CONTENTS

	Pag e
ACKNOWLEDGEMENT	i
ABSTRACT	iii
บท คักยอ	vi
LIST OF TABLES	xvi
LIST OF FIGURES	xviii
LIST OF PLATES	xxx
1. INTRODUCTION	1
1.1 General Iocation of Deposits	ر 1
1.2 Type of Occurrence	5 1
1.2.1 Fissure Vein Type	1
1.2.2 Pegmatite Type	1
1.2.3 Cavity Filling Type	2
1.2.4 Replacemen: Type	2
1.3 Mineral Assemblages	2
1.3.1 Fluorite - (Quartz)	2
1.3.2 Fluorite - Stibnite - (Quartz)	2
1.3.3 Fluorite - Tin-Tungsten Minerals - (Quartz)	3
1.3.4 Fluorite - Stibnite - Tungsten Minerals - (Quartz)	3
1.3.5 Fluorite - Calcite	3
1.4 Topography and Climate of Northern Thailand	ers _{4.} T
1.4.1 Rainy Seasons	4
1.4.2 Winter	5
1.4.3 Summer	5

		Tabe
1.5	Geologic Setting of Deposits	5
1.6	Fluorite Districts	7
	1.6.1 Fang District	8
	1.6.2 Pai District	8
	1.6.3 Mae La Noi District	8
	1.6.4 Mae Cham District	8
	1.6.5 Ban Hong District	9
	1.6.6 Doi Tao District	9
	1.6.7 Thoen District	9
	1.6.8 Mae Tun District	10
	1.6.9 Other Deposits	10
1.7	Previous Work	11
1.8	Problems of Fluorite Genesis	. 13
	1.8.1 Age of the Fluorite Mineralization	- 13
	1.8.2 The Relationship between Fluorite Deposits	
	and Hct Springs.	14
	1.8.3 The Pressure-Temperature Conditions of Formation	14
2. THE	FLUORITE DEPOSITS	15
2.1	Introduction	15
2,2	District 1: Fang Fluorite Deposit	. 15
	2.2.1 Location	15
	2.2.2 Mine Production	ers ¹⁷
	2.2.3 Geology	17
A I	2.2.4 Fluorite Deposits	21
	2.2.5 Thermal Water	22

			Page
2.3	Distri	ct 2 : Amphoe Pai Fluorite Deposits	2 2
	2.3.1	Iocation	22
	2.3.2	Mine Production	25
	2.3.3	Geology	25
	2.3.4	Fluorite Deposits	25
		2.3.4.1 Vein no. 1	27
		2.3.4.2 Vein no. 2	28
		2.3.4.3 Vein no. 3	28
		2.3.4.4 Vein no, 4	29
		2.3.4.5 Vein no. 5	30
		2.3.4.6 Old V ein	30
		2.3.4.7 Vertical Changes in Veins	31
		2.3.4.8 Paragenesis	31
	2.3.5	Thermal Springs	32
2.4	Distri	ct 3 : Mae La Noi Fluorite Deposit	33
	2.4.1	Location	33
	2.4.2	Mine Production	33
	2.4.3	Geology	33
	2.4.4	Fluorite Deposits	36
	2.4.5	Thermal Springs	39
2.5	Mae Th	a Fluorite Deposit	. 40
	2.5.1	Location Chang Mail Iniv	40
	2.5.2	Mine Production	40
	2.5.3	Geology	42
	2.5.4	Structure	47

