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August 28, 1985

MEMO TO: Don Cross
David Carson

FROM: Elizabeth Clemson

SUBJECT: Rare Earth Element Mineralogy
Gem Prospect, B.C.

A mineralogical study of three samples from the Gem prospect in central British Columbia was undertaken in order to identify the mineral phases containing reported rare earth elements (REE). Detailed petrographic descriptions of each sample are in Appendix I. In addition to petrographic observations and electron microprobe analysis of mineral phases, whole rock samples were analyzed for REE, Au, As and Co by X-ray Assay Laboratories (Table 1).

Several rare earth-bearing minerals have been identified by electron microprobe. These are:

Allanite $(Ca,Ce,Th)_2(Al,Fe,Mn,Mg)_3(SiO_4)_3OH$,

Bastnaesite $CeFCO_3$, and

Monazite $(Ce,Y)PO_4$.

The abundance and relative proportions of these minerals varies from sample to sample.

Allanite is the Ce-rich member of the epidote group in which REE substitute for Ca^{+2}. In the Gem samples allanite forms euhedral, strongly zoned, prismatic grains intergrown with sulfides and silicates (Figures 1 and 2). It is commonly twinned and zoned from a dark brown core to a light brown margin (Figures 3 and 4). Textural relationships indicate allanite formed early in the crystallization history along with the sulfides. Allanite commonly forms euhedral inclusions in the sulfides. Allanite is the principal rock forming mineral constituting 45% of sample GM-2, it is partly altered to chlorite and calcite in sample GM-1, and was not observed in the massive sulfide sample GM-3. The rare earth content of the Gem allanites ranges from 6.01 to 9.12 wt% La_2O_3 and 9.71 to 13.42 wt % Ce_2O_3 (Table 2). The cores of several grains are slightly enriched in Ce_2O_3. The Gem samples are unusual in that they contain such large amounts of allanite. Allanite is typically a characteristic accessory mineral in granites, granodiorites, monzonites and syenites. In rare instances allanite has been observed in limestone skarns and in pegmatites as a major mineral phase.

Bastnaesite is a rare earth fluorcarbonate and was observed in trace to minor amounts in the Gem samples. It is distinguished from calcite (also present) by its pale yellow to grey colour, very high relief, bladed habit and abundance of solid inclusions(Figures 5 and 6). Bastnaesite occurs interstitial to allanite and sulfides and is commonly associated with late crystallizing phases such as quartz and chlorite. Samples GM-1 and GM-2 contain 1 and 4% bastnaesite respectively, with only a few grains noted in GM-3. Electron microprobe analyses of bastnaesite indicate it has a rare earth oxide content ranging from 74.5 to 76.25 wt. % (Table 3), and it is enriched in cerium over lanthanum. Bastnaesite is one of the more common rare earth minerals and is usually associated with cerite ($(Ce,Ca)_9(Mg,Fe)Si_7(O,OH,F)_{28}$) and fluocerite ($(Ce,La)F_3$) in carbonatite plutons, veins, pegmatites, and skarns.

Monazite is a rare earth phosphate occurring in trace amounts in samples GM-1 and GM-2. As it is only an accessory phase it does not contain a significant proportion of the measured REE. Monazite is distinguished by its extremely high relief, euhedral form, pale yellow colour and high birefringence (Figures 7 and 8). Electron microprobe analyses of monazite were not calibrated for phosphorous resulting in low totals. Monazite is enriched in cerium, containing 67 to 69 wt % rare earth oxides (Table 4).

Numerous other mineral phases (chlorite, biotite, hematite, sericite) were examined by electron microprobe. The detection limit for REE using energy dispersive analyses is approximately 500 to 1,000 ppm REE. These minerals do not contain REE in amounts greater than this detection limit (Table 5). Both hematite and sericite are secondary alteration products replacing allanite (Figure 9), but themselves do not contain detectible REE.

It is possible that other rare earth-bearing minerals could be present in the Gem samples in trace amounts. The composition of the three rare earth minerals identified to date and their abundance in the Gem samples appear to account for the whole rock REE content.

