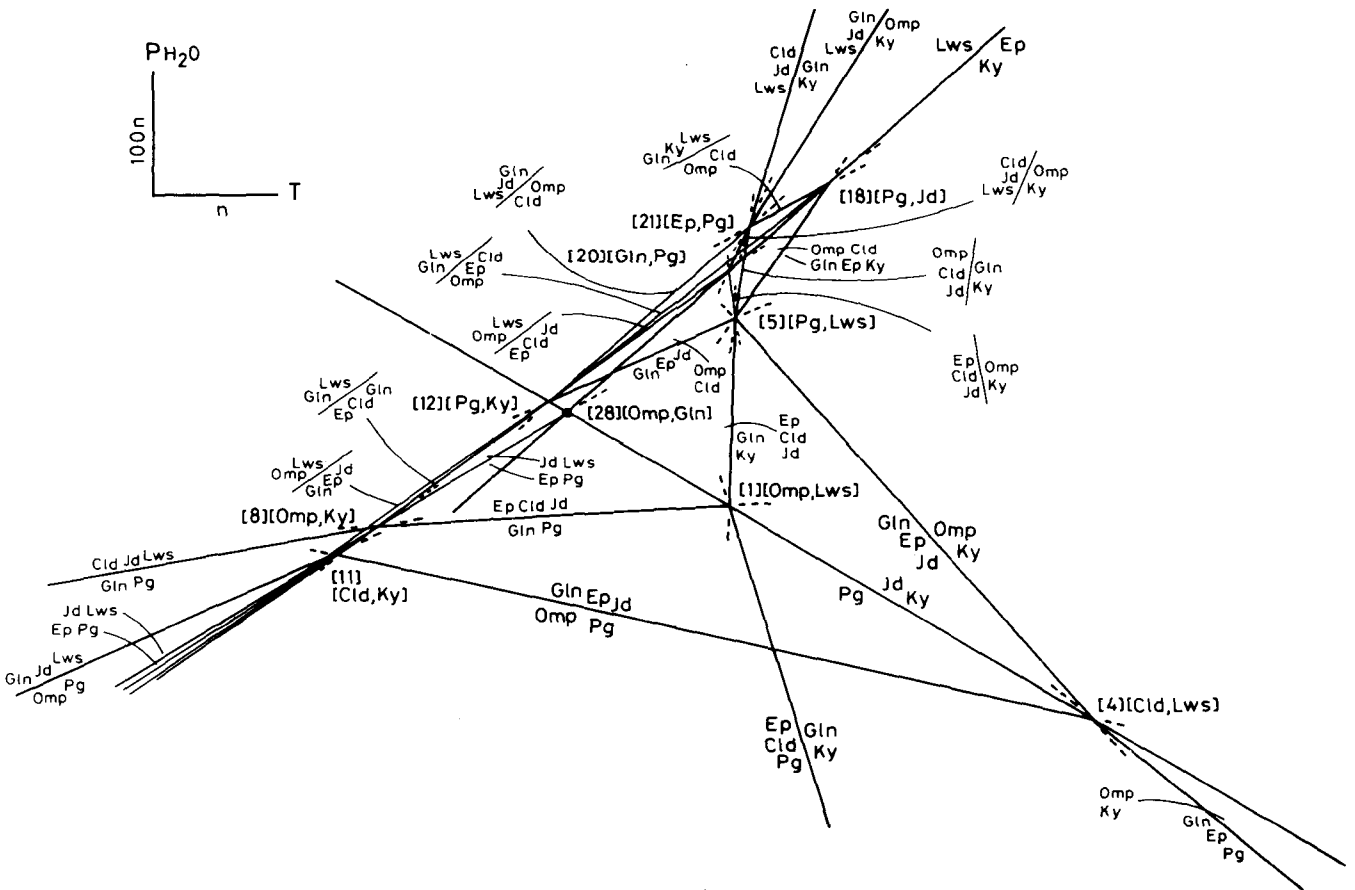
PH2O
100n
n
T
[1][Omp,Lws]
[2][Ep,Pg]
[4][Cld,Lws]
[5][Pg,Lws]
[8][Omp,Ky]
[11]
[Cld,Ky]
[12][Pg,Ky]
[18][Pg,Jd]
[20][Gln,Pg]
[28][Omp,Gln]
Gln Ep Jd
Omp Pg
Ep Cld Jd
Gln Pg
Jd Lws
Ep Pg
Omp Cld
Gln Ep Ky
Ep Cld Pg Ky
Pg Jd Ky
Gln Ep Omp Ky
Omp Ky
Gln Ep Pg