			${f P}$	age
		2.5.5	Fluorite Deposits	49
		2.5.6	Thermal Springs	52
	2.6	Distri	ct 5 : Ban Hong Fluorite Deposit	52
		2.6.1.	Location	52
		2.6.2	Mine Production	54
		2.6.3	Geology	54
		2.6.4	Fluorite Deposit	56
	2.7	Tha So	ng Yang Stibnite-Fluorite Deposit	65
	2.8	Distri	ct 8 : Ban Sop Lan Fluorite Deposit	69
	2.9	Ban Mu	ang Ngai Fluorite Deposit	71
	2.10	Other	Deposits	73
	2.11	Summar	y of Fluorite Varieties	75
3.	FLUI	O INCLU	SION STUDY	77
	3 _• 1	Fluid	Inclusions and Geothermometry	77
		3.1.1	Classification of Fluid Inclusions	77
			3.1.1.1 Primary Inclusions	78
			3.1.1.2 Pseudo-secondary Inclusions	80
			3.1.1.3 Secondary Inclusions	81
			3.1.1.4 Changes Since Trapping: Necking Down	
			and Coalescence.	82
		3.1.2	Fluid Inclusions in Geothermometry	83
	Co	3.1.3	Principle of Critical Phenomena of Fluid Inclusions	86
ż		3.1.4	Corrections for External Pressure and Salinity	88
		3.1.5	Type of Inclusions in Fluorite from Northern Thailand	94

			Page
3.2	Descr:	iptions of Fluid Inclusions in the Deposits	96
	3.2.1	Fang	96
	3.2.2	Amphoe Pai	99
	3.2.3	Mae La Noi	106
	3.2.4	Mae Tha	109
	3.2.5	Ban Hong	113
	3.2.6	Tha Song Yang	116
	3.2.7	Ban Sop Lan (Omkoi)	119
	3.2.8	Ban Muang Ngai	121
	3.2.9	Pa La Door	123
	3.2.10) Mae Phu	123
	3.2.11	Chom Thong	123
3.3	Heatin	g Experiments	124
	3.3.1	Homogenization Temperatures in Fang	126
	3.3.2	Homogenization Temperatures in Amphoe Pai	128
	3.3.3	Homogenization Temperatures in Mae La Noi	131
	3.3.4	Homogenization Temperatures in Mae Tha	133
	3.3.5	Homogenization Temperatures in Ban Hong	135
	3.3.6	Homogenization Temperatures in Tha Song Yang	138
	3.3.7	Homogenization Temperatures in Ban Sop Lan (Omkoi)	140
	3.3.8	Homogenization Temperatures in Ban Muang Ngai	142
	3.3.9	Critical Phenomena of Homogenization Temperatures	orcit
		in the Deposits.	144
A	3.3.10	Corrections for External Pressure and Salinity	
		(Northern Thailand)	145
	3.3.11	Summary of Results	150

			Page
4•	META	LIOGENESIS OF FLUORITE	150
٠.	4.1	Temperature - Pressure Conditions of Fluorite Deposition	
		in Northern Thailand	150
	4.2	Association with Hot spring : Model for Fluorite Deposition	152
	4.3	Chemistry of Fluorite Deposition	∮ 59
	4.4	Evidence of Mixing of Fluorine-rich Water with	
•		Shallow Ground Water.	168
	4.5	Genesis of Minor Sulphides Associated with Fluorite	173
	4.6	Tectonic Setting of the Fluorite Province	176
		4.6.1 Relation to Granites	176
		4.6.2 Relation to Cenozoic Fracturing	181
		4.6.3 Age of Mineralization	183
	4•7	Comparison with Other Major Fluorite Provinces in the World	185
	•	4.7.1 Regional Setting of the Deposits.	185
		4.7.2 Relation of Fluorite Deposits to Geophysical Propertie	s189
	4.8	Sources of Fluorine	193
	4.9	Plate Tectonic Model of Fluorite Mineralization in	
		Northern Thailand	193
•	SUMMA	RY	200
	APPEN	DIX A. GEOGRAPHICAL DATA FOR THE FLUORITE DEPOSITS	216
	APPEN	DIX B. PRODUCTION DATA FOR FLUORITE IN THAILAND	232
	APPEN	DIX C. HEATING STAGE, CALIBRATION, AND SAMPLE PREPARATION	235
	A	C.1 History and evolution of heating stage	236
		C.2 Problems	237
		C.3 The first heating stage in Thailand	238