Table 1. Summary of Analytical Results for Whole Rock Samples

Sample	GM-1	GM-2	GM-3
Au (oz/t)	0.048	0.450	1.56
La (ppm)	19700	49600	< 10
Ce (ppm)	15400	33400	< 16
Nd (ppm)	6000	17200	< 91
Sm (ppm)	800	1200	<1.6
As (wt %)	2.25	32.4	40.6
Co (ppm)	2500	48000	60000

Table 2. Electron microprobe analysis of Allanite[1]

Sample	GM2B-A	GM2B-B	GM2B-C	GM2B-D	GM1A-RIM(A)	GM1A-CENTRE(A)
SiO_2	33.46	33.69	33.84	33.67	33.43	34.36
Al_2O_3	14.85	16.51	15.48	16.28	18.82	18.47
FeO*	15.45	13.81	15.10	14.19	11.62	12.98
Ce_2O_3	13.38	13.23	13.68	11.86	13.42	12.34
La_2O_3	6.23	6.77	6.01	6.85	8.25	7.75
CaO	12.87	13.19	13.47	13.22	12.37	13.61
Total	96.24	97.20	97.59	96.07	97.91	99.50

Sample	GM1A-RIM(B)	GM1A-CENTRE(B)	GM2C-RIM	GM2C-CENTRE
SiO_2	35.09	33.57	35.29	34.54
Al_2O_3	18.46	18.13	20.87	16.97
FeO*	14.35	12.79	9.89	14.84
Ce_2O_3	10.07	12.45	9.71	11.68
La_2O_3	8.05	9.12	7.70	6.86
CaO	15.58	13.05	15.67	14.07
Total	101.59	99.12	99.12	98.96

1. A Ce metal standard was used to calibrate Ce. There is considerable difficulty in precisely determining REE contents because of the overlap of X-Ray peaks.

* Total Fe reported as FeO

Table 3. Electron microprobe analyses of Bastnaesite

Sample	GM2B-1	GM2B-4	GM2C-1
Ce_2O_3	41.95	42.88	41.13
La_2O_3	34.30	34.51	33.02
Total	76.25	77.39	74.15

Table 4. Electron microprobe analyses of monazite[1]

Sample	GM1B-1	GM1B-2
Ce_2O_3	40.78	42.04
La_2O_3	26.94	27.09
P_2O_5	20.66	21.17
Total	88.38	90.31

1. Phosphorous has not been calibrated resulting in low totals.

Table 5. Electron microprobe analyses of chlorite, sericite, biotite and hemaitite

	Chlorite		Hematite
Sample	GM2-B(4)	GM1-A	GM2B
SiO_2	23.79	25.17	0.95
$A2_2O_3$	20.18	19.56	0.41
MgO	3.96	7.93	
FeO	37.61	34.36	50.40
Ce_2O_3	0.00	0.00	0.00
La_2O_3	0.00	0.00	0.00
Total	85.54	87.02	51.76

	Sericite	Biotite
Sample	GM2B-3	GM1A
SiO_2	50.99	37.75
Al_2O_3	30.69	11.93
K_2O	7.92	7.30
FeO	3.14	22.76
Ce_2O_3	0.00	0.00
La_2O_3	0.00	0.00
TiO_2	0.00	3.45
MgO	0.00	9.03
Total	92.74	92.22

APPENDIX I - PETROGRAPHIC DESCRIPTIONS

SAMPLE GM-1

Offcut: massive, dark green, medium grained, containing 1-2% disseminated sulfides.

Mineralogy:

	%
Sulfides (Arsenopyrite/ Skutterudite/ Molybdenite)	2
Chlorite	40
Feldspar (potassic?)	25
Allanite	**20**
Calcite	7
Biotite	5
Bastnaesite	**1**
Monazite	**trace**
Muscovite	trace

Textural Features:

Primary textural features are obscured as a result of secondary alteration. The sample is composed principally of chlorite, feldspar, biotite and allanite randomly intergrown with arsenopyrite/skutterudite. Biotite is strongly pleochroic from light to dark brown and occurs as ragged blades in the cores of secondary chlorite. Biotite has been replaced along grain margins and cleavage planes by secondary dark green chlorite. Primary chlorite occurs as fine grained radial blades forming aggregates interstitial to primary silicates and sulfides.

