บทความวิจัย

APPLICATION OF CHEMISTRY TO CONSTRAIN TYPE OF PROTOLITHS AND METAMORPHISM CONDITIONS OF THE HOST ROCKS OF FLUORITE MINE AT KHAO CHONG INSI, KANCHANABURI PROVINCE, THAILAND

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ABSTRACT

Khao Chong Insi is a small mountain range in Hui Krajao District, Kanchanaburi Province that lies in north-south trending. Eventhough the mountain is very narrow with the width of 7 km and length of 34 km, but it has a very high potential of mineral resources including pure quartz for solar cell industry, feldspar for ceramic industry, limestone for construction aggregate and fluorite for chemical industry. At least 5 mines have been operated on the Khao Insi and some of them are still being run currently. These mines last longer than 30 years especially the fluorite mine. Here we apply some publish methods to find out the source of basement rocks which play as a role of host-rock for fluorite deposit in the area. Basement rocks found in the area which is a host for fluorite are mainly gneiss intercalated with schist, quartzite, calc-silicate and marble. Eleven representative metamorphic samples were analyzed using wave length dispersive X-ray fluorescence (WD-XRF) and two samples that contain appropriate mineral constituents were selected for P-T calculation based on their mineral chemistry. As a result, the protolith of these representative samples are mainly pelitic rocks (shale or mudstone) and quartzo-felsparthic rock (granite or sandstone), however, one sample has been calcareous rocks. This could be concluded that these host-rock of fluorite deposit have been metamorphosed from both igneous and sedimentary rocks before the metamorphism event. Thermodynamic principles were applied to calculate the pressure and temperature conditions of metamorphism in this area. The result shows that most metamorphic rocks have experience the conditions of around 4-6 kbar and 630-720 ^{0}C at the depth of around 25-29 km.

Keywords: chemistry, protolith, metamorphic rocks, P-T conditions, Kanchanaburi

Introduction

Basement rocks in Thailand mainly distribute in north-south trending and restrict to the western part of the country. It frequently shows a close relationship with granites and exposes continuously from Chiangmai running southward to Tak, Kampeng Phet and terminates at Ban Rai District of Utai Thani Province. The metamorphic basement rocks can be found again at Kanchanaburi Province in the mode of either isolated mountain for instance Khao Insi and Khao Chon Kai or a narrow elongate body within unmetamorphosed sediments. This topography is the same as Thabsila metamorphic complex (Nantasin et al., 2012). The main lithologies of this belt which align along the western mountain range are paragneiss, orthogneiss, calc-silicate, marble and schist. However, gneissic rocks of this belt are mainly quartzofelspathic gneiss and biotite gneiss.

Metamorphic complex generally reveals tectonic evolution of a corresponding orogen or geological terrane via structures, reaction textures, mineral assemblage and mineral chemistry preserved within each rock unit of the complex. Bulk rock chemistry or chemistry of any metamorphic rock also reflect its original rock type before metamorphism. In addition, chemical composition of each phase present in those textures can be used for P-T calculations based on the principles of thermodynamics.

Fluorite mine at Khao Insi or some people call it as Khao Chong Insi is one of the main fluorite mine that supply this mineral to the market both domestic and overseas over 40 years and last until current time. Even though the genesis model of fluorite found in this mine has never been reported but, according to personal conversation of the author with mine workers, fluorite occurs as veins cut through metamorphic rocks including augen gneiss, sillimanite gneiss, sillimanite-garnet gneiss, and calc-silicate. This study we focus on these metamorphic rocks which play a role as host rock. Chemical composition of whole-rock and also some essential minerals were analyzed in order to constrain the type of protolith and metamorphism conditions, respectively.

