GEOCHEMICAL AND THERMOBAROMETRIC CHARACTERISTICS OF FLUIDS ASSOCIATED WITH QUARTZ–SCHEELITE VEINS OF METAGGITSI–SALONIKIO, E. CHALKIDIKI PENINSULA

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A B S T R A C T

Primary aqueous CO_2-bearing fluid inclusions with variable CO_2/H_2O volumetric ratios coexist in quartz and scheelite from vein systems hosted by two-mica gneisses and schists of the Vertiskos Formation in the Pirgadikia, Metaggitsi-Salonikio area, E. Chalkidiki. Inclusions with low CO_2 volumetric percentage of 5-25 vol% homogenize to the H_2O-phase at temperatures between 230 and 325°C, whereas those with high CO_2 volumetric percentage of 55-85 vol% homogenize to the CO_2 phase at temperatures ranging from 220 to 331°C. Salinities are less than 10 equiv wt.% NaCl. These veins formed from boiling CO_2-luden fluids at temperatures of 250-400°C and pressures between 1 and 2 kbars during retrograde greenschist facies metamorphism.

Σ Υ Ν Ο Ψ Η

Πρωτογενή ρευστά εγκλείσματα περιέχοντα CO_2 με μεταβλητή αναλογία του CO_2 προς το H_2O κατ΄όγκο, συνυπάρχουν σε χαλαζία και σεελίτη από συστήματα φλεβών που φιλοξενούνται μέσα σε διμαρμαρυγιακούς, γνεύσιους και σχιστολίθους της σειράς του Βερτίσκου, στην περιοχή Πυργαδίκια-Μεταγγίτσι-Σαλονικιό στην Αν. Χαλκιδική. Εγκλείσματα με χαμηλή κατ΄όγκο αναλογία σε CO_2 (5-25%) ομογενοποιούνται στην υδάτινη φάση σε θερμοκρασίες μεταξύ 240-325°C, ενώ εκείνα με υψηλή κατ΄όγκο αναλογία σε CO_2 (55-85%) ομογενοποιούνται στην φάση του CO_2 σε θερμοκρασίες 250-328°C. Αλατότητες είναι μικρότερες των 10% κ.β. ισοδύναμο NaCl. Οι φλέβες αυτές σχηματίστηκαν από αναβράζοντα διαλύματα πλούσια σε CO_2 κάτω από θερμοκρασίες 250-400°C και πιέσεις 1-2 kb κατά την διάρκεια ανάδρομης μεταμόρφωσης πρασινοσχιστολιθικού βαθμού.

ΕΙΣΑΓΩΓΗ - INTRODUCTION

Scheelite mineralization of the Pirgadikia-Metaggitsi-Salonikio area in E. Chalkidiki Peninsula (Fig. 1) occurs within quartz veins and veinlets developed in two-mica gneisses and schists of the Vertiskos Formation. The Vertiskos, and Kerdilia Formation to the east, comprise the Paleozoic or older (Kockel et al,1977) Sercomacedonian Massif (Fig. 1). Intense exploration for tungsten in the area was carried out during the years 1963-1972 by various mining companies,and IGME since 1984 (Veranis and Bitzios, 1984).

Σ.Π. ΚΙΛΙΑΣ. Γεωχημικά και θερμοβαρομετρικά χαρακτηριστικά ρευστών που σχετίζονται με φλέβες χαλαζία-σεελίτη της περιοχής Μεταγγίτσι-Σαλονικιό, Α. Χαλκιδική

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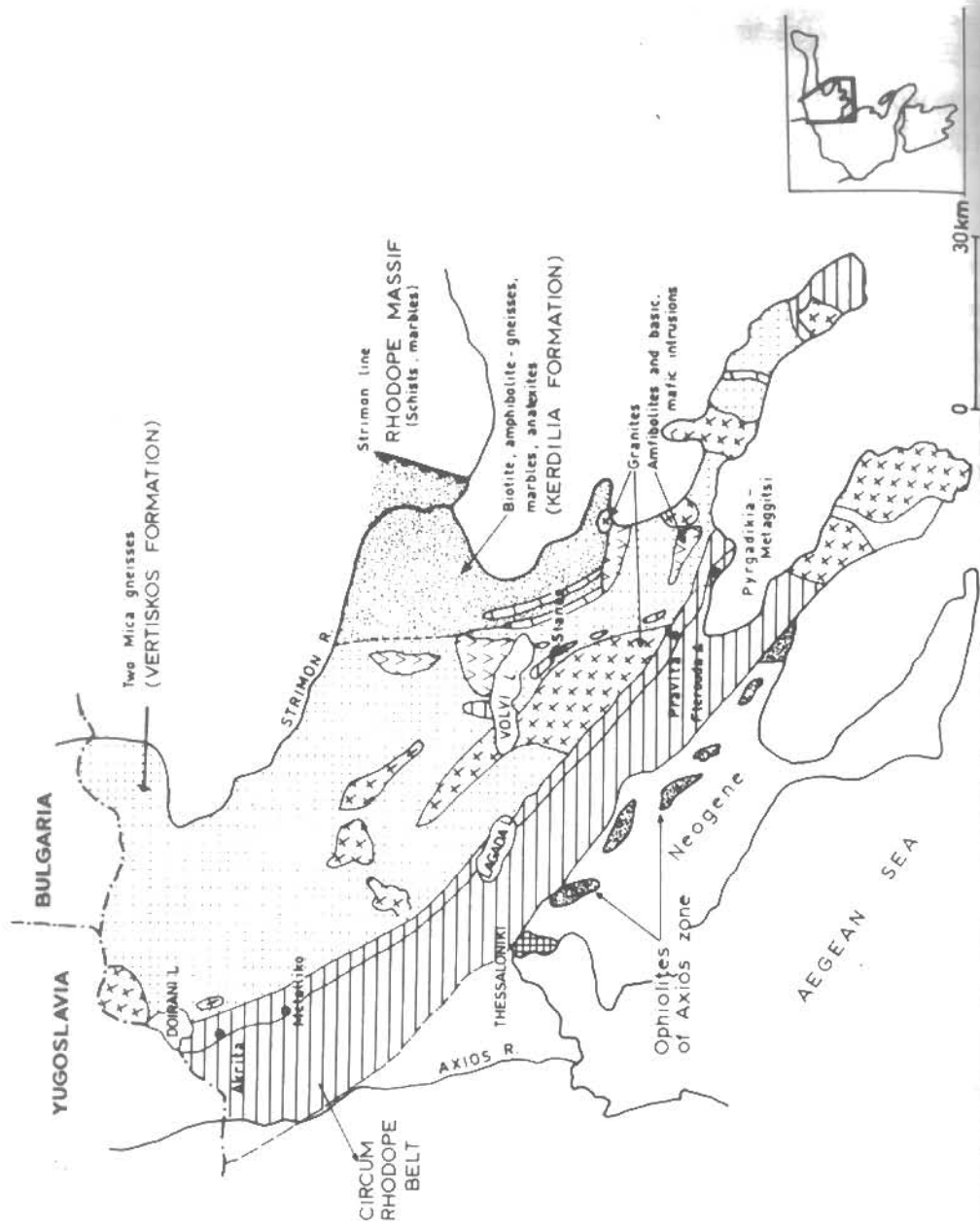
This paper reports fluid inclusion data in an attempt to decipher the geochemical and thermobarometric characteristics of the fluids responsible for the genesis of the quartz-sheelite veins in the area.