Allanite is found as subhedral dark brown pleochroic grains. It is partly replaced by fine grained calcite and chlorite.

Feldspar occurs as anhedral grains intergrown with chlorite. Accessory monazite and bastnaesite were noted.

Sulfides consists of arsenopyrite and skutterudite which form diamond shaped disseminated grains intergrown with allanite and chlorite.

SAMPLE GM-2

Offcut: massive, medium grained, dark grey to brown, containing 45-50% arsenopyrite as euhedral disseminated grains intergrown with silicates.

Mineralogy:

	%
Sulfides (Arsenopyrite/ Skutterudite/ Molybdenite)	40
Allanite	45
Feldspar (potassic?)	5
Bastnaesite	4
Chlorite	2
Quartz	2
Calcite	1
Hematite	1
Monazite	trace
Sericite	trace

Textural Features:

The specimen consists of a coarse intergrowth of euhedral allanite and arsenopyrite/skutterudite plus bastnaesite and feldspar.

Allanite occurs as 1) euhdral, twinned prismatic grains up to 3 mm in length, and 2) coarse irregular masses (up to 4 mm in size) of intergrown anhedral allanite. Allanite is strongly pleochroic from pale brown-green to dark brown. Euhedral allanite is commonly strongly zoned from a dark brown core to a pale yellow rim. Small inclusions of allanite occur within arsenopyrite/ skutterudite. Minor hematite and sericite occur along fractures in allanite.

Bastnaesite occurs as dark grey to yellowish, high relief anhedral grains characterized by abundant inclusions. Bastnaesite is intergrown with chlorite, quartz and feldspar interstitial to allanite and arsenopyrite. Bastnaesite appears to be a late-forming primary phase.

Secondary minerals include hematite and sericite. Hematite is very abundant occurring with sericite along fractures in allanite and partly rimming sulfides.

PHOTOMICROGRAPHS

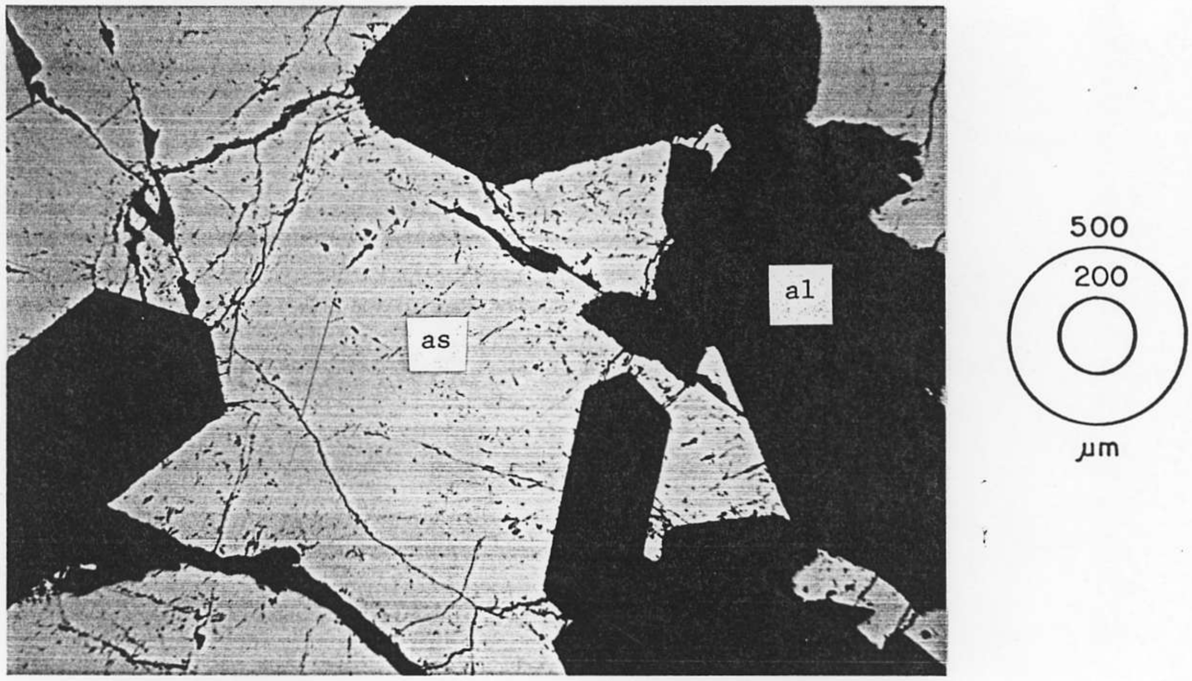


Figure 1. Euhedral allanite(al) intimately intergrown with arsenopyrite/skutterudite (as); reflected light, sample GM-2(c).