Fig. 4-4

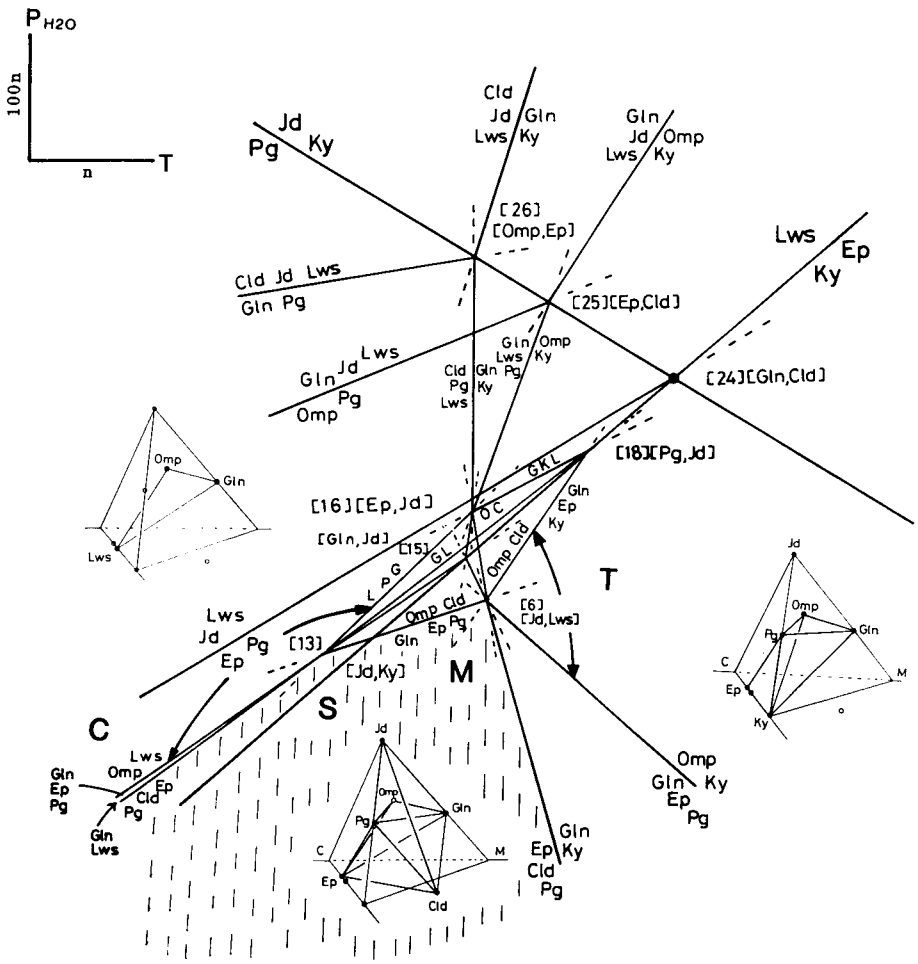
P H2O
100n
n
T
Jd Pg Ky
Cld Jd Gln Lws Ky
Gln Jd Omp Lws Ky
[26] [Omp,Ep]
Lws Ep Ky
Cld Jd Lws Gln Pg
[25][Ep,Cld]
Gln Jd Lws Pg Omp
Gln Omp Lws Ky
Cld Gln Pg Ky Lws
[24][Gln,Cld]
[18][Pg,Jd]
[16][Ep,Jd]
[Gln,Jd]
[15]
GKL
GL
OC
Omp Cld
Gln Ep Ky
T
[6] [Jd,Lws]
Lws Jd Pg Ep
[13]
[Jd,Ky]
M
S
C
Omp Gln Ky Ep Pg
Gln Ep Pg
Lws Omp Ep Cld Pg
Gln Lws
Gln Ep Ky Cld Pg
Omp
Gln
Lws
Jd
Pg
Ep
Cld
Ky
C
M