ΓΕΝΙΚΗ ΓΕΩΛΟΓΙΑ - GENERAL GEOLOGY

Vertiskos formation is a heterogeneous assemblage consisting of litho-logical units of the Upper-Paleozoic to Triassic Perirhodope Zone to the west (Fig. 1), two-mica gneisses/schists, amphibolites, portions of metaophiolitic units, granitic bodies (i.e. Arnea), and few occurrences of marble.

These rocks are considered to be of volcanosedimentary, sedimentary, and igneous parental origin (Fournaraki, 1981; Papadopoulos, 1982; Dixon and Dimitriadis, 1985; Kougoulis, 1986; Kougoulis et al., 1987). Regarding the deformation-metamorphic history of this heterogeneous rock assemblage, and de-spite recent developments (Patras et al., 1986; Dixon and Dimitriadis, 1985; Sakellariou, 1988) a complete and thorough description of the successive events is not possible at this stage. However, K/Ar dating of amphiboles from amphi-bolites and gneisses (E. Simos, 1989, writ. commun.) gives an upper limit of 95-110 m.y. (Upper Cretaceous) for the regional amphibolite facies metamorphism (T=550°C, P=4-5 kb) event (which was followed by retrograde greenschist facies metamorphism)/must have commenced in Jurassic since it has also affected rocks of Upper Paleozoic-Lower Mesozoic age (S. Kalogeropoulos, pers. commun.).

Vertiskos Formation in the area of Metaggitsi-Salonikio where scheelite mineralization occurs is underlain by E-W trending two-mica gneisses of possible para-origin, metabasic rocks of igneous origin, tourmaline-and/or garnet-bearing mica schists, cherts with banded iron formation, and a limited number of dykes of granitic composition (Veranis and Bitzios, 1984) (Fig.2).

Veranis and Bitzios (1984) have observed two major stages of deforma-tion (D_1 and D_2), and two minor secondary (D_3 and D_4), of probable Alpine age in the area: D_1 is characterized by numerous closed and reccumbent isoclinal folds with b_1 axes plunging 0 to 15° from NW to SE. D_2 is accompanied by S-type fracture, strain-slip or crenulation cleavage and microfolds. This second stage is also characterized by folding with b_2 axes parallel to b_1 plunging to higher angles of 0-60°, suggesting that the two deformation stages belong to the same tectonic process.

Two types of faults have been observed in the area: (a) normal, and (b) reverse, trending E-W and dipping less than 45°. Shear zones in the area
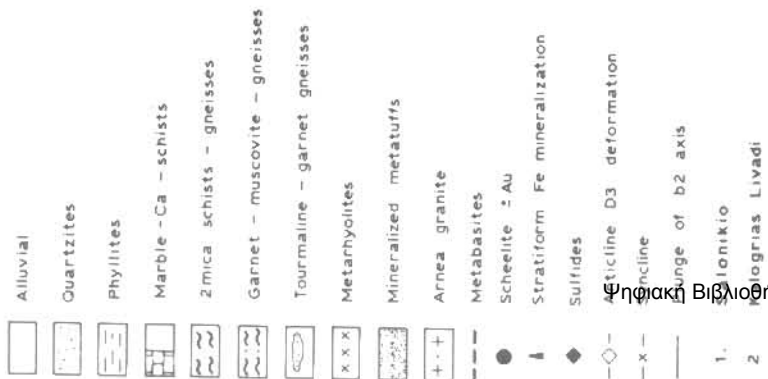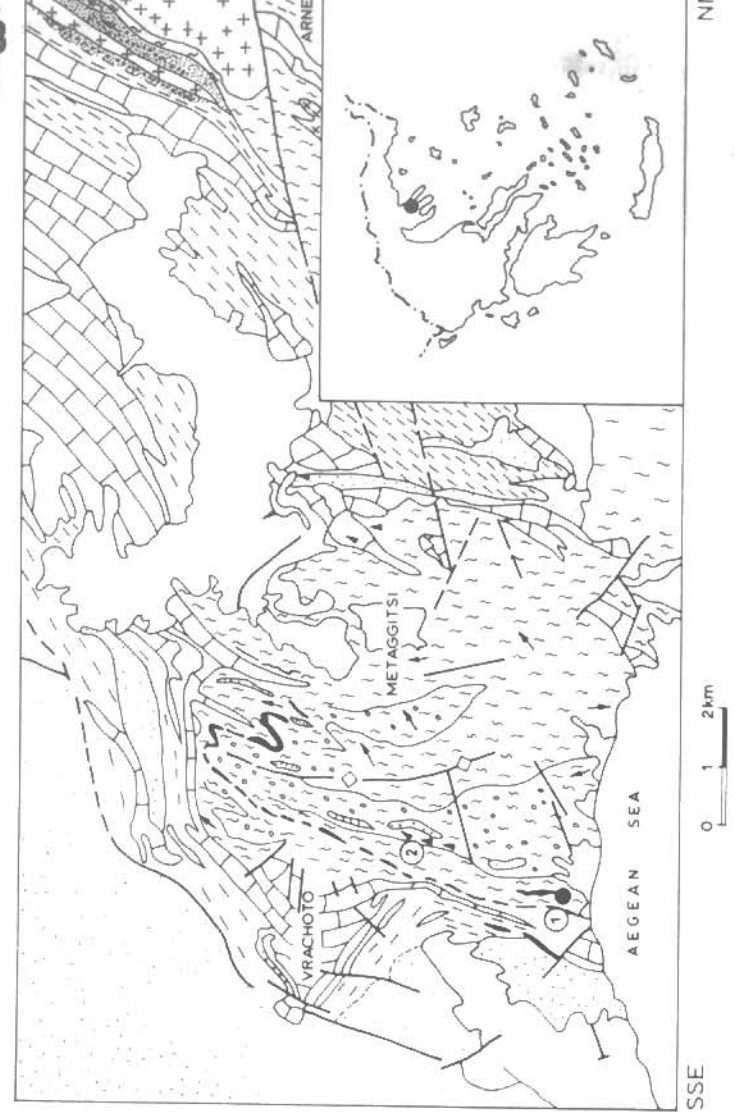

