

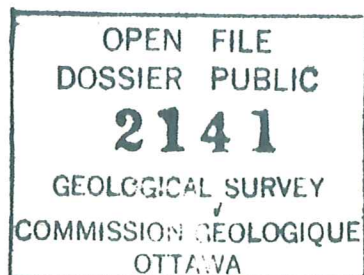
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EVALUATION OF PETROGRAPHIC AND MINERALOGIC ANALYSIS FOR
MARINE PLACER SEDIMENTS

by

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PURPOSE

The purpose of this project was three-fold:

1. to investigate the requirements of various communities for petrographic information on shallow water marine sediment samples: namely the scientific community, by consultation with scientists at AGC and the Terrain Sciences Division of the GSC and literature review; and the industrial community by consultation with Mineral Policy Sector, CANMET and published literature on placer minerals, aggregates and other significant industrial uses of seabed materials off Eastern Canada.
2. to prepare a documented and justified set of recommendations for the conceptual procedures to be used to provide both reconnaissance and more detailed petrographic information on marine samples by the Atlantic Geoscience Centre, in order to maximise the benefit to the diverse client group.
3. to assess the effectiveness of the proposed scheme by reviewing the results of analyses of suites of samples from the Dawson 87-023 cruise collected in the Gulf of St. Lawrence (Praeg et al., 1987) and from samples collected in a coastal area of Cape Breton, cruise Navicula 87-047 (Miller, 1987). These procedures were analyzed in conjunction with Soft Sediment Lab personnel.

ACKNOWLEDGEMENTS

This work was carried out in co-operation with Mr. K. Asprey, Manager, Soft Sediment Lab at AGC and his staff. Consultation was conducted with the following people, who gave advice concerning the effectiveness and appropriateness of various laboratory schemes: Dieter Birk (GeoFuel Resources, Sydney, N.S.), Alan Breakey (Ocelot Ltd., Calgary), Margot Emery-Moore (C-Core), Terry Day (Consulting Geologist, Halifax), Gordon Fader (AGC), Milton Graves (Cuesta Research, Dartmouth), Peter Hale (Ocean Mining Division, EMR, Ottawa), Anne Jennings (INSTAAR), Helen Joseph (Ocean Mining Division, EMR), Bill Languile (NSDME, Stellarton, NS), Fred Longstaffe (Univ. Western Ontario), Steven Morrison (placer geologist, DIAND, Whitehorse), Bernie Pelletier (Terrain Science Division), John Peters (Earth & Ocean, Research Ltd., Dartmouth), Rick Richardson (Alta Research Council, Edmonton), Maria Rockwell (TUNS, Halifax), Charles Schafer (AGC), Bill Shilts (Terrain Sciences Division), Jim Syvitski (AGC), B.G. Thom (Univ. Sydney, Australia), and Marcos Zentilli (Dalhousie Univ., Halifax).

LITERATURE REVIEW & METHODS

The results of the library research are summarized in a separate volume (Hein, 1988, Appendix 1), which includes an annotated reference list of various procedures appropriate for evaluation of marine placers and xerox copies of some of the more pertinent articles. Revised flow-charts of the recommended procedures are shown in Figures 1 and 2. Standard methods were used for the following procedures: Franz magnetic separator (Flinter, 1959; Hess, 1959; Engelhardt et al., 1967); magnetic susceptibility (Currie and Bornhold, 1983; Andrews and Jennings, 1987); petrographic examination of thin sections of grain mounts (Kerr, 1959; Moorhouse, 1959; Scholle, 1979); settling tube analysis and XRD.

New techniques were used for the separation of heavy minerals by using a non-toxic heavy liquid (sodium polytungstate) and the MAGSTREAM™ separator. These are discussed in Appendices 1 and 2. In addition, a suite of "standard mixes" of garnet, ilmenite, hornblende, magnetite and quartz were prepared to calibrate the magnetic susceptibility coil, and to assess the initial separation procedures using the sodium polytungstate with separatory flasks and centrifuge methods. A list of the proportions of the different components used and grain size-variations are given in Table 3. Garnet, ilmenite and hornblende standards were obtained by crushing relatively pure bulk samples. Quartz and magnetite were obtained from natural sediments. The XRD results of the standard mixes are shown in Table 2 and Figures 3-9. Petrographic examination of thin sections of grain mounts of the standard mixes (Figs. 10-14) show that the mixes are quite pure, with 92-99.9% of the dominant mineral type (Table 3). Accessory minerals and grains include hornblende and cassiterite in the garnet; tourmaline and igneous rock fragments in the hornblende; pyroxene, rutile, hypersthene and feldspar in the ilmenite; feldspar, mica, igneous and sedimentary rock fragments in the magnetite (obtained by removing magnetite from an offshore marine sample); and feldspar and sedimentary rock fragments in the quartz (Table 3).

Five samples from the Sept-Iles area (CSS/Dawson 87-023) and five samples from offshore Cape Breton Island (Navicula 87-047) were run as test samples for the various procedures. The textural properties of the samples are summarized in Table 1, with the grain-size distributions given in Appendix 3. Samples were selected specifically for their dark colour, and apparently high

concentration of heavy minerals, as visible by eye. Sediments are mainly quartz, feldspar, with variable percentages of garnet, pyroxene, hornblende and opaques (Tables 4 and 5). Accessories include hypersthene, cassiterite, sedimentary and igneous rock fragments, and for the Cape Breton samples, an unknown amorphous material (Tables 4 and 5).

RESULTS

Results of the analysis are shown as follows: heavy liquid separation using sodium polytungstate by separatory funnel (SPSF 16-20) and centrifuge methods (C26-C35) (Tables 6 and 7); MAGSTREAM™ results (Table 8); Magnetic susceptibility (Table 9) and Franz magnetic separator (Table 10).

1. Heavy Liquid Separation: Separatory Flask versus Centrifuge Method

Analysis of these results show that the heavy liquid separation using sodium polytungstate with the centrifuge method shows the least contamination of both the light and heavy fractions (Table 6). Within the heavy-fraction residue, the percentage of light minerals varied from 5.6 to 12.9% using the separatory flask method (SPSF 16H-20H), compared with a contamination of 3.9 to 6.6% of lights in the heavy fraction for the centrifuge method (C26H-C30H). Similarly, within the light-fraction, the percentage of heavy minerals varied from 4.4 to 57.6% using the separatory flask method (SPSF 16L-SPSF 20L), compared with a contamination of 0.6 to 1% for the centrifuge method (C26L-C30L). In the most contaminated sample (SPSF 19AL), on the basis of the grain-counts, the % heavies exceeds the % lights within the light fraction. However, the grain-size of the heavy minerals is $\sim 1/4$ - $1/2$ the size of the lights, so in terms of a weight percentage this contamination would be much less. Weight percentages between the two methods differ by 0.04-6.55 Wt% (Table 7). The weight percentages of the heavy fraction are usually higher in the centrifuge method, compared with the separatory flask method. Correspondingly, the weight percentages of the light fraction are usually less in the centrifuge method, compared with the separatory flask method. The findings presented in these two tables suggest that there is proportionately a higher percentage of the heavy fraction (although finer-grain size) remaining in the light fraction using the separatory flask method. This is presumably due to the difficulty in washing the heavies along the sides of the flask to properly remove them by settling. Sodium polytungstate is quite "sticky" and the lab personnel in the Soft Sediment Lab noted great difficulty in adequately

washing the sides of the funnels during the separations.

2. MAGSTREAM™ versus Heavy Liquid Separation, Centrifuge Method

The MAGSTREAM™ results are given in Table 8. Compared with the results using the sodium polytungstate by the centrifuge method, the MAGSTREAM™ method consistently underestimated the percentage of heavies (4747: -0.39%; 4755: -4.12%; 4745: -19.43%; 4749: -14.06%; 4754: -6.93%). This may be in part due to operator error. The analysis were run by other lab personnel (with the MAGSTREAM™ company in New York) and if the feed rate and/or amount of sediment processed was not consistent there may be spurious results.

3. Magnetic Susceptibility Results

The magnetic susceptibility results are given in Table 9. Due to time-constraints, magnetic susceptibility values were obtained only from the standard mixes. There are some difficulties with the consistency of the readings using this method. As shown in Table 9, there is a grain-size influence on the results, with an increase in the magnetic susceptibility with decreasing grain-size. This differs from the findings of Andrews and Jennings (1987) who noted higher magnetic susceptibility values in the sands, compared with the silt and mud fractions. Currie and Bornhold (1983) found that magnetic susceptibility was highest in the silt and fine sand fractions; lowest in clay and coarse sand. Fine sand contributed more to overall susceptibility than any other size. Another effect is seen in sample 6. In the first run, the sample was inadvertently stratified, with an exceptionally high value obtained (0.2432 SI/gram). Upon re-running the sample, with mixing an even higher value resulted (0.4528-0.4487). This was particularly puzzling because the sample is mainly quartz (92 wt%), with minor percentages of magnetite, hornblende, ilmenite and garnet. Other workers have noted an increase in the magnetic susceptibility values when there is obvious stratification or lamination within the deposit (Jahren, 1963). The high values obtained upon mixing are not explainable. Further documentation of the magnetic susceptibility in relation to sediment texture and composition must be undertaken before this tool can be reliably used.

4. Franz Magnetic Separation

Results of the Franz magnetic separator are given in Table 10. The data are quite reliable, but only give an assessment of the magnetic mineral distribution, and further separation procedures are needed to obtain the distributions of the non-magnetic heavy fractions. This procedure is quite time-consuming and care must be taken to ensure a proper feed-rate and grain-size during analysis (i.e. a too rapid feed-rate of coarse-grains will clog the flow). For detailed isodynamic separations of various mineral types the time-constraints of this system may be warranted.

RECOMMENDATIONS

On the basis of the laboratory results, the most reliable methods appear to be the heavy-liquid separation with the centrifuge method (for a quick assessment of % heavies) or in combination with the Franz magnetic separator (for a detailed assessment of the magnetic and non-magnetic heavy fractions).

Any further recommendation must take into account the cost and person-hours involved in conducting these procedures. Consultation with Ken Asprey shows the following assessment of the various methods.

<u>Method</u>	<u>Personnel-Time or Cost/Sample</u>
Magnetic susceptibility	5 minutes/sample
Heavy-Liquid Flotation	15 minutes/for a batch of 10 samples
MAGSTREAM™	15 minutes/sample
Thin section petrography	1/2 hour/sample
Binocular examination of grains	1/2 hour/sample
SEM/EDAX analysis	1/2 hour/sample
Epoxy grain mounts	\$7/sample
Thin sections	\$7/sample
Polished thin sections	\$15/sample
† Franz magnetic separator	3-4 hour/sample (separation into 7 classes)
XRD	quick look: 1 hour/sample detailed analysis: 2 hour/sample

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FIGURE CAPTIONS

Fig. 1. Flow-chart illustrating initial preparation of marine samples.

Fig. 2. Flow-chart illustrating procedures for the laboratory evaluation of heavy minerals in marine placer sediments.

Figs. 3-9. X-ray diffraction results for the "standard mixes:" garnet-GAR >63<355 MIC; hornblende-HOR >63<355 MIC; ilmenite-ILM >63<355 MIC; magnetite-MAG >63<355 MIC; quartz-QTZ >63<355 MIC.

Fig. 10. Thin section of a mineral separate of garnet used in the standard mixes. Note the garnet was crushed and sieved, accounting for the fracture patterns. Note the lack of cleavage, pale yellow-pink color, irregular to conchoidal fracture and high relief. Plain light.

Fig. 11. Thin section of a mineral separate of hornblende used in the standard mixes. Note the hornblende was crushed and sieved, accounting for the fracture patterns and angularity of the grains. Relief is high and cleavages are well developed, intersecting at 124° . Hornblende is characterized by moderate birefringence (second-order colors), positive elongation, a biaxial negative figure, and a $2V$ of $70-85^\circ$. Crossed polarizers.

Fig. 12. Thin section of a mineral separate of ilmenite used in the standard mixes. Note the ilmenite was obtained from a natural sample. Ilmenite is opaque and difficult to distinguish from magnetite, and is frequently intergrown with magnetite. Ilmenite is best distinguished by its lack of magnetism and occurrence as tabular crystals. Plain light.

Fig. 13. Thin section of a mineral separate of magnetite used in the standard mixes. Note the magnetite was obtained from a natural sample. Magnetite is opaque and difficult to distinguish from ilmenite. It is best distinguished by its magnetism and occurrence as square or rectangular cross sections. Plain light.

Fig. 14. Thin section of a mineral separate of quartz used in the standard mixes. Note the quartz was obtained from a natural sample. Note its low birefringence, lack of cleavage and twinning, and low positive relief. Plain light. Crossed polarizers..