	Page
C.3.1 Heating stage chamber	240
C.3.2 Heating equipment	242
C.3.3 Temperature-measuring equipment	244
C.4 Testing of the heating stage	245
C.5 Improvements	245
C.6 Optical limitations	246
C.7 Calibration	246
C.8 Sample preparation	249
C.8.1 Suitable materials	249
C.8.2 Polished thin sections	250
C.8.3 Technique for preparing doubly polished	
thin sections	251 ⁻
APPENDIX D. HOMOGENIZATION DATA FOR FLUID INCLUSIONS IN	
FLUORITE FROM NORTHERN THAILAND	253
APPENDIX E. HOMOGENIZATION DATA FOR FLUID INCLUSIONS IN FLUORITE	
FROM OTHER COUNTRIES	284
APPENDIX F DATA FOR HOT SPRINGS IN NORTHERN THAILAND	287
APPENDIX G SOLUBILITY DATA FOR FLUORITE	305
REFERENCES	354
VITA	3 66

ลืบสิทธิบหาวิทยาลัยเชียงใหม Copyright[©] by Chiang Mai University All rights reserved

LIST OF TABLES

Table	4.1	Comparison of the characteristics of hot springs	
	•	associated with fluorite deposits and normal	
		hot springs.	170
Table	4.2	Comparison of deposits in limestone country rocks	
		with those in granites and other rock types	172
Table	4.3	Comparison of northern Thailand fluorite province	
		and western United States province ,	192
Table	A-1	Location of deposits	217
Table	A-2.1	Climatic data: Mean rain fall (mm) in northern	
		Thailand during 1951-1975.	227
Table	A-2.2	Climatic data : Mean temperature (c) in northern	
		Thailand during 1951-1975	228
Table	A-2.3	Climatic data : Mean relative humidity (%) in	
		northern Thailand during 1951-1975.	229
Table	A-3	Comparison of elevation of fluorite deposits with	
		the nearest stream, mountain and basin elevations	230
Table	B-1	Production and export of fluorite in metric tonnages	
		during 1972-1978	233
Table	B-2	Production (in metric tonnages) of Mae Tha Mine	
Copy	rig	of Universal Mining Co., Mae Tha, Lamphun Province, 1967 - 1977.	234
Table	C-1	Calibration between temperatures in heating stage	
		recorded by melting point standards versus millivolts	
•		output recorded from DC microvoltmeter	247

			Page
Table	C-2	Mineral Samples and Index Liquids	250
Table	D-1	Homogenization temperature & phase of gaseous	
		inclusions	254
Table	D-2	Homogenization temperature for gas - liquid inclusions	255
Table	D-3	Decrepitation temperature of gaseous inclusions	274
Table	D-4.1	Statistics for primary fluid inclusions in separate	
		veins in Mahalanna Mine, Amphoe Pai	276
Table	D-4.2	Statistic for primary fluid inclusions in separate	
		colours in Mahalanna Mine, Amphoe Pai ; South Pacific	
		Mine, Tha Song Yang; and Ban Sop Lan deposit, Omkoi	277
Table	D-4.3	Statistics for primary fluid inclusions in separate	
		zones in deposits	279
Table	D-5	Summary of data of homogenization temperatures for	
		each deposit	282
Table	E-1	Homogenization temperatures for fluid inclusions in	
		fluorite from other countries	285
Table	F-1	General descriptions of hot springs in northern	
		Thailand	288
Table	F-2	Chemical analysis of thermal waters in northern	
		Thailand Tha	298
Table	F-3	Subsurface temperature of hot springs	303
Table	G-1	Solubility (L) of fluorite from 20°c to 350°c	306
Table	G - 2	Solubility (L) of CaF in the ternary system	
		4 E M-43 II 0	307
		<u> </u>	<i>~</i> ~ 1