Fig. 1.- Geotectonic map of the Servomacedonian Massif (Veranis, 1989, modified after Kockel et al., 1977).
Εικ. 1.- Γεωτεκτονικός χάρτης της Σερβομακεδονικής μάζης.

Fig. Geological map of S.E. Chalkidiki Peninsula (Veranis and Bitzios, 1984, modified after Kockel et al., 1977). Γεωλογικός χάρτης της ΣερβομακεδονικήςΖώνης (Κockel et al., 1977, τροποποιημένος από Βεράνη και Μπίτζιο, 1984)

Alluvial
Quartzites
Phyllites
Marble – Ca – schists
2 mica schists – gneisses
Garnet – muscovite – gneisses
Tourmaline – garnet gneisses
Metarhyolites
Mineralized metatuffs
Arnea granite
Metabasites
Scheelite ± Au
Stratiform Fe mineralization
Sulfides
Anticline D3 deformation
Syncline
Plunge of b2 axis
1. Salonikio
2. Paleologrias Livadi

are probably due to the secor

Bitzios, 1984).

Scheelite mineralization in the Salonikio area is contained within systems of quartz veins and veinlets trending from NE to E and dipping 50 to 70° from NW to N. They follow the S-type fracture cleavage which are related to the D_2 deformation event. The veins are hosted by two-mica gneisses and schists, biotite/epidote schists, and locally metabasites. The veins have sharp contacts and measure up to 1 km length. The width of the veins varies from a few cm to 1 m.

Scheelite is the main tungsten-bearing mineral, accompanied by traces of powellite, and stolzite. The two wolframates are associated with traces of arsenopyrite, molybdenite, and goethite, and gangue calcite and white mica.

ΜΕΛΕΤΗ ΡΕΥΣΤΩΝ ΕΓΚΛΕΙΣΜΑΤΩΝ - FLUID INCLUSION STUDY

Fluid inclusions were studied in double-polished chips of 200-300 μ thickness from vein quartz samples. Microthermometric measurements were conducted on carefully selected fluid inclusions using a temperature programmable Linkam TH600 heating-freezing system (Shepherd, 1981). The stage was calibrated in the range -100 to 600°C using various melting point standards according to the method of Macdonald and Spooner (1981). The uncertainty in the measurements of the temperatures of the phase changes described is ±0.5°C.

On the basis of the microscopy and heating-freezing studies four types of fluid inclusions in quartz and scheelite were distinguished :

Type A, mixed CO_2-H_2O inclusions (CO_2, 5-25 vol.%; modal value 10 vol.%) with low salinity ($\bar{x}$: 3.8 equiv. wt% NaCl) and average bulk density of 0.93 g/cm³ (Fig. 3A).

Type B, mixed CO_2-H_2O inclusions (CO_2, 55-85 vol.%, modal value 80 vol.%) with low salinity ($\bar{x}$: 2.1 equiv. wt% NaCl), and average bulk density 0.88 g/cm³ (Fig. 3A,B).

Type C, pure CO_2 inclusions with average bulk density 0.80 g/cm³ (Fig. 3C).

Type D, pure aqueous inclusions (gas 5-20 vol.%) (Fig. 3D).