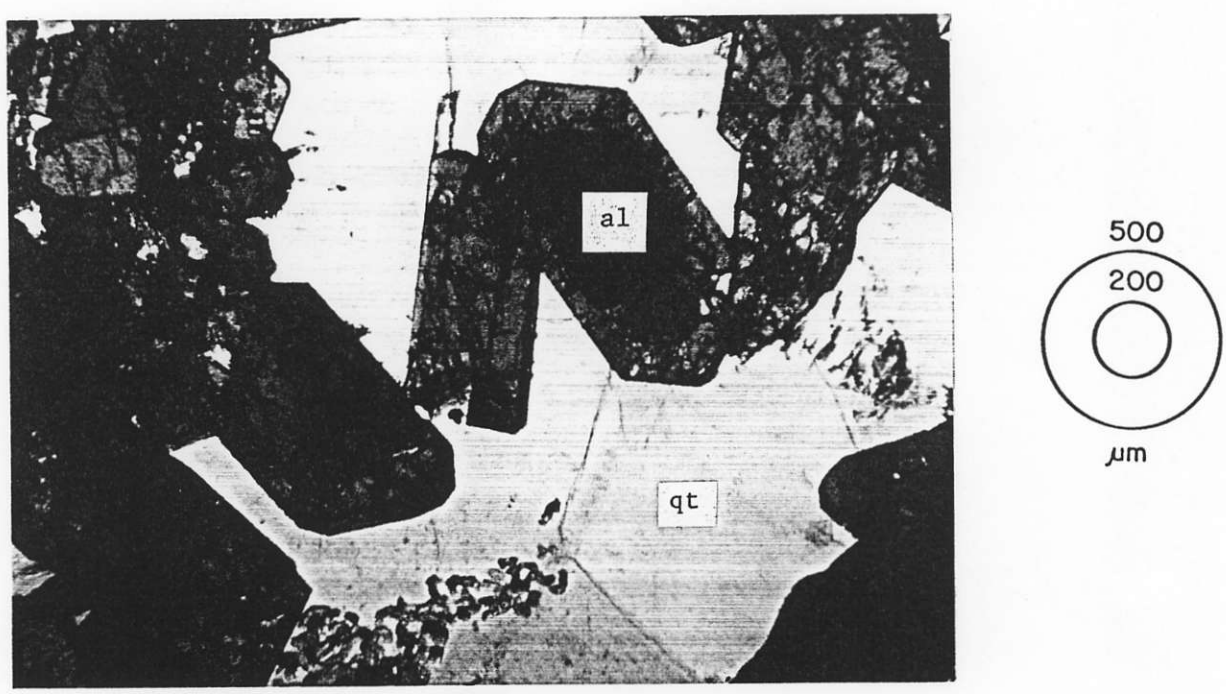


Figure 2. Coarse grained quartz (qt) occurs interstitial to zoned allanite (al); plain polarized transmitted light, sample GM-2(c).

