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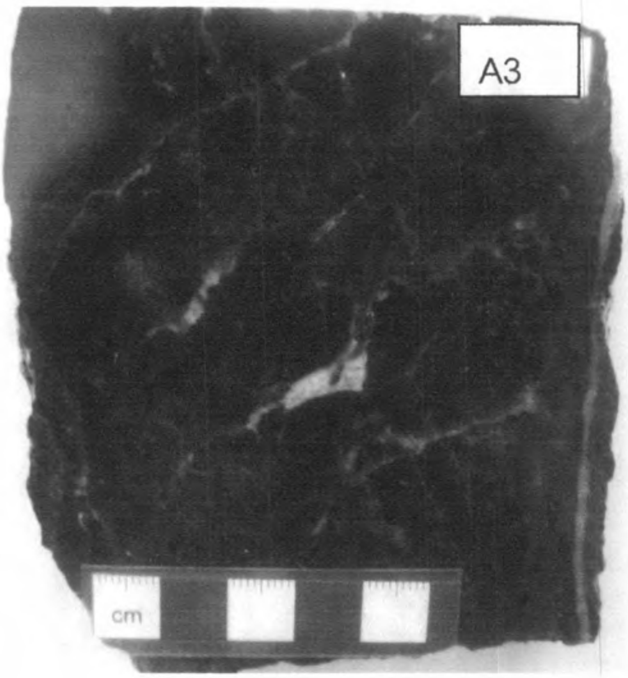
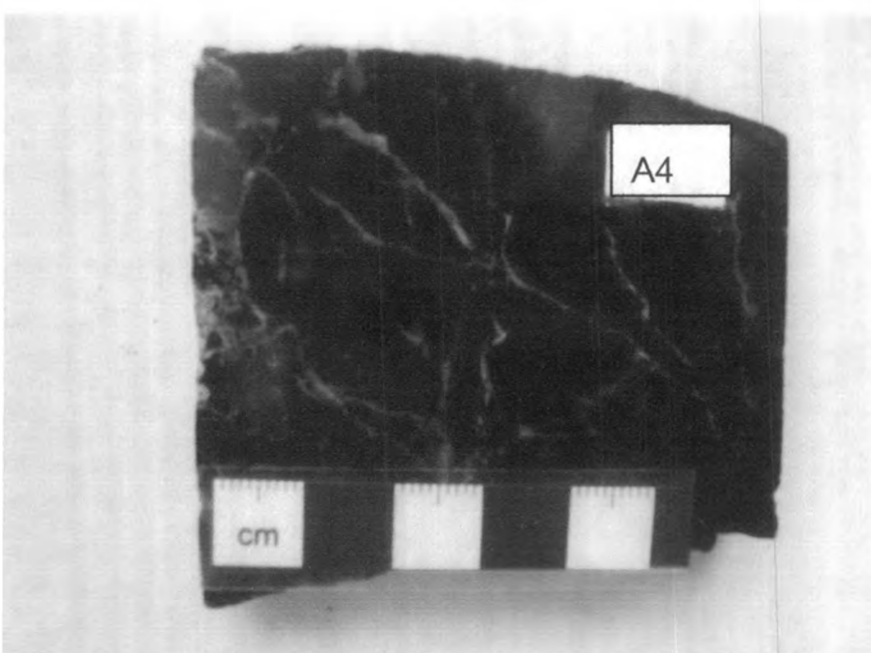
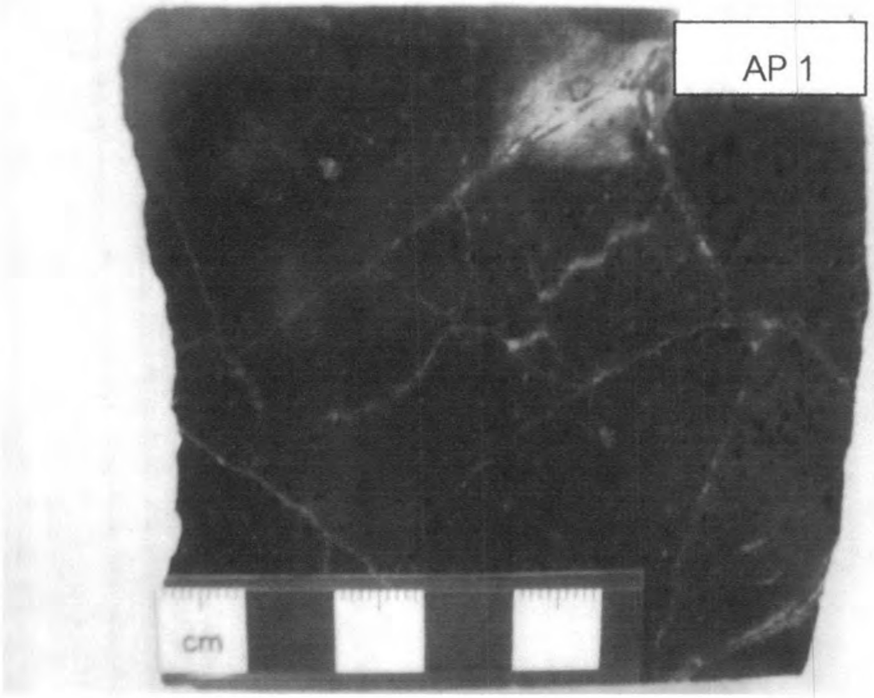
Appendix

APPENDIX A.

Figure Isotope samples



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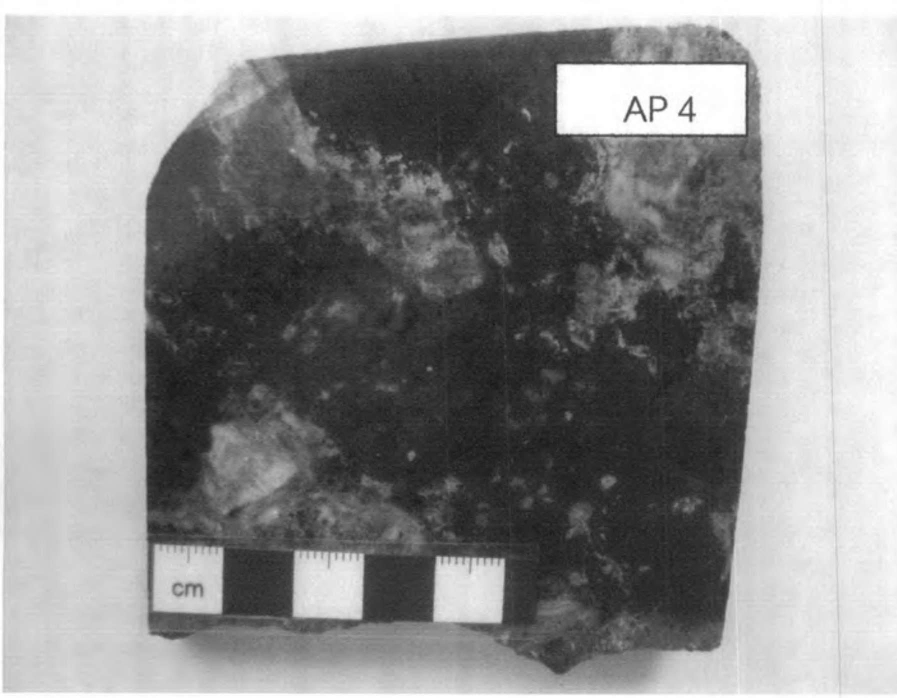
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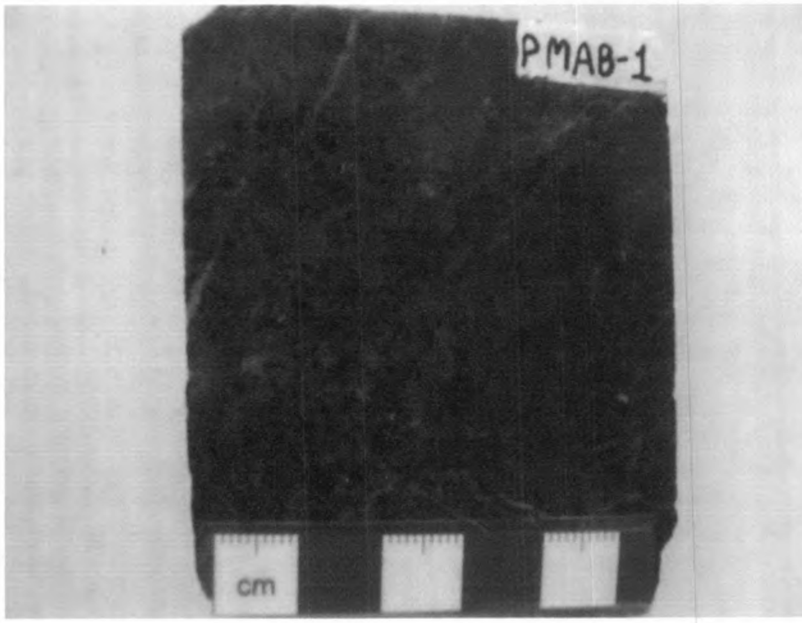
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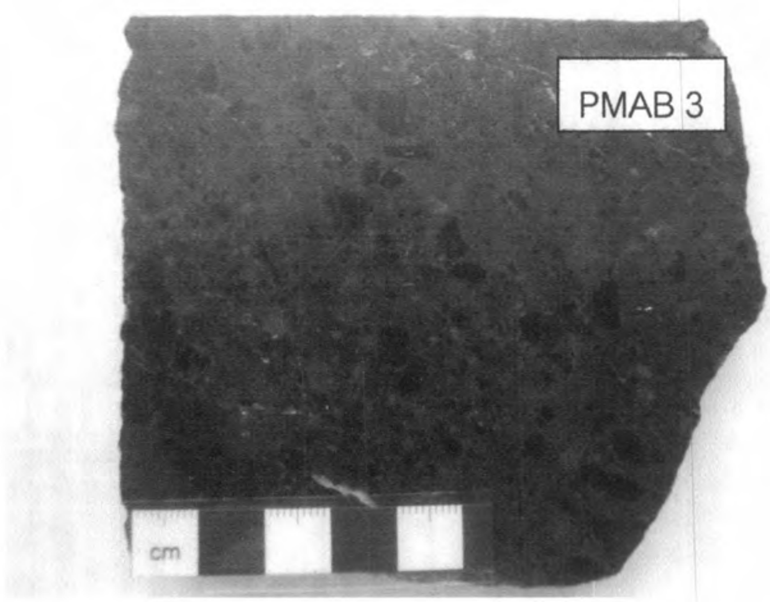
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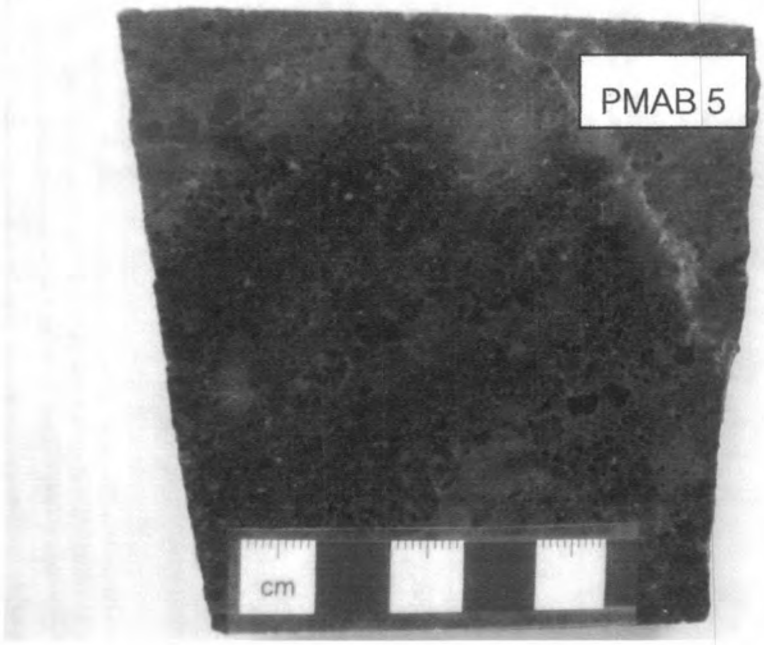
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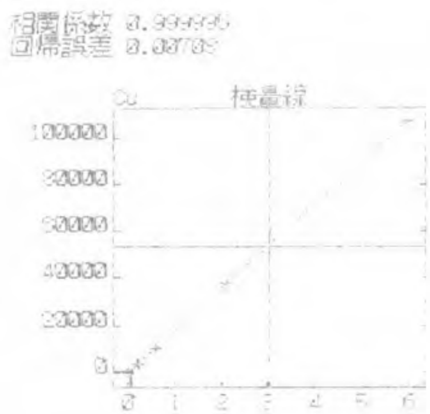
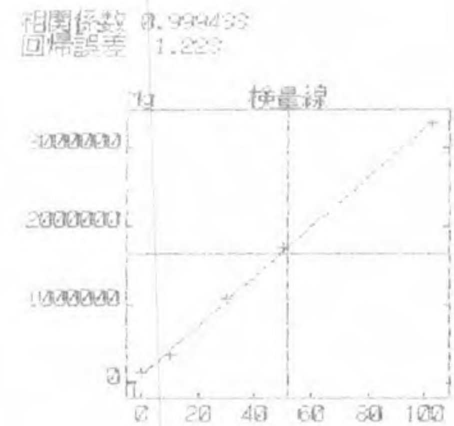
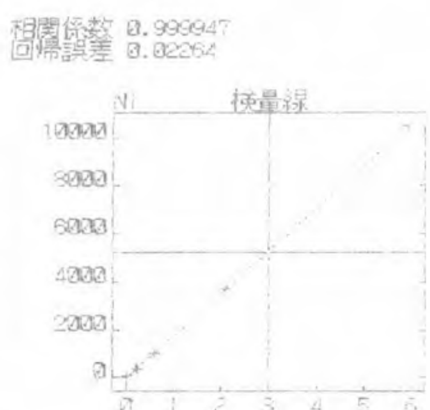
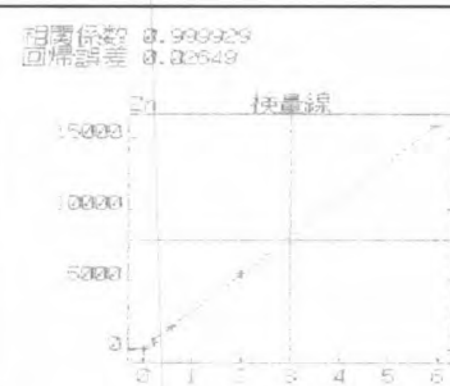
APPENDIX B.