Fig. 4–5

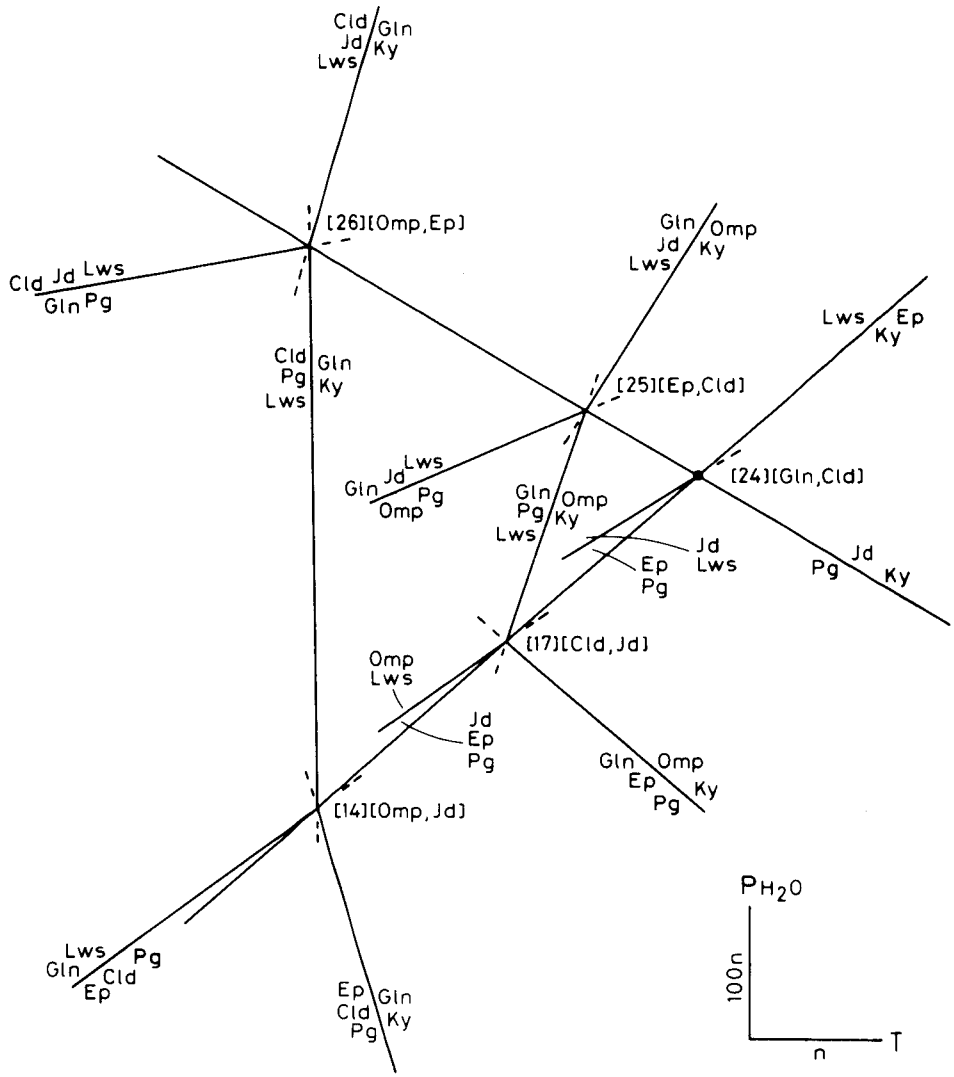
Cld Gln Jd Ky Lws
[26][Omp,Ep]
Cld Jd Lws Gln Pg
Gln Omp Jd Ky Lws
Lws Ep Ky
Cld Gln Pg Ky Lws
[25][Ep,Cld]
Gln Jd Lws Pg Omp
Gln Omp Pg Ky Lws
[24][Gln,Cld]
Jd Lws Ep Pg
Jd Pg Ky
[17][Cld,Jd]
Omp Lws
Jd Ep Pg
Gln Omp Ep Pg Ky
[14][Omp,Jd]
Lws Gln Pg Cld Ep
Ep Cld Pg Gln Ky
PH2O
100n
n
T