Geological setting of Khao Chong Insi

The study area is the southern hill of Khao Insi mountain range which has been reported by Khaowwiset et.al. (2010). This mountain range is actually the boundary between Bo Phloi District and Huai Krachao District, Kanchanaburi Province. Kanchanaburi Province is located at 19° 54’ 0” N, 99° 49’ 0” E. The geology of Khao Insi is made up of three main units ranking from the oldest to younger sequences which is inferred Precambrian rocks, Silurian-Devonian sedimentary rocks, and Triassic clastic sediments, respectively. All of these units are covered by younger sediments (DMR, 2007). The Precambrian unit consists of various kinds of metamorphic rocks, including, augen gneiss, mica schist, quartz mica schist, quartzite, calc-silicate and marble. Foliation of these rocks are mostly strike to NE with the high variation of dipping angle ranging from nearly horizon along the edge of the mountain and become steeper at the core of the mountain. This trend is consistent with the grade of metamorphic rocks as well. Precambrian unit contacts with Silurian-Devonian sedimentary sequence with a fault contact which is part of Sri Sawat fault zone. The Silurian-Devonian (SD) sedimentary rock is predominantly consisted of sedimentary rocks of the Bo Phloi Formation. It is made up of sandstone, shale and siltstone. Some parts of them were changed into quartzite, phyllite and slate. Index fossil found in this area is Tentaculate. As same as the contact between Precambrian and Silurian-Devonian rocks aforementioned, the contact between SD rocks also contact with Triassic unit with fault contact. Some mylonitic rocks which formed in fault zone are also found in the area. Triassic unit that cropping out at southeastern part of the Khao Insi consists of various types of sedimentary rocks including sandstone, mudstone, conglomerate and limestone with subordinate dolomite. Fossils of marine animals such as bivalves and brachiopod have been reported by Department of Mineral Resources (DMR, 2007).

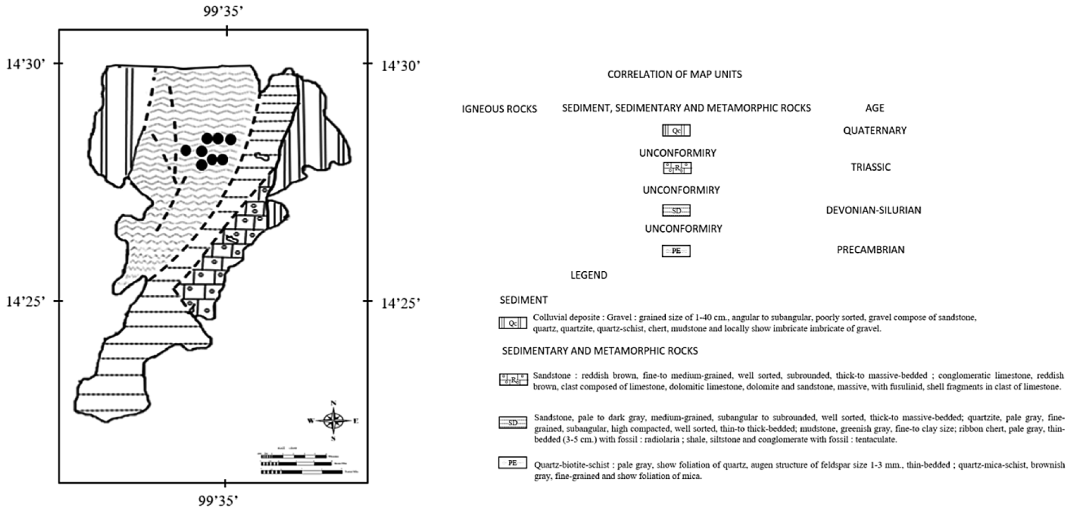

Figure 1 Geological map of the lower part of Khao Insi showing rock unit and location of samples collected for this study.
Geological map was modified from (Khaowwiset, et al., 2010)