Calibration curves of trace element by ICP-OES

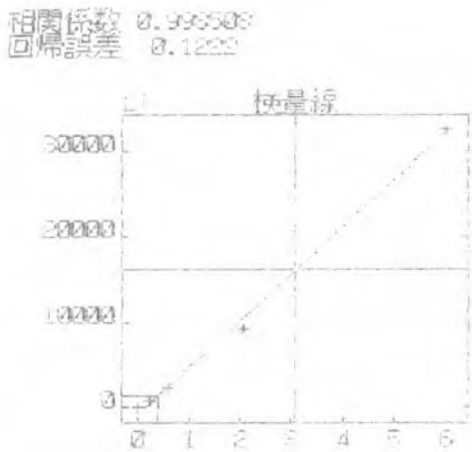


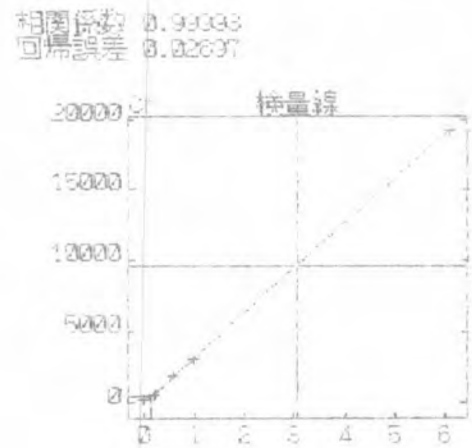


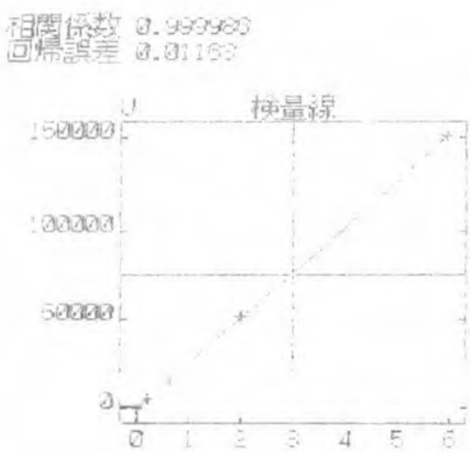


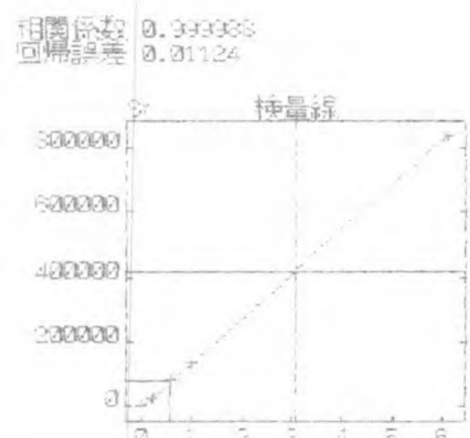


APPENDIX B. (cont.)









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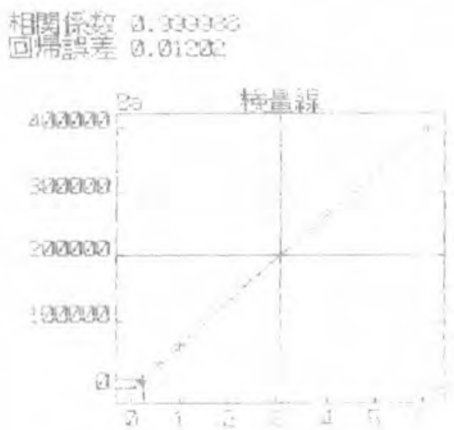

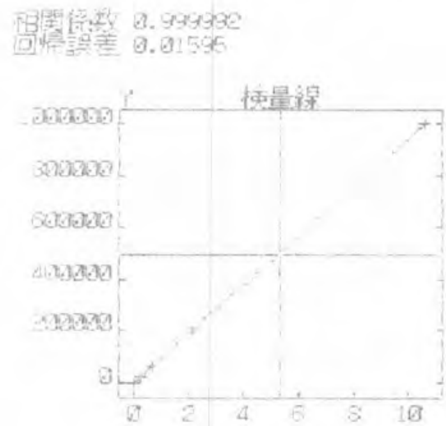

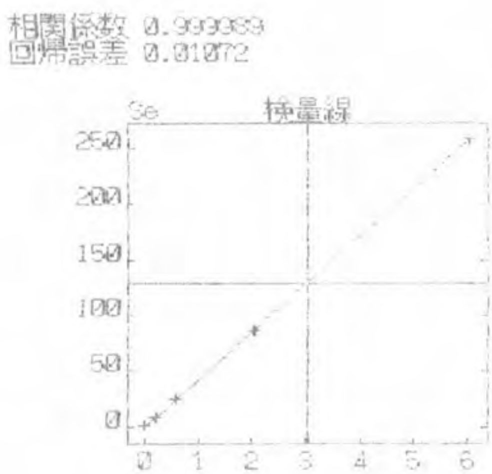

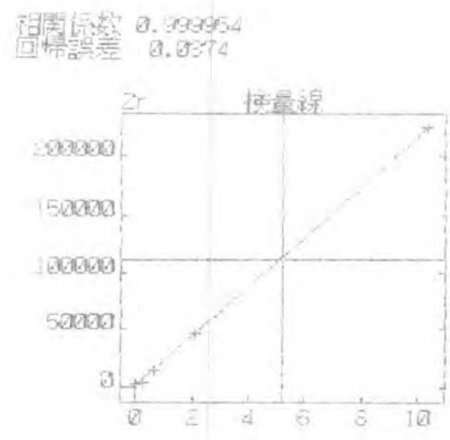

APPENDIX B. (cont.)

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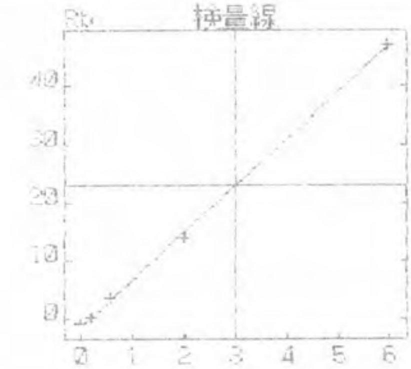

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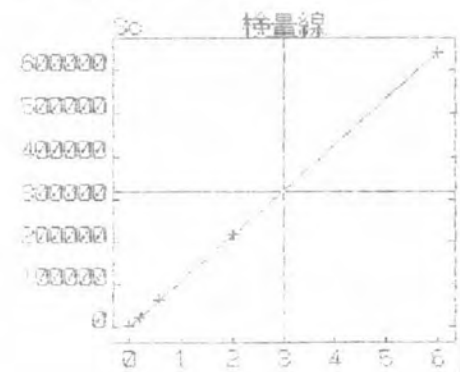

APPENDIX C.

Abstract in GRACE

Stratigraphy and petrochemistry of Volcanic rocks in the Chatree Gold mine, Central Thailand: Implication for tectonic Setting

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Abstract

Permo-Triassic volcanic rocks of the Chatree mine, central Thailand were remapped, petrographically classified, and geochemically analyzed. The volcanic rocks belong to both coherent and non-coherent suites, the former being older in stratigraphy. Petrographic investigation reveals that the coherent rocks are mainly andesite to basaltic andesite. Compositionally, the non-coherent suite also bears similar characteristics. Polymictic and monomictic breccias are classified in the non-coherent suite. Only the coherent and monolithic breccia units show strong alteration with associated Au-Ag mineralization. Results of the trace and rare – earth element analyses reveal that the volcanic rocks at the Chatree mine are mainly calc – alkaline and occurred in the subduction zone of the volcanic arc setting.

Key words: Gold, Chatree mine, Petrochemistry, Volcanic arc, Calc- alkaline

1. Introduction

Volcanic rocks within the open- pit Chatree gold mine in Pichit area, central Thailand were investigated. These volcanic rocks occurred within the so-called the Loei - Phetchabun - Nakhon Nayok Volcanic Belt[1] (Figure 1). This volcanic belt with the almost north - south trend and the length of about 600 km is considered to have formed from Middle Paleozoic to Cenozoic[1] with multiple styles of tectonic settings[2]. There are several kinds of mineralization recognized in this volcanic belt. Major economic minerals are Cu, Fe, Au, Pb and Zn ores.

The Chatree gold mining area in Pichit, central Thailand (Figure 2), was selected for this study with the purpose of explaining the relationship between tectonic setting and volcanism associated with mineralization. The Chatree volcanic rocks were dated using LA ICP-MS U-Pb zircon age method, and the age was assigned to be ca. 250+/- 6 Ma [3].

2. Materials and methods

In this study we remapped the open pit mine of the C and H prospects(Fig 3) in detail. Structural/lithological surveys and stratigraphic correlation along with rock sampling are important for this first step of work. Sample preparation in the laboratory was carried out for petrographic investigations and geochemical analyses. It forms the major task of the second step of study. Rock samples were then classified petrographically and geochemically. Then all the results are compiled, integrated, and discussed for tectonic setting.