Inclusion types A, B, and C are generally small (10-50 μ in the longest dimension), and they are either randomly distributed in the host crystal or occupy healed micro-fractures. Inclusion types A, B, and C with no obvious planar distribution which were considered primary (Roedder, 1984) and cogenetic with the host mineral and each other, were exclusively studied. Type D inclusions
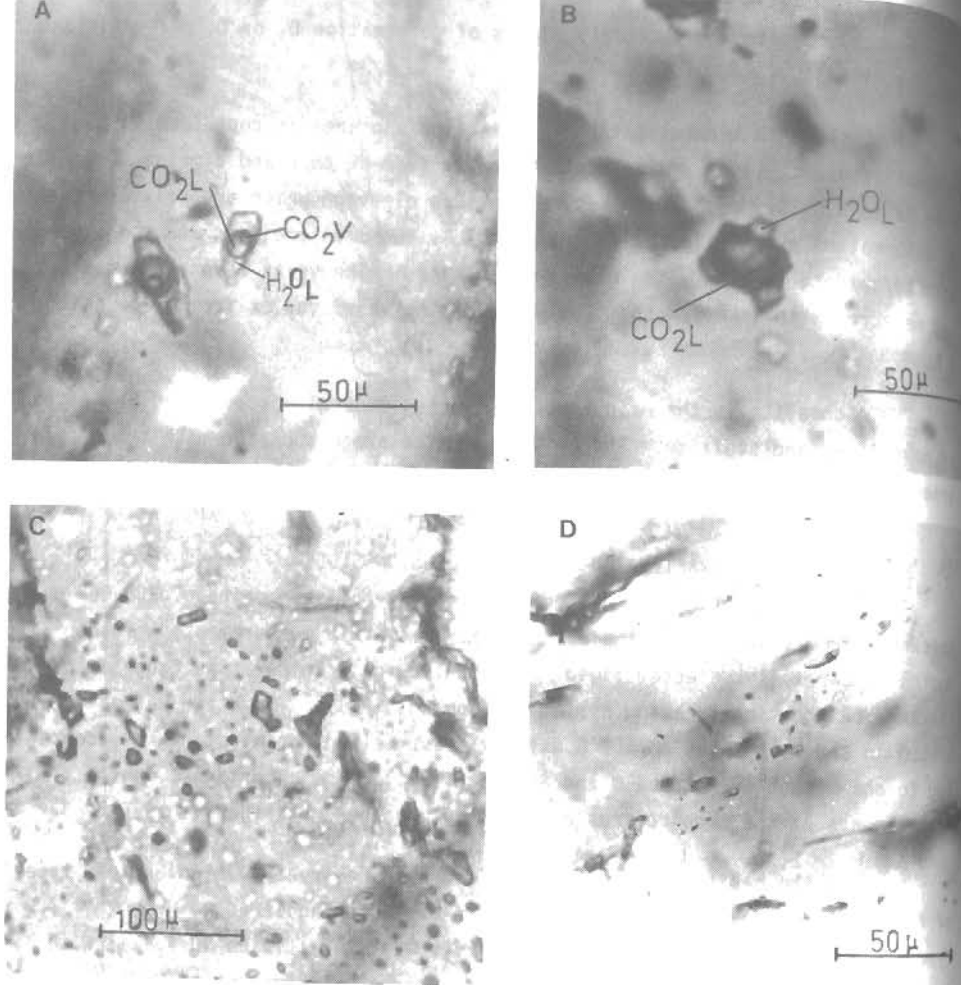
Fig. 3. Fluid inclusion types.
   A. Coexisting primary A and B type inclusions. CO_2 (liquid+vapor)-phase
      representing about 25% (A), and about 70% (B) of the inclusion volume
      ($CO_2L:CO_2$ liquid; $CO_2V:CO_2$ vapor; $H_2OL:H_2O$ liquid).
   B. Representative primary B type inclusion. CO_2-phase occupying more than
      70% of the inclusion volume.
   C. Three-dimensional cluster of monophase C type inclusions. CO_2 (liquid)-
      phase representing 100% of the inclusion volume.
   D. Healed fracture containing secondary D type aqueous inclusions.
Εικ. 3. Τύποι ρευστών εγκλεισμάτων
   Α. Συνυπάρχοντα πρωτογενή εγκλείσματα τύπου Α και Β. Η φάση του CO_2 (υγρό
      και αέριο) καταλαμβάνει περίπου 25% (Α), και περίπου 70% (Β) του όγκου
      του εγκλείσματος ($CO_2L:CO_2$ υγρό; $CO_2V:CO_2$ αέριο; $H_2OL:H_2O$ υγρό).
   Β. Αντιπροσωπευτικό πρωτογενές έγκλεισμα τύπου Β. Η φάση του CO_2 καταλαμ-
      βάνει περισσότερο από 70% του όγκου του εγκλείσματος.
   C. Τρισδιάστατη κατανομή μονοφασικών εγκλεισμάτων τύπου C. Η φάση του CO_2
      (υγρή) καταλαμβάνει το 100% του όγκου του εγκλείσματος.
   D. Επουλωμένη ρωγμή περιέχουσα δευτερογενή εγκλείσματα τύπου D.

were not found outside extensive bands that occupy healed microfractures, are
considered secondary and non-related to the tungsten-mineralizing event, and
will be not dealt further.

ΣΤΟΙΧΕΙΑ ΚΡΥΟΜΕΤΡΙΑΣ - FREEZING DATA

The CO_2 phase in type A, B, and C inclusions melted at temperatures
between -57.5 and -56.3°C, indicating that the non-condensable gas in these in-
clusions is CO_2 with traces of CH_4 (Swanenberg, 1979; Heyen et al.,1982). The
CO_2 clathrate melted at temperatures between 6.8 and 10°C (average value, 8.0°C)
(Fig. 5A), and 5.5-10°C (average value 8.5°C) (Fig. 5B) for inclusion types A and
B respectively.

Salinities of the inclusion fluids, expressed in terms of equivalent
wt percent NaCl were estimated in the system H_2O-CO_2-NaCl from the melting
temperature of clathrate (Fig. 5) (Collins, 1979).

CO_2 molar composition is calculated in the system H_2O-CO_2-NaCl from the
density of the CO_2 fluid phase (Angus et al., 1976), salinity and density of the
aqueous liquid phase (Potter and Brown, 1977) combined with estimates of volume
proportions of phases observed in fluid inclusions using equations given by
Nicholls and Crawford (1985).

ΣΤΟΙΧΕΙΑ ΘΕΡΜΟΜΕΤΡΙΑΣ - HEATING DATA

The CO_2 phases in type A inclusions homogenized at temperatures between
18.4 and 28°C (average value, 23.6°C), the gaseous phase dissappearing (Fig. 6A).
The CO_2 and aqueous phases homogenized into a liquid (aqueous) phase at tempera-
tures in the range 230-325°C (average value, 270°C) (Fig. 7A). The CO_2 phases
in type B inclusions homogenized into a liquid CO_2 phase at temperatures between
10 and 24°C (average value, 17.3°C) (Fig. 6B). The total homogenization of these
inclusions occurred with the disapearance of the liquid (aqueous) phase at
temperatures in the range 220-331°C (average value,292°C) (Fig. 7B). A large
number of type A and B inclusions decrepitated before total homogenization denot
ing high internal pressures. The CO_2 phases in type C inclusions homogenized
into the liquid CO_2 phase at temperatures between 6.5 and 23.9°C (average value,
15.6°C) (Fig. 6C). The secondary type D inclusions homogenized into a liquid
phase at temperatures in the range 110-135°C (aver age value,115°C). Freezing
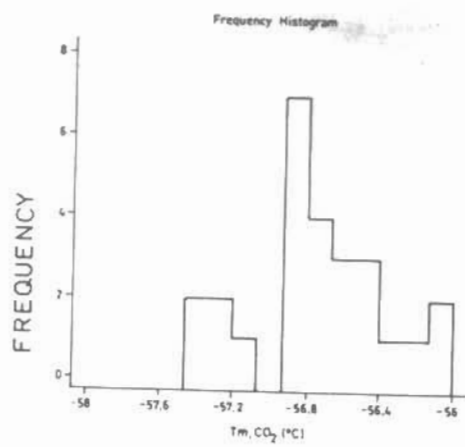and heating data are summarized in Table 1.