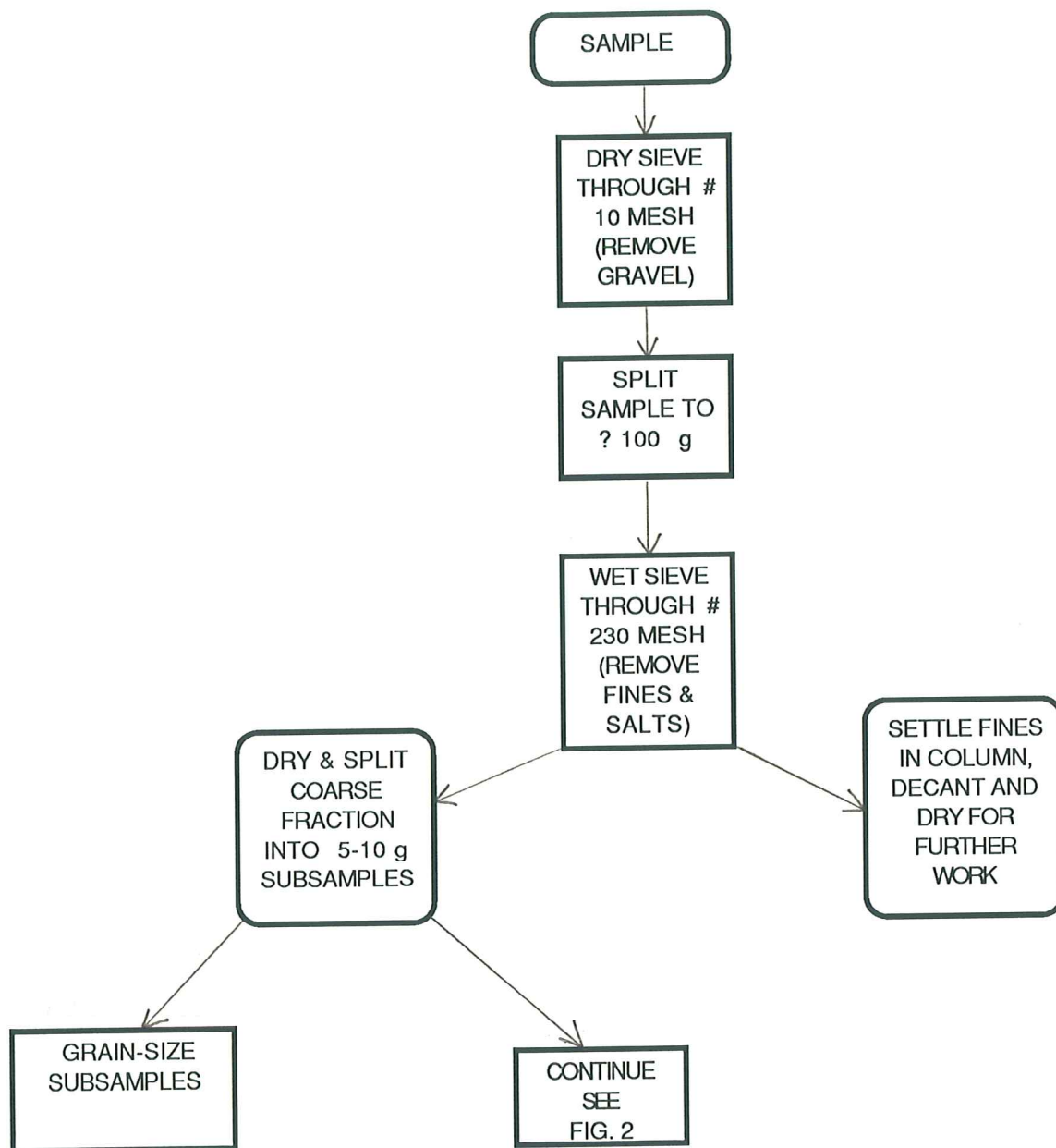


Fig. 1

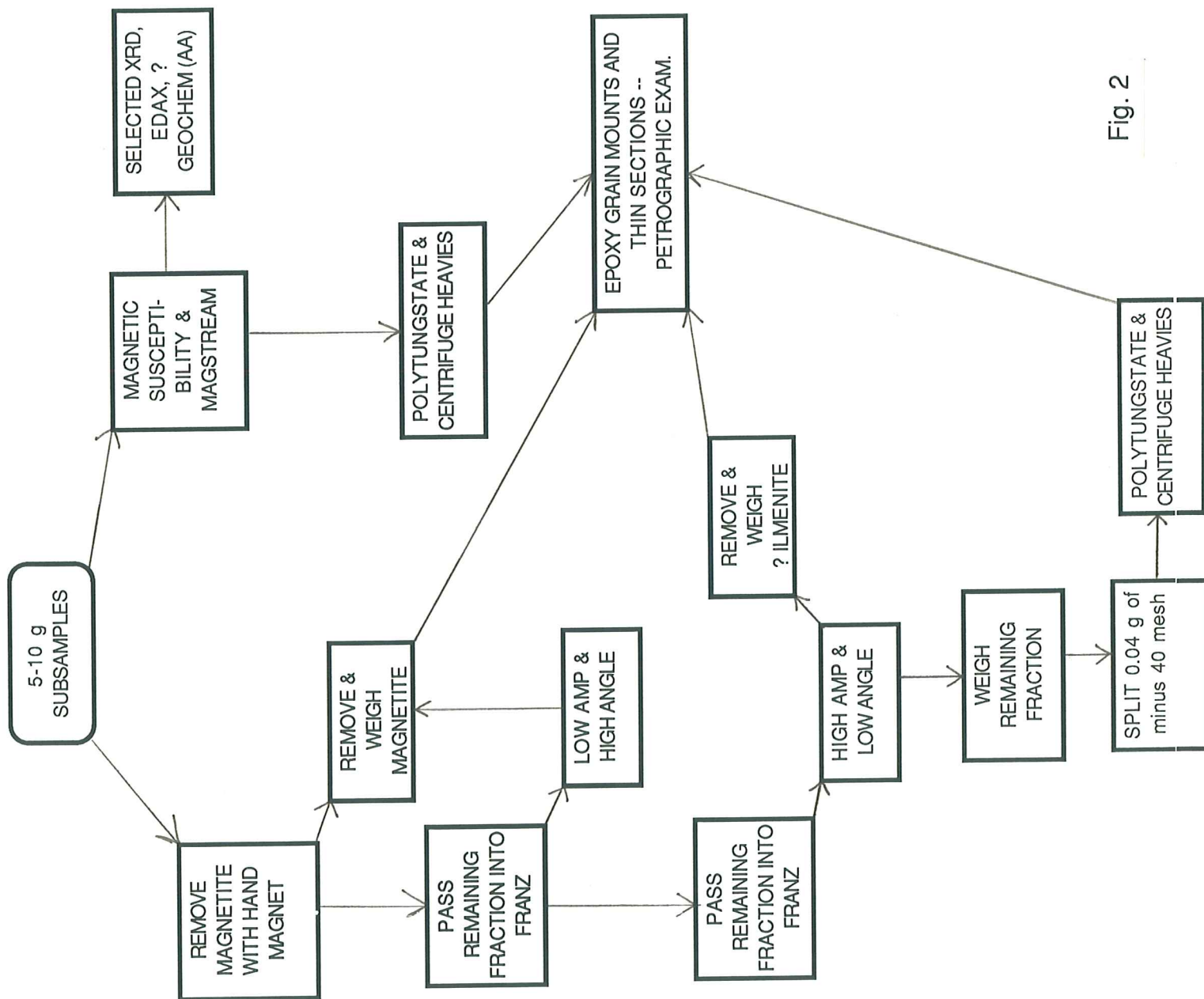
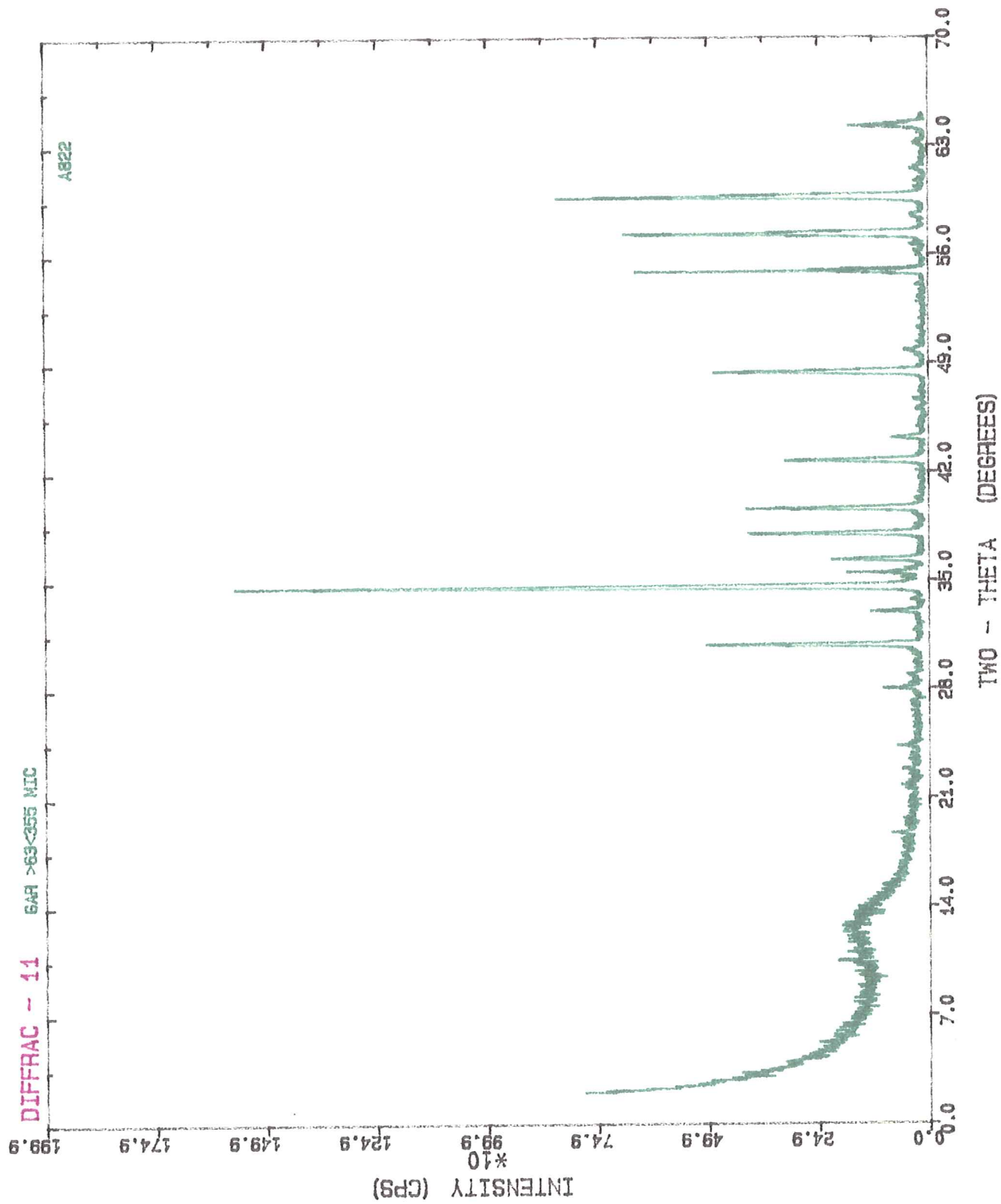