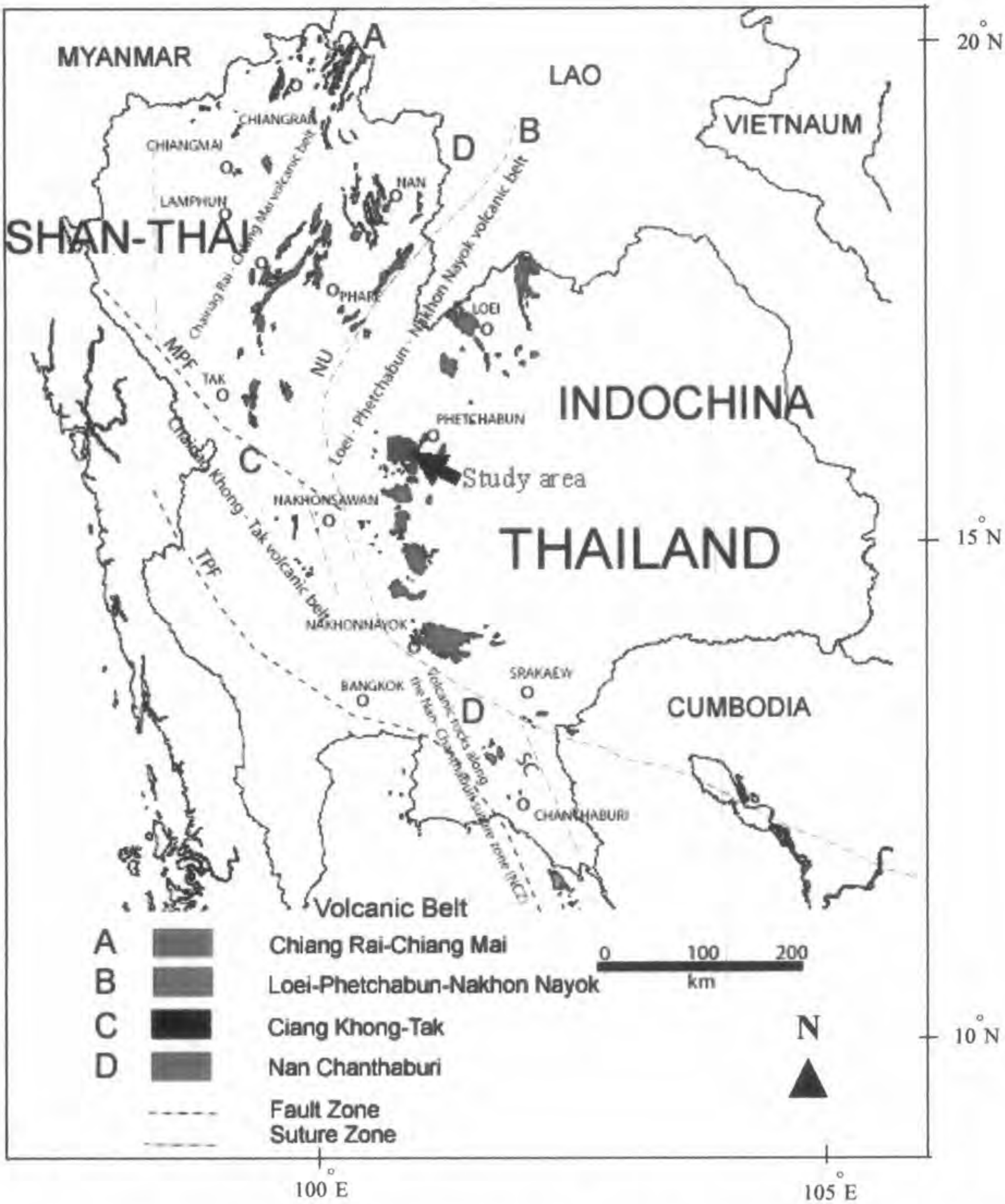
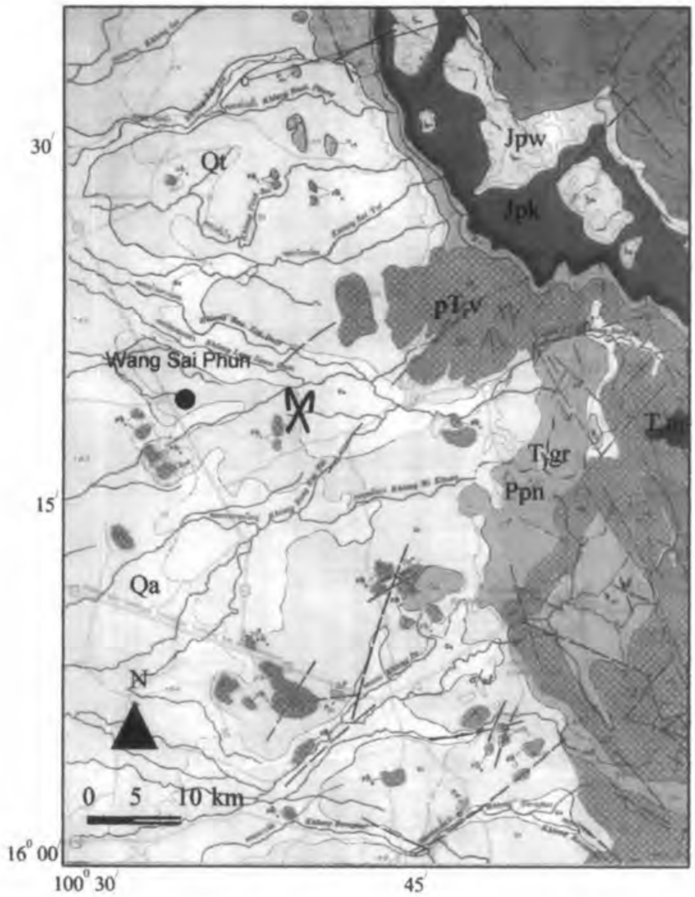


Figure 1. Location of the Chatree Gold Mine deposit with in the Loei - Phetchabun -Nakhon Nayok Volcanic Belt and major faults with sutures in Thailand . (modified from Charusiri et al.[4])



Legend

Sediments and Sedimentary rocks

Qa — Alluvial deposit,river gravel sand, silt and clay, Quaternary

Qt — Terrace, talus and colluvial deposits: gravel, sand, silt and clay, Quaternary

Jpw — Sandstone, wite pink, orthoquartzitic, cross-bedded, massive, with pebbly layers on the upper bed; some intercalations of reddish brown and gray shale of Phra Wihan formation, Lower-Middle Jurassic

Jpk — Shale, brown, reddish brown, purplish red, micaceous; siltdstone and sandstone, brown, gray, micaceous, small scale cross-bedding with some lime-nodule conglomerate of Phu Kradung formation, Lower Jurassic

$T_r$np — Sandstone, reddish brown, brown, cross-bedded, conglomerate, pebbles consisting of quartz, quartzite, chert, red siltstone and sandstone, up to 10 cm.in diameter; shale and siltstone, brown, reddish brown of Nam Phong formation, Upper Triassic

Ppn — Limestone gray, massive to thick bedded; chert, black, nodular or thin bedded; with intercalations of thin bedded gray shale of Pha Nok Khao formation, Lower-Middle Permain

Igneous rocks

pT_rv — Tuff, agglomerate, Ryeorite and andesite, Permo-Triassic

$T_r$gr — Granite and Diorite, Triassic

---- Faults and fracture

River

Town

Mine

Figure 2. Geology of the Chatree gold mine and its surrounding, based on 1:250,000 geological map of Department of Mineral Resources[5] .

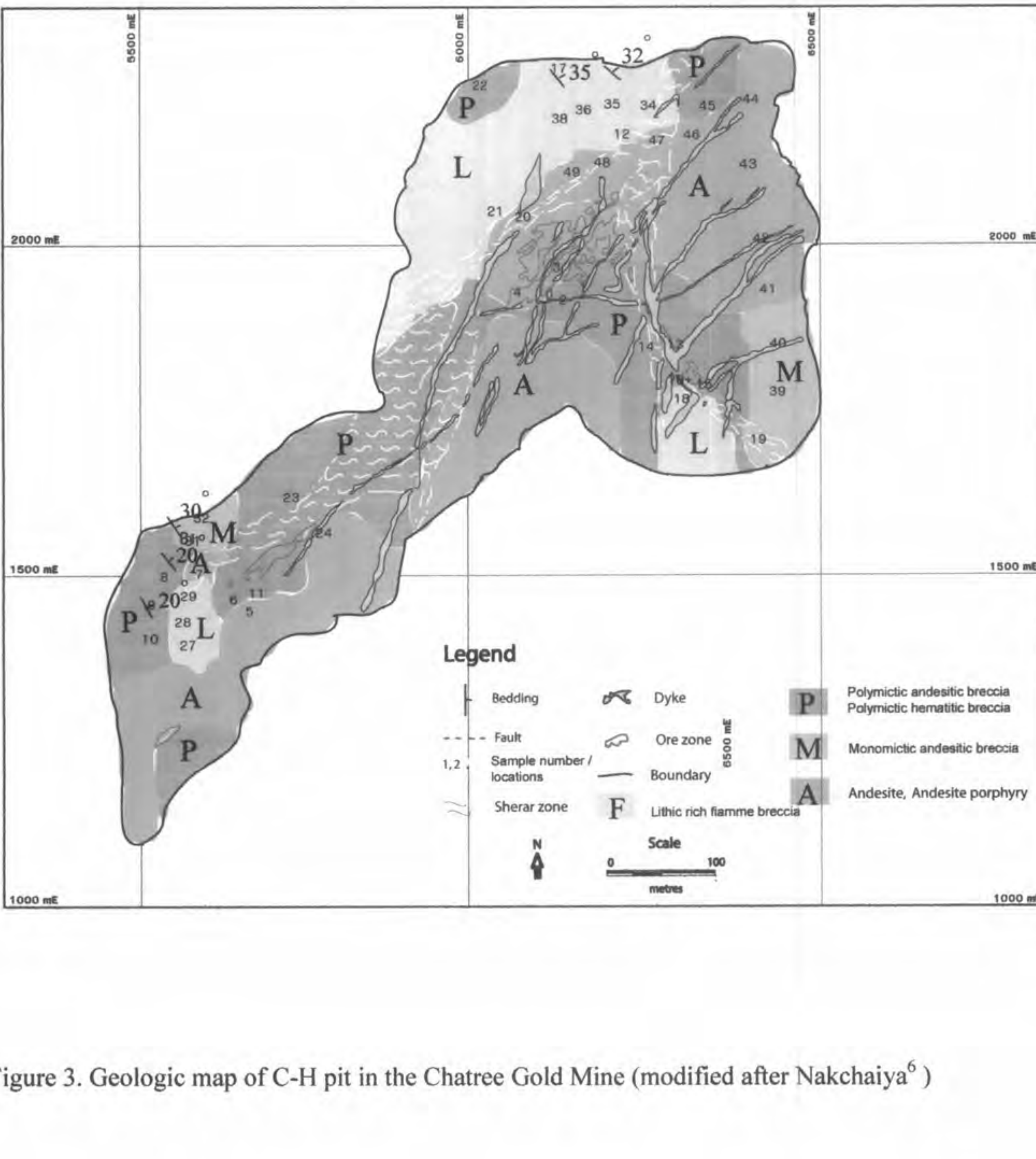


Figure 3. Geologic map of C-H pit in the Chatree Gold Mine (modified after Nakchaiya[6])

3. Results and Interpretation

3.1 Field relation and structural data

Stratigraphically, the Chatree volcanic rocks are attained up to 250 m in thickness and they are overlain by the partly tilted and folded, Permo-Triassic mainly clastic and minor non-clastic rocks with the minimum thickness of 100 m. Structurally, these volcanic strata have the dominant strikes varying from 330° to 345 ° in the northwest direction and dips ranging from 20 ° to 35 ° to the northeast direction.

3.2 Petrography

Two major kinds of volcanic rocks(Figure 4) are recognized based on 60 rock slaps and 75 thin sections. Following the classification of McPhie et al.[7], they are mainly coherent and non-coherent suites. Field survey supports that the coherent suite has the thickness of about 100 m and represents the lower sequence. The volcanic rocks are mainly porphyritic with abundant plagioclase and less common amphibole phenocrysts. They are classified as andesitic and basaltic andesite in composition Petrographically, their average plagioclase composition indicates andesine for feldspar phenocrysts, suggesting intermediate volcanic composition. Flow and hyaloclastic textures are dominant in the middle sequence; the latter supports the volcanism occurring in the marine environment.