Frequency Histogram

FREQUENCY

Tm, CO₂ (°C)

Fig. 4. Histogram of CO₂ melting temperatures, Tm, CO₂, of inclusion types A and B.
Εικ. 4. Ιστόγραμμα θερμοκρασιών τήξης του CO₂, Tm, CO₂, εγκλεισμάτων τύπου Α και Β.

A

F R E Q U E N C Y
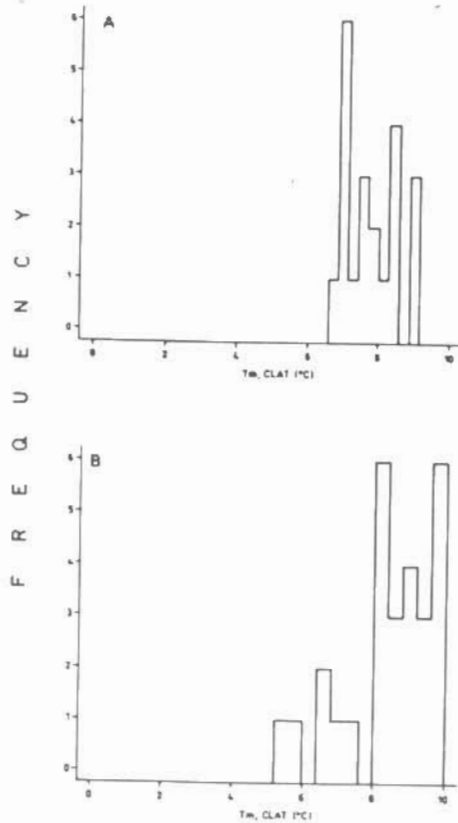
Tm, CLAT (°C)

B

F R E Q U E N C Y

Tm, CLAT (°C)

Fig. 5. Histograms of CO₂-hydrate (clathrate) melting temperatures Tm, CLAT of inclusion types A (5A) and B (5B).
Εικ. 5. Ιστογράμματα θερμοκρασιών τήξης του clathrate, Tm, CLAT, εγκλεισμάτων τύπου Α (5Α) και Β (5Β).

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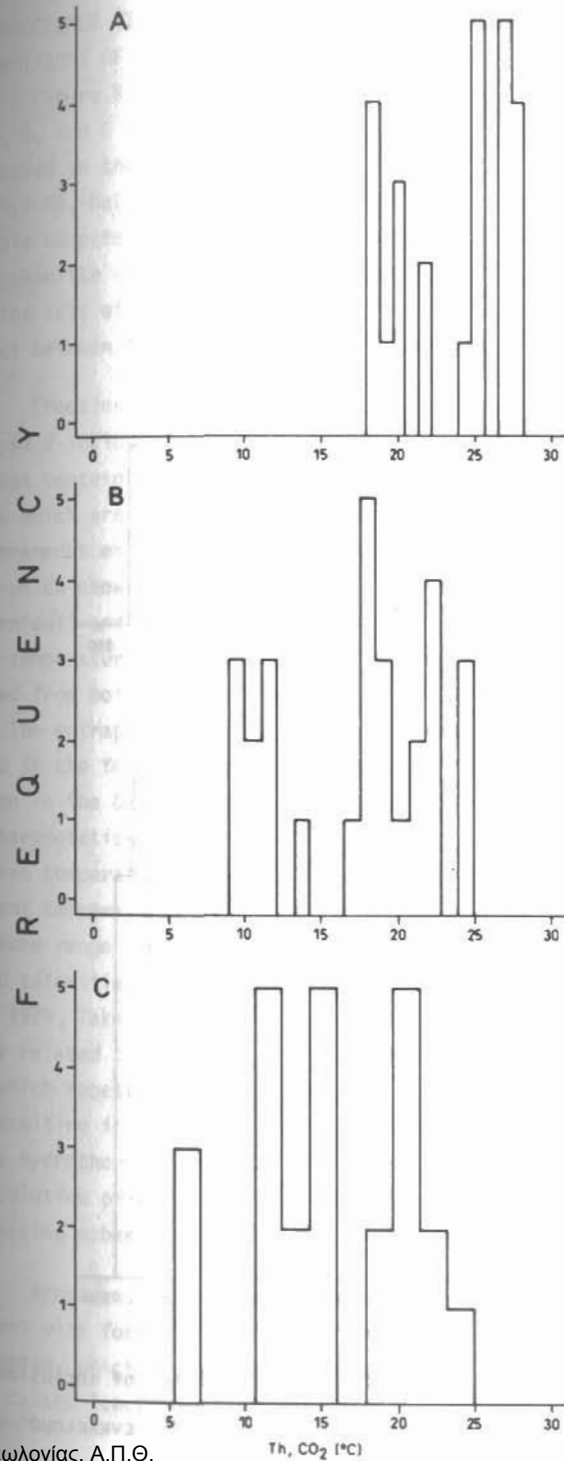
A

B

C

F R E Q U E N C Y

Th, CO₂ (°C)

Fig. 6. Histograms of CO₂-phase (liquid and vapor) homogenization temperatures, Th, CO₂, of inclusion types A (6A), B (6B) and C (6C).
Εικ. 6. Ιστογράμματα θερμοκρασιών ομογενοποίησης της μάζας του CO₂ (υγρό και αέριο), Th, CO₂, εγκλεισμάτων τύπου Α (6Α), Β (6Β) και C (6C).