Fig. 4-6

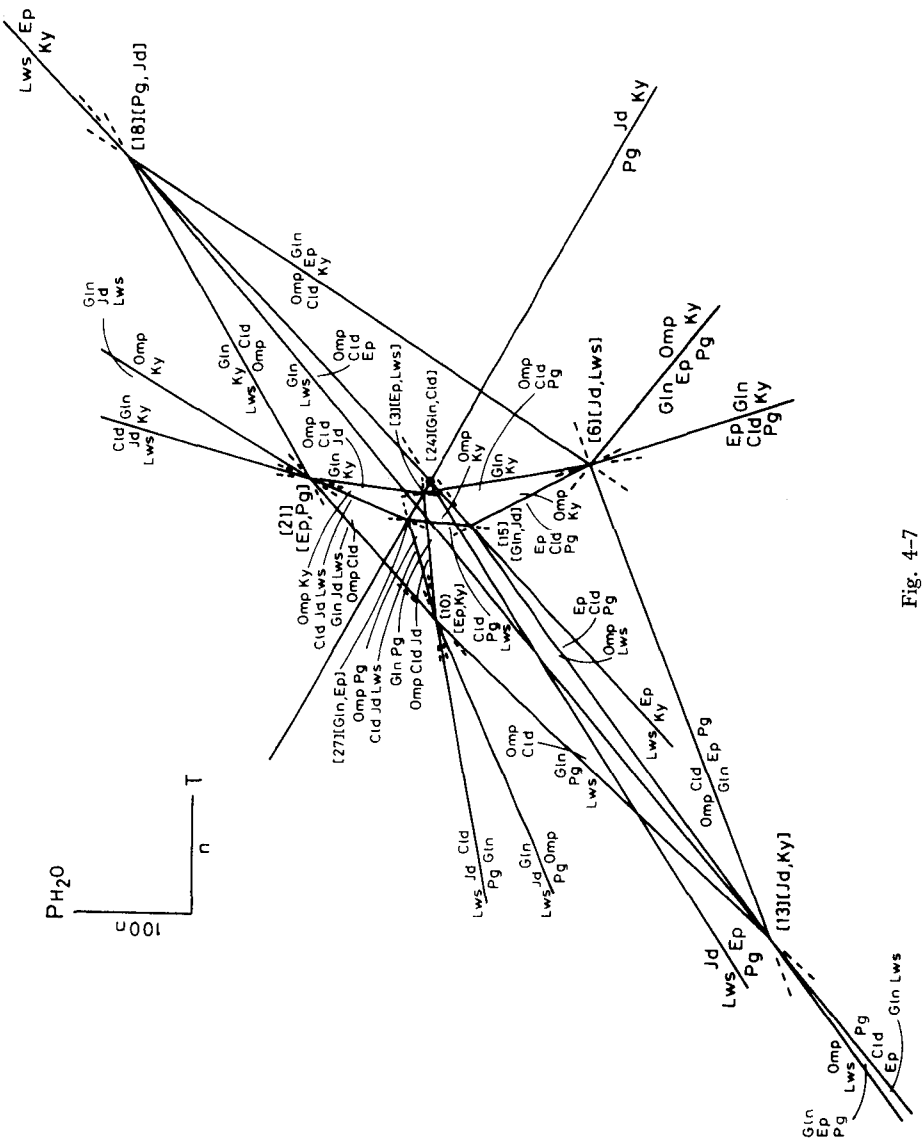
Lws Ep Ky
[18][Pg, Jd]
Gln Jd Lws
Omp Ky
Cld Gln Ky
Jd Lws
Gln Ky Cld
Lws Omp
Omp Gln
Cld Ep Ky
Gln Lws
Omp Cld Ep
[31][Ep,Lws]
[24][Gln,Cld]
Omp Cld Pg
Jd Ky
Pg
[6][Jd,Lws]
Gln Omp Ky
Ep Pg
Ep Gln
Cld Ky
Pg
[2]
[Ep,Pg]
Omp Ky
Cld Jd Lws
Gln Jd Lws
Omp Cld
Gln Jd
Ky
[27][Gln,Ep]
Omp Pg
Cld Jd Lws
Gln Pg
Omp Cld Jd
[10]
[Ep,Ky]
Cld
Pg
Lws
[15]
[Gln,Jd]
Ep
Cld
Pg
Omp
Ky
Ep
Cld
Pg
Omp
Lws
Omp
Cld
Gln
Pg
Lws
Lws Jd Cld
Pg Gln
Gln
Jd
Lws
Pg
Omp
Lws Ep Ky
Omp Cld Ep Pg
Gln
Jd
Lws
Ep
Pg
[13][Jd,Ky]
Omp
Lws
Pg
Cld
Ep
Gln Lws
Gln
Ep
Pg
T
n
P_{H_2O}
100 n