The non-coherent suite with the overall thickness of about 150 m is more prominent in the upper sequence. The suite consists principally of monomictic and polymictic breccia sequences. The latter is more abundant in the lower stratigraphic unit. The thickness of polymictic breccia is about 50 m. Their clasts which are mainly subangular to subrounded vary in size from 0.3 to 3 cm from west to east, suggesting the volcanic source or possibly vent is located westward. In general, majority of the clasts includes dark-colored volcanic breccias, flow green andesite, and deep red basaltic (?) breccias. Essential alteration assemblage includes quartz - chlorite - epidote - albite - calcite assemblage. Mineralization pattern is predominated by the appearance of pyrite - Au - Ag and telluride ores. The monomictic breccia sequence is less common and its thickness ranges from 30 to 50 m. The sequence consists largely of red - coloured andesite, and brownish green. The clasts are mainly subangular to angular. The alteration assemblage and mineralization style are similar to those of polymictic breccia. However, the rock sequence is less altered and weakly mineralized.

Both volcanic and sedimentary rocks of the Chatree mine are cross-cut by mafic to intermediate dyke rocks. The dykes trend in the northern to northeastern direction they show variation in thickness from 10 to 40 m. They contain abundantly hornblende phenocrysts with minority of plagioclase feldspar and rare quartz. Both volcanic and sedimentary rocks were subject to strongly dynamic deformation with the shearing pattern in the northeast – southwest direction. However, shear zones do not penetrate into the dyke rocks. Generally the Au mineralization is mainly limited to the lower sequences of volcanic stratigraphy and it was also rarely found in the sedimentary rocks.

3.3 Geochemistry

Nineteen least altered and least weathered volcanic samples of the mine area were selected for geochemical analyses. All major and some trace elements of all selected volcanic rocks were analyzed using XRF and ICP OES methods. Trace and rare – earth elements of 3 volcanic samples were analyzed by ICP MS. All of the chemical results are present in Tables 1, 2 and 3.

Classical classification of volcanic rocks using silica versus alkali concentration[8] (Fig.5) and trace-element ratio[9] (Fig.7) in the Harger diagram is not definitely applicable(see Fig.5). This is because the rocks were subject to subsequent intense alteration. However,

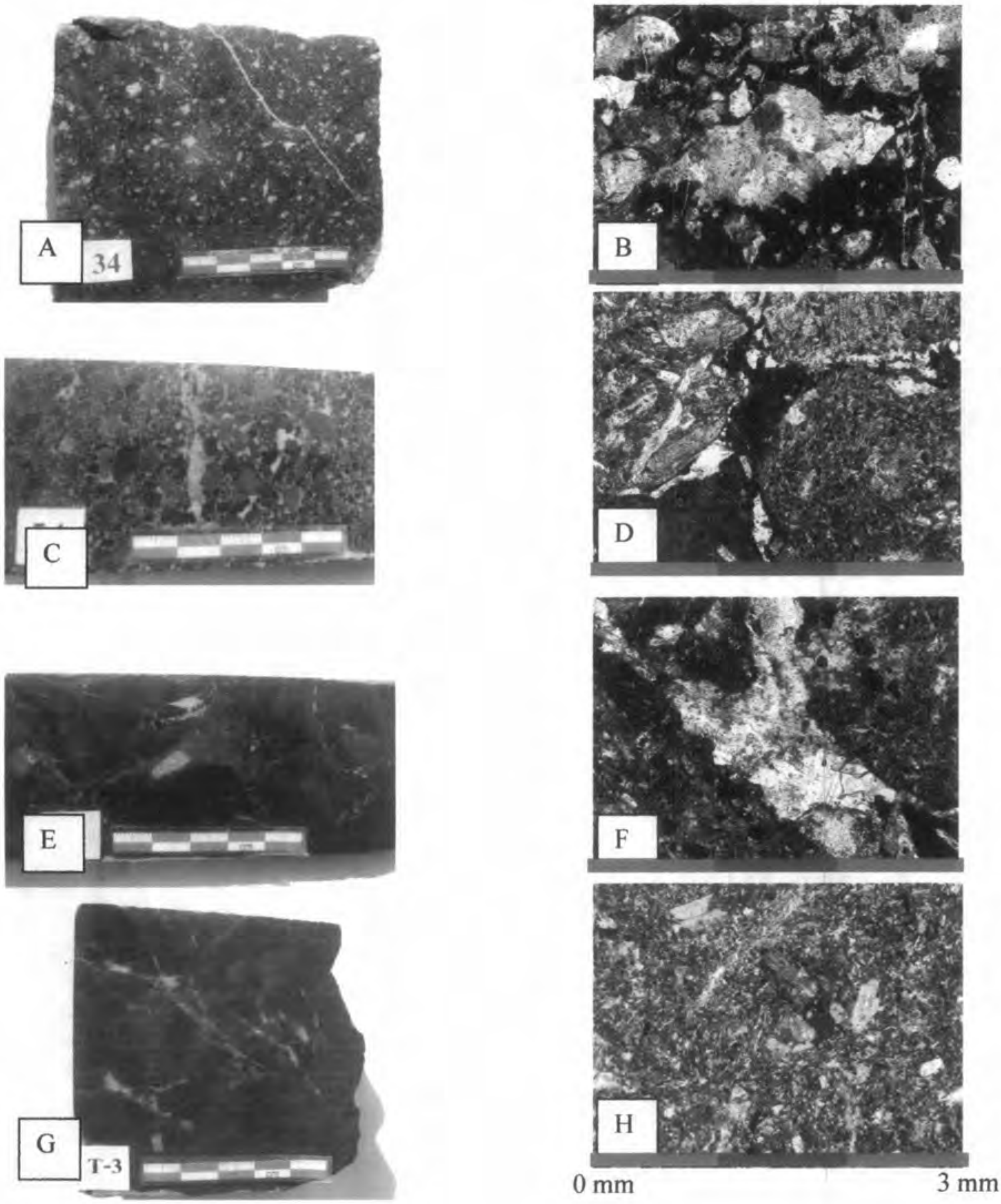


Figure 4. Handspecimen (left) and thin-section (right)of some volcanic rocks at the chatree Au mine. A and B – Fiamme breccia showing stretched feldspar phenocryst. C and D – Polymictic breccia showing different kins of rock fragment, a= andesite porphyry fragment and b= strongly altered and inequigranular volcanic fragment. E and F – Monomictic breccia showing veinlets with calcite mineral assemblage-epidote-opaque.G and H- Andesite showing microlite and deritrified glass ingroundmass and flow texture.(Long axis of all photomicrographs is about 3 mm)

Table 1. Major-oxide content of the Chatree volcanic rocks* determined using XRF method[6].

Sampleno	Na_2O	P_2O_5	MgO	Al_2O_3	SiO_2	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
1	0.01	0.26	4.35	16.95	61.57	1.84	4.68	1.47	0.67	0.26	7.89
2	0	0.28	3.72	16.72	58.03	0.64	4.49	6.9	0.67	0.37	7.90
3	1.79	0.21	6.21	14.69	58.18	0.21	4.05	3.38	0.88	0.38	9.61
4	0.59	0.31	6.66	16.66	52.55	1.37	9.9	2.04	0.78	0.50	8.80
5	2.79	0.14	7.52	17.09	51.28	0.09	3.62	3.79	0.81	0.28	11.67
6	1.83	0.22	5.72	15.76	56.41	0.54	2.57	5.22	0.68	0.37	10.35
7	0	0.57	3.09	15.57	55.45	8.15	6.71	1.91	0.49	0.17	7.32
8	0.17	0.20	3.84	17.05	59.81	0.84	0.14	8.37	0.43	0.16	8.67
9	0.42	0.22	5.33	20.55	49.31	0.54	0.55	9.91	0.62	0.22	11.71
10	1.03	0.17	5.82	17.50	52.97	0.47	4.52	5.79	0.64	0.33	10.24
11	0.73	0.23	6.31	15.86	55.53	0.12	4.95	4.28	0.71	0.37	10.40
12	1.88	0.09	2.59	15.85	67.06	0.06	1.33	3.90	0.41	0.11	6.40
13	1.60	0.12	6.28	14.87	59.10	0.48	4.75	3.42	0.56	190.07	8.03
14	1.46	0.16	5.15	13.59	65.83	1.26	4.60	2.18	0.44	0.22	5.34
15	0	0.11	0.33	3.03	90.57	1.87	1.96	0.56	0.13	0	1.20
16	0	0.30	5.07	15.25	49.55	2.48	2.39	8.60	0.43	0.46	15.47
17	3.25	0.21	7.28	16.21	53.36	0.16	0.38	9.85	0.81	0.17	7.98
18	2.57	0.06	2.07	13.18	72.78	0.26	1.86	3.33	0.31	0.09	3.50
19	1.41	0.12	5.16	15.02	60.78	0.57	5.81	2.68	0.54	0.23	7.38

* see location in Fig.3

Sample no.	Cr	Sr	Ba	Li	V	Zn	Mg	Cu	Ni	Rb	Sc	Ce	Y	Zr
T-1	7.247642	47.2921	23.93694	260.0277	260.0277	65.72182	19119.97	78.14635	0	386.5902	48.24366	20.67797	15.17074	37.99835
T-2	10.98817	121.4105	694.1159	101.7973	175.1793	65.72813	14083.23	83.28434	4.592359	285.1089	45.31606	25.41583	14.85341	31.03669
T-3	4.291564	94.55237	1091.861	203.4428	203.4428	70.06434	24005.17	114.064	9.213806	863.24	904.6282	29.49403	21.08828	53.11488
T-4	4.618939	147.9753	1566.856	230.499	230.4988	89.7408	25364.34	117.2653	0	518.1374	37.95195	26.77292	17.95314	46.41834
T-5	31.64797	245.7673	1383.181	248.7753	248.7753	57.05313	27022.57	138.5646	8.003218	203.261	40.27251	17.83095	18.92566	22.70291
T-6	8.162258	124.3612	409.3175	255.3235	255.3235	76.6597	22776.27	99.98043	5.560358	847.0631	884.6461	25.45044	19.80335	45.2297
T-7	11.64348	80.34251	1879.767	211.1648	211.1648	71.6408	13413.49	118.3136	0	473.0567	36.84384	14.17983	12.17745	10.84253
T-8	27.646	243.3455	53.30513	160.1454	160.1454	55.97269	15848.96	180.0141	0	813.6046	843.9596	16.72282	14.64856	21.81877
T-9	23.46831	280.7424	110.1219	225.0874	225.0874	71.37363	21165.34	158.1917	0	808.7792	837.1094	21.89187	16.37664	26.90448
T-10	31.88909	134.9655	1298.524	126.0417	197.8658	68.88159	22458.87	83.49722	4.54387	211.8061	55.80953	13.54478	12.20864	21.36391
T-11	10.98443	78.89476	1024.57	220.5577	220.5577	70.39692	24614.78	82.90227	5.842268	843.5077	886.4797	23.82294	21.35083	5.658792
T-12	13.65285	200.5796	27.83236	101.0171	101.0171	47.89534	6921.726	32.26628	0	884.2756	920.8905	21.9188	20.03288	38.41056
T-13	20.35748	164.5924	1623.484	144.9707	144.9707	46.93545	20910.65	51.95045	2.139597	271.8332	30.34053	16.36531	18.09786	30.12657
T-14	[illegible]	[illegible]	[illegible]	119.2749	120.1822	47.27547	17948.54	39.82198	0	196.9612	43.10705	18.52152	13.07345	29.70891
				104.5952	24.76784	9.671008	387.8206	28.4632	0	72.3301	25.98684	10.23789	6.022536	8.724792
				142.1881	178.2824	91.30588	20941.49	69.02666	4.718524	88.24127	45.62862	25.66975	8.138238	12.77893
				223.5327	223.5327	71.34646	22950.27	41.90748	14.06377	867.1188	899.4156	23.77726	16.54964	62.09784
T-18	2.214706	171.1564	422.451	29.34899	29.34899	33.71765	6180.189	25.52711	0	144.9776	27.13981	21.88196	41.91924	41.93029
T-19	19.8163	118.4917	1354.122	134.2519	134.2519	54.82234	18274.11	70.58256	0	338.4095	44.06575	17.60696	12.38579	24.74741

* see location in Fig.3

Table 2. Trace and selected REE concentrations of the Chatree volcanic rocks* determined using ICP OES method[6].

Table 3. Trace and REE concentrations of the chatree volcanic rocks* determined using ICP MS method[6].