xviii

LIST OF FIGURES

		Libi or rigorms	?age
Fig.	1.1	Fluorite districts and fluorite province, northern	
		Thailand	6
Fig.	2.1	Location map of the Fang fluorite deposits (Thepnithi Mir	1e)16
Fig.	2.2	Geologic map of Amphoe Fang	18
Fig.	2.3	Geologic map of Thepnithi fluorite mine, Fang, Chiang Mai	<u>i</u> 20
Fig.	2.4	Location map of the Amphoe Pai fluorite deposits	
		(Mahalanna Mine)	23
Fig.	2.5	Geologic map of Amphoe Pai	24
Fig.	2.6	Geologic map of Mahalanna Mine, Amphoe Pai	26
Fig.	2.7	Breccias of early fluorite and quartz filled by late	
		fluorite at Vein no.1, Mahalanna Mine, Amphoe Pai	27
Fig.	2.8	Changes in attitude of the Vein no. 2, Mahalanna Mine,	
÷		Amphoe Pai	28
Fig.	2.9	Cross section of the Vein no. 4, Mahalanna Mine, Amphoe	
		Pai	29
Fig.	2.10	Cross section of the Vein no. 4, Mahalanna Mine, Amphoe	
		Pai	30
Fig.	2.11	Cross section of the Vein no. 5, Mahalanna Mine, Amphoe	
		Pai	30
Fig.	2.12	Ideal vertical section of fluorite veins at Mahalanna Min	ie. 31
Fig.	2.13	Paragenesis of ore minerals at Amphoe Pai deposits	I, II t
		(Mahalanna Mine)	32
Fig.	2.14	Location map of the Mae La Noi fluorite deposits	
		(S.P. Mine)	34
Fig.	2.15	Geologic map of Mae La Noi fluorite deposit	. 35

			Page
F i g	. 2.16	Idealized geologic cross section of the Ordocician	
		formation at S.P. Mine, Mae La Noi	36
Fig	. 2.17	Fluorite and calcite filled the cavity at Location G,	
		S.P. Mine, Mae La Noi. Calcite filled later than	
		fluorite	37
Fig.	2.184	Fluorite deposit at crest of anticline, Japanese open	
		cut, S.P. Mine, Mae La Noi	3 8
Fig.	2.18E	The true-scale size of the thin-layered pale purple	
		fluorite described in Fig. 2.18A.	38
Fig.	2.19	Paragenesis of ore minerals at Mae La Noi deposits	
		(S.P. Mine)	39
Fig.	2.20	Location map of the Mae Tha fluorite deposits	
		(Universal Mine and Thepnithi Mine)	41
Fig.	2,21	Geologic map of Mae Tha fluorite deposit, Universal	
٠		Mining Co., Mae Tha, Lamphun	43
Fig.	2,22	Geologic map of Thepnithi open cut mine, Mae Tha,	
		Lamphun	44
Fig.	2,23	Stratigraphic column in the Universal Mine, and	
		Thepnithi Mine region, Mae Tha	46
Fig.	2.24	Section on the north flank of the vein in Universal's	lui
		claim.	48
Fig.	2.25	Paragenesis of ore minerals at Mae Tha deposits	
		(Universal Mine and Thepnithi Mine)	51
Fig.	2.26	Location map of the Ban Hong fluorite deposits	
·		(Universal Mine and Thai Fluorspar Mine)	53

		Æ	Page
Fig.	2.27	Ban Hong fluorite deposits	57
Fig.	2.28	Geologic map of fluorite deposit, Universal Mining Co.,	-
		Ban Hong, Lamphun,	58
Fig.	2.29	Geologic map of Universal fluorite mine, Ban Hong,	
		Lamphun	59
Fig.	2.30	Geologic map of fluorite deposit, Thai Fluorspar &	÷
		Minerals Co. s Mine	60
Fig.	2.31A,	B X-section perpendicular to the length of fluorite vein	
		at Thai Fluorspar Mine, Ban Hong.	62
Fig.	2.32	Concentrically layered fluorite surrounded rock nucleus	64
Fig.	2.33	Vugs in fluorite.	64
Fig.	2.34	Paragenesis of ore minerals at Ban Hong deposits	
		(Universal Mine and Thai Fluorspar Mine)	65
Fig.	2.35	Location map of the Tha Song Yang fluorite deposit	
		(South Pacific Mine)	66
Fig.	2.36	Pockets of stibnite-fluorite concentrate at the	
		intersection of joints in sandstone.	68
Fig.	2.37	Fluorite, quartz, and stibnite filled in cavity at	
		crest of anticline, South Pacific Mine, Tha Song Yang	68
Fig.	2.38	Location map of the Omkoi fluorite deposit (Ban Sop Lan)	70
Fig.	2.39	Location map of the Chiang Dao fluorite deposit	
		(Ban Muang Ngai)	72
Fig.	3.1	Necking down of a long tubular inclusion	83
Fig.	3.2	Temperature-density diagram for the system H20, plotted	e
		from the data of Kennedy (1950 b), and Maier and Franck	
		(1966)	07