Whole-Rock Geochemistry

Eleven representative samples were analyzed using wavelength dispersive X-ray fluorescence spectrometer (WD-XRF) at Department of Petrology and Geochemistry, Institute of Earth Science, University of Graz. For each sample, a mixture of one gram of sample powder and seven grams of $Li_2B_4O_7$ flux were fused to be a glass bead for XRF measurement. About 60 rock standards were used as internal standard. The detection limit is approximately 0.02 %. The results are list in Table 1 and only major oxides are listed in this table. The diagram proposed by Eskola (1915) was adopt based on major oxides. The plotting result shows that those representative samples were metamorphosed from two main groups of protoliths, firstly, pelitic rocks for example shale or mudstone that contain high percentage of clay minerals and another main group is quartzo-feldsparthic rocks for instance granite or sandstone that contained high percentage of feldspar (Fig. 2). There is one sample was delivered from calcareous rocks like limestone or clay stone that contained high content of carbonate minerals.

Table 1 Whole-rock chemistry of representative metamorphic rocks collected from Khao Chong Insi.

Sample	Inse1	Inse2	Inse3	Inse4	KC55	KC58	KC198	KC201	KC204	KC206	KC205
SiO_2	66.53	59.37	68.23	65.02	64.28	65.98	60.74	28.96	64.46	62.32	60.07
TiO2	0.86	1.05	0.78	0.82	0.73	0.79	0.93	0.47	0.98	0.79	1.11
Al2O3	13.15	17.98	13.85	15.20	16.21	14.31	15.28	10.41	17.10	15.13	19.15
Fe2O3	0.55	0.78	0.49	0.55	0.75	0.49	0.79	0.45	0.72	0.75	0.90
FeO	4.98	6.98	4.36	4.91	6.70	4.36	7.14	4.00	6.49	6.75	8.06
MnO	0.078	0.052	0.107	0.112	0.322	0.069	0.152	0.762	0.092	0.127	0.053
MgO	2.75	2.32	2.32	2.64	2.81	2.38	3.56	1.65	2.14	2.21	2.71
CaO	3.37	0.61	2.44	2.41	0.19	3.46	1.13	30.14	1.22	2.67	0.42
Na2O	2.18	0.56	3.12	3.03	0.21	2.35	1.38	0.16	2.17	2.63	0.60
K2O	3.46	4.10	2.43	3.28	5.07	3.60	5.34	2.79	3.00	2.48	4.47
P2O5	0.308	0.07	0.091	0.094	0.079	0.295	0.103	0.072	0.083	0.832	0.068
LOI	0.71	4.65	0.67	0.79	1.66	0.79	1.91	18.39	2.00	2.10	4.32
Sum	99.20	98.76	99.10	99.07	99.25	99.13	98.72	98.42	100.65	98.98	102.18