Sample no	Sc	Mn	Co	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr
1	23.32	3303	25.83	83.32	76.32	23.01	136.80	35.86	14.99	72.08	2.71	1.89	208.9	5.51	12.34	1.67
11	25.30	3688	22.33	95.77	101.50	21.06	97.86	71.51	14.96	67.67	2.53	0.94	786.1	6.70	14.78	1.82
19	22.50	1887	15.89	79.89	79.91	13.32	74.62	111.60	10.78	44.44	1.01	0	1074	3.56	8.35	1.12

Sample no	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Bi	Th	U
1	7.74	2.03	0.61	2.47	0.39	2.44	0.52	1.53	0.25	1.68	0.29	1.48	0.17	7.19	0.01	0.95	0.33
11	8.17	2.17	0.91	2.01	0.33	2.30	0.46	1.34	0.21	1.28	0.22	1.16	0.20	1.17	0	0.70	0.19
19	4.92	1.19	0.87	1.61	0.25	1.73	0.41	1.42	0.21	1.36	0.20	1.04	0.07	2.26	0.02	0.59	0.19

* see location in Fig.3

classification of rocks using immobile trace elements[9] displays a much better result. As shown in Fig.7 , the studied volcanic rocks are mainly limited to andesite and basaltic andesite (Fig. 6), corresponding to that of the petrographic investigation. By using the Zr-Ti diagram[10] shown in Fig. 8 , they are limited to calc - alkaline composition.

4. Discussion

More importantly, our geochemical results, particularly those of the trace and REE concentrations in spider and discrimination diagrams, were used in deciphering the tectonic setting of the volcanic rocks within the Chatree mine.The Th-Ta-Hf/3[11] tectonic discrimination diagram proposed by shows that the volcanic rocks are plotted in the volcanic arc basalts field (Fig. 9). The 2Nb-Zr/4-Y diagram[12] as shown in Fig.10 also indicates that the volcanic rocks are in the volcanic arc basalts field. When comparing the results of the studied volcanic samples with that of the REE in spider diagram [13] where the tectonic setting is subduction (Fig. 11), it is found that they are quite similar in pattern. It is quite clear that several geochemical diagrams support that the Permo-Triassic calc- alkaline volcanic rocks of the Chatree mine occurred in the volcanic arc environment of the subduction - related tectonic setting. The volcanic rocks may have situated close to the western edge of the Indochina block. These volcanic rock suites may have taken place from the partial melting of the Paleotethys oceanic slab subducted beneath Indochina block and gave rise to the generation of intermediate magma which may have extruded to become volcanic rocks of the Loei - Phetchabun - Nakhon Nayok Volcanic Belt at Chatree mine. Alteration associated with low-temperature sulfide and Au-Ag mineralization may have happened immediately afterward. Contemporaneously, structural deformation zone as part of the strike – slip compression tectonics took place. Sheared rocks may have formed and gave rise to fractures, and open spaces developed enough for the Au - Ag ore precipitation.

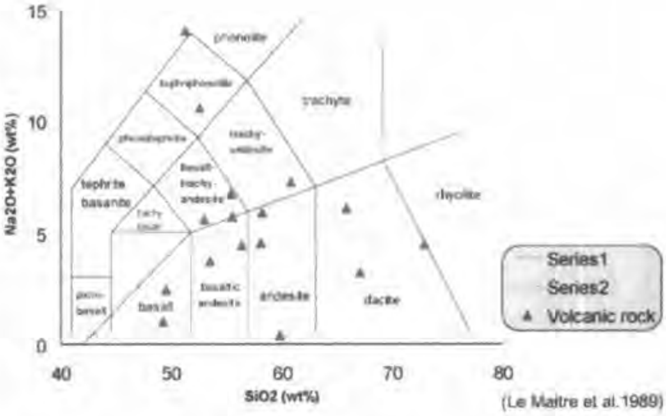


Figure 5. Plots of SiO_2 versus Na_2O+K_2O for the Chatree volcanic rocks based on the diagram of Le Maitre et al.[8]

5. Conclusions

Field, petrographic and geochemical investigations on volcanic rocks of the Chatree gold mine in Central Thailand reveal that the area is dominated by calc – alkaline, andesite to basaltic andesite. These volcanic rocks occurred as a result of compressive eastward subduction of oceanic plate beneath the Indochina block.Hydrothermal alteration and associate Au-Ag mineralization may have taken place in Permo-Triasic immediately after the calc-alkaline volcanism. Movement along the strike slip faults may have caused sheared and fractured rocks and perhaps gave rise to

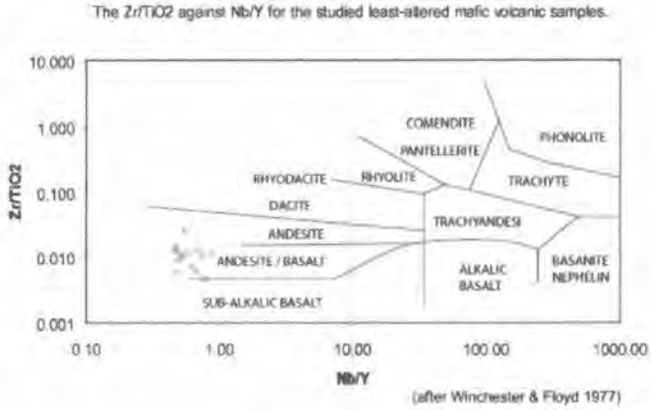


Figure 7. Plots of Nb/Y versus Zr/TiO_2 for the Chatree volcanic rocks based on the diagram of Winchester & Floyd.[9]

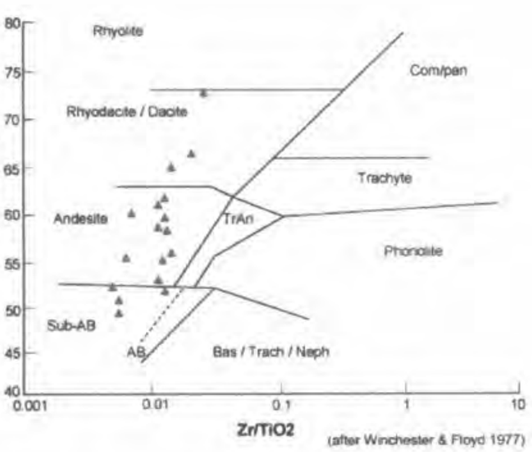


Figure 6. Plots of Zr/TiO_2 versus SiO_2 for the Chatree volcanic rocks based on the diagram of Winchester & Floyd.[9]

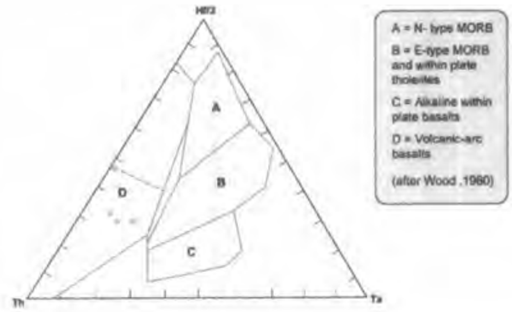


Figure9. Th-Ta-Hf/3 varition triangular diagram showing data of the Chatree volcanic rocks plotted in the field of volcanic-arc basalts. Diagram from Wood.[11]

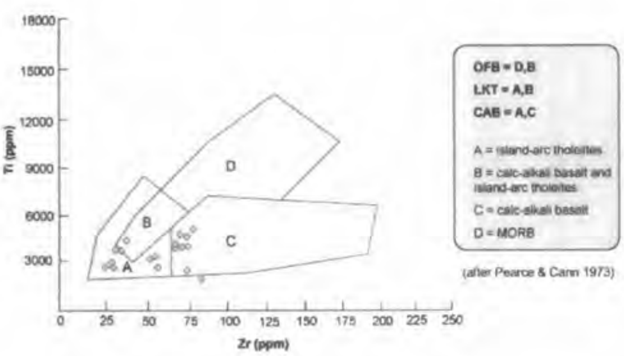


Figure 8. Plots of Zr versus Ti for the Chatree | volcanic rocks based on the diagram of Pearce & Cann.[10]

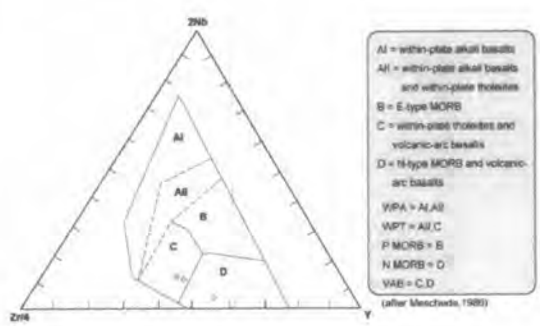


Figure10.2Nb-Zr/4-Y varition triangular diagram showing data of the Chatree volcanic rocks in the field of volcanic-arc basalts. Diagram from Meschede.[12]

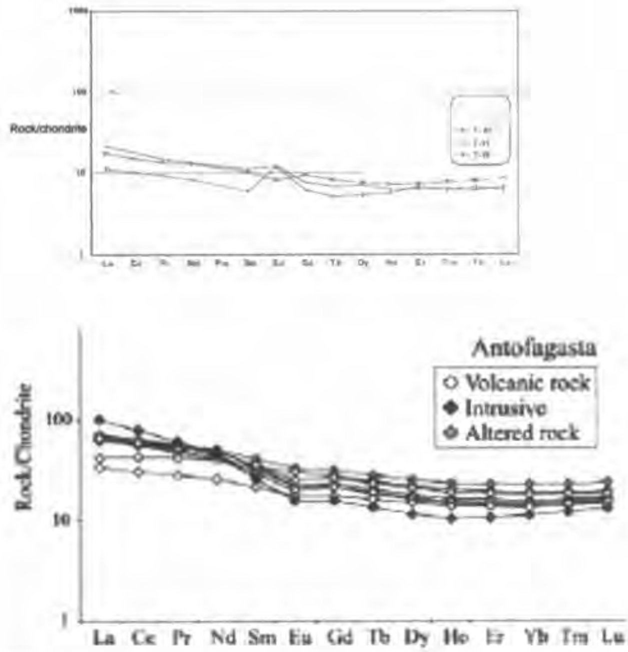


Figure11. Chondrite-normalized REE patterns for the volcanic rocks from 3 samples of the Chatree gold mine in comparision with Antofagasta volcanic rocks which is the field of subduction[13].

fluids enriched in Au-Ag ores during Permo-Triassic period.

Acknowledgements

We acknowledge Mr. Ron James and Mr. Supanit Supananthi, two senior executive managers of the Chatree mine, with sincere gratitude for their assistance during our fieldwork. We also thank Miss Teerarat Napradit, Chulalonghorn University for her administrative and non-technical work, and Miss Satou Hinako, Akita university for ICP MS analysis of volcanic rocks. We thank Department of Geology for providing facilities. This project was supported logistically by the Akara Mine and financially by research grants through PC, IT and TM.

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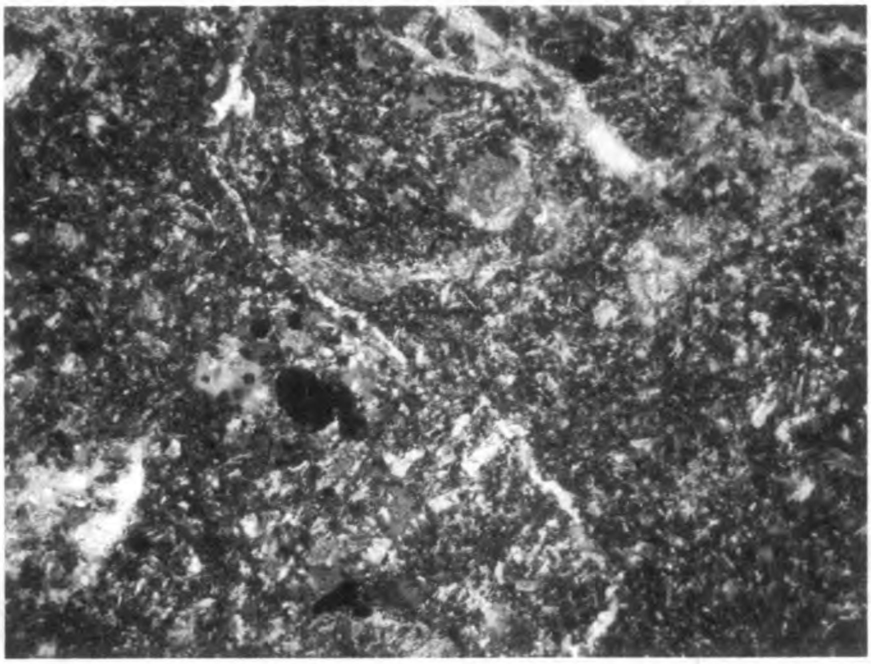
APPENDIX D.