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Figure 8 shows groups of calculated isochores of selected inclusion types A, B, and C with molar volumes (types A and B) and densities (type C) as shown, based on the microthermometry data and calculated properties in the system H_2O-CO_2-NaCl and H_2O-CO_2, with the use of Fortran programs in an IBM compatible computer (Nicholls and Crawford, 1985). Common fluid entrapment, during scheelite deposition, is indicated by the intersection of the three corresponding sets of calculated isochores at temperatures of 250-400°C and pressures between 1 and 2 kbars as indicated by the shaded area of Figure 8.

Freezing studies have shown that type A inclusions contain 3-12 mole% CO_2. Type B inclusions are richer in CO_2 and contain 20-45 mole% CO_2. Type C inclusions contain almost pure CO_2. The apparently primary inclusion types A, B, and C which are cogenetic are characterized by highly variable composition. Contemporaneous entrapment of inclusions, with large variation in the CO_2/H_2O ratios, which show both homogenization in the CO_2 fluid phase (type B, high CO_2 molar content) and the aqueous phase (type 1, low CO_2 molar content), at almost similar temperatures (Table 1), suggests that the fluids in these inclusions were entrapped from boiling hydrothermal solutions at the above mentioned P-T conditions. The entrapment of different proportions of two immiscible fractions resulted in the formation of a large number of mixed inclusion which exhibit variation in the CO_2/H_2O ratio and salinity as in inclusion types A, B, and C. This interpretation is supported by the large range of overlapping final homogenization temperature observed for type A and B inclusions which coincide with entrapment temperatures indicated by intersecting isochores, and the wide temperature range over which CO_2 and saline H_2O are immiscible for pressure around 1 kb and salinities up to 6 equiv. wt% NaCl (Todheide and Franck, 1963; Gehrig et al., 1979, Takenouchi and Kennedy, 1965; Bodnar et al., 1985). Boiling is probably related to the tectonic development of the scheelite-bearing veins during which repeated hydraulic fracturing caused significant pressure fluctuations resulting in CO_2-H_2O unmixing. In addition CO_2 separation from the low salinity hydrothermal fluid may have caused rapid cooling and had a marked effect on the solution pH with a shift from weakly acid to weakly alkaline at around 300°C causing scheelite deposition (Higgins, 1985).

Pressure, temperature and composition of the mineralizing fluids are consistent with formation during the last stages of retrograde greenschist facies metamorphism, which probably either remobilized preexisting tungsten mineralization or caused leaching of tungsten from the surrounding rocks, and deposition in
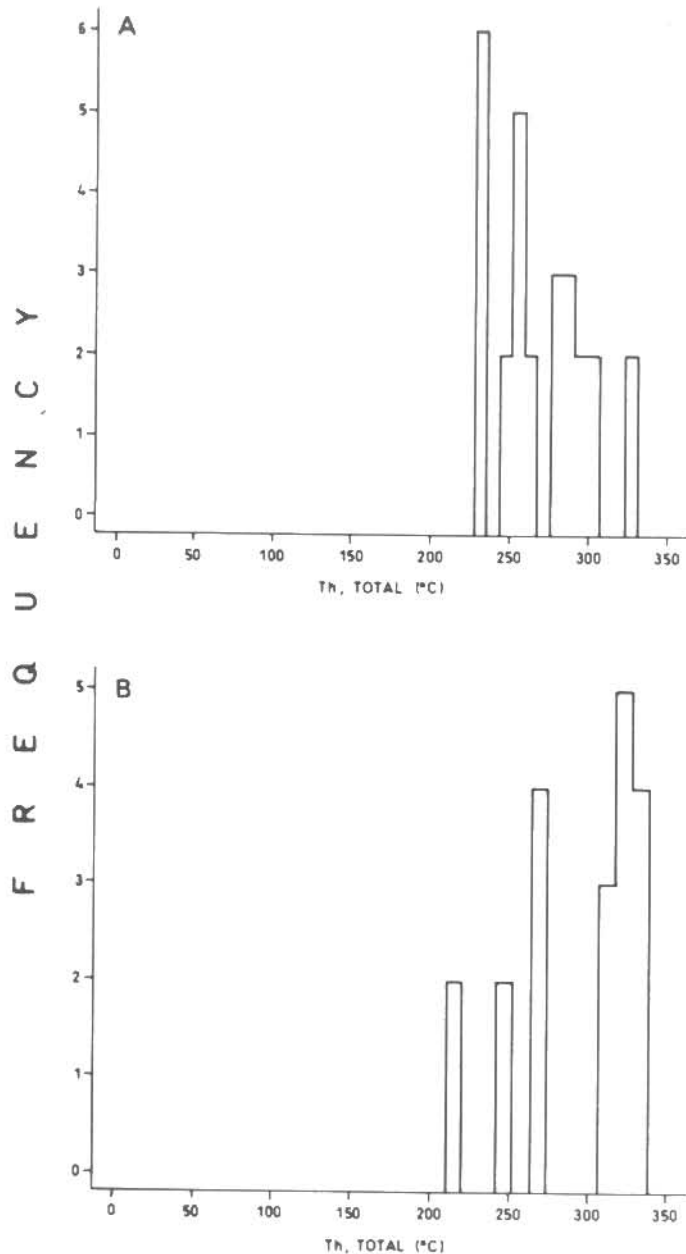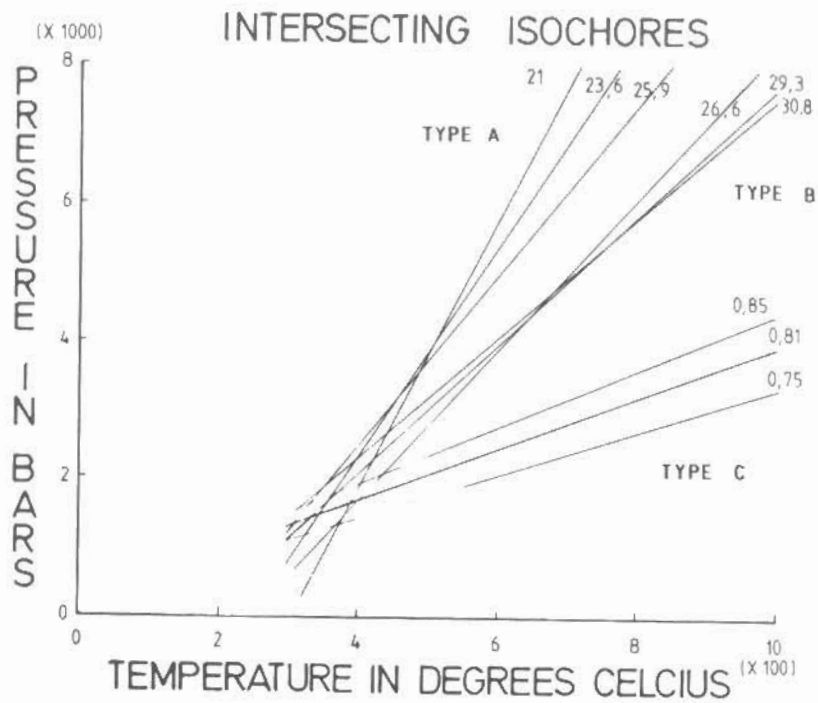
Fig. 7. Histograms of total homogenization temperatures Th, TOTAL, of inclusion types A and B (7B).