Fig. 2



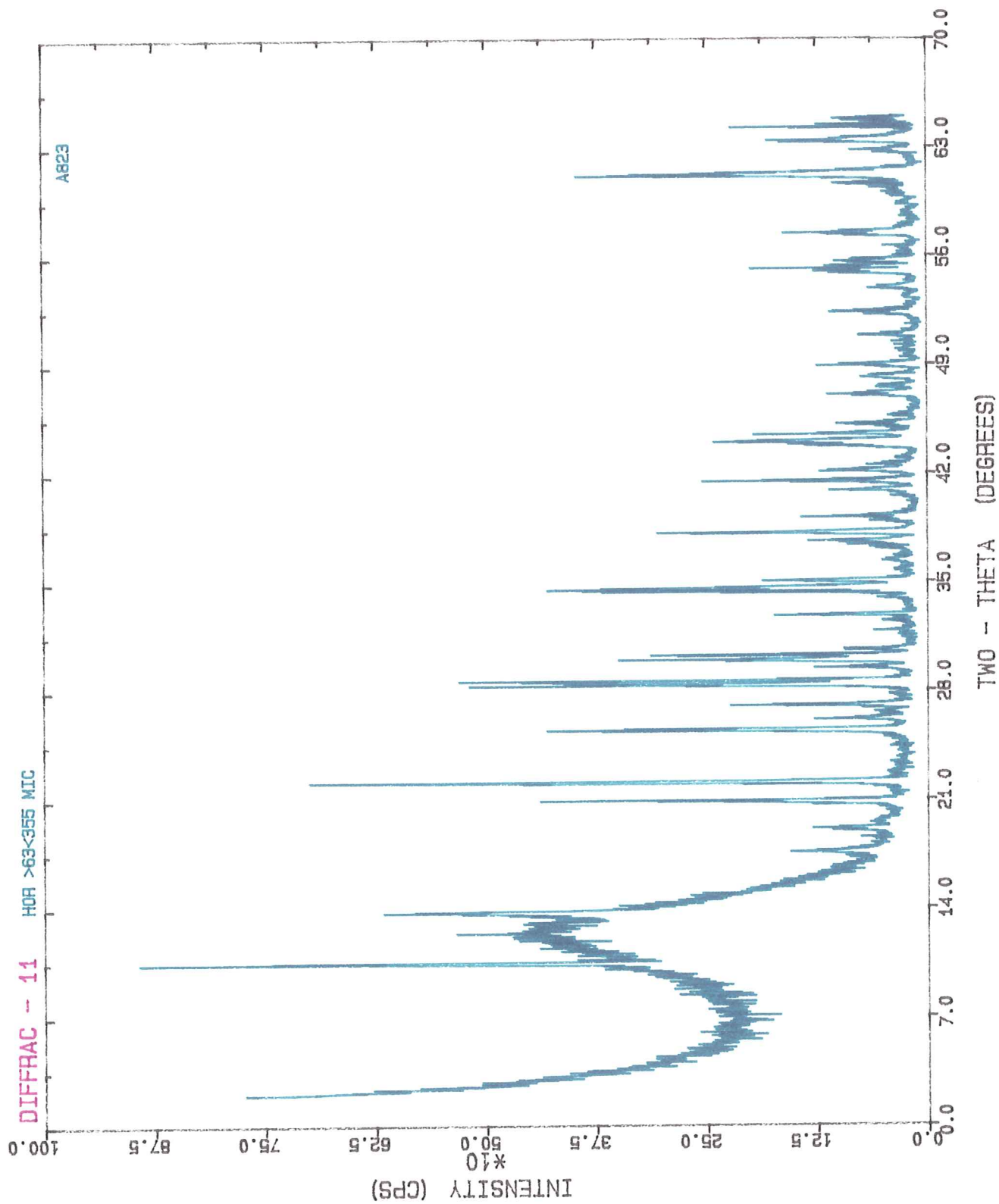


Fig. 4

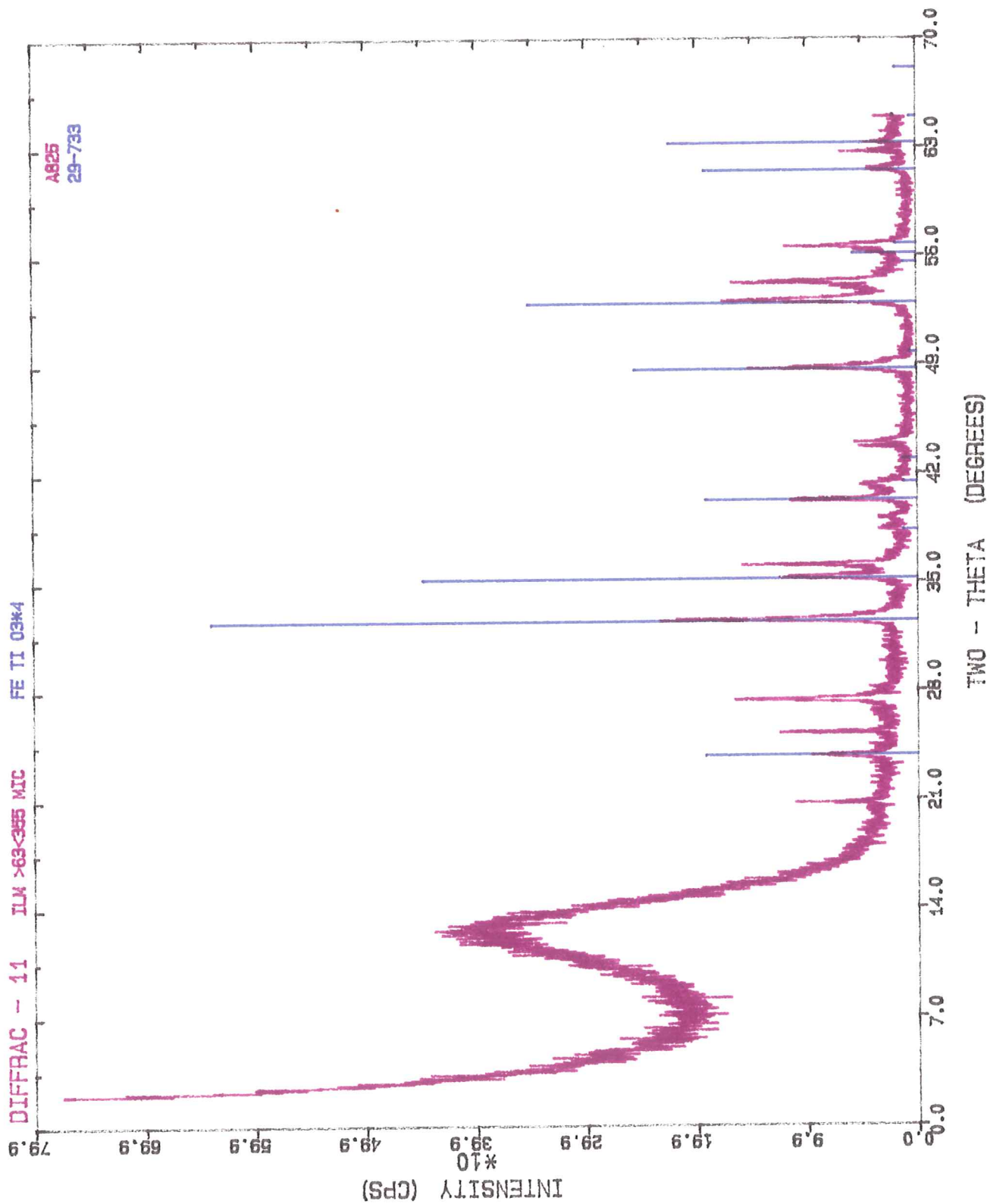


Fig. 5

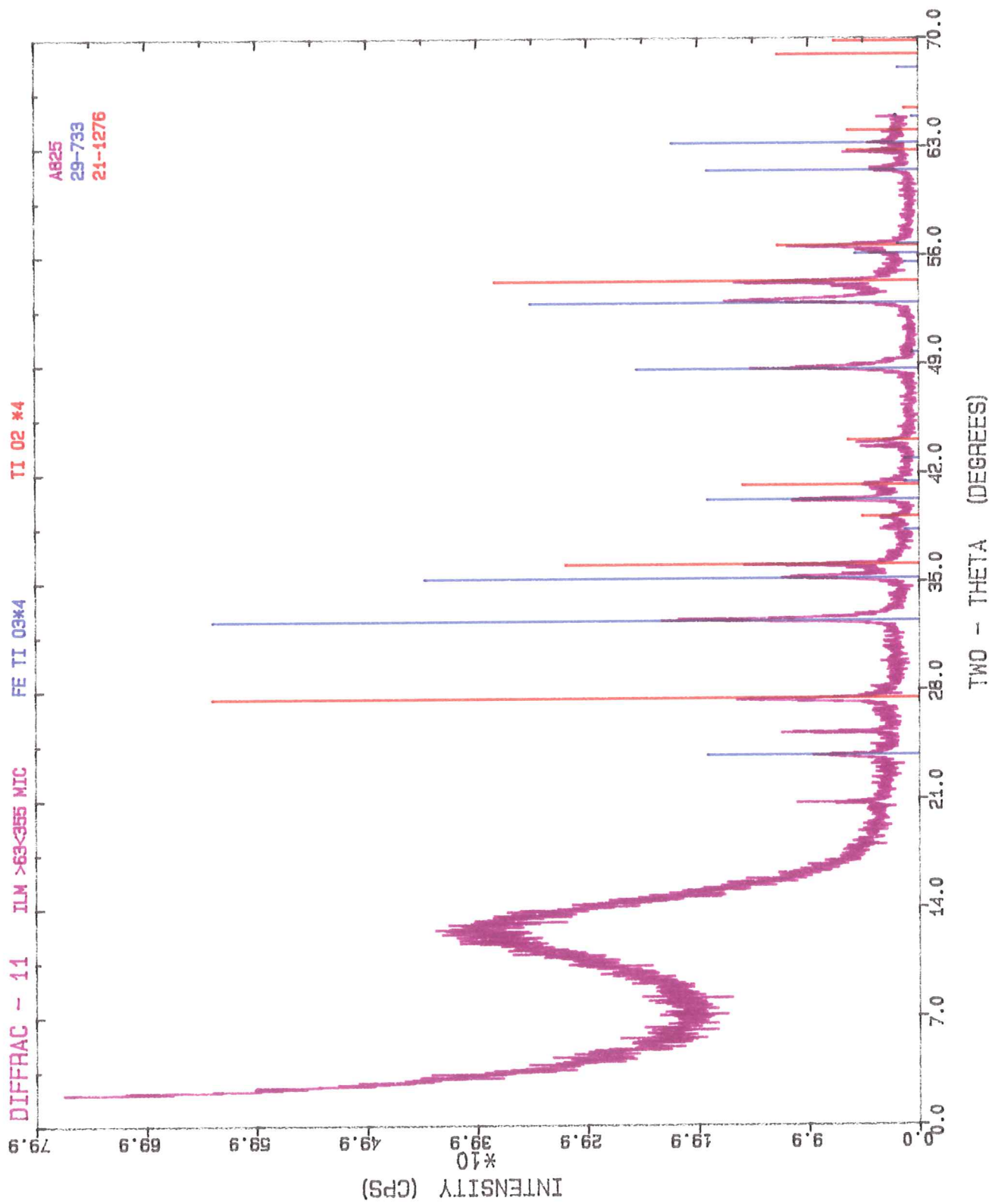
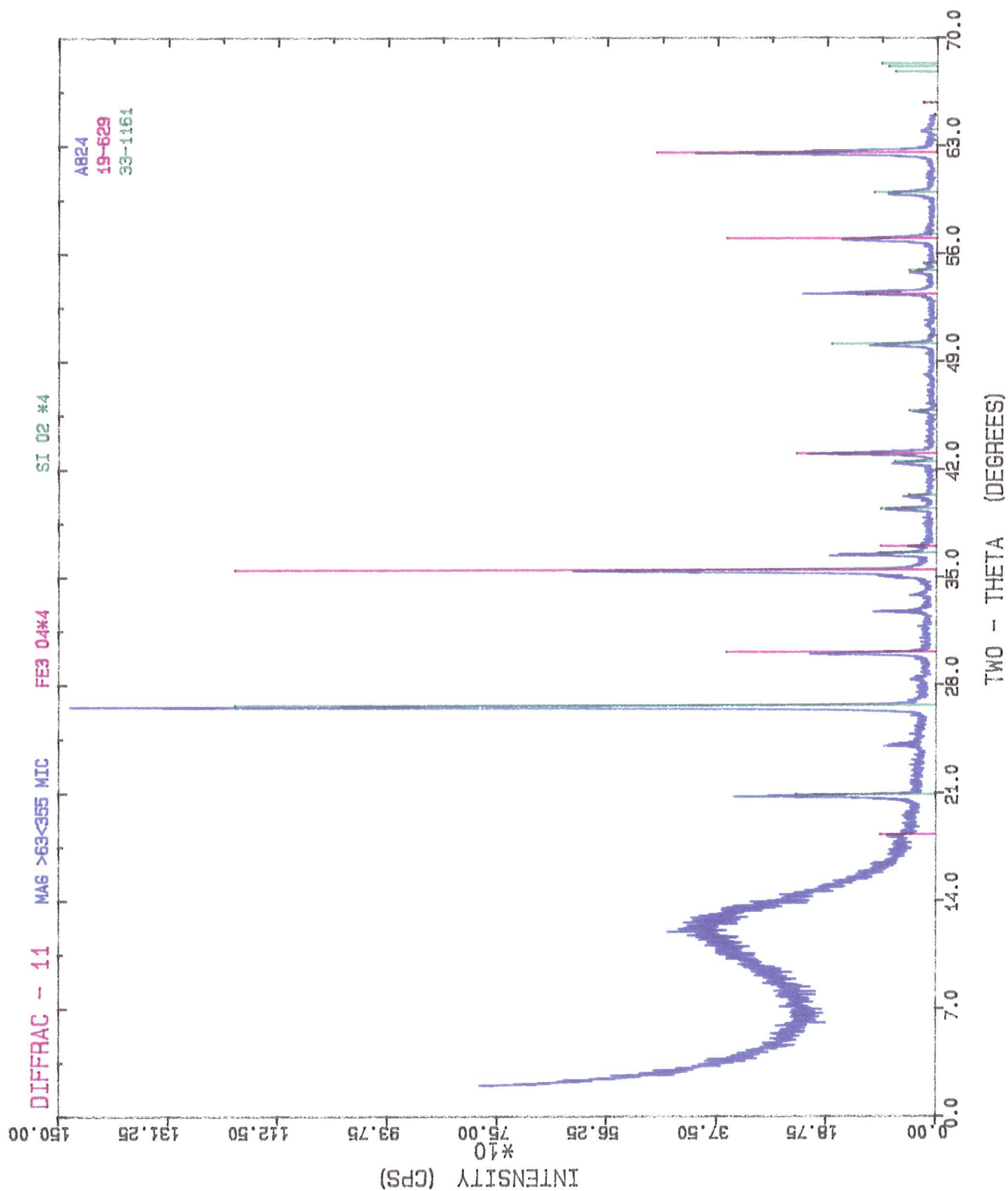
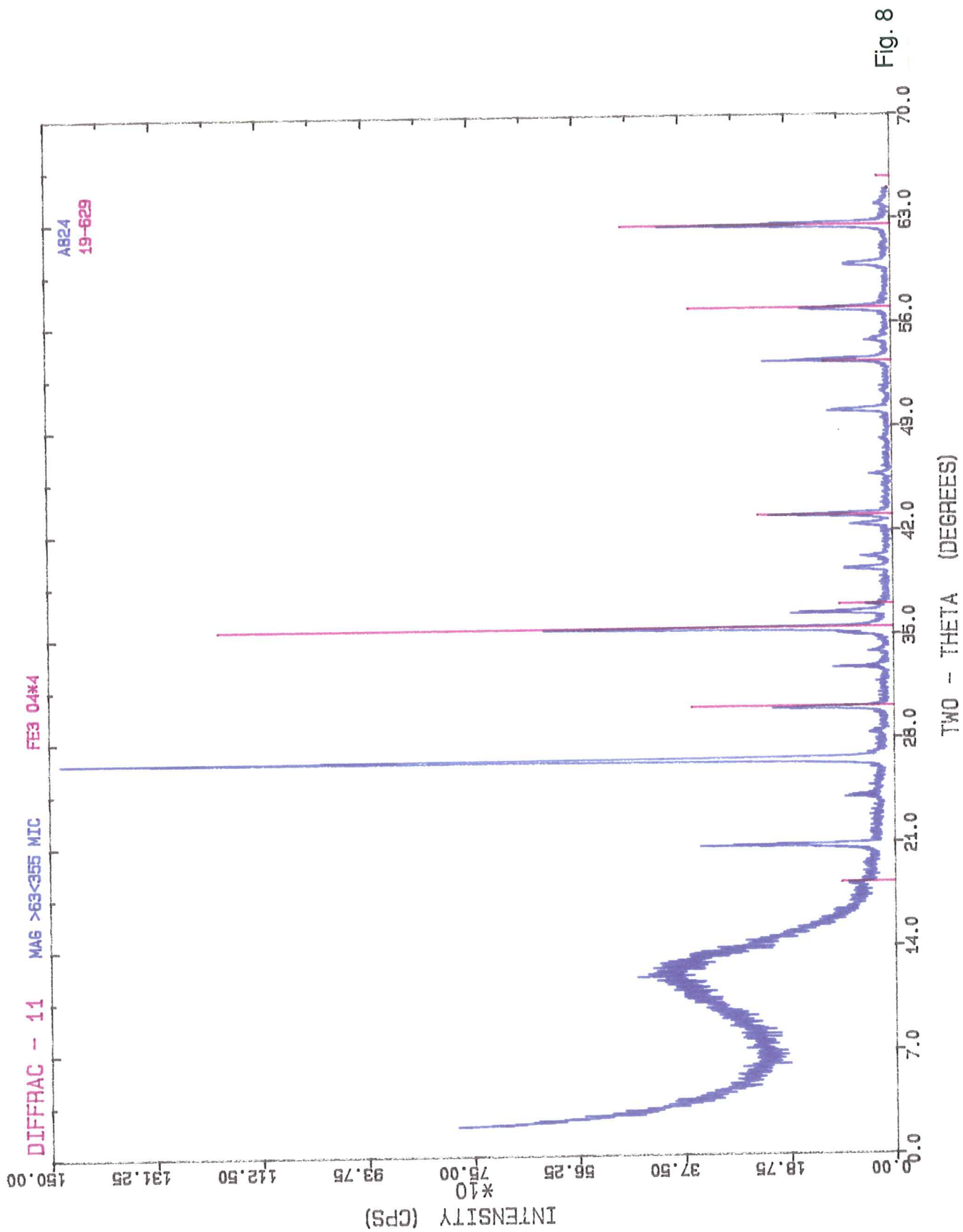