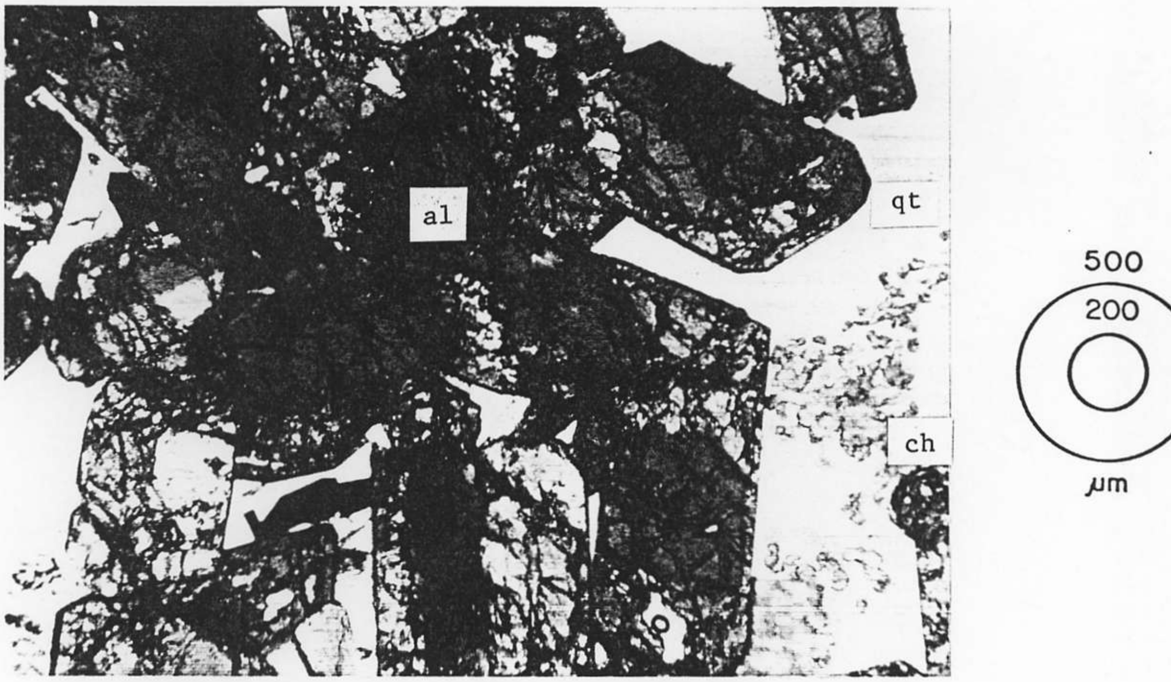


Figure 3. Pleochroic, strongly zoned allanite crystals (al)intergrown with quartz(qt) and chlorite(ch); plain polarized light, sample GM-2(c).

Figure 4. Detail of a strongly zoned allanite crystal(al) characterized by a dark coloured core and light coloured rim; plain polarized rim, sample GM-2(c).