			Page
Fig.	3.3	P-X diagram of coexisting liquid and gas phases in the	
		system NaCl-H ₂ O	90
Fig.	· 3•4	Critical point curve for solutions of NaCl	91
Fig.	3 •5	The temperature at formation of the fluid inclusions	•
		versus depth of burial can be inferred from the	
		homogenization temperature and the pressure corrections	
		of Lemmlein and Klevtsov (1961)	93
Fig.	3.6	Primary fluid inclusions in fluorite from Fang	
		(Thepnithi Mine)	97
Fig.	3. 7	Primary and pseudo-secondary fluid inclusions in fluorite	е
		from Amphoe Pai (Mahalanna Mine)	101
Fig.	3.8A.	Necking down.	104
	3.8B.	Primary fluid inclusions with 2 liquids and 1 vapour	
		bubble.	104
Fig.	3. 9	Primary fluid inclusions in fluorite from Mae La Noi	
		(S.P. Mine)	108
Fig.	3.10	Primary fluid inclusions in fluorite from Mae Tha	
		(Universal Mine and Thepnithi Mine)	111
Fig.	3.11	Primary fluid inclusions in fluorite from Ban Hong	
		(Universal Mine and Thai Fluorspar Mine)	115
Fig.	3.12	Fluid inclusions in fluorite from Tha Song Yang	
		(South Pacific Mine)	117
Fig.	3.13	Fluid inclusions in fluorite from Ban Sop Lan (Omkoi)	120
Fig.	3 . 14	Primary fluid inclusions (Types 2,3) in fluorite from	
		Ban Muang Ngai (Chiang Dao)	122

xxii

			Page
Fig.	3.15	Histogram for fluid inclusions in fluorite from Fang	
		(Thepnithi Mine)	127
Fig.	3.16	Histogram for fluid inclusions in fluorite from	<i>:</i>
		Amphoe Pai (Mahalanna Mine)	129
Fig.	3.17	Histogram for fluid inclusions in fluorite from	
		Mae La Noi (S.P. Mine)	132
Fig.	3.18	Histogram for fluid inclusions in fluorite from	
		Mae Tha (Universal Mine and Thepnithi Mine)	134
Fig.	3.19	Histogram for fluid inclusions in fluorite from	
		Ban Hong (Universal Mine and Thai Fluorspar Mine)	136
Fig.	3,20	Histogram for fluid inclusions in fluorite from	
		Tha Song Yang (South Pacific Mine)	139
Fig.	3.21	Histogram for fluid inclusions in fluorite from	
		Ban Sop Lan (Omkoi)	141
Fig.	3.22	Histogram for fluid inclusions in fluorite from	
		Ban Muang Ngai (Chiang Dao)	142
Fig.	3.23	Boiling-point curves for H20 liquid (o wt percent) and	
		for brine at constant composition given in wt percent	
		NaCl.	146
Fig.	3.24	The difference (in c) of boiling temperature between	
		H ₂ O and 25 wt % NaCl brine at different depths	147
Fig.	3 . 25	Comparison for the results of each deposits	149
Fig.	4.1	Schematic model for a hot-spring having a heat source of	
		unspecified nature and interconnected permeability	155