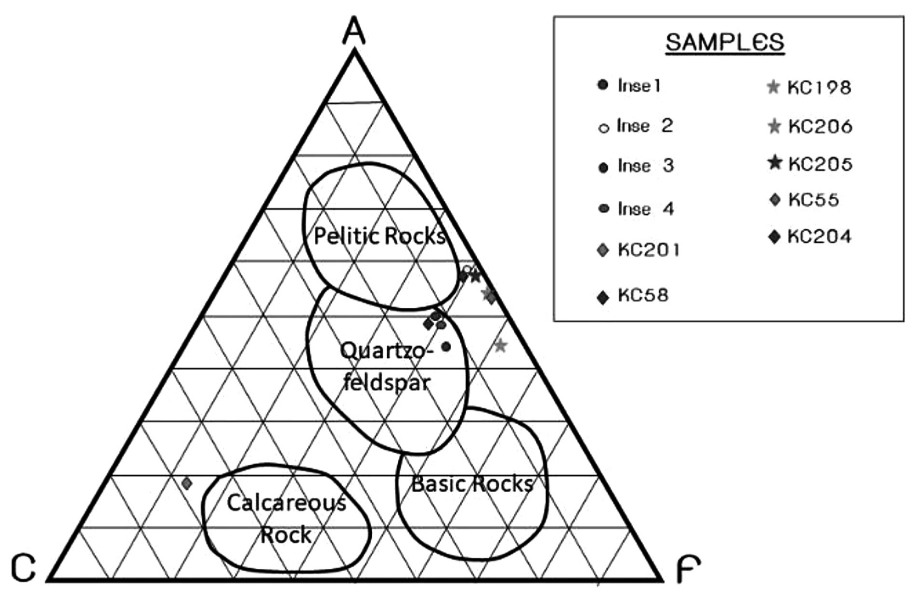

Figure 2 ACF diagram (Eskola., 1915) which plot from major oxide that obtained from WD-XRF showing spots of representative samples from Khao Insi.

Geothermobarometery

All rock samples were prepared to be thin section then examined their mineral constituents under polarizing microscope. Some representative examples that contain crucial minerals will be further polished for mineral chemistry analysis which has carried out at the Institute of Earth Sciences, Karl-Franzens University Graz, Austria using a JEOL 6310 scanning electron microscope (SEM) equipped with a LINK ISIS energy dispersive system and a MICROSPEC wavelength dispersive system. Accelerating voltage and sample current were set at 15 kV and 15 nA, respectively. The Phi-Rho-Z procedure was applied to do a matrix correction. The beam current was calibrated time to time using cobalt metal. Many natural mineral standards were used for standardization i.e. adularia for K, Al and Si, garnet for Fe and Mg, titanite for Ca and Ti, rhodonite for Mn and atacamite for Cl. Na and F contents, which were analyzed by WDS, were standardized against albite and synthetic F-phlogopite standards, respectively. Two representative samples (KC55 and KC204) that used in this study contain an appropriate mineral assemblage especially garnet, biotite, plagioclase, sillimanite and andalusite. These two samples contain an assemblage quartz + plagioclase + alkali feldspar + biotite + muscovite + garnet + sillimanite. This assemblage is suitable for P-T calculations because all required phases present according to thermodynamic rules. Their representative analyses are shown in Table 2 and 3.

The Fe–Mg exchange reaction between garnet and biotite was selected for temperature calculation and net-transfer reactions pressure calculation. Equations of these reactions were calculated using Mathematica package PET (Dachs, 1998, 2004). All symbols for rock-forming minerals used in this study follow Kretz (1983). Sample KC55 yields P–T conditions of 650– 720 ^{o}C and 4.7–6.3 kbar (Figure 3) on the basis of Grt–Bt thermometer (Holdaway, 2000) and Grt–Pl–Bt barometer (Hoisch, 1990), respectively. The sample KC204 also yields the same interval of P-T conditions at 630– 690 ^{o}C and 4.3–7.2 kbar (Figure 4).

Discussion and Interpretation

Concerning the type of protoliths that obtained from geochemical approach, the host rock of fluorite deposit in the Khao Chong Insi could be divided to be two main groups. The first group could be derived from pelitic rocks or very fine-grained sedimentary rocks that has been made up of clay minerals. This clue is well consistent with field evidences that rock sequence shows an alternation of different characteristic in terms of composition, color and grain size that reflect the nature of bedding of sedimentary rocks. Because sedimentary rock layer commonly has a unique composition bed to bed or layer to layer. Even though within the same bed it also displays the variation due to the temporal variation of sediments supplied to such layer. Second group are those samples fall into the field of quartzo-feldspathic rock.