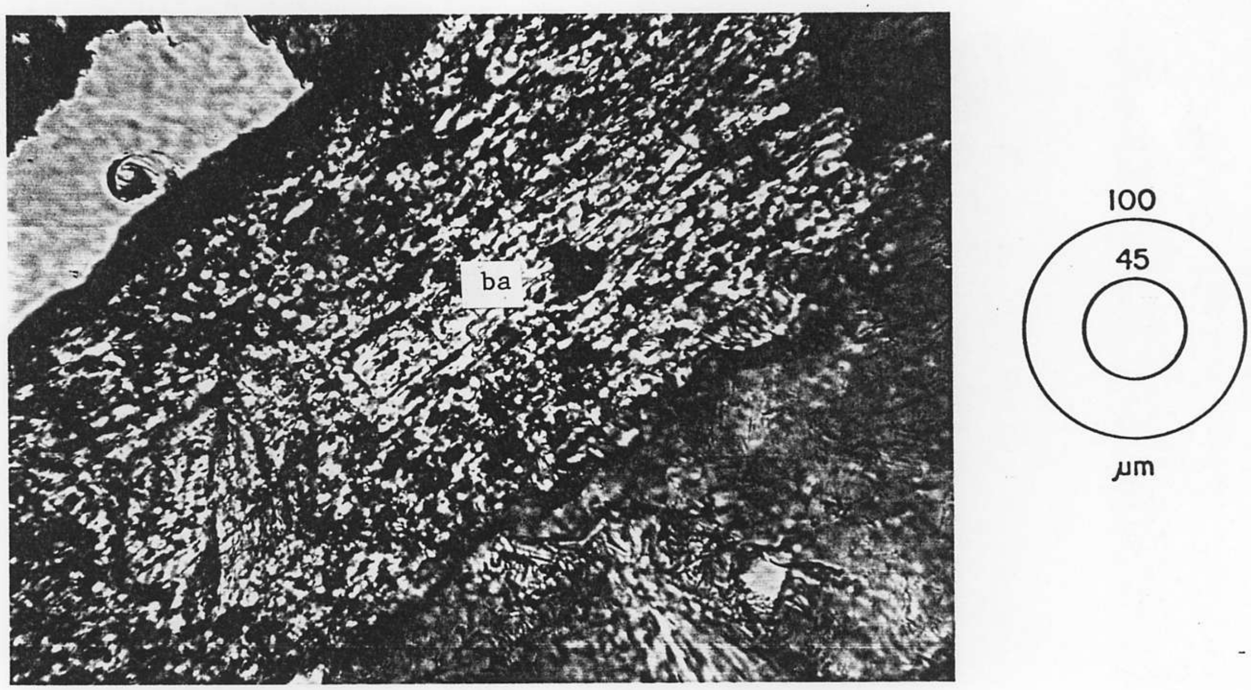


Figure 5. Blade of colourless to yellow bastnaesite (ba) containing numerous solid inclusions; plain polarized light, sample GM-2(B).

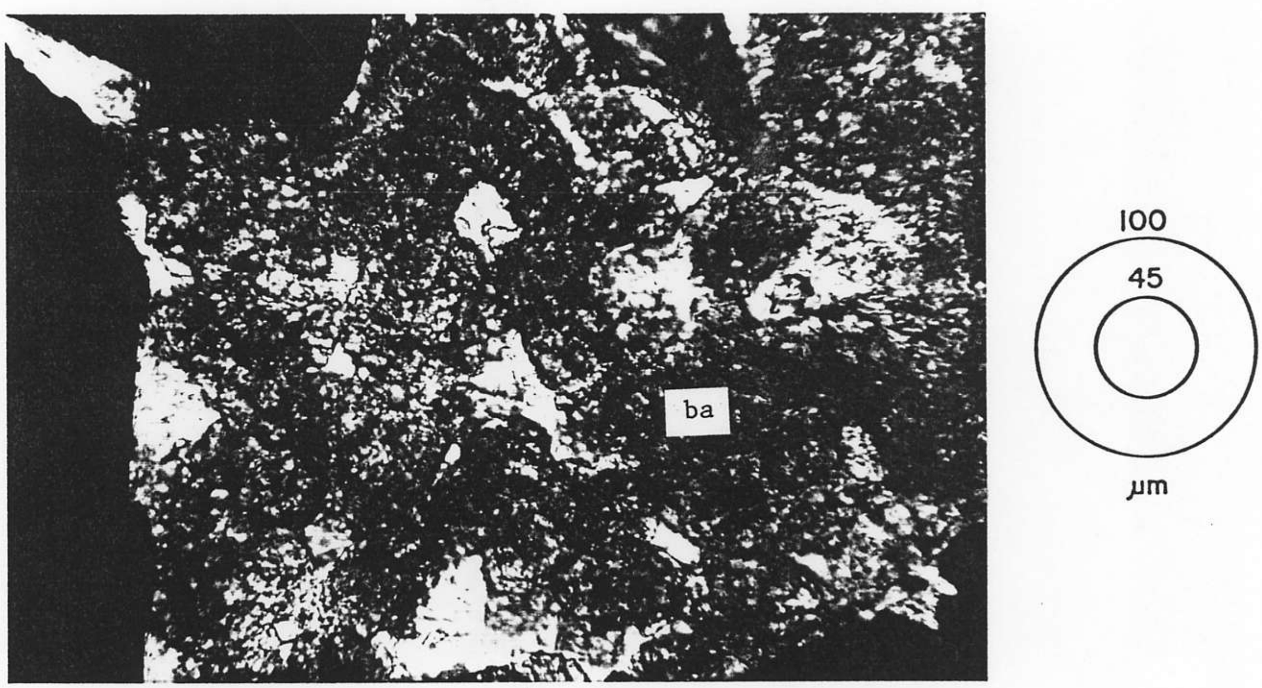


Figure 6. Worm-like grains of bastnaesite (ba) interstitial to opaque sulfides; plain polarized light, sample GM-3.