Fig. 4–7

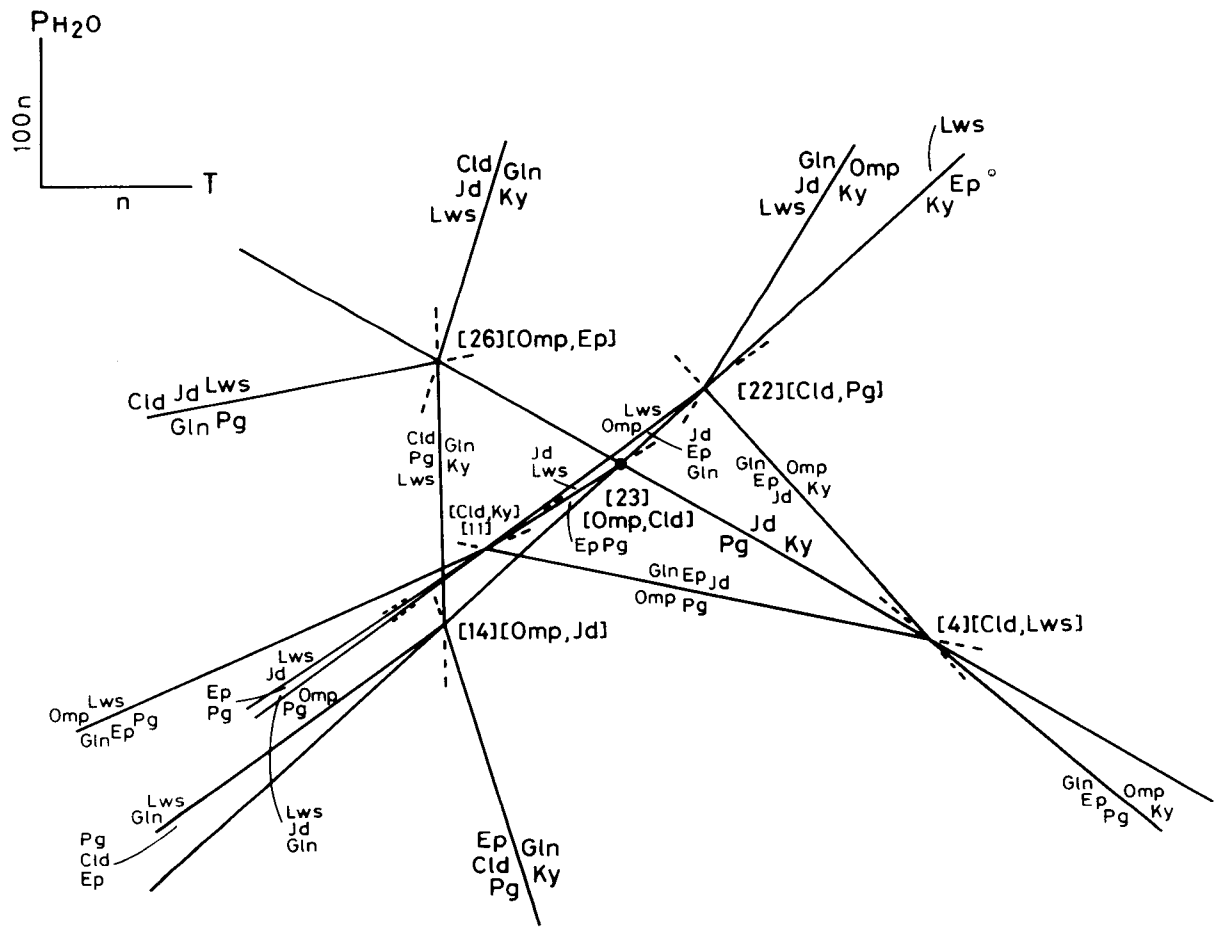
PH2O
100 n
n
T
Cld Jd Lws Gln Ky
Gln Jd Lws Omp Ky
Lws Ep Ky
[26][Omp,Ep]
Cld Jd Lws Gln Pg
[22][Cld,Pg]
Cld Pg Lws Gln Ky
Jd Lws
Lws Omp Jd Ep Gln
Gln Ep Jd Omp Ky
[23] [Omp,Cld]
[Cld,Ky] [11]
Ep Pg
Jd Pg Ky
Gln Ep Jd Omp Pg
[14][Omp,Jd]
[4][Cld,Lws]
Lws Jd Omp Gln Ep Pg
Ep Pg
Lws Jd Omp Pg
Gln Ep Omp Pg Ky
Lws Gln Pg Cld Ep
Lws Jd Gln
Ep Cld Pg Gln Ky

Fig. 4–8

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±30°C at 19.5 kabr. 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±30°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± 30°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**

$$\mathrm{Ep+Cld+Pg = Gln+Ky} \qquad \cdots\cdots(4)$$

$$\mathrm{Gln+Ep+Pg = Omp+Ky} \qquad \cdots\cdots(5)$$

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 $N(NaAlO_2)$-CaO-$A(Al_2O_3+Fe_2O_3)$-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)--Pg=Jd+Ky-- 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.

Acknowledgments

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References

ALBEE, A. L., (1965): A petrogenetic grid for the Fe-Mg silicates of pelitic schists. *Am. J. Sci.*, **263,** 512–536.

CARON, J. M., and PEQUIGNOT, G., (1986): The transition between blueschists and lawsonite-bearing eclogites based on observations from Corsican metabasites. *Lithos*, **19**: 205–218.

CHOPIN, C. and MONIE, P., (1984): A unique magnesio chloritoid-bearing, high pressure assemblages from the Monte Rosa, Western Alps: petrologic and $^{40}Ar/^{39}Ar$ radiometric study. *Contrib. Mineral. Pertrol.*, **87,** 388–398.

COLEMAN, R. G., LEE, D. E., BEATTY, L. B., and BRANNOCK, W. W., (1965): Eclogites and eclogites: Their differences and similarities. *Geol. Soc. Am. Bull.*, **76,** 483–508.