Fig. 6





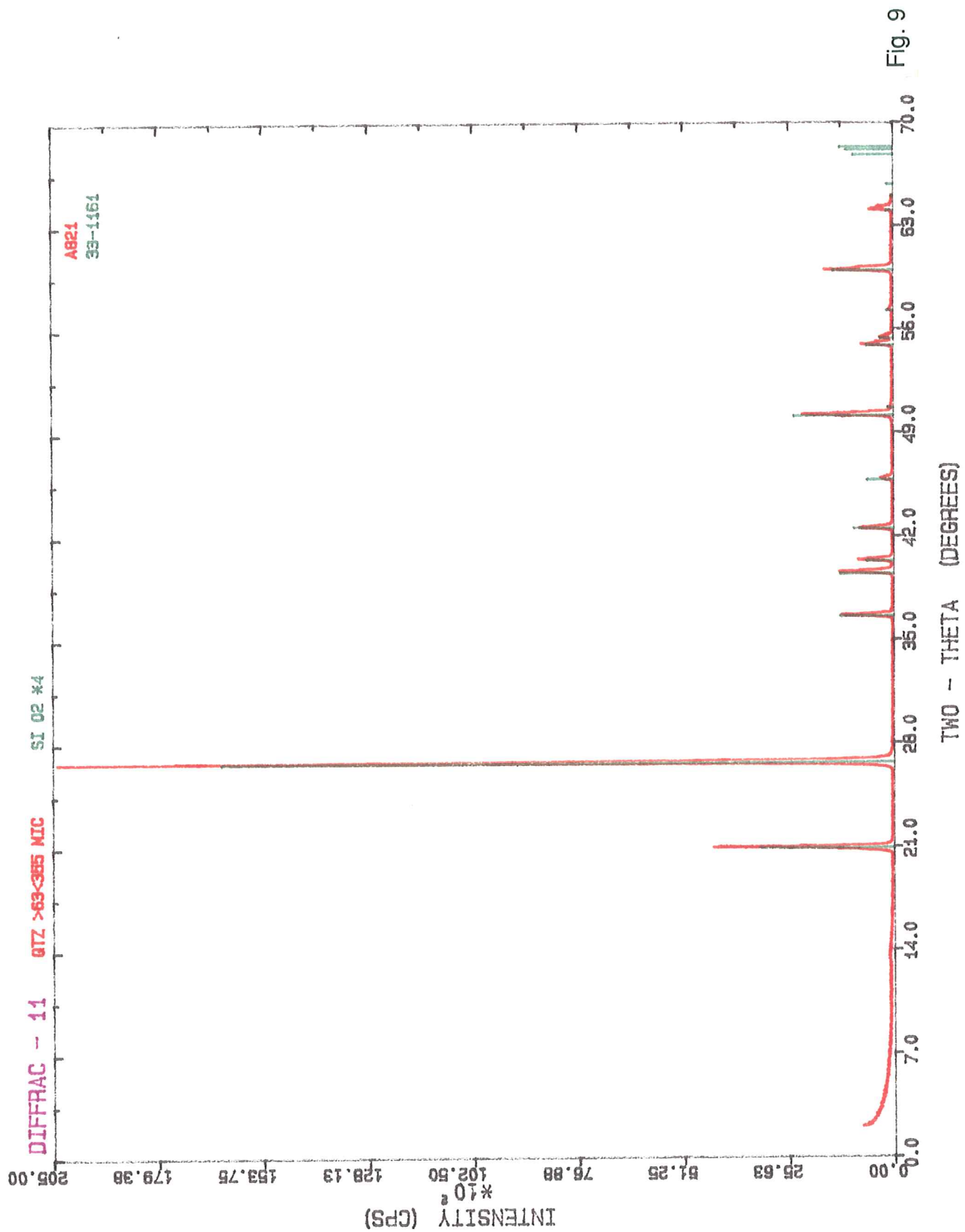


Fig. 9



Fig. 10

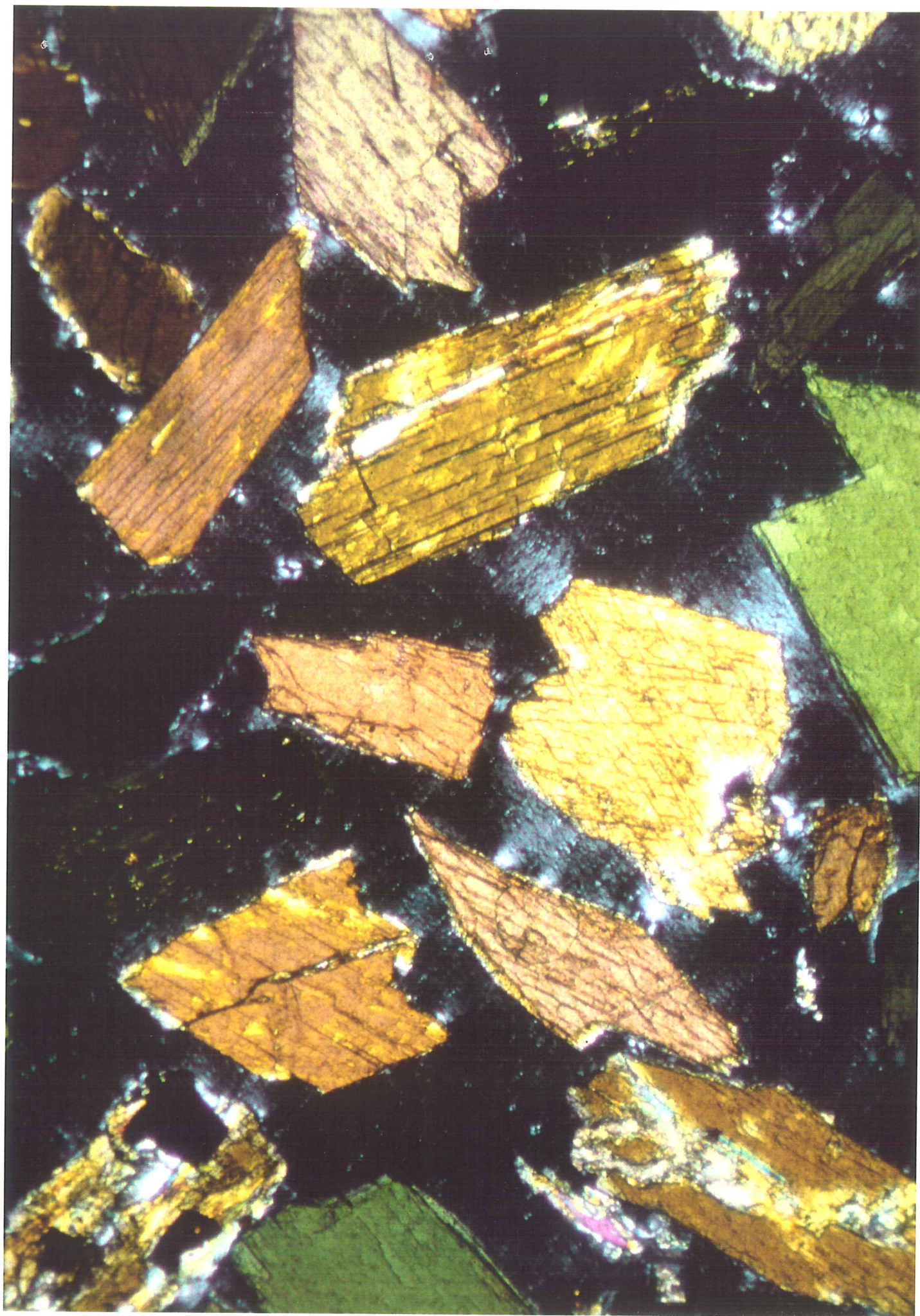


Fig. 11



Fig. 12

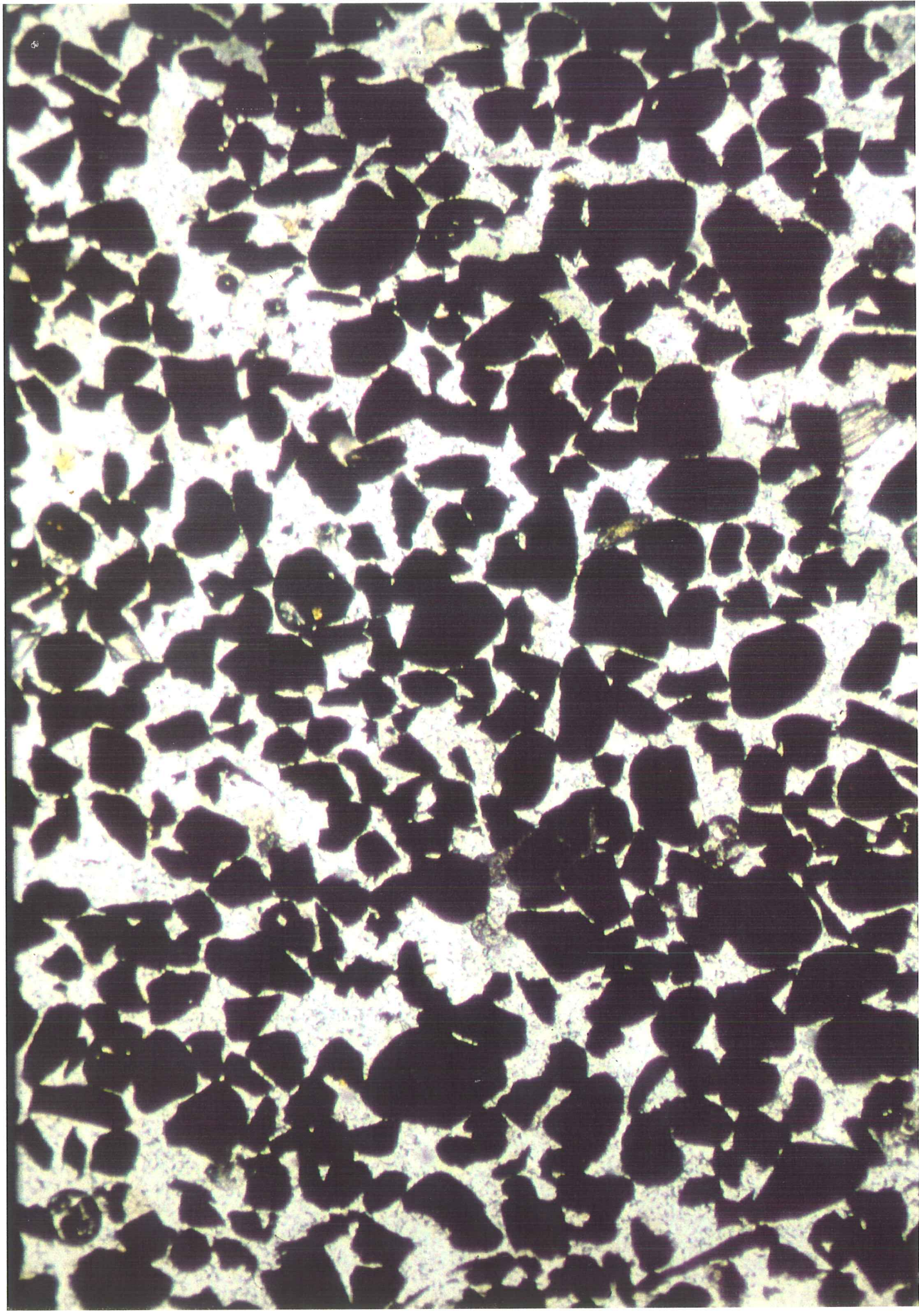


Fig. 13

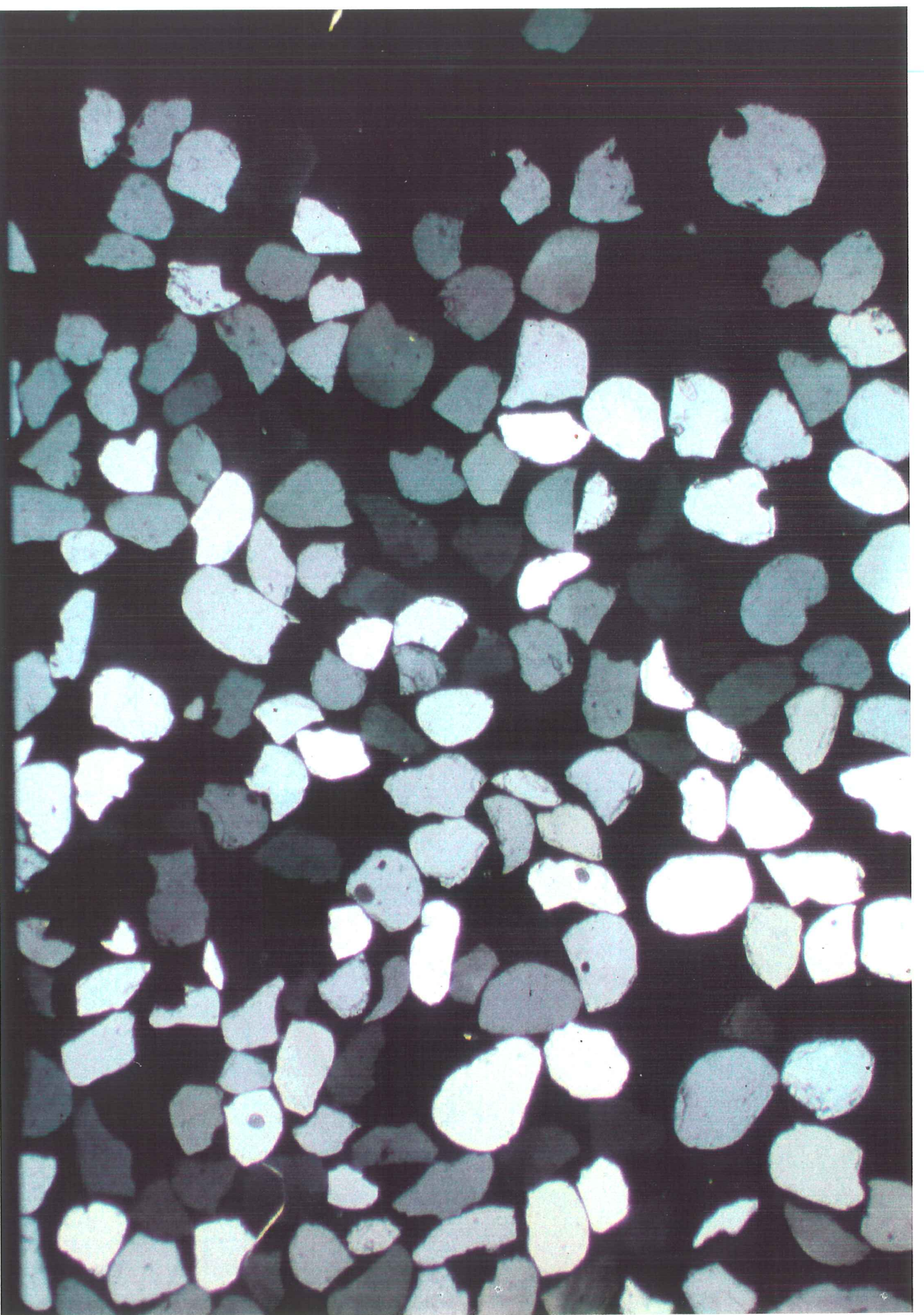


Fig. 14

Table 1. Textural Properties of Samples from Sept Iles and Cape Breton

SAMPLE #	LAB #	% GRAVEL	% SAND	% MUD	MEAN (PHI)	STD. DEV (PHI)	KURTOSIS	SKEWNESS
87023-SLG. CONC.	4745	0.01	99.99	- - -	1.75	0.34	7.34	-0.26
87023-SLG5. Base of Cliff	4747	- - -	100	- - -	1.65	0.35	5.18	0.31
87023-SL8 Base of Cliff 5 cm.	4749	0.06	99.94	- - -	1.43	0.45	16.33	1.23
87023-SLG2 Base of Cliff	4754	- - -	100	- - -	1.81	0.35	6.17	0.41
NV 87047-001	4782	0.16	99.31	0.53	1.87	0.57	79.71	5.66
NV 87047-005	4783	2.77	95.67	1.56	2.17	1.15	18.65	-1.01
NV 87047-009	4784	0.1	95.07	4.83	2.82	1.14	17.66	3.57
NV 87047-017	4785	0.12	88.63	10.25	3.44	1.24	11.54	2.57
NV 87047-024	4786	0.52	99.29	0.19	1.84	0.57	52.47	-0.75

TABLE 4. PETROGRAPHY OF SEPTILES

SLIDE #	TOTAL # GRAINS	GARNET %	PYROXENE %	HORNBLende %	OPAQUE %	FELDSPAR %	QUARTZ %	ACCESSORIES
4745	207	15.5	1.2	9	13.6	34	26.7	HYPERSTHENE 0.5%
4745	171	9.4	1.2	11.1	15.5	41	21.8	CASSITERITE -- trace
4747	143	15	...	7	13.3	22	42	SED. ROCK FRAG. -- trace
4747	170	15.5	0.9	7.4	17.7	38.6	19.9	HYPERSTHENE -- 0.5%
4749	115	17.9	6.5	5.2	9.6	10	50.8	HYPERSTHENE -- 1%
4749	129	14.4	5	5	15.9	13	40	SED. ROCK FRAG. -- trace
4754	317	12.6	4.8	2.9	23.4	20.6	33.8	SED. ROCK FRAG. -- 6.7%
								CASSITERITE -- trace
								HYPERSTHENE -- trace
								IGNEOUS ROCK FRAG. -- tr
4754	455	11.8	3.7	0.5	29	5	47.5	SED. ROCK FRAG. -- trace
4755	288	7.5	6.6	1.4	30	27.3	21.8	SED. ROCK FRAG. -- 2.5%
								SED. ROCK FRAG. -- 4%
4755	341	9.8	5	1.2	29.5	24.5	24.5	IGNEOUS ROCK FRAG -- 1%
								SED. ROCK FRAG. -- 5%
								IGNEOUS ROCK FRAG - 0.5%