Εικ. 7. Ιστογράμματα θερμοκρασιών ολικής ομογενοποίησης Th, TOTAL, εγκλεισμότων τύπου Α και B (7B).

INTERSECTING ISOCHORES

TYPE A — 21 / 23,6 25,9 / 26,6 / 29,3 30,8

TYPE B

0,85
0,81
0,75

TYPE C

(X 1000)
PRESSURE IN BARS

TEMPERATURE IN DEGREES CELCIUS (X 100)

Fig. 8. Calculated isochores of selected type A, B, and C inclusions. Numbers
correspond to molar volumes (cm³/a) (Tvpes A, B), and densities (g/cm³)
(Type C).

Eιk. 8. Υπολονισμένες ισόχωρες ευθείες από επιλεγμένα εγκλείσματα τύπου A, B, και
C. Οι αριθμοί αντιστοιχούν σε μοριακούς όγκους (cm³/a) (Τύπος A και B),
και πυκνότητες (g/cm³) (Τύπος C).

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Ψηφιακή Βιβλιοθήκη "Θεόφραστος" - Τμήμα Γεωλογίας. Α.Π.Θ.

ΤΜΗΜΑ ΓΕΩΛΟΓΙΑΣ
ΒΙΒΛΙΟΘΗΚΗ

TABLE 1. Microthermometry data and properties of inclusion types A, B, C; and D.[1]
ΠΙΝΑΣ 1. Στοιχεία μικροθερμομετρίας και ιδιότητες εγκλεισμάτων τύπου A, B, C, και D.

INCLUSION TYPE	MELTING TEMPERATURES Tm,CO2 [2] (°C)	Tm,CLAT (°C)	APPARENT SALINITY (EQUIV WT% NaCl)	HOMOGENIZATION TEMPERATURES Th,CO2 (°C)	Th,TOTAL (°C)	CO2, MOLE%	DENSITY BULK (g/cm³)
A	R:-56.3 to -57.5 X:-56.7±0.36 M: -56.8	R:6.8-10 X:8.0±0.98 M: 7	R:0.0-6.12 X:3.8±1.10 M: 3.1	R:18.4-28.0 X:23.6±3.60 M: 28	R:230-325 X:270± 28 M: 260	R:3-17 X:9± 4 M:13	R:0.81-0.99 X:0.93±0.03 M: 0.92
B		R:5.5-10 X:8.5±1.2 M: 10	R:0.0-8.3 X:2.2±1.0 M: 2	R:10.0-24.0 X:17.3± 4.8 M: 21.9	R:220-331 X:292± 37 M: 318	R:20-58 X:33±10 M: 25	R:0.83-0.92 X:0.88±0.02 M: 0.91
C				R:6.5-23.9 X:15.6±5.1 M: 14.6	-	100	R:0.75-0.88 X:0.80±0.04 M: 0.75
D			R:10-15 X:11± 2 M: 12		R:110-135 X:115± 5 M: 115		R:1.04-1.08 X:1.04±0.04 M: 1.04

[1]Data are from Figures 4, 5, 6, and 7; R=range, X=average, ±=standard deviation

[2]Melting temperatures of CO_2 refer to both inclusion types A and B.

Tm,CO_2:Melting temperature of solid CO_2

Tm,CLAT:Melting temperature of CO_2-hydrate(clathrate)

Th,CO_2:CO_2-phase(liquid and vapor) homogenization temperature

Th,TOTAL:Total homogenization temperature of the CO_2- and aqueous- phases

the veins. Hydrothermal solutions rich in CO_2 are associated with tungsten deposits in various geologic environments many of which contain evidence of a heterogeneous CO_2-H_2O hydrothermal fluid (e.g. Shepherd et al., 1976; Kelly and Rye, 1979; Cheilletz, 1984), and CO_2 is known to play a very important role in transportation of tungsten in solution in carbonic complexes, and its deposition (Ivanova and Khodakovskii, 1968; Higgins and Kerrich, 1982; Higgins, 1985).

Recognition of such fluids accompanied with deposition mechanisms, such as boiling, based on fluid inclusion studies, constitute very important evidence which may be used in exploration for tungsten deposits.

ΒΙΒΛΙΟΓΡΑΦΙΑ - REFERENCES

ANGUS, S. ARMSTRONG, B. de REUCK, K.M. ALTUMIN, V. V. GADETSKII, O.G. CHAPALA, G.A. and ROWLINSON, J.S. (1976). International thermodynamic tables of fluid state, Vol. 3, Carbon dioxide.-Oxford.

BODNAR, R.I. REYNOLDS, T.J. and KUEHN, C.A. (1985). Fluid inclusion systematics in epithermal systems. *In B.R. Berger and P.M. Bethke (eds.)"Geology and geochemistry of epithermal systems : Reviews in Economic Geology*, 2, 73-97.