Table 2 Representative analyses of mineral chemistry of some mineral in the samples KC55.

	k55Grt53	k55Grt55	k55Grt60	k55Bt7	k55Bt8	k55Bt9
SiO_2	37.32	37.24	37.20	35.70	37.55	36.03
TiO2	0.00	0.00	0.00	2.24	2.39	2.46
Al_2O_3	21.62	20.90	21.00	18.72	18.94	19.30
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00
Fe_2O_3	0.00	0.00	0.00	0.00	0.00	0.00
FeO	30.99	30.39	30.14	18.28	16.78	17.74
MnO	6.85	6.34	6.40	0.20	0.25	0.24
MgO	2.68	3.39	3.35	9.34	9.06	9.28
CaO	1.13	1.12	1.19	0.00	0.00	0.00
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	9.96	9.29	9.57
F	0.00	0.00	0.00	0.59	0.70	0.59
Cl	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.59	99.38	99.28	94.78	94.67	94.96
Cations (atom per formula unit) on the basis of 12 Oxygen (garnet), 8 Oxygen (plagioclase) and 11 Oxygen (biotite)						
Si	2.990	3.010	3.008	2.735	2.832	2.736
Ti	0.000	0.000	0.000	0.129	0.136	0.140
Al	2.041	1.991	2.001	1.690	1.683	1.727
Cr	0.000	0.000	0.000	0.000	0.000	0.000

Table 2 (Continue)

	k55Grt53	k55Grt55	k55Grt60	k55Bt7	k55Bt8	k55Bt9
Cations (atom per formula unit) on the basis of 12 Oxygen (garnet), 8 Oxygen (plagioclase) and 11 Oxygen (biotite)						
Fe_3	0.000	0.000	0.000	0.000	0.000	0.000
Fe_2	2.076	2.054	2.038	1.171	1.058	1.127
Mn	0.465	0.434	0.438	0.013	0.016	0.015
Mg	0.320	0.408	0.404	1.067	1.019	1.051
Ca	0.097	0.097	0.103	0.000	0.000	0.000
Na	0.000	0.000	0.000	0.000	0.000	0.000
K	0.000	0.000	0.000	0.973	0.894	0.927
F	0.000	0.000	0.000	0.143	0.167	0.142
Cl	0.000	0.000	0.000	0.000	0.000	0.000
Total	7.989	7.994	7.992	7.921	7.805	7.865

Table 3 Representative analyses of mineral chemistry of some mineral in the samples KC204.

	k204Pl5	k204Pl6	k204Pl7	k204Grt8	k204Grt9	k204Grt10
SiO_2	63.10	62.24	64.73	37.21	37.19	37.43
TiO_2	0.00	0.00	0.00	0.00	0.00	0.00
Al_2O_3	23.63	23.41	21.42	20.91	21.21	21.57
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00
Fe_2O_3	0.12	0.00	0.10	0.00	0.00	0.00
FeO	0.00	0.00	0.00	35.78	36.04	34.91
MnO	0.00	0.00	0.00	2.98	3.18	2.69
MgO	0.00	0.00	0.00	2.41	2.55	3.36
CaO	4.36	4.34	2.15	0.83	0.79	0.74
K_2O	0.08	0.21	0.07	0.00	0.00	0.00
Na_2O	8.77	8.90	10.71	0.00	0.00	0.00

Table 3 (Continue)

	k204Pl5	k204Pl6	k204Pl7	k204Grt8	k204Grt9	k204Grt10
F	0.00	0.00	0.00	0.00	0.00	0.00
Cl	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.06	99.10	99.18	100.12	100.96	100.70
Cations (atom per formula unit) on the basis of 12 Oxygen (garnet), 8 Oxygen (plagioclase) and 11 Oxygen (biotite)						
Si	2.784	2.777	2.874	3.011	2.985	2.989
Ti	0.000	0.000	0.000	0.000	0.000	0.000
Al	1.229	1.231	1.121	1.994	2.006	2.030
Cr	0.000	0.000	0.000	0.000	0.000	0.000
Fe_3	0.004	0.000	0.003	0.000	0.023	0.000
Fe_2	0.000	0.000	0.000	2.421	2.396	2.331
Mn	0.000	0.000	0.000	0.204	0.216	0.182
Mg	0.000	0.000	0.000	0.291	0.305	0.400
Ca	0.206	0.208	0.102	0.072	0.068	0.063
K	0.005	0.012	0.004	0.000	0.000	0.000
Na	0.750	0.770	0.922	0.000	0.000	0.000
F	0.000	0.000	0.000	0.000	0.000	0.000
Cl	0.000	0.000	0.000	0.000	0.000	0.000
Total	4.978	4.998	5.026	7.993	7.999	7.995