TABLE 5. PETROGRAPHY OF CAPE BRETON SAMPLES

SAMPLE #	# GRAINS	GARNET %	PYROXENE %	HORNBLende %	OPAQUES %	FELDSPAR %	QUARTZ %	ACCESSORIES & OTHER GRAINS %
4782	160	...	1.3	...	3.1	4.4	50	SED. ROCK FRAGS. -- 31.3%
						BADLY WEATHERED		IGNEOUS ROCK FRAGS. -- 9.4%
4782	194	0.5	...	1	1	6.7	57.7	HYPERSTHENE -- 0.6%
						BADLY WEATHERED		SED. ROCK FRAGS. -- 27.3%
4783	195	...	...	1.5	3.6	6.2	51.3	IGNEOUS ROCK FRAGS. -- 5.2%
								HYPERSTHENE -- 0.5%
4783	174	0.6	...	1.7	2.9	6.9	39.1	SED. ROCK FRAGS. -- 36.9%
								IGNEOUS ROCK FRAGS. -- 0.5%
								SED. ROCK FRAGS. -- 41.4%
								IGNEOUS ROCK FRAGS. -- 1.7%
								WEATHERED ? -- 10%
4784	305	...	...	1	2.3	10.5	42	SED. ROCK FRAGS. -- 39.3%
4784	278	...	0.7	2.2	3.6	7.2	38.8	SED. ROCK FRAGS. -- 47.5%
4785	247	...	2	2.8	6.1	13	40.5	SED. ROCK FRAGS. -- 35.6%
								? AMORPHOUS MATERIAL -- 10%
4785	271	...	1.1	3	4.4	9.2	36.2	SED. ROCK FRAGS. -- 36.9%
								? AMORPHOUS MATERIAL -- 10%
4786	210	...	...	...	0.5	1	72.4	SED. ROCK FRAGS. -- 17.1
								? AMORPHOUS MATERIAL -- 10%
4786	178	...	...	1.7	...	2.8	74.1	SED. ROCK FRAGS. -- 20.2%
								IGNEOUS ROCK FRAGS. -- 1.1%

TABLE 6. RESIDUES FROM HEAVY LIQUID SEPARATION

SAMPLE #	VIAL #	# GRAINS	% HEAVIES	% LIGHTS
4745	SPSF 16L	541	4.4	95.6
4745	C26 L	532	0.6	99.4
4745	SPSF 16H	998	92.4	7.6
4745	C26 H	358	96.1	3.9
4747	SPSF 17L	275	34.2	65.8
4747	C27 L	317	0.9	99.1
4747	SPSF 17H	405	90.4	9.6
4747	C27 H	491	95.7	4.3
4749	SPSF 18L	586	30.2	69.8
4749	C28 L	432	0.9	99.1
4749	SPSF 18H	639	91.7	8.3
4749	C28 H	273	93.4	6.6
4754	SPSF 19AL	1041	57.6	42.4
4754	C29 L	576	0.5	99.5
4754	SPSF 19AH	396	87.1	12.9
4754	C29H	454	94.3	5.7
4755	SPSF 20L	894	45.3	54.7
4755	C30 L	552	1	99
4755	SPSF 20H	594	94.4	5.6
4755	C30 H	538	95.7	4.3

TABLE 7. COMPARISON OF SEPARATION METHODS

SAMPLE #	VIAL #	SEPARATORY FUNNEL METHOD	CENTRIFUGE METHOD	DIFFERENCE	FRACTION
4745	C26	93.21%	92.30%	-0.91%	HEAVY
		6.79%	7.70%	0.91%	LIGHT
4747	C27	86.64%	89.84%	3.20%	HEAVY
		13.36	10.16	-3.20%	LIGHT
4749	C28	82.04	84.62	2.58%	HEAVY
		17.96	15.38	-2.58	LIGHT
4754	C29	94.73	94.77	0.04	HEAVY
		5.27	5.23	-0.04	LIGHT
4755	C30	87.75	94.3	6.55	HEAVY
		12.25	5.7	-6.55	LIGHT
4782	C31	1.02	1.16	0.14	HEAVY
		98.98	98.84	-0.14	LIGHT
4783	C32	1.09	1.73	0.64	HEAVY
		98.91	98.27	-0.64	LIGHT
4784	C33	5.31	6.53	1.22	HEAVY
		94.69	93.47	-1.22	LIGHT
4785	C34	7.75	6.23	-1.52	HEAVY
		92.25	93.77	1.52	LIGHT
4786	C35	0.69	0.86	0.17	HEAVY
		99.31	99.14	-0.17	LIGHT

TABLE 8. MAGSTREAM RESULTS

	A	B	C	D	E	F	G	H
1	SAMPLE #	MAGNETITE %	% > 4.25	% < 4.25	% < 3.31	% < 2.90	HEAVY %	LIGHT %
2	4747	9.02	38.37	35.62	6.44	10.55	89.45	10.55
3	4755	50.2	9.76	24.56	5.66	9.82	90.18	9.82
4	4745	24.85	12.36	28.24	7.42	27.13	72.87	27.13
5	4749	21.07	9.84	29.58	10.07	29.44	70.56	29.44
6	4754	34.67	14.39	31.01	7.77	12.16	87.84	12.16

TABLE 9. MAGNETIC SUSCEPTIBILITY RESULTS

SAMPLE #	QUARTZ Wt%	MAGNETITE Wt%	HORNBLende Wt%	ILMENITE Wt%	GARNET Wt%	GRAIN SIZE	MAGNETIC SUSCEP.(S/GRAM)
1	92	2	2	2	2	>63 <355 um	0.0199, 0.0200
2	92	3	3	1	1		0.0395, 0.0389
3	8	23	23	23	23		0.1912, 0.1912
4	8	10.4	10.4	35.6	35.6		0.0835, 0.0819
5	92	2	2	2	2	> 25 < 63 um	0.0227, 0.0225
6 Stratified	92	3	3	1	1		*0.2432
7	8	23	23	23	23		0.2121, 0.2077
8	8	10.4	10.4	35.6	35.6		0.0939, 0.0932
9	92	2	2	2	2	< 25 um	0.0239, 0.0236
10	92	3	3	1	1		0.0451, 0.0446
11	8	23	23	23	23		0.2057, 0.1988
12	8	10.4	10.4	35.6	35.6		0.103, 0.1016
6 Mixed	92	3	3	1	1	> 25 < 63 um	0.4528, 0.4487
							0.4518
							0.4515
							0.4507

TABLE 10. RESULTS OF FRANZ MAGNETIC SEPARATOR METHOD

	SAMPLE ID	Fe-Mg %	20° 0.4A %	20° 0.8A %	20° 1.2 A %	5° 1.2 A %
1	4745	32.3	15.1	43.9	0.8	1.1
2	4747	11.8	34.0	43.1	0.8	1.3
3	4749	11.3	25.3	46.5	1.0	2.0
4	4754	19.0	36.0	6.0	1.2	0.6
5	4755	47.5	15.9	28.6	0.5	1.4
6	4782	0.1	1.0	2.0	3.5	16.2
7	4783	0.4	0.6	2.5	3.0	30.7
8	4784	0.8	2.0	8.7	6.9	15.8
9	4785	0.1	0.5	10.0	5.3	12.7
10	4786	0.1	0.5	2.2	2.2	12.3

Separation of heavy minerals with the FRANTZ isodynamic magnetic separator at varying current intensities and side inclinations (after Hess, 1959).

	Side inclination 20°			Side inclination 5°	
A	B	C	D	E	F
Hand magnet	Magnetic at 0.4 A	Magnetic at 0.8 A	Magnetic at 1.2 A	Magnetic at 1.2 A	Non-magnetic at 1.2 A
Magnetite Pyrrhotite	Ilmenite Garnet Olivine Chromite Chloritoid	Hornblende Hypersthene Augite Actinolite Staurolite Epidote Biotite Chlorite Tourmaline (dark)	Diopside Tremolite Enstatite Spinel Staurolite (light) Muscovite Zoisite Clinozoisite Tourmaline (light)	Sphene Leucoxene Apatite Andalusite Monazite Xenotime	Zircon Rutile Anatase Brookite Pyrite Corundum Topaz Fluorite Kyanite Sillimanite Anhydrite Beryl

TABLE 11. LABORATORY ERRORS IN FRANZ MAGNETIC SEPARATOR METHOD

	Sample ID	Initial Wt (g)	New Wt (g)	% Wt Loss	% Magnetic	% Non-Magnetic
1	4745	17.01	15.85	6.82	93.12	6.88
2	4747	12.28	11.96	2.61	91.05	8.95
3	4749	14.69	14.48	1.43	86.05	13.95
4	4754	15.63	14.51	7.17	98.55	1.45
5	4755	13.49	12.93	4.15	93.97	6.03
6	4782	16.00	15.31	4.51	22.53	77.47
7	4783	16.14	14.58	9.79	37.16	62.84
8	4784	12.49	11.73	6.08	34.10	65.90
9	4785	15.47	14.81	4.27	28.43	71.57
10	4786	15.71	14.87	5.35	17.35	82.65

APPENDIX 1:
ANNOTATED REFERENCE LIST
RE: METHODS FOR LABORATORY ASSESSMENT OF MARINE PLACERS

compiled by

Frances J. Hein

Callahan, J., 1987, A nontoxic heavy liquid and inexpensive filters for separation of mineral grains: *Journal of Sedimentary Petrology*, v. 57, p. 765-766.

**** Sodium polytungstate & coffee filters in centrifuge**

Analyzed minus 40-mesh (< 0.420 mm) fraction of beach sand, Panama and placer deposits, North Carolina

1. 20 grams of sand -- heavy fraction ~ 15% of total weight
magnetic fraction (30% by weight) separated from concentrate using a **Sepor Automagnet**.
2. petrographic examination -- mainly hornblende, minor zircon & biotite
3. 0.04 g of minus 40-mesh gold placed in sodium polytungstate in centrifuge & 100% of gold sunk after 1 minute of centrifuging.

** Clifton, H.E., et al., 1969, Sample size and meaningful gold analysis. U.S. Geological Survey Professional Paper 625-C, 17 pp.

** Clifton, H.E., Hubert, A., Phillips, R.L., 1967, Marine sediment sample preparation for analysis for low concentrations of fine detrital gold. Geological Survey Circular 545, U.S. Department of the Interior, 11 p. (not @ BIO; ordered).

* Fisher, R.P. and Fisher, F.S., 1968, Interpreting pan-concentrate analyses for stream sediments in geochemical exploration for gold: United States Geological Survey, Circular 592, 9 p.

* Fricker, A.G., 1976, Placer gold-measurement and recovery: Symposium on Sampling Practises in the Mineral Industries: Australas Inst. Min. Metall, Ponkville, Australia, p. 115-127.

* Gesner, A., 1867, Gold and its separation from other minerals: N.S. Inst. Nat. Sci., v. 1, p. 54-60.

* Gleeson, C.F., 1970, Heavy mineral studies in the Klondike area, Yukon Territory: Geological Survey of Canada Bulletin 173, 63 p.

* Griffith, S.V., 1960, Alluvial prospecting and mining: 2nd edition, Pergamon Press Inc., New York, 245 p.

Hand, B.M., 1967, Differentiation of beach and dune sands using settling velocities of light and heavy minerals: *Journal of Sedimentary Petrology*, v. 37, p. 514-520.

1. Samples obtained by inserting a flat-bottomed aluminum trough (2.5 cm wide x 1 mm deep into a vertical sediment face & depth of insertion of ~ 2 cm. Contents retrieved by sliding a steel spatula into the sediment along the top of the aluminum trough & withdrawing the spatula and trough sampler together.
2. Magnetic separations & flotation in bromoform - monomineralogic quartz & ilmenite.
garnet and hornblende differentiated visually
3. Microsplit applied to a representative sample of 50-200 grains -- measured settling velocities in a settling tube.

* Harrison, H.L.H., 1962, *Alluvial mining for tin and gold*: Mining Publications Ltd., London, 313 p.

Hughes, R. L., 1986, *Sedimentology of the Sixtymile River Placer Gravels, Yukon Territory*: M.Sc. Thesis, University of Alberta, 210 p.

29 bulk samples (one cubic foot) collected from representative facies.

Bulk samples sluiced and then hand-panned (Fig. 4) and evaluated by binocular microscope for the presence of gold.

Libby, F., 1969, *Gold in the Sea*: *Sea Frontiers*, v. 5 (no. 4), p. 232-241.
Sluice box used onboard to wash dredge samples.

* Lock, A.G., 1882, *Gold; its occurrence and extraction*: E & F.N. Spon Pub., London, 1229 p.

* Langridge, C.C., 1913, *Gold and tin dredging*: Min. J., London, 425 p.

** MacDonald, E.H., 1983, *Alluvial Mining: the geology, technology and economics of placers*: Chapman & Hall, London, 508 pp.

* Mertie, J.B., 1954, *The gold pan: a neglected geological tool*: *Econ. Geol.*, v. 49, p. 639-651.

Grab sampling and vibracoring

Holocene black sands with up to 94% heavy minerals (? by weight).

Highest concentration in nearshore fine sand zone.

1. Grain-size analyses: used size-fraction 0.06-0.25 mm for float-sink analysis using bromoform (S.G. = 2.83 g/cm³).
2. nonmagnetic fraction examined microscopically to determine %age rutile.
3. heavy mineral fractions separated with Franz magnetic separator into 4 fractions (0.1, 0.3, 0.5, 1.5 amp).
4. Further work involved chemical analysis, microscopic and microprobe analyses -- to determine mineral constituents and intergrowth with particular consideration of occurrences of various titanium minerals and their properties, identification of chromiferous phases as well as zircon and monazite components.
5. Calculation of ore reserves carried on by variogram analysis : heavy mineral bearing nearshore area divided into 3 sections, each was done on a grid basis to get areal % age.

*McLeod, C.R., 1959, Trial study of heavy-mineral content of certain deposits of sand and gravel in New Brunswick, Nova Scotia and Prince Edward Island: Geological Survey of Canada paper 59-7, 21 p.

Morison, S.R., 1985, Sedimentology of White Channel placer deposits, Klondike area, West-central Yukon: M.Sc. Thesis, University of Alberta, 149 pp.

Lab work:

1. samples initially split and sieved through a #10 (U.S. Standard Sieve Number) screen to separate gravel size from sand and mud.
2. Grain-size analysis of sand size and muddy fractions was done by wet sieving through #18, #35, #60, #120 and #230 screens. Mud weights were calculated through subtractions of the total sand and gravel weight from initial sample weight.
3. Grain-size results plotted on ternary diagrams of mud-sand-gravel (Folk, 1954).
4. Bulk samples were concentrated by a hand-rocker or a portable sluice box.
5. Concentrates were then panned, and only black sand and gold retained

*Nolan, F.J., 1963, Heavy mineral analysis of the black sands of Nova Scotia: M.Sc. Thesis, Dalhousie University, Halifax, Nova Scotia.