Photomicrograph of sample in C-H pit.The long axis of photo is about 3 mm (XPL).



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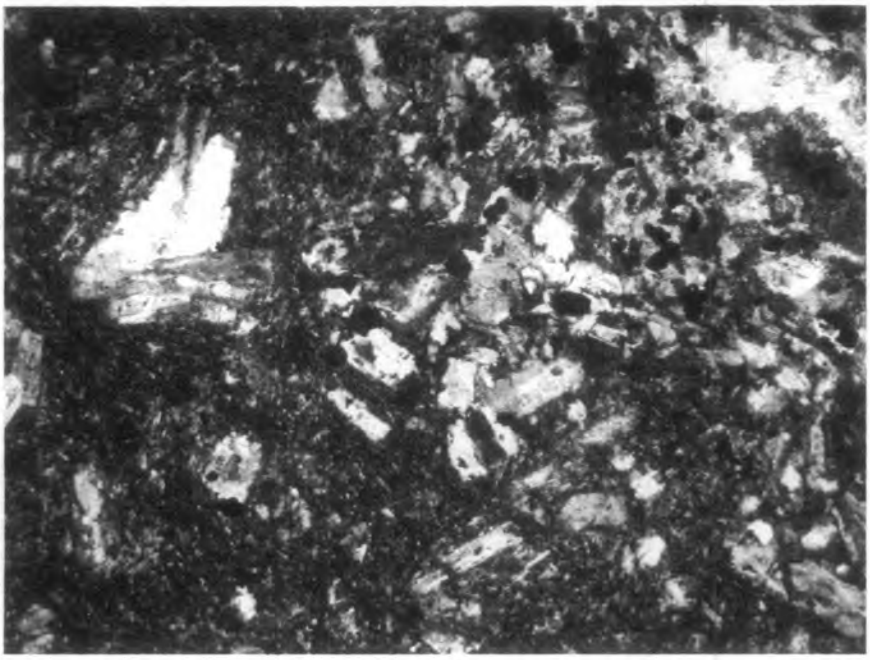

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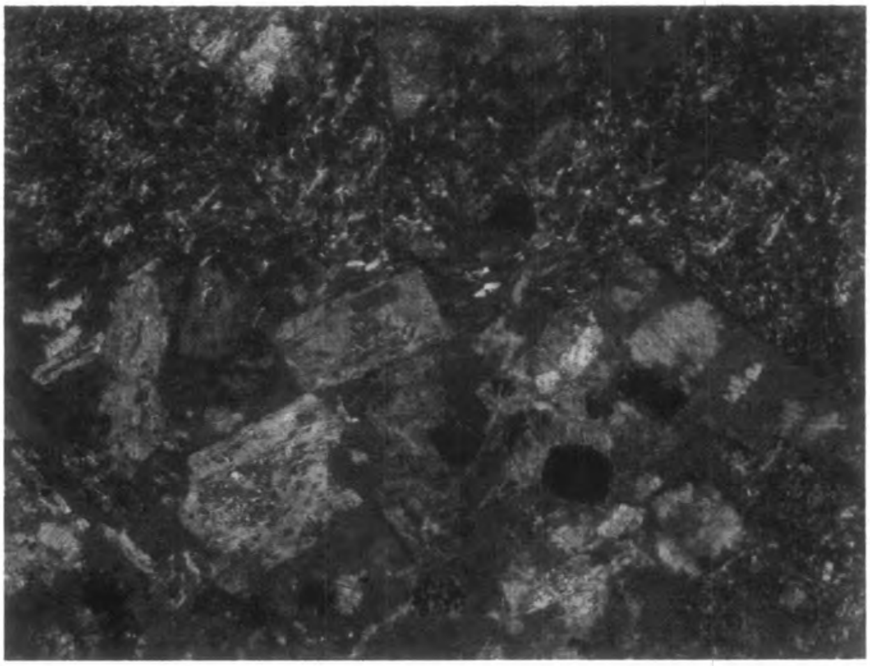

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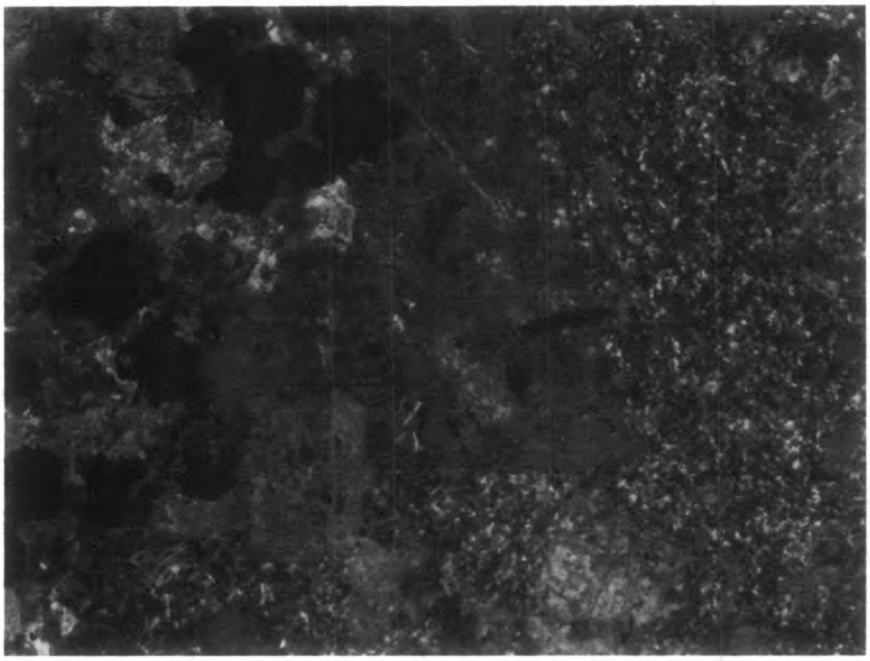

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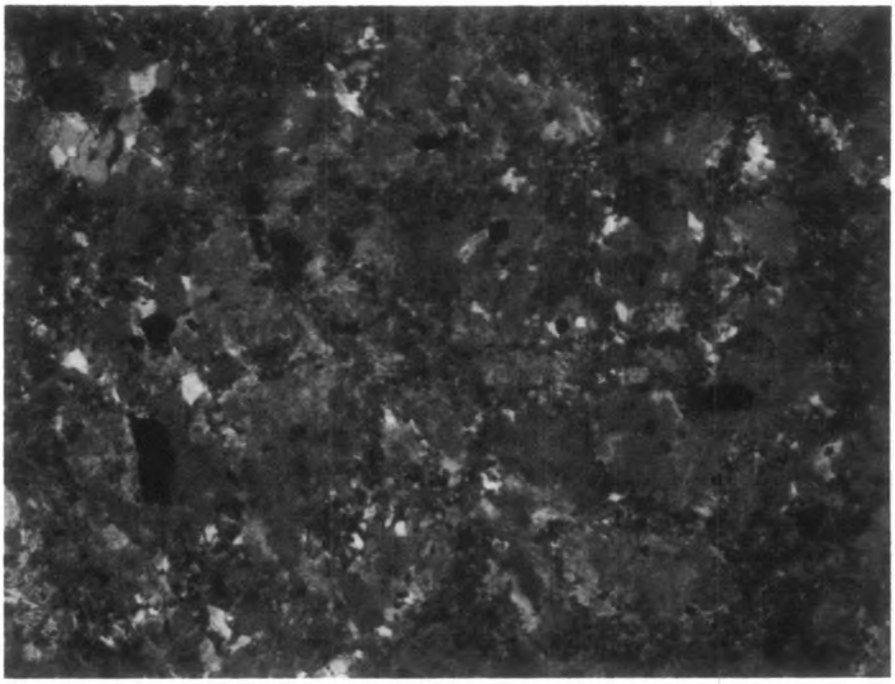

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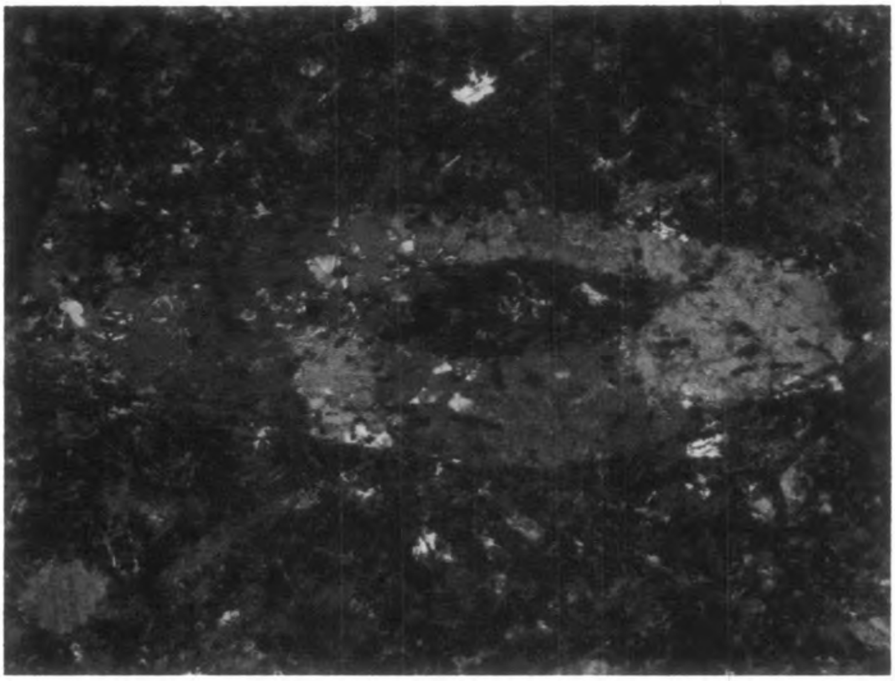

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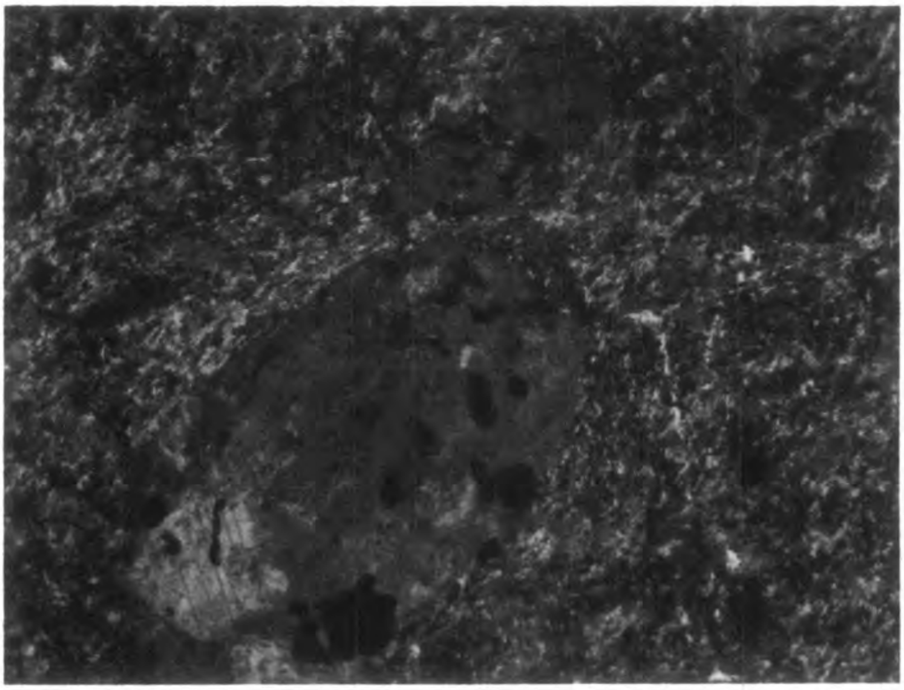