ELLIS, D. J. and GREEN, D. H., (1979): An experimental study of the effect of Ca upon garnet-clinopyroxene Fe-Mg exchange equilibria. *Contrib. Mineral. Petrol.*, **71,** 13–22.

FYFE, W. S., TURNER, E. J. and VERHOOGEN, J., (1958): Metamorphic reactions and metamorphic facies. *Geol. Soc. Am., Mem.*, **73.**

HALBACH, H. and CHATTERJEE, N. D., (1982): An empirical Redlich-Kwong-Type equation of state for water to 1,000°C and 200 kbar. *Contrib. Mineral. Petrol.*, **79,** 337–345.

HELGESON, H. C., DELANY, J. M., NESBITT, H. W. and BIRD, D. C., (1978): Summary and critique of the thermodynamic properties of rock forming minerals. *Am. J. Sci.*, **278A,** 1–229.

HIRAJIMA, T., (1983): The analysis of the paragenesis of glaucophanitic metamorphism for a model ACF system by Schreinemakers' method. *J. Geol. Soc. Jpn.*, **89,** 679–691 (in Japanese, with English abstract).

HIRAJIMA, T., BANNO, S., HIROI, Y. and OHTA, Y. (1988): Phase petrology of eclogites and related rocks from the Motalafjella high-pressure metamorphic complex in Spitsbergen and its significance. *Lithos,* **22,** 75–97.

HOLLAND, T. J. B., (1979)a: High water activities in the generation of high pressure kyanite eclogites of the Tauern Window, Austria. *J. Geol.*, **87,** 1–27.

HOLLAND, T. J. B., (1979)b: Experimental determination of the reaction paragonite=jadeite+kyanite+H_2O, and internally consistent thermodynamic data for part of the system Na_2O-Al_2O_3-SiO_2-H_2O, with applications to elcogites and blueschits. *Contrib. Mineral. Petrol.*, **68,** 293–301.

KRETZ, R., (1983). Symbols for rock-forming minerals. *Am. Mineral.*, **68,** 277–279.

KROGH, E. J., (1980): Compatible P-T conditions for eclogites and surrounding gneisses in the Kristiansund Area, Western Norway. *Contrib. Mineral. Petrol.*, **75,** 387–393.

MYER, G. H., (1966): New data on zoisite and epidote. *Am. J. Sci.*, **264,** 364–385.

OBERHANSLI, R., (1986): Blue amphiboles in metamorphosed Mesozoic mafic rocks from the Central Alps. *Mem. Geol. Soc. Am.*, **164,** 239–248.

PERKINS, E. H., BROWN, T.H. and BERMAN, R. G., (1986): PTX-SYSTEM: three programs for calculation of pressure-temperature-composition phase diagrams. *Comp. Geosci.*, **12,** 749–755.

RÄHEIM, A. and GREEN, D. H., (1974): Experimental determination of the temperature and pressure of the Fe-Mg partition coefficient for coexisting garnet and clinopyroxene. *Contrib. Mineral. Petrol.*, **48,** 179–203.

REINSCH, D., (1979): Glaucophanites and eclogites from Val Chiusella, Sesia-Lanzo Zone (Italian Alps). *Contrib. Mineral. Petrol.*, **70,** 257–266.

ROBIE, R. A. and WALDBAUM, D. R., (1968): Thermodynamic properties of minerals and related substances at 298.15°K (25.0°C) and one atmosphere (1.013 bars) pressure and high temperature. *Geol. Sur. Bull.*, **1259.**

TANABE, Y., SHIBAKUSA, H., HIRAJIMA, T. and BANNO, S., (1988): Computer graphics of Schreinemakers' bundles for n+4 phases system. *J. Jpn. Assoc. Min. Pet. Econ. Geol., Sendai, Jpn.* **82,** 110–111. (in Japanese).