Nelson, C.H. and Hopkins, D.M., 1972, Sedimentary processes and distribution of particulate gold in the northern Bering Sea: U.S. Geological Survey Professional Paper 689, 27 p.

Table 1 various methods used. Table 2 gold content wrt texture.

TABLE 1.—Methods of study						
Sample source (cruise)	Location method	Sampling method	Typical sample size (kg)	Method of preconcentrating gold	Method of gold analysis	Additional analyses at selected locations
Norne Beach (1967).	U.S. Geol. Survey topographic maps and aerial photographs.	Channel samples.	5	Panning.	Color count, AA. ¹	Texture, heavy minerals, ² lithology, roundness. ³
Bluff Beach (1968).	do.	do.	5	do.	do.	Texture, heavy minerals.
Tip City and Wales Beaches (1968).	do.	do.	5	do.	Color count, AA, emission spectrometer.	Tin content by emission spectrometer, wet chemical, and X-ray fluorescence.
Northeast Cape Beach, St. Lawrence Island (1968).	do.	do.	5	do.	Color count, AA.	do.
RV Virginia City (U.S. Bur. Mines) (1967).	Raylist, PRS (Precision Ranging System), sextant.	Shipek grab sampler, SCUBA diver, Becker drill, Sonico drill, Drill cuttings flushed every 6-12 ft of drilling. Maximum sediment penetration of 244 ft.	2-5; 5-10; 9-12	> 5 mm screened out, remainder panned; whole phi size fractions <0.5 mm analyzed by AA.	Color count, AA, amalgamation and weighing.	Pebble lithology and roundness, texture. Stratigraphic and lithologic correlation of drill holes. Clay, heavy mineral, pollen, Foraminifera, Ostracoda, Mollusca, and radiocarbon dating studies in progress on selected drill samples. Texture, mineralogy, Foraminifera.
RV Thomas G. Thompson (Univ. Wash.) (1967).	Loran A, radar.	10 gal Van Veen, Shipek, chain dredge.	0.5-10	Elutriation	AA.	do.
OSS-1 Oceanographer (1965).	Loran C, radar, satellite.	Campbell grab, 10 gal Van Veen, box cover.	10-30	> 2 mm removed by screening.	Color count, AA.	Studies of texture, heavy minerals, Foraminifera, Mollusca in progress, as well as studies of pebble roundness and lithology.
OSS-32 Surveyor (1968).	Radar, Raydist.	10 gal Van Veen	10-12	Clay and silt size removed by settling and siphoning techniques.	do.	Do.
MV Tomcod (1968).	PRS.	10 gal Van Veen	10-30	Panning	do.	Do.
Eskimo skin boat (1965).	Compass triangulation fixes.	5 gal Van Veen	5-10	do.	do.	Do.

TABLE 2.—*Size and weight classification of visible gold particles*

[Compiled from data of J. C. Antweiler (oral commun., 1969); A. Dailey (written commun., 1969); H. Heginbotham (written commun., 1967); Clifton and others (1969); Hite (1933)]

Visual gold particle size	Estimated modal weight ¹ (mg)	Estimated modal diameter ¹ (mm) Spheres Flakes ²		Comparable grain size
Visible gold ³				
1 color	15	1.20	2.40	Very coarse sand.
2 color	4	.70	1.40	Coarse to very coarse sand.
3 color	1	.50	1.00	Coarse sand.
4 color or very good trace.	.3	.30	.50	Medium sand.
Good trace .....	.03	.16	.30	Fine sand.
Very fine trace .....	.003	.07	.125	Very fine sand.
Subvisible gold				
Ultra fine trace	0.0001	0.060	0.100	Very fine sand.
Smallest size particulate gold observed.	.000003	about 0.005-0.010		Very fine silt.
"Carlin type" gold.	.....	about 0.001		Coarse clay.

¹ Range of panner's qualitative visual estimates probably is about ± 50 percent in the No. 2 to 4 color size classes; larger sizes are classified as $1\frac{1}{4}$, $1\frac{1}{2}$, and so forth. Estimates for trace-sized gold are highly variable and probably exceed ± 100 percent.

² Diameter approximately 10 times the thickness.

³ Expert panning normally will recover all visible gold; however, panning efficiency is highly variable and poor for subvisible gold.

Preconcentrate samples by screening out gravel and siphoning off suspended silt and clay size material. Material that remained — sand with all gold > 10 μ m in diameter panned and gold particles counted. Pan concentrates were analyzed by amalgamation or by atomic absorption techniques (Van Sickle and Larkin, 1968) to determine the gold content. Few samples were preconcentrated by elutriation to wash out the low density silt and clay. Gold particle size distribution estimated by atomic absorption of different size fractions. To correct for the small sample size effect, a moving average was done for gold tenor calculations for groups of samples from similar environments.

* Raeburn, C. and Miller, H.B., 1927, Alluvial prospecting: Thomas Murby & Co., London, 478 p.

* Romanowitz, C.M., Bennett, H.J., and Dare, W.L., 1970, Gold placer mining: Placer evaluation and selection: U.S. Bureau Mines Information Circular 8462, 56 p.

Properties of placer minerals in Table 2.

Methods: gravity separation as a first step.

Cleaning and upgrading: magnetic or electrostatic separation, flotation, and heavy media techniques. Upgraded conc treated by an amalgamation process for gold recovery. Extensive procedures for analysis of clays.

Table 1
Main Applications of Placer Minerals

Mineral	Metal	Applications
Ilmenite Rutile	Titanium	Aerospace Industry, High Strength and Corrosion Resistance, Oxide form used in Pigments.
Platinum Group		High Temperature Applications, Catalyst, Jewelry, Dental Alloy.
Zircon	Zirconium	Refractories, Ceramics, Abrasives, Chemicals.
Chromite	Chromium	Increases Hardness and Toughness in Steel, Electroplating, Refractory Pigments, Chemicals.
Cassiterite	Tin	Plating, Bearing Metals, Bronze, Solders.
Gold	Gold	Jewelry, Currency, Electronics, Dentistry, Plating.
Monazite	Thorium	Radioactive metal.

Table 2
Characteristic Properties of Valuable Placer Minerals^a

Mineral	Percent Valuable	Relative Density	Hardness (Mohs)	Magnetic Property	Electric Property
Gold	Au	15.6-19.3	2.8	NM	C
Platinum	Pt	17.0	4.5	NM	C
Monazite	9 ThO	4.9-5.3	5.0-5.5	M	C
Chromite	46.2 Cr	4.3-4.6	5.5	WM	C
Ilmenite	31.6 Ti	4.5-5.0	5.0-6.0	M	C
Rutile	60.0 Ti	4.2	6.0-6.5	NM	C
Cassiterite	78.8 Sn	6.8-7.1	6.0-7.0	NM	C
Zircon	67.2 ZrO	4.2-4.7	7.5	WM	NC
Diamond		3.5	10.0	NM	C
Scheelite	63.9 W	5.9-6.1	4.5-5.0	NM	NC
Magnetite	72.4 Fe	5.2-5.6	5.5	M	C

M Magnetic

WM Weakly Magnetic

NM Non Magnetic

C Conductor

NC Non Conductor

^a Compiled from Weiss, 1985

1. Sampling -- relevant sample thickness is ~ 1 grain diameter to document dispersive equivalence.
2. Sampled by sequentially applying pieces of adhesive tape (6 cm wide X 20 cm long) to the sediment surface -- obtaining sasmples ~ 1 grain diameter thick through the thickness of the experimental flow. ~ 1 cm trimmed from the borders of each tape and sediment collected from the remaining tape for further analysis.
3. Portion of each sample (S.G. < 2.9 g/cm³ and 3.1-3.3 g/cm³) separated using heavy liquids.
4. Binocular microscope with a micrometer eyepiece measured long axes of 400 grains in each fraction.
5. Weight % ages of all heavy minerals determined for each sample.

* Sanderson, L., 1964, Gold, its properties, occurrences and extraction: Can. Min. J., v. 85, no. 4, p. 113-116 and no. 5, p. 81-85.

* Savage, E.M., 1934, Prospecting for gold and silver: Mc-Graw Hill Book Co., Inc., New York, 307 p.

Siddiquie, H.N., Rajamanickam, G.V., and Almeida, F., 1979, Offshore ilmenite placers of Ratnagiri, Konkan Coast, Maharashtra, India: Marine Mining, v. 2 (no. 1-2), p. 91-118.

1. Samples washed to remove salts.
2. Dried and separated into sand, silt and clay fractions.
3. Sand and silt separated into light and heavy fractions using bromoform (S.G. = 2.89).
4. Heavy mineral fractions separated by a Cooks Magnetic Separator.
5. Initial magnetic separation with lowest magnetic intensity and a vertical feed to separate magnetite; subsequently nonmagnetic fraction separated on inclined feed on the magnetic separator into ilmenite, hornblende, augite and diopside.
5. Selected samples mounted in Canada Balsam and examined petrographically.

* Theobald, P.K., 1957, The gold pan as a quantitative geologic tool: U.S. Geological Survey Bulletin, 1071-A, 54 p.

* Thompson, C.E., Nakagawa, H.M., and Van Sickle, G.H., Rapid analysis for gold in geologic materials: U.S. Geologic Survey Professional Paper, 600-B, p. 130-132.

* Washington, R.A. and Holman, R.H.C., 1966, A rapid and sensitive method for determining gold in rocks and other geologic materials: Geologic Survey of Canada Paper 65-7, 18 p.

* Wells, J.H., 1973, Placer examination -- Principles and Practise: U.S. Dept. Interior Bureau of Land Management, Technical Bull. 4, 204 p.

* West, J.M., 1971, How to mine and prospect for placer gold: U.S. Bureau Mines Information Circular 8517, 43 p.

* Wise, E.M. (ed.), 1964, Gold: recovery, properties and applications: D. Van-Nostrand Co. Inc., Princeton, N.Y., 367 p.

Bowman, J.A., 1978, the determination of tin in tin ores and concentrates by atomic absorption spectrophotometry in the nitrous-oxide-acetylene flame: *Anal. Chim. Acta.*, v. 42, p. 285-291.

* Eales, H.V., 1968, Determining fineness variation characteristics in gold ores by reflectometry: *Econ. Geology*, v. 63, p. 688-691. [followed by discussion by E.F. Stumpfl, *Econ Geology*, v. 64, p. 341-342.]

**Economic Geology*, 1978, Special Issue devoted to the Geology and Geochemistry of Uranium, v. 73 (no. 8), p. 1401-1748.

Foster, R.P., Furber, F.M.V., Gilligan, J.M., and Green, D., 1986, Shamva Gold mine, Zimbabwe: a product of calc-alkaline-linked exhalative, volcanoclastic and epiclastic sedimentation in the Late Archaean, In Keppie, J.D., Boyle, R.W., and Haynes, S.J. (editors), *Turbidite-hosted gold deposits: Geological Association of Canada, Special Paper 32*, p. 41-66.

70 one-kilogram samples obtained from underground workings. small number analyzed for major element analysis (XRF) and all analyzed for wide range of trace elements (XRF; CO₂-infra-red). Gold determined using 50 g (double assay tonne) splits by standard fire assay procedures. Many samples in which gold was not detected (< 0.2 ppm) submitted for neutron activation analysis (NAA) and direct irradiation of 50 g splits.

*Frens, G., 1973, Controlled nucleation for the regulation of the particle size in monodisperse gold suspensions: *Nature*, v. 241, p. 20-22.

*Hawley, J.E., 1952, Spectrographic studies of pyrite in some eastern Canadian gold mines: *Econ. Geol.*, v. 47, p. 260-304.

*Huffman, C., Mensik, J.D. and Riley, L.B., 1967, Determination of gold in geologic materials by solvent extraction and atomic absorption spectrometry: *U.S. Geological Survey Circular 544*, 6 p.

*Hummel, R.V., 1957, Determination of gold in sea water by radioactivation analysis: *Analyst*, v. 82, p. 483-488.

*Lassiter, J.B., 1971, Some chemical aspects of the evolution and utilization of the Red Sea heavy mineral deposits: *Am. Chem. Soc., Div. Water, Air, Waste Chem., Gen. Pap.*, v. 11 (no. 2), p. 114-121.

Lombard, P.A. and Mills, R.F., 1987, Regional geochemical surveys: *N.S.D.M.E.*

*MacDiarmid, R.A., 1963, The application of thermoluminescence to geothermometry: *Econ. Geol.*, v. 58, p. 1218-1228.

*McDougall, D.J., 1964, A review of thermoluminescence as applied to mineral exploration and rock mechanics: *Can. Min. J.*, v. 85, p. 50-54.

*McDougall, D.J., 1968, Thermoluminescence of geological materials: Academic Press, London and New York, 678 p.

*Mutch, A.D., 1952, Variation of thermoelectric properties of pyrite in association with gold ore: *Min. Eng.*, v. 4, p. 880-883.

Owen, R.M., 1978, Geochemistry of platinum-enriched sediments: applications to mineral exploration: *Marine Mining*, v. 1, p. 259-282.

1. samples air-dried in a dust-free environment.
2. sample splitter used -- half for trace element; half for grain-size.
3. transition metals analyzed by atomic absorption spectrophotometry using a mixed acid procedure. See: Bodnar, W.F., 1969, Some principles of geochemical analyses: *Quarterly of the Colorado School of Mines*, v. 64, p. 19-22.
4. Pt analyzed by a fire assay technique See: Dorrzapt. A.F. and Brown, F.W., 1970. Direct spectrographic analysis for platinum, palladium and rodium in gold beads from fire assay: *Applied Spectroscopy*, v. 24 (4), p. 415-418.
5. Grain-size analysis @ 0.5 phi intervals in range from -1 phi (2 mm) to 4 phi (0.6 mm).

*Plant, J. and Cokleman, R.F., 1973, Application of neutron activation analyses to the evaluation of placar gold concentrations In *Geochemical exploration 1972*, M.J. Jones (ed.), Inst. Min. Metall (London), p. 373-381.

*Presant, E.W., 1971, Geochemistry of iron, manganese, lead, copper, zinc, arsenic, antimony, silver, tin and cadmium in the soils of the Bathurst area, New Brunswick, Geological Survey of Canada, Bulletin 174, 93 p.

Podolak, W.E. and Shilts, W.W., 1978, Some physical and chemical properties of till derived from the Meguma Group, southeast Nova Scotia: Geological Survey of Canada, Paper 78-1A, p. 459-464.

Trace element content of the clay (< 2 μ m) fractions and the fine sand-size heavy mineral (S.G. > 3.3) fractions were analyzed for all till samples.

1. Hot, mixed acid leach and atomic absorption and fluorescence techniques (Bondar-Clegg & Co. Ltd.).
2. Grain-size analysis of fine sand-size heavy mineral and magnetic fractions was done to determine weight percentages.
3. Complete grain-size distributions (fractions: > 2 μ m and < 2 mm) & Atterberg Limits calculated.