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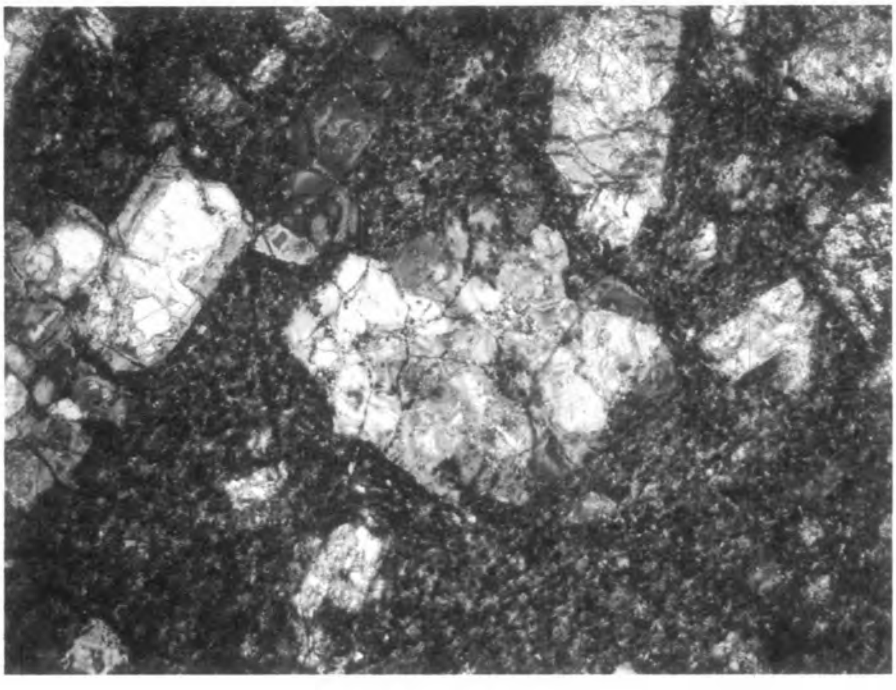

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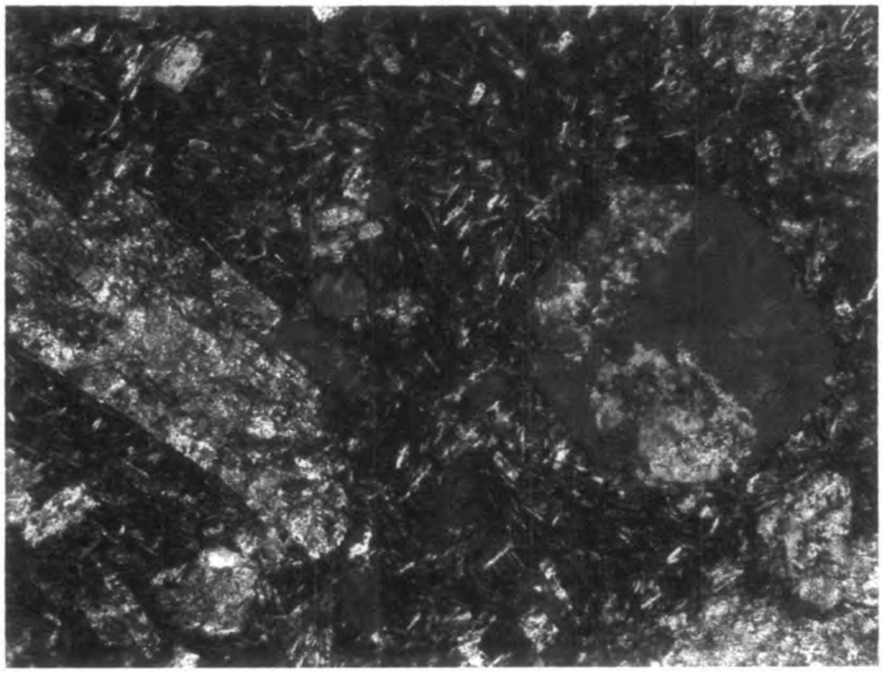

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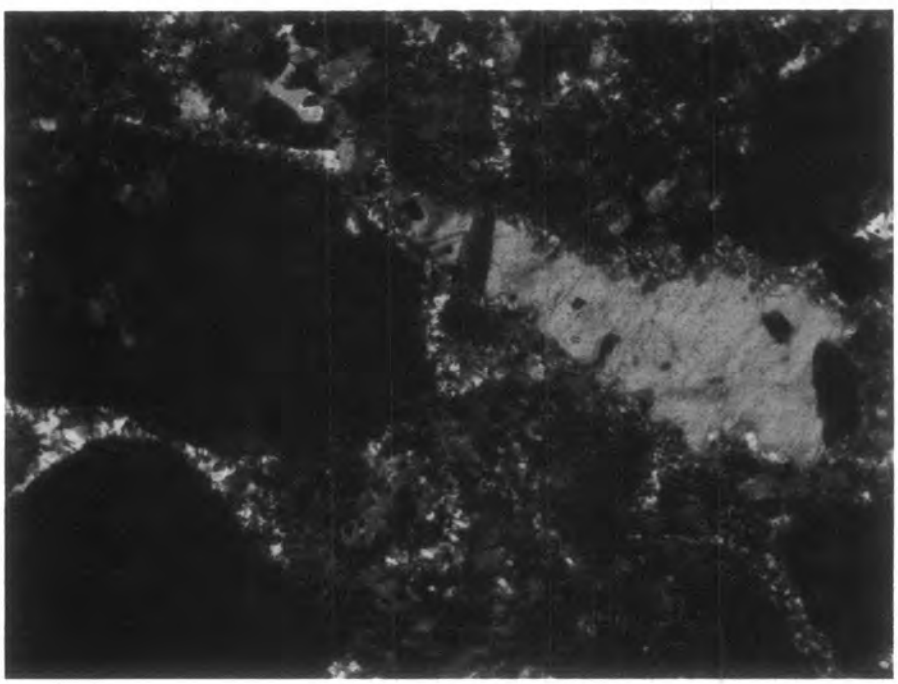

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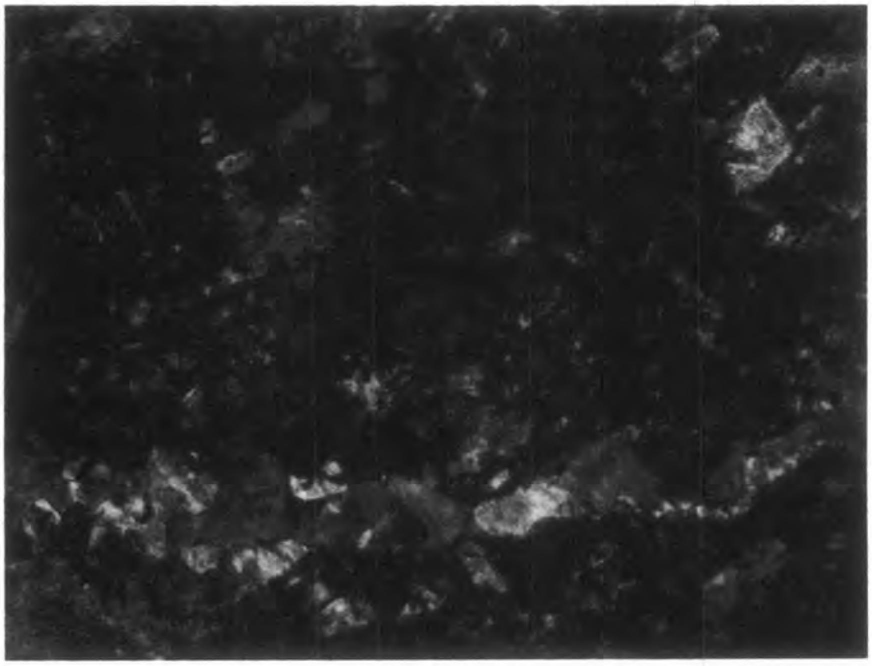

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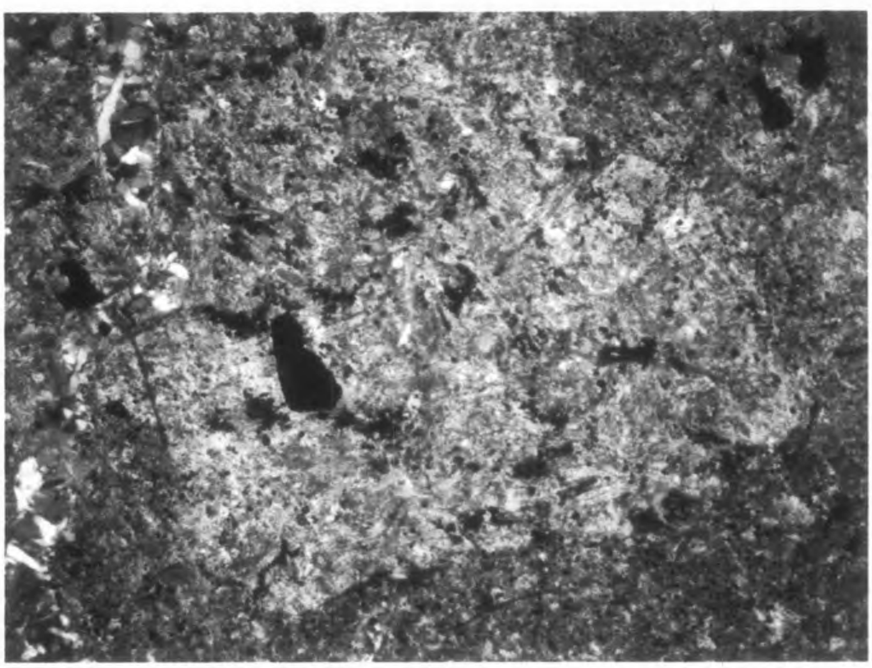

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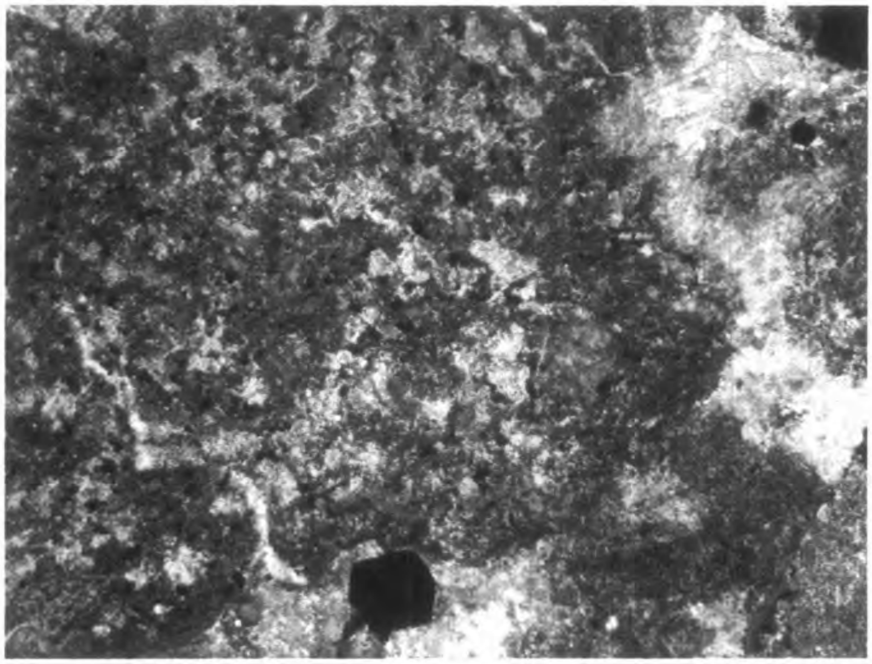