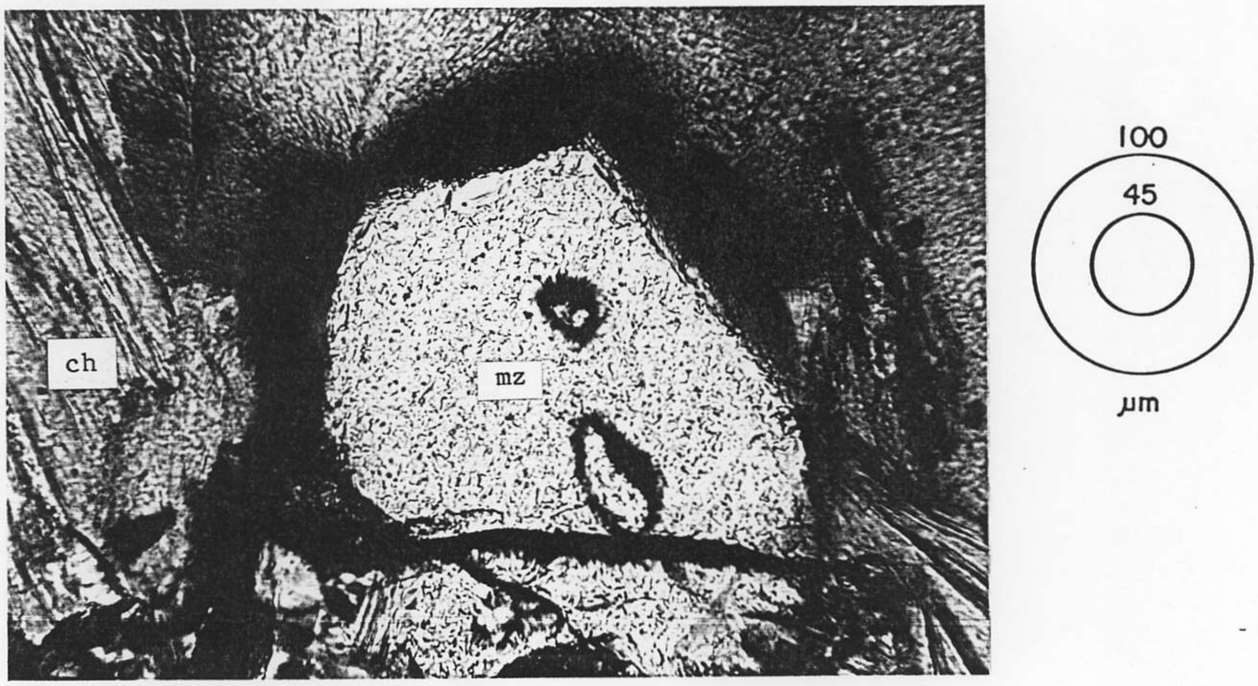


Figure 7. Euhedral, pale yellow grain of monazite (mz) showing characteristic high relief. Monazite is intergrown with chlorite (ch); plain polarized transmitted light, sample GM-1.