* Safronov, N.I., Polikarpochkin, V.V. and Utgof, A.A., 1960, Spectrographic aurometric surveying as a method for porspecting for gold ore deposits not accompanied by mechanical haloes (placers): Int. Geol. Rev., v. 2, no. 3, p. 254-258.

*Seeland, D.A., 1973, Geochemical reconnaissance for gold in the sedimentary rocks of the Great Lakes region, Minnesota to New York: U.S. Geological Survey, Bulletin no. 1305, 16 p.

*Sengupta, J.G., 1973, A review of the methods for the determination of the platinum-group metals, silver and gold by atomic absorption spectroscopy: Miner Sci Eng., v. 5, p. 207-218.

*Sighinolfi, G.P. and Santos, A.M., 1976, Determination of gold in geological samples at parts per milliard levels by flameless atomic-absorption spectroscopy: Mikrochim. Acta II, no. 1-2, p. 33-40.

*Smith, W.H., 1968, Geochemical investigation of a portion of the Forty-mile district, east-central Alaska: Alaska Dept, Nat. Res. Div. Mines Miner, Geochem Rept no. 16, p. 1-17.

*Soeharto, O., 1976, Comparitive study of low grade gold ore analysis: 25 Int. Geol. Congress, Sydney, Australia, Abstr., v. 2, p.459.

*Sutton, A.L., Havers, R.G., and Sainsbury, C.L., 1973, A spectrochemical method for determining the composition of native gold: u.S. Geological Survey, J. Research, v. 1, no. 3, p; 301-307.

*Stumpfl, E.F., 1969, Determining fineness variation characteristics in gold ores by reflectometry: Econ Geol., v. 64, p. 341-342.

Tixerant, M., LeLann, F., Horn, R., and Scolari, G., 1978, Ilmenite prospection on the continental shelf of Senegal: Methods and Results: Marine Mining, v. 1, p. 171-187.

1. Seismic reflection of old shorelines.
2. Magnetometry -- I.D. 5 anomalous zones, related to subsurface volcanic rocks. Resolution too poor to detect 3-5% ilmenite.
3. In Situ gamma-ray spectrometry
Ilmenite associated with zircon, monazite which contain traces of Th, U or natural isotopes of K

Measure in situ gamma radiation by way of scintillation spectrometry emitted by radioactive elements of their descendents.

4. Map Isovalues of gamma radiation
accuracy down to 1-2 ppm; 2-3 % ilmenite and zircon

*Van Sickle, G.H. and Lackin, H.U., 1968, An atomic absorption method for the determination of gold in large samples of geologic materials: U.S. Geological Survey, Circular 561, 4 p.

Yim, W.W.-S., 1979, Geochemical exploration for tin placers in St. Ives Bay, Cornwall: Marine Mining, v. 2 (no. 1/2), p. 59-78.

Shipek grab samples.

Atomic absorption method of Bowman, J.A., 1978, the determination of tin in tin ores and concentrates by atomic absorption spectrophotometry in the nitrous-oxide-acetylene flame: Anal. Chim. Acta., v. 42, p. 285-291.

Andrews, J.T. and Jennings, A.E., 1986, Influence of sediment source and type on the magnetic susceptibility of fiord and shelf deposits, Baffin Island and Baffin Bay, N.W.T.: Canadian Journal of Earth Sciences, v. 24, p. 1386-1401.

Fiords which head into Proterozoic Foxe Fold Belt have mass magnetic susceptibilities (MS) of $\sim 2-4 \times 10^{-7} \text{ m}^3/\text{kg}$ compared with $25-60 \times 10^{-7} \text{ m}^3/\text{kg}$ in sediments derived from Archaean gneisses and granites. MS values are higher in Lehigh cores compared with piston cores from the same sites, suggesting a coarsening in texture or an increase in the flux of magnetic minerals during 0.3 - 3 ka. Specific comparison of MS signals with lithofacies logs shows that MS variations are frequently associated with changes in texture; other significant changes are associated with changes in source materials.

Collinson, D.W., 1968, An estimate of the haematite content of sediments by magnetic analysis: Earth and Planetary Science Letters, v. 4, p. 417-421.

Table 1. Observed and calculated susceptibilities of clay and other minerals.

Mineral	FeO (%)	Fe ₂ O ₃ (%)	Susceptibility (gauss.cm ³ .Oe ⁻¹ .g ⁻¹ × 10 ⁶)	
			Observed	Calculate
Illite	1.4	4.7	12	11
Montmorillonite	2.8	3.0	11	10
Nontronite	0.2	28.0	52	51
Chamosite	14.0	40.0	70	95
Biotites *	19.2	7.9	63	50
Orthopyroxenes **	24.0	1.0	40	41
Ilmenite	46.4	—	80 - 90	77

* Reference [8]; mean value of 5 samples.

** Reference [9]; mean value of 8 samples.

Currie, R.E., and Bornhold, B.D., 1983, The magnetic susceptibility of continental-shelf sediments, West Coast, Vancouver Island, Canada: Marine Geology, v. 51, p. 115-127.

magnetic susceptibility highest in silt and fine sand fractions; lowest in clay and coarse sand. Fine sand contributed more to overall susceptibility than any other size.

No significant correlations between magnetic susceptibility and grain size statistics -- highest values concentrated within a narrow range of size, sorting, skewness and kurtosis.

Highest susceptibility in finest fraction 3.5 to 4 phi.

p. A15

Majority of samples can be characterized by their sand-fraction susceptibility -- conservative in that it underestimates the magnetite concentration.

Samples with susceptibility $>12,500 \times 10^{-6}$ have a mean grain size of 2.12-3.44 phi; a standard deviation of 0.30-0.75 phi; a skewness of -1.85 to +0.60; kurtosis of 2.8 to 11.6.

Magnetite concentrated in well sorted sands with a finer mean size.

Hamano, Y., 1980, An experiment on the post-depositional remanent magnetization in artificial and natural sediments: Earth and Planetary Science Letters, v. 51, p. 221-232.

Artificial and natural sediments were consolidated at a constant loading rate in a known magnetic field and the resultant remnant magnetization was observed. Both artificial and natural sediments acquire remanent magnetization during consolidation process. This acquisition is a function of the void ratio. Artificial sediment acquired remanence with the void ratio from 1.4 to 0.9; range of void ratio for natural sediments is 6-3. These void ratios correspond to depths of 15 cm and 2.5 m. Gradual acquisition of remanence during consolidation shows that remanence indicates an average of the ambient field over time, which depends on the sedimentation rate.

Henshaw, P.C., Jr. and Merrill, R.T., 1980, Magnetic and chemical changes in marine sediments. Reviews of Geophysics and Space Physics, v. 18, p. 483-504.

Analysis of cores from the Pacific Ocean show that although low-temperature oxidation of titanomagnetites occurs in some of the cores, such oxidation has had only a minor effect on altering the natural remanent magnetization in most cases. On the other hand, the ferromanganese phases are magnetic and form authigenically. At least one of these phases (probably todorokite) sometimes carries a remanence sufficiently large to mask the depositional remanence carried by the titanomagnetite grains.

Jahren, C.E., 1963, Magnetic susceptibility of bedded-iron formation: Geophysics, v. 28, no. 5 (pt. 1), p. 756-766.

effects of the directions of magnetization demonstrated by layering stacked disks of magnetic and non-magnetic material

show magnetic susceptibilities as much as three-times greater parallel to the layering than across them. Independent of the details of layering if $< 1/2$ volume is magnetic. Natural layered samples show the same range of susceptibility anisotropy as artificial layers. (layer susceptibility as high as 0.5 cgs.)

Susceptibility (k), Volume % magnetite (V)

$\sim k = 0.00116 V^{1.39}$ cgs. for $10 < V < 40$ (comes to a susceptibility of 0.7 for pure magnetite).

Along the layer susceptibility of a bedded sample w/ 20% volume of magnetite there is twice the susceptibility than in a homogeneous sample with the same total volume % of magnetite. (for a 1% volume of magnetite, 3 x as great).

Radhakrishnamurty, C., Likhite, S.D., Amin, B.S., and Somayajulu, B.L.K., 1968, Magnetic susceptibility stratigraphy in ocean sediment cores: Earth and Planetary Science Letters, v. 4, p.464-468.

Verosua, K.L., Ensley, R.A., and Ulrick, J.S., 1979, Role of water content in the magnetization of sediments: Geophysical Research Letters, v. 6, p. 226-228.

Experimental procedure done to determine the magnetic direction recorded by a sediment as a function of the water content present when that sediment experiences a change in the direction of an applied magnetic field. Experiments show that regardless of the water content, the sediment does not become remagnetized. Analysis of the magnetic properties of sediment samples initially stirred in zero and non-zero magnetic fields suggests that the magnetization of sediments may arise from small-scale, shear-induced liquefaction.

Tixerant, M., LeLann, F., Horn, R., and Scolari, G., 1978, Ilmenite prospection on the continental shelf of Senegal: Methods and Results: Marine Mining, v. 1, p. 171-187.

1. Seismic reflection of old shorelines.
2. Magnetometry -- I.D. 5 anomalous zones, related to subsurface volcanic rocks. Resolution too poor to detect 3-5% ilmenite.
3. In Situ gamma-ray spectrometry
Ilmenite associated with zircon, monazite which contain traces of Th, U or natural isotopes of K

Measure in situ gamma radiation by way of scintillation spectrometry emitted by radioactive elements of their descendents.

4. Map Isovalues of gamma radiation
accuracy down to 1-2 ppm; 2-3 % ilmenite and zircon

Flinter, B.H., 1959, Magnetic separation of some alluvial minerals in Malaya: American Mineralogist, v. 44, p. 738-751.

Isolate by various angles of slope and tilt on the Franz isodynamic separator: allanite, anatase, andalusite (and chiastolite), arsenopyrite, brookite, cassiterite, columbite, epidote, gahnite, pink garnet, ilmenite, manganese oxide, monazite, pyrite, rutile, scheelite, siderite, staurolite, thorite, topaz, tourmaline, uranoan monazite, wolframite, xenotime and zircon.

Gaudin, A.M. and Spedden, H.R., 1943, Magnetic separation of sulphide minerals: American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1549, p. 1-13 (with discussion)

*McAndrew, J., 1957. Calibration of a Franz Isodynamic Separator and its application to mineral separation: Proc. Aust. I.M.M., v. 181, p. 59-73.

Reid, I. and Frostick, L.E., 1985, Beach orientation, bar morphology and the concentration of metalliferous placer deposits: a case study: Lake Turkana, North Kenya: Journal of the Geological Society (London), v. 142, p. 837-848.

1. Frantz isodynamic separator used (set @ 1.1A w/ a sideslope of 12°).
2. Both magnetic and nonmagnetic fractions analyzed for grain-size and mineralogy.
3. optical mineralogy and SEM work done on magnetically susceptible minerals, mainly ilmenite and magnetite.

Wassef, S.N., 1981, Distribution and properties of placer ilmenite in East Rosetta beach sands, Egypt: Mineralium Deposita, v. 16, p. 259-267.

Lab Work:

1. 1/4'd using a Jones-splitters down to 75 g
2. clays removed by washing; organics removed by hydrogen peroxide and hot water.
3. cleaned with distilled water and dried.
4. 1/2'd for grain-size and mineral separation.
5. magnetite removed by a small hand magnet (99.5% recovered).
6. Franz-isodynamic separator used for magnetic fractionation of the magnetite-free samples. Done twice -- concentrate all heavies and to separate ilmenite (20° side slope and a current of 1.5 amp and a tilt of 3°).

NOTES ON OPERATION OF
FRANTZ ISODYNAMIC MAGNETIC SEPARATOR

p. A19

H. H. Hess
Princeton University

More than twenty years ago, Mr. Samuel G. Frantz saw the types of magnetic separators we were using in the Department of Geology and concluded that a greatly improved separator could be made by designing one, which at any given current, had a magnetic pull of uniform strength in the area in which the separation was to be performed. This resulted in construction of a pilot model of the Isodynamic separator which was tried out at Princeton and proved to be highly successful. Since then, a Frantz separator has been in almost continuous use in this department and tens of thousands of separations have been made.

While it takes little more than common sense to operate this instrument, there are a few tricks learned over the course of years which are perhaps worth passing on. Furthermore, this account will indicate the variety of uses to which the instrument has been put.

PREPARATION OF SAMPLE FOR SEPARATION.

In general, the sample should be at least roughly sized. Ordinarily, separations are made in the range -80 to +100 or -100 to +120 mesh. Thirty mesh is about the largest size on which separations are convenient and +400 mesh about the smallest. With the finer sizes, difficulties may be encountered from electro-static charge on the particles and consequent "balling up". If, however, the sample can be disaggregated, good separations can be made to perhaps 400 mesh.

For routine separations near, for example, 100 mesh, it is advisable to wash the sample before treatment in order to remove dust adhering to the grains. This is ordinarily done by stirring the sample in a beaker of water, allowing it to settle for 20 seconds and decanting the water several times. If the grains are dust coated, the quality of the separation is often materially reduced.

Magnetite or iron filings, from previous crushing in an iron mortar, must be removed with a hand magnet before the sample is placed in the separator. Either of these will stick to the pole pieces of the magnet and may block free flow of the sample down the chute. Iron filings should be removed before washing the sample to avoid staining of the grains by iron oxide. A small alnico magnet, wrapped in paper combed through the sample until no more magnetite or iron is picked up, is satisfactory for this preliminary step.

INSTRUMENT SETTINGS FOR SEPARATIONS WITH THE CHUTE.

In discussing instrument settings, the direction at right angles to the length of the chute will be called side slope and parallel to the length, forward slope. Normally, a side slope of approximately 20° is used and a forward slope near 30° . * A steeper forward slope may cause the grains to bounce when coarser grain sizes are being separated whereas too small a slope with finer grain sizes will impede free flow of the sample down the chute. A satisfactory setting can easily be determined by trial and error. Smaller side slopes (2° – 10°) are used to separate the minerals with very small magnetic susceptibilities which would separate on the nonmagnetic side of the chute at a 20° side slope and maximum current.

* While standard settings of 20° side slope and 30° forward slope have been used at Princeton, these values are not at all critical. Many other laboratories use 10° to 15° side slopes and smaller forward slopes.

The separator consists basically of an electromagnet whose poles are shaped so that between them there is a long open space which continuously widens in one direction.

The fine sand sample (1-4Ø) which have been washed clean of silt and clay is poured into the narrow vibrating chute via a small funnel.

It is important to remove magnetite and pyrrhotite from your sample before pouring it into the separator because it will clog the chute if you don't.

Instrument settings

In discussing instrument settings the direction at right angles to the length of the chute will be called "side slope", and parallel to the length "forward slope". Normally a side slope of approximately 20° is used and a forward slope near 30°. A satisfactory setting can easily be determined by trial and error. Smaller side slopes (2°-10°) are used to separate the minerals with very small magnetic susceptibilities which would separate on the non-magnetic side of the chute at a 20° side slope and maximum current.