The second group could be interpreted to be either granitic rocks or sandstone that contain high amount of feldspar mineral. This interpretation is also fit well with the characteristics of some rock types in the field. The augen gneiss with porphyroclast of alkali feldspar preserves many common feathers of igneous rocks for instance homogeneous texture throughout the rock body, well develop twinning and zoning of feldspar porphyroclast.

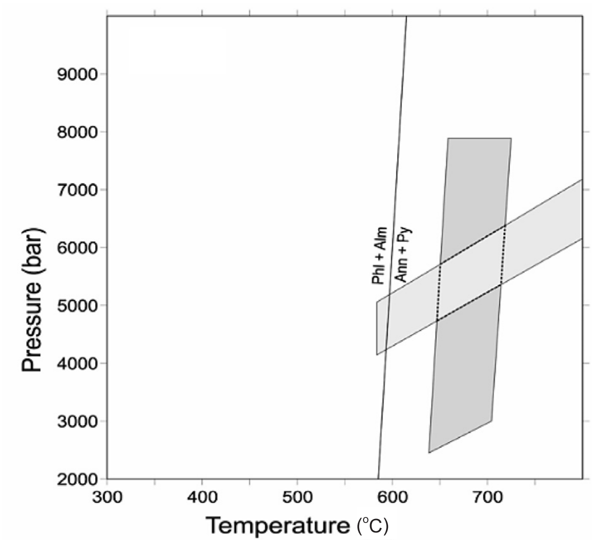

Figure 3 P-T conditions of sample KC55 which calculated by PET program (two boxes) after Dachs (1998). It yields 4.7-6.3 kbar, 650-720 °C. The figure also shows the temperature obtained from TWEEQUE software of Berman (2007) which yields slightly lower temperature around 600 °C.

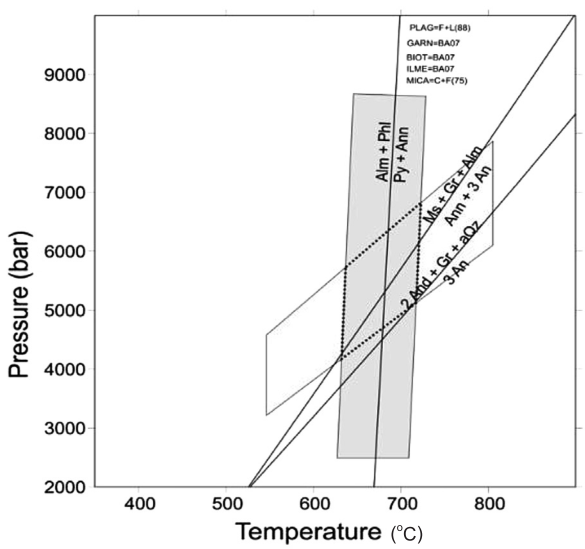

Figure 4 P-T conditions of sample KC204 which calculated by PET program (two boxes) after Dachs (1998). It yields 4.3-7.2 kbar and 630-690 °C. The figure also shows the temperature obtained from TWEEQUE software of Berman (2007) which yields the same temperature and pressure.

The metamorphic conditions of two representative samples collected from this area show a range of amphibolite facies which is similar to the report of Nantasin et al. (2016). The P-T conditions of this area is very similar to the Thabsila metamorphic complex reported by Nantasin et al. (2012). These similarity might suggest that the metamorphic basement rocks in Khao Chong Insi and Thabsila metamorphic complex have experienced the same orogenic event called the Indosinian Orogeny during Triassic or 250-220 Million years ago.