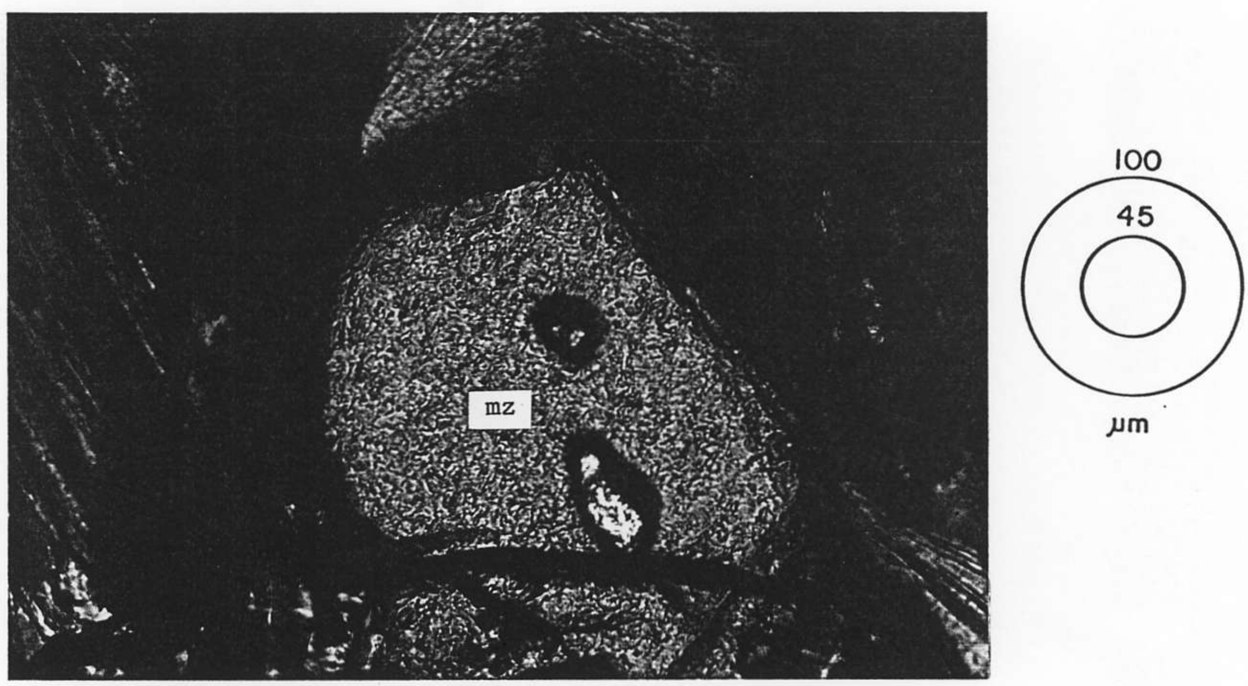
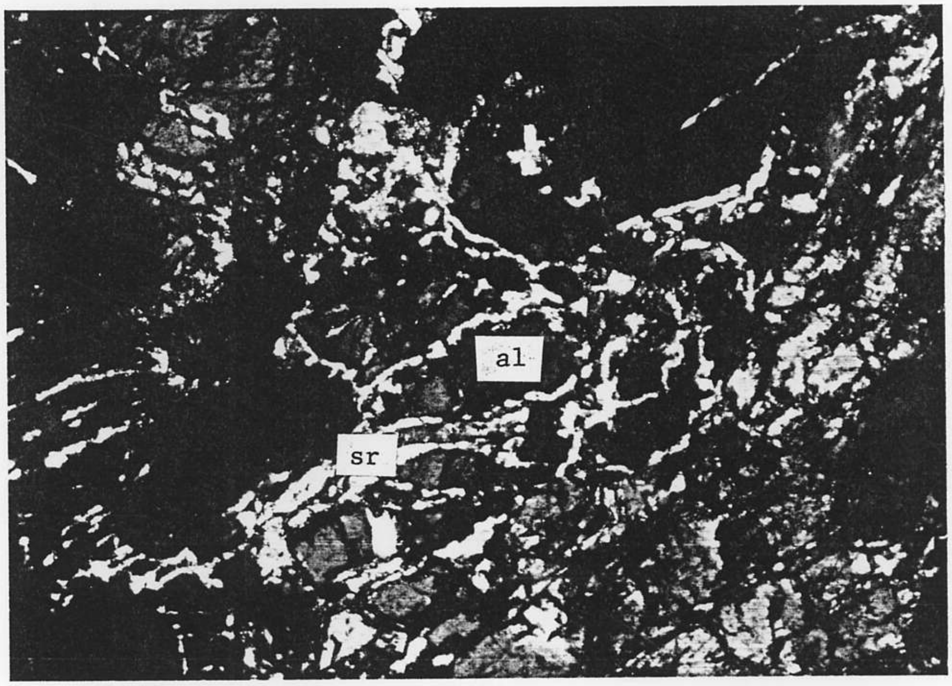


Figure 8. Same field as above, monazite displaying high birefringence; transmitted light, crossed nicols, sample GM-1.



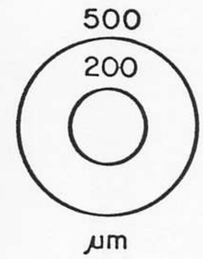


Figure 9. Fined grained sericite (sr) replacing allanite (al) along fractures and grain boundaries; transmitted light, crossed nicols, sample GM-2.