xxiii

			Page
Fig.	4.2	Schematic model (A) for obtaining a mixed-water waxm	
		spring in which both the enthalpy and silica content of	
	•	the hot-water content are the same as in the original	
		deep water (model I) and schematic model (B) in which	
		the hot-water component has lost steam before mixing	
		with cold water (model 2)	156
Fig.	4•3	Location of hot springs of northern Thailand	157
Fig.	4•4	Solubility of fluorite in the system CaF2-NaCl-H2O in	
		solutions of constant NaCl concentrations	160
Fig.	4.5	Schematic model for early stage fluorite deposition	164
Fig.	4.65	Schematic model for late stage fluorite deposition	166
Fig.	4.7	Generalized geological map with sample localities and	
		ages of intrusions	178
Fig.	4.8	Location of fluorite deposits and hot springs of	
		northern Thailand	182
Fig.	4.9	The main fluorite producing countries of the world	186
Fig.	4.10	Tectonic setting of Malay peninsula during the	
		Carboniferous to Late Triassic	196
Fig.	4.11	Post-Jurassic evolution of Burmese Malayan orogen	196
Fig.	4.12	Model for fluorite generation and deposition in norther	n
		Thailand	197
Fig.	5.1	Ideal cross section of fluorite ore body	210
Fig.	C•1	Heating stage equipments	239
Fig.	C.2	Side view of the heating stage	241
Fig.	C. 3	Heating stage and thermocouple	243

		Page
Fig. C.4	The thermocouple	244
Fig. C.5	Calibration between millivolts output from DC	
	microvoltmeter versus temperature of heating stage by	
	using M.P. standard.	248



ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่ Copyright[©] by Chiang Mai University All rights reserved

LIST OF PLATES

	•	
		Page
Plate 1	Photomicrographs of fluid inclusions in fluorite	
	from Ban Sop Lan	309
Plate 2	Photomicrographs of primary fluid inclusions in fluorite	312
Plate 3	Photomicrographs of primary and pseudo-secondary fluid	
	inclusions in fluorite from Mahalanna Mine, Amphoe Pai	315
Plate 4	Photomicrographs of primary and pseudo-secondary fluid	
	inclusions in fluorite from Universal Mine, Mae Tha	317
Plate 5	Photomicrographs of solid and fluid inclusions in	22
	fluorite	319
Plate 6	Photomicrographs of secondary fluid inclusions in	
	fluorite	321
Plate 7	Photomicrographs of fluid inclusions in fluorite	323
Plate 8	Photomicrographs of primary fluid inclusions in fluorite	326
Plate 9	Photomicrographs of primary fluid inclusions in fluorite	329
Plate 10	Photomicrographs of primary fluid inclusions in fluorite	331
Plate 11	Photomicrographs of primary fluid inclusions in fluorite	334
Plate 12	Photomicrographs of fluid inclusions in fluorite	337
Plate 13	Serial photomicrographs of inclusions in fluorite to	Tui
	show homogenization with increasing temperature. Taken	
	on heating stage	339
Plate 14	Serial photomicrographs of inclusions in fluorite to	
~ I	show homogenization with increasing temperature. Taken	
	on heating stage.	34 1

	Page
Serial photomicrographs of inclusions in fluorite to	
show homogenization with increasing temperature. Taken	
on heating stage.	343
Serial photomicrographs of inclusions in fluorite to	
show homogenization with increasing temperature. Taken	
on heating stage.	345
Varieties of fluorite in hand specimen	347
Varieties of fluorite in hand specimen	349
Fluorite and gangues in fluorite deposits	351
Fossils in limestone from Universal Mine, Mae Tha,	,
Lamphun	353
	show homogenization with increasing temperature. Taken on heating stage. Serial photomicrographs of inclusions in fluorite to show homogenization with increasing temperature. Taken on heating stage. Varieties of fluorite in hand specimen Varieties of fluorite in hand specimen Fluorite and gangues in fluorite deposits Fossils in limestone from Universal Mine, Mae Tha,

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่ Copyright[©] by Chiang Mai University All rights reserved

FC MAI