CHEILLETZ, A. (1984). Caractéristiques geochimiques et thermobarometriques des fluides associés à la scheelite et au quartz des mineralisation de tungstene du Ibel Aouam (Maroc Central).-*Bull. Mineral.*, 107, 255-272.

COLLINS, P.L.F. (1979). Gas hydrates in CO_2-bearing fluid inclusions and the use of freezing data for estimation of salinity.-*Econ. Geol.*, 74, 1435-1444.

DIXON, J.E. and DIMITRIADIS, S. (1985). Metamorphosed ophiolitic rocks from the Servo-Macedonian Massif, near Lake Volvi, north-east Greece. *In J.E. Dixon, and A.H.F. Robertson (eds.) "The geological evolution of the eastern Mediterranean*, Special Publication of the Geological Society, 17, 603-618, Oxford.

FOURNARAKI, A. (1981). Mineralogical and petrological study of amphibolitic rocks of the Servomacedonian Massif.-"*Unpub. Ph.D. thesis, Univ. of Thessaloniki, Greece* (in Greek).

GEHRIG, M. LENTZ, H. and FRANCK, E.U. (1979). Thermodynamic properties of water-carbon dioxide-sodium chloride mixtures at high temperatures and pressures. *In K.O. Timmerhaus and M.S. Barder (eds.) "High pressure science and technology*, 539-542, New York.

HEYEN, G. RAMBOZ, C. and DUBESSY, J. (1982). Simulation des équilibres de phases dans le système CO_2-CH_4 en dessous de 50°C et de 100 bar. Application aux inclusions fluides.-*C.R. Acad. Sc. Paris*, t. 294, II, 203-206.

HIGGINS, N.C. and KERRICH, R. (1982). Progressive [18]O depletion during CO_2 separation from a carbon dioxide-rich hydrothermal fluid : Evidence from the Grey River tungsten deposit, Newfound land.-*Canadian Jour. Earth Sci.*, 19, 2247-2257.

HIGGINS, N.C. (1985). Wolframite deposition in a hydrothermal vein system : The Grey River tungsten prospect, New foundland, Canada.-*Econ. Geol.*, 80, 1297-1327

IVANOVA, G.F. and KHODAKOVSKII, I.L. (1968). Transport of tungsten in hydrothermal solutions.-*Geochemistry Internat.*, 5, 779-780.

KELLY, W.C. and RYE, R.O. (1979). Geologic, fluid inclusion, and stable isotope studies of the tin-tungsten deposits of Panasqueira, Portugal.-*Econ. Geol.*, 74, 1721-1822.

KOCKEL, F. MOLLAT, H. and WALTHER, H. (1977). Erlauterung zur geologischen karte der Chalkidiki und angrenzender aebiete 1:100000, Nordgriechenland.-*Bundesant. Geowiss. Rohst.*, Hannover, 119 p.

KOUGOULIS, H. (1986). Retrograde metamorphism and determination of protoliths of Vertiskos Formation, Servomacedonian Massif (North of Volvi lake and Lipsidrio-Laodikino).-*Unpub. report, IGME*,(in Greek).

KOUGOULIS, H. DABITZIAS, S. and PAPADOPOULCS, H. (1989). 1. Geological and metallogenetic study of amphibolites from the Servomacedonian Massif, related to ophiolitic complexes. 2. Geology (origin) of isolated serpentinites from the Servomacedonian Massif and their metallogenetic significance.- *Unpub. report IGME*, (in Greek).

MACDONALD, A.J. and SPOONER, E.T.C. (1981). Calibration of a Linkam TH 600 programmable heating-cooling stage for microthermometric examination of fluid inclusions.-*Econ. Geol.*, 76, 1248-1258.

NICHOLLS, J. AND CRAWFORD, M.L. (1985). Fortran programs for calculation of fluid properties from microthermometric data on fluid inclusions.-*Computers and Geosciences*, 11, 619-645.

PAPADOPOULOS, C. (1982). Geologie des Servo-Mazedonischen Massivs nördlich des Volvi-Sees (Nord-Griehenland).-*Dissertation, Un. Wien.* (in German).

PATRAS, D. KILIAS, A. CHADZIDIMITRIADIS, E. and MUNTRAKIS, D. (1986). Study of the formation phases of the internal Hellenides in Northern Greece.-*Bull. Geol. Soc. Greece*, 20, 139-157, (in Greek with English abs.).

POTTER, R.W.II and BROWN, D.L. (1977). The volumetric properties of aqueous sodium chloride solutions from 0°C to 500°C at pressures up to 2000 bars based on a regression of available data in the literature.-*U.S. Geol. Survey Bull.*, 1421-C.

ROEDDER, E. (1984). Fluid inclusions, -Reviews in Mineralogy.-*Mineral. Soc. Amer.*, 12, 644 p.

SAKELLARIOU, D.O. (1988). Deformation and metamorphism of the Servomacedonian Massif.-*4th Congress Geol. Soc. Greece, Athens.*

SHEPHERD, T.J. BECKINSALE, R.D. RUNDLE, C.C. and DURHAM, J. (1976). Genesis of Carrock Fell tungsten deposits, Cumbria : Fluid inclusion and isotopic study. -*Inst. Mining Metallurgy Trans.*, 85, B63-B73.

SHEPHERD, T.J. (1981). Temperature programmable heating-freezing stage for microthermometric analysis of fluid inclusions.-*Econ. Geol.*, 76, 1244-1247.

SWANENBERG, H.E.C. (1979). Phase equilibria in carbonic systems, and their application to freezing studies of fluid inclusions.-*Contrib. Mineral. Petrol.*, 68, 303-306.

TAKENOUCHI, S. and KENNEDY, G.C. (1965). The solubility of carbon dioxide in NaCl solutions at high temperatures and pressures.-*Am. Jour. Sci.*, 263, 445-454.

VERANIS, N. and BITZIOS, D. (1984). Preliminary report on the geology and metallogenesis of the Pirgadikia-Metaggitsi-Salonikio area.-*Unpub. report IGME*, (in Greek).

VERANIS, N. (1989). Gold-bearing mineralisations of the Servomacedonian Massif-Application of panning in exploration for gold-Selection of research targets. -*Unpub. report IGME*, (in Greek), 88 p.

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