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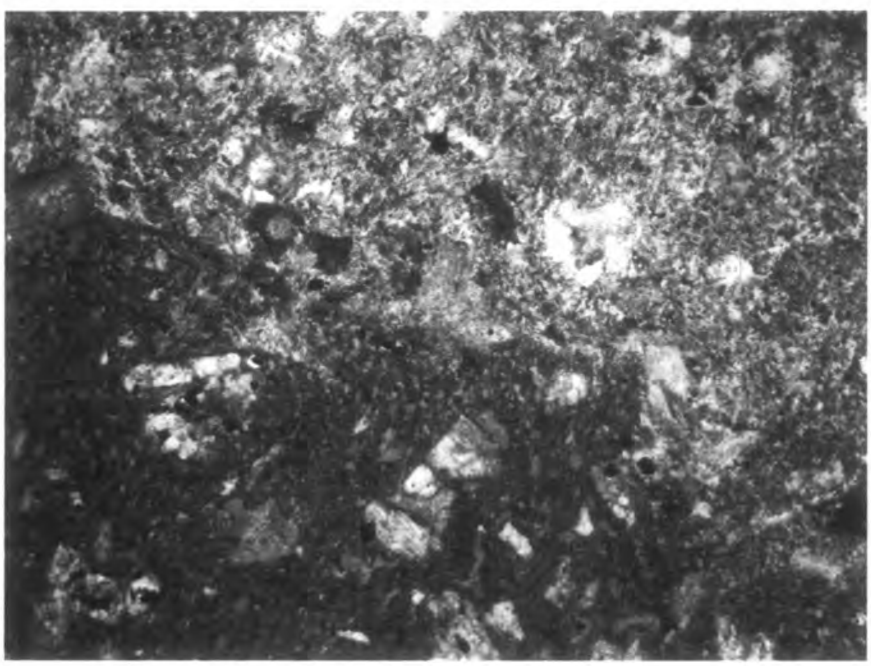

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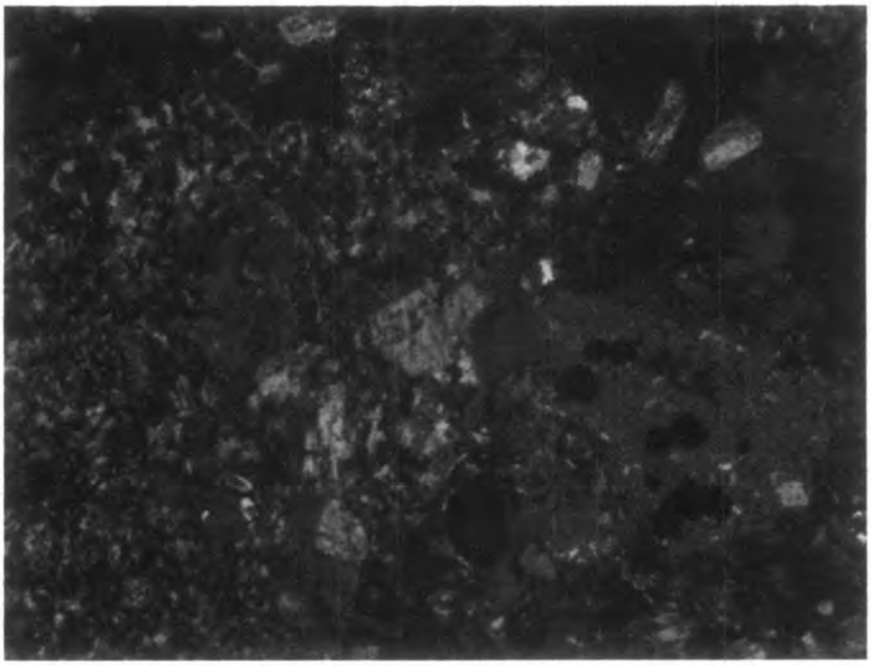

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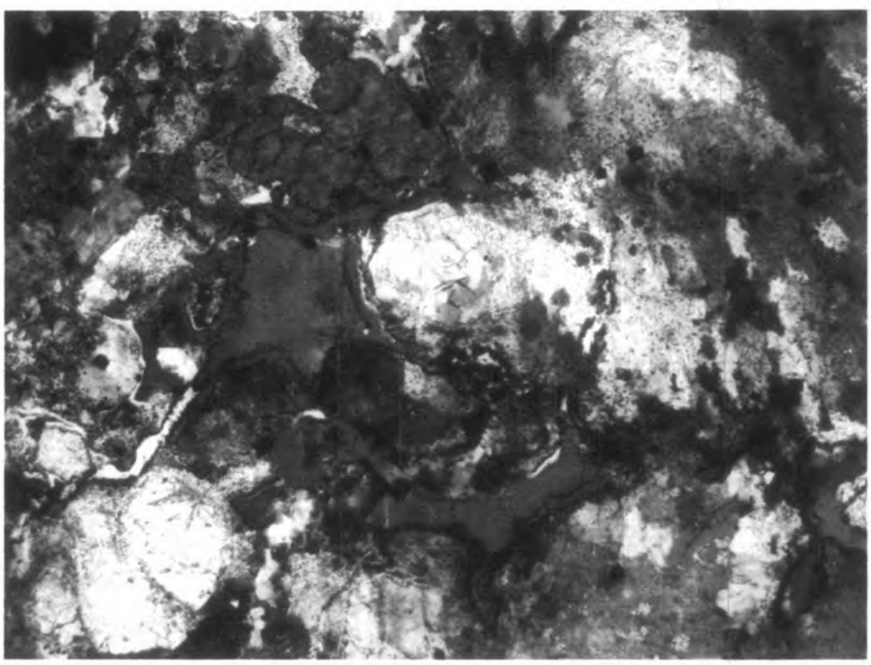

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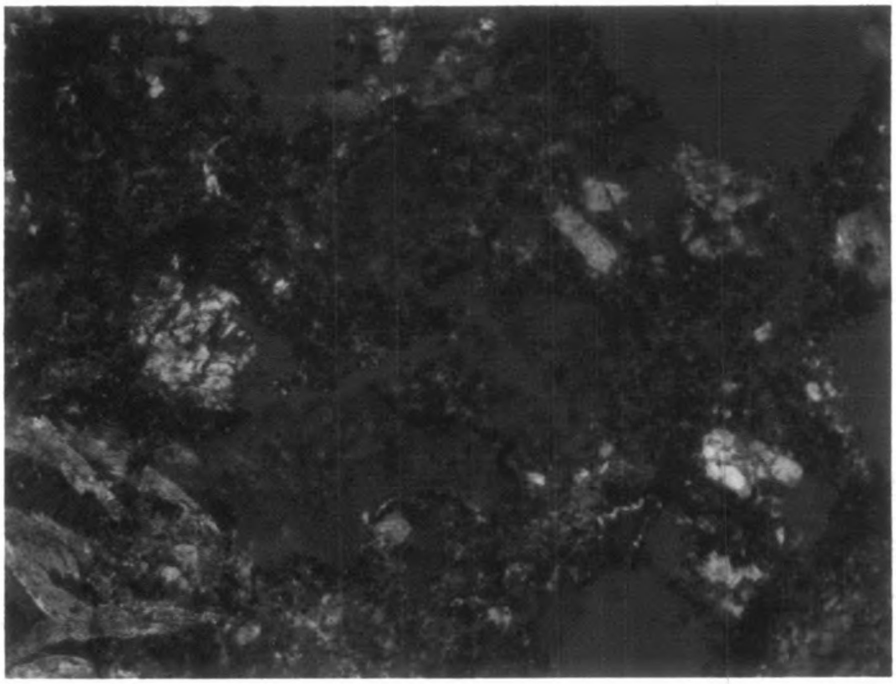

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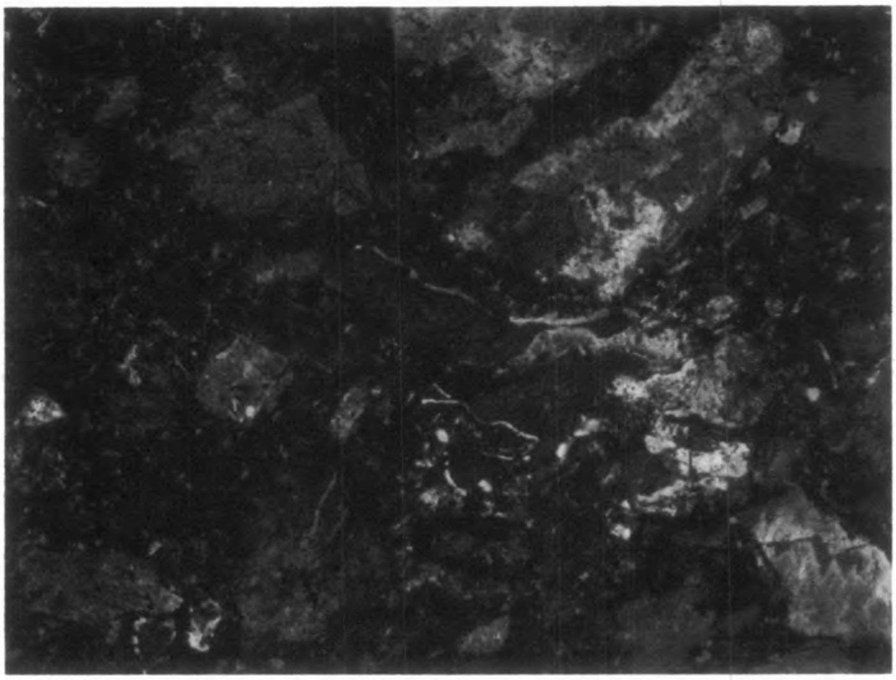

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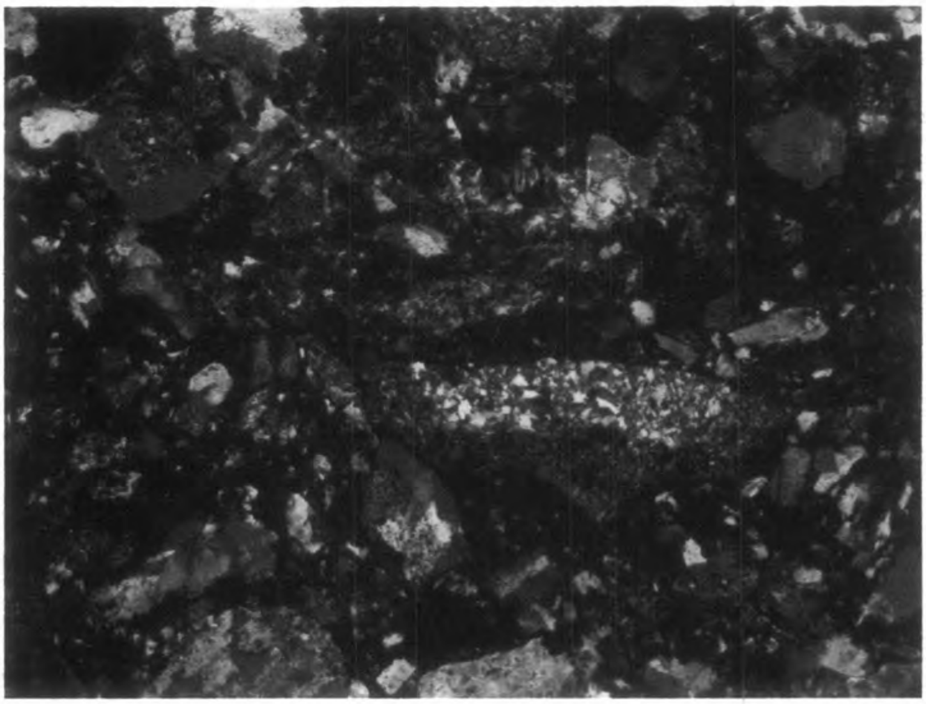

Sample no.FBR2

BIOGRAPHY

Mr. Taweewath Nakchaiya was born on February 26, 1980, at Amphoe Wisetchaichan Changwat Angthong, central Thailand. In the middle of the year 2002, after he graduated in geology from Chulalongkorn University, he started his work in Geological Survey Division, Department of Mineral Resources. In 2006, he moved to start his work in Geological Resources Conservation and Management Division . In 2008, he has worked in Bureau of Mineral Resources. He has experience in geological survey, geological mapping, Geological Resources Management and Mineral Resources survey. Contemporaneously, he also present study in Master course in geology, Department of Geology, Faculty of Science, Chulalongkorn University.