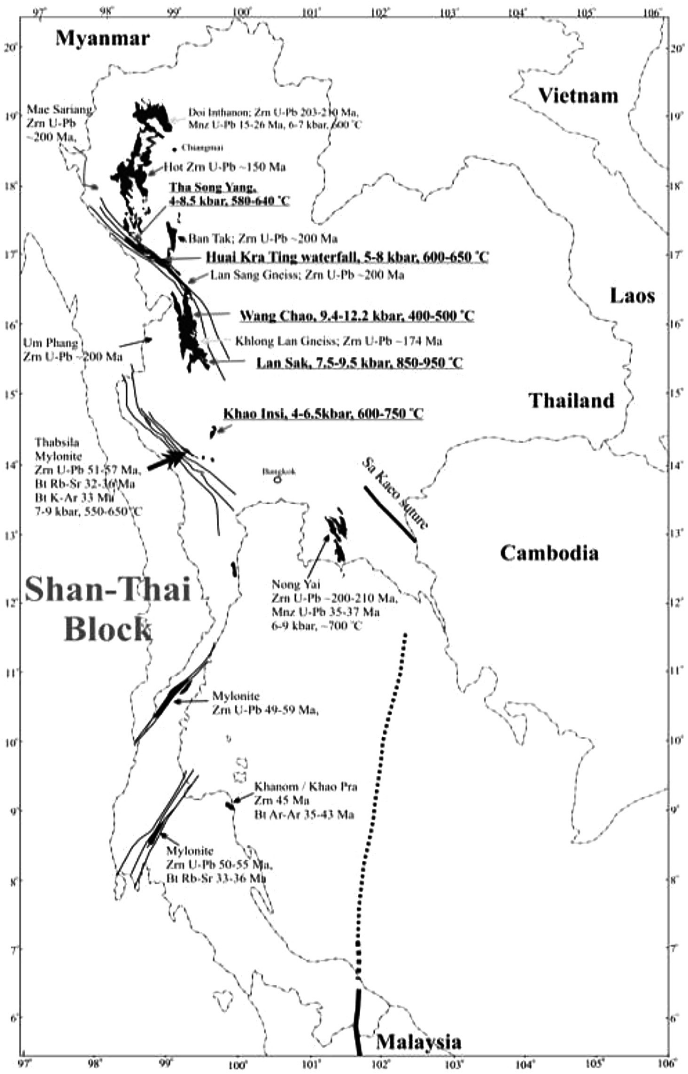

Figure 5 Map of Thailand and surrounding countries showing the distribution of metamorphic belt with their P-T conditions and published radiometric ages.

According to field relationship that fluorite vein cut through these host rocks both parallel and also discordant. The strike of fluorite veins is mostly concordant to the major fault that runs through the area. These relationships might imply that fluorite deposits at Khao Chong Insi are younger than metamorphic rocks and fluorite ore bodies were controlled by fault and fractures that have been developed much later than the metamorphism of this area.

Based on P-T conditions obtained from this study, it indicates that these metamorphic rocks were metamorphosed since they were still at the depth around 25-29 kilometers. Since this metamorphic body is also very close related to major fault zone as same as those metamorphic complexes i.e. Thabsila or Inthanon, therefore, we prefer to note that it was exhumed to shallower depth by the activity of fault. Finally, denudation process unraveled them to the present surface.

Conclusion

Metamorphic rocks at Khao Chong Insi were metamorphosed at amphibolite facies conditions which indicated by the presence of sillimanite, garnet and biotite accompanied with the calculated pressure-temperature conditions around 4-6 kbar and 630-720 ^{0}C. Based on the similarities that found in Thabsila metamorphic complex and Inthanon metamorphic complex, this metamorphism event could take place during Triassic age and exhumed to shallower depth by an activity of Sri Sawat fault zone. Their protoliths are both sedimentary rocks and igneous rocks.

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