Rate of flow is controlled by screwing the input funnel up or down. The proper rate of flow of the sample down the chute can be judged by eye after a little practice. Using a fine sand a rate of 1 to 2 cc per minute would be normal for a 30° forward slope. Rapid initial separations such as the removal of 90% quartz plus feldspar from a rock in which it is desired to concentrate a magnetic mineral present in small amount, can be made at a rate of 5 cc per minute. Final purification of the desired mineral would be made at perhaps 0.3 cc per minute. Finer powders will flow at somewhat slower rates and coarser at faster. The thickness of the stream of powder should be kept the same as it was in the case of the fine sand for the rates given above. Similarly a steeper forward slope will increase rate of flow or a gentler slope decrease it. A 1 cc 2.75 to 3Ø sample can be prepared and passed through the separator with a 30° forward slope at various rates to become familiar with the optimum stream thicknesses. Once having observed the proper stream thickness there is no difficulty in adjusting the flow for any grain size or slope to conform to this thickness.

Heavy mineral concentrates can quickly be separated (for routine investigations within 5 minutes) into five groups (six including hand magnet separations) by passing through four times at various current intensities and sideward inclinations. These six groups are shown in Table 3. Further separation is possible by the use of smaller steps in field strength, using Figure 7.

At an appropriate position of the magnet, the Frantz magnetic separator can be used in an inclined position (by changing the direction of forward slope to 2-3°) as well as in vertical free-fall position (vertical position of the magnet to 2-5° forward and sideward) for the separation of diamagnetic minerals (e.g. quartz and zircon).

TABLE 3. Separation of heavy minerals with the FRANTZ isodynamic magnetic separator at varying current intensities and side inclinations (after Hess, 1959).

Side inclination 20°

A: Hand Magnet	Magnetite, Pyrrhotite
B: Magnetic at 0.4 A	Ilmenite, Garnet, Olivine, Chromite, Chloritoid
C: Magnetic at 0.8 A	Hornblende, Hypersthene, Augite, Actinolite, Staurolite, Epidote, Biotite, Chlorite, Tourmaline (dark)
D: Magnetic at 1.2 A	Diopside, Tremolite, Enstatite, Spinel, Staurolite (light), Muscovite, Zoisite, Clinozoisite, Tourmaline (light)

Side inclination 5°

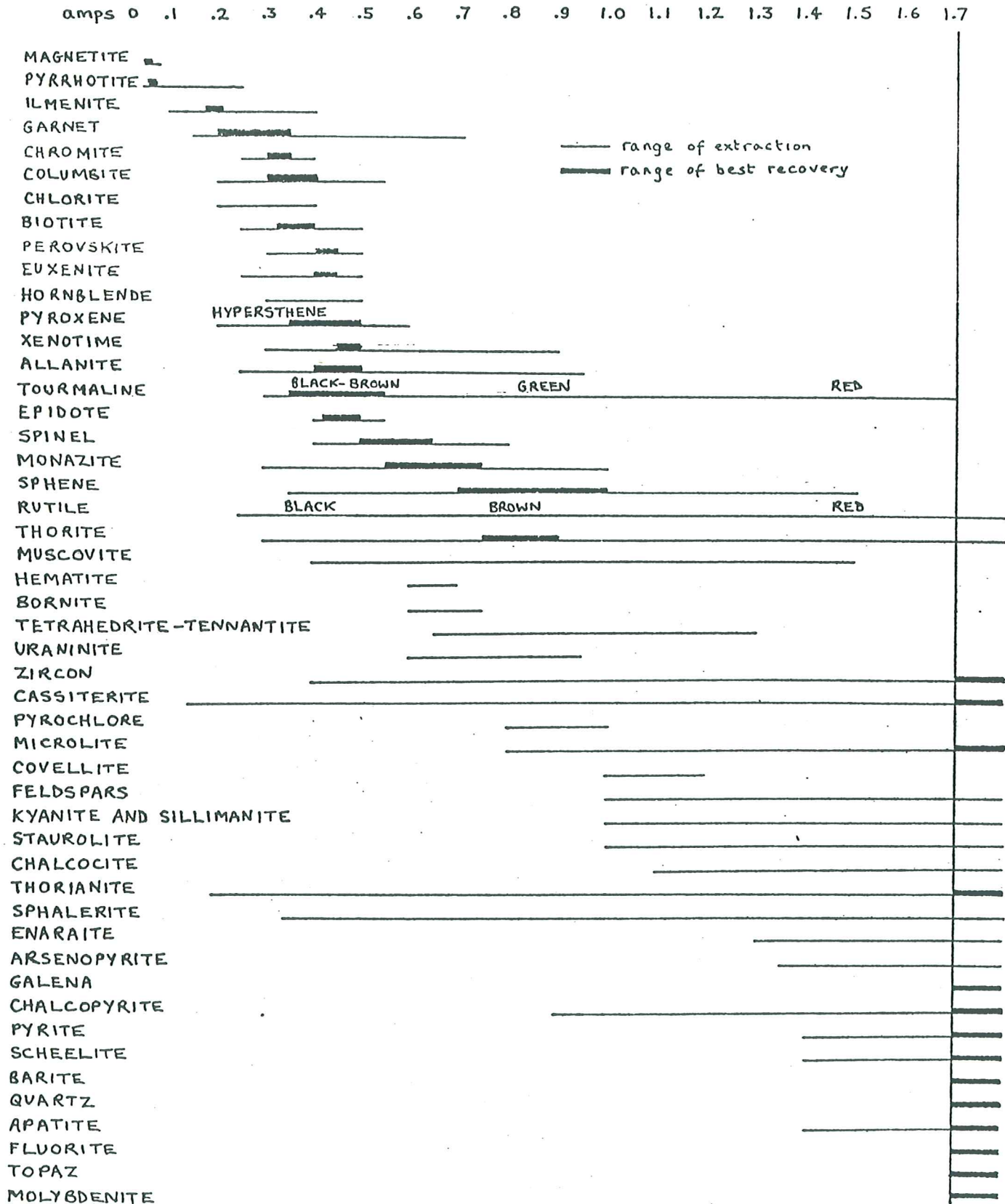
E: Magnetic at 1.2 A	Sphene, Leucosene, Apatite, Andalusite, Monazite, Xenotime
F: Non-magnetic at 1.2 A	Zircon, Rutile, Anatase, Brookite, Pyrite, Corundum, Topaz, Fluorite, Kyanite, Sillimanite, Anhydrite, Beryl

bulk
 h. min
 l. min
 3 major { mas.
 heavies { garnet
 { px
 { amph.
 quartz

FIGURE 7

p. A22

FRANTZ MAGNETIC SEPARATOR: CURRENT FOR BEST SEPARATION



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counts to determine frequency distribution of occurrences of heavy minerals ~ binomial, Poisson or negative binomial distributions.
Goodness of fit tested by chi-square.

1. population of a mount of mineral grains (if mount homogeneous) ~ Poisson frequency distribution.
2. if heavies concentrated by preparation techniques ~ binomial distribution.
3. If frequency distribution determined by natural conditions:
 - homogenous throughout rock ~ fixed probability model
 - occur in pay streaks (i.e. one grain leads to concentrate other grains) ~ the negative binomial distribution or a mixed Poisson distribution.

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Accessories assoc with gold; chpt on placers and gold in sediments

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1. Gabbroic source for littoral marine sands
 Iron minerals: magnetite-ilmenite and hematite
 heavy minerals: 17% by weight of sand @ Riviere Moise area (p. 17)
 heavy mineral peak @ 1/2 - 1 phi
 medium-coarse grained sand
2. Granitic & mafic tills heavy mineral description (p. 8)
 Granitic: hornblende, magnetite, augite, hypersthene, garnet
 Mafic: garnet, augite, hornblende, hypersthene, magnetite
3. Heavy minerals in tills are more abundant in the fine fraction (p. 9, Fig. 10). 0.25 - 0.12 mm (2-3 phi) & 0.12-0.06 mm (3-4 phi)
4. heavy minerals are more abundant in gabbroic till than in granitic till.

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APPENDIX 2. SPECIFICATIONS OF HEAVY-LIQUID SEPARATION USING SODIUM POLYTUNGSTATE AND MAGSTREAM™

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INTRODUCTION

Two heavy liquids commonly used to separate minerals, bromoform and tetrabromoethane, are both toxic (Sax and Lewis 1986; Hauff and Airey 1980). In addition, acetone, which is used to clean samples prepared with bromoform or tetrabromoethane, is flammable and acts as an irritant and narcotic (Sax and Lewis 1986). Sodium polytungstate, $3\text{Na}_2\text{WO}_4 \cdot 9\text{WO}_3 \cdot \text{H}_2\text{O}$, a nontoxic solid that can be made into a heavy liquid (sp. gr. > 1.0–3.1) has been on the market for approximately three years. A similar chemical, sodium metatungstate ($\text{Na}_6[\text{H}_2\text{W}_{12}\text{O}_{40}]$), used for separation of heavy minerals, was originally described by Plewinsky and Kamps (1984). Sodium polytungstate is available in liquid or powdered form from Sometu, Falkenried 4, D-1000 Berlin 33, West Germany at DM 130 (\$65, U.S.) per kilogram for the solid and at a higher price for the liquid. According to the manufacturer, a 1,250-g solution with an approximate density of 2.90 g/cm³ can be made by adding 250 g of distilled water to 1,000 g of powdered sodium polytungstate. The main purpose here is to report results obtained in heavy mineral separations using sodium polytungstate and to compare the results with those obtained from tetrabromoethane separations. In addition, several types of filter paper were used in the separations in an attempt to determine which one(s) could best be used in separations with the sodium polytungstate.

METHODOLOGY

Heavy mineral separates from splits of the minus 40-mesh fraction (< 0.420 mm) of a beach sand from Panama and gold grains from a placer deposit in North Carolina were concentrated using sodium polytungstate and tetrabromoethane. The samples were separated in standard 250-mL separatory funnels and recovered on various types of filter paper. In a separate test, a gold concentrate was separated using a small laboratory-model centrifuge to test the efficiency of separating fine gold (less than 40-mesh) with the sodium polytungstate liquid.

ANALYTICAL RESULTS

Essentially identical weights of heavy concentrates were obtained from the Panama beach sand using the two different heavy liquids in duplicate experiments. Twenty grams of sand were used in both experiments. The heavy fraction represented 15 percent of the total weight of the sand for both the sodium polytungstate and the tetrabromoethane separations. The magnetic fraction (30% by weight) of the concentrate was separated using a Sepor Automagnet. Petrographic examination of the nonmagnetic fraction of the concentrates showed that it consisted almost entirely of hornblende with minor zircon and biotite. Other heavy sep-

aration tests using 0.04 g of minus 40-mesh gold placed in sodium polytungstate and tetrabromoethane showed great differences in the recovery rates for the gold. Only 40 percent of the gold was recovered in heavy concentrates in the first experiment using sodium polytungstate, and 89 percent of the gold was recovered in the tetrabromoethane heavy concentrates. In a second experiment, great care was taken to stir the sodium polytungstate-gold-grain mixture, and the recovery rate improved to 83 percent and remained almost the same (88%) for the tetrabromoethane separation.

In a separate experiment, the sodium polytungstate-gold concentrate that was recovered from the second experiment noted above was centrifuged for one minute. When the minus 40-mesh gold concentrate was first placed on the sodium polytungstate in the centrifuge tube, most of it floated. After one minute of centrifuging, 100 percent of the gold sank to the bottom. In another experiment, some gold grains in the greater than 40-mesh range were placed in the sodium polytungstate liquid. After stirring, 100 percent of them were recovered in the heavy portion of the concentrate.

One of the major problems encountered with the use of the sodium polytungstate was the slow rate at which it passed through even one of the more rapid laboratory grades of filter paper (Whatman #4). Several varieties of filter paper with various sample materials and amounts in them were tested to determine which paper allowed both heavy liquids to pass through most rapidly. After several experiments, it was determined that both the tetrabromoethane and sodium polytungstate passed through coffee filter paper at least twice as fast as the Whatman #4. The coffee filters are one-tenth the cost of the laboratory-grade filter paper. In addition, the wet strength of the coffee filters appears to be better than the laboratory-grade filter papers we used.

DISCUSSION AND CONCLUSIONS

It appears that identical results can be obtained for heavy mineral separations using the heavy liquids tetrabromoethane and sodium polytungstate. For fine-grained gold, the recovery rate may be increased by stirring the sample repeatedly or by using a centrifuge in the separation process. Fine gold tends to float in the sodium polytungstate-water solution, as gold is not readily wettable by water.

The main advantage of sodium polytungstate, according to the supplier, is that it is nontoxic. According to Kazantzis (1979), there appears to be little potential for tungsten compounds to be extremely hazardous unless inhaled or ingested. No direct reference to the toxicity of sodium polytungstate could be found by the author, and it is not listed in the widely quoted *Registry of Toxic Effects of Chemical Substances* (1983). Other advantages are that the heavy mineral separates can be cleaned with distilled water, and the specific gravity of the sodium polytungstate solution can be changed by adding either distilled water or powdered sodium polytungstate. A table is available from the supplier for making changes in the specific gravity. According to the supplier, the maximum

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specific gravity that can be attained by adding powdered sodium polytungstate to distilled water is 3.1. The biggest disadvantage is that the cost of 1 kg of the powdered sodium polytungstate solid is DM 130, which at the present rate of exchange is \$65, or \$151 per liter, when made into a solution. This is approximately 1.6 times more expensive than the purified grade of tetrabromoethane at \$96 per liter. Two other disadvantages are recognized. Sodium polytungstate passes through standard laboratory filter paper rather slowly as a result of its higher viscosity. This problem can be avoided by using a rapid filter paper such as coffee filters. In addition, the manufacturer indicates that sodium polytungstate has rather high trace element contents (Mo-2 ppm, As-5 ppm, U-10 ppm). These might interfere with chemical analysis of the concentrates if they are not cleaned carefully with distilled water to remove any residue. However, because essentially identical results may be obtained using nontoxic sodium polystungstate and toxic tetrabromoethane, the use of sodium polytungstate is recommended as a safe way to carry out effective heavy mineral separations.

tool in deep-water tracks of the Gulf of Mexico.

Zonation of clay minerals in a Jurassic playa-lake setting:
A case for low-temperature formation of illite

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Some workers have suggested that the unusual pore-water chemistry of playa lakes might be conducive to formation of authigenic illite at low temperatures. Playa-lake deposits in the Brushy Basin Member of the Jurassic Morrison Formation, Colorado Plateau, provide a natural laboratory to test this hypothesis. In this ancient playa lake, which extended 500 km from Gallup, New Mexico to Grand Junction, Colorado, volcanic ash altered shortly after deposition to various authigenic minerals in four concentrically zoned diagenetic facies. Clay separates from tuff beds collected from each of these early diagenetic facies across the playa lake reveal a pattern of increasing illite content toward the center of the lake.

The trend in clay composition accompanies the systematic basinward change from zeolites to feldspars; this change reflects a steep hydrogeochemical gradient, with salinities and alkalinities increasing toward the center of the lake. Randomly interstratified smectitic clay (~80-100% expandable layers) occurs either as the predominant mineral or with clinoptilolite in the two outermost playa-lake facies. Ordered illitic mixed-layer clay (0-30% expandable layers) occurs in association with authigenic albite in the central playa-lake facies. Mixed-layer clay of highly variable composition occurs with analcime and authigenic potassium feldspar in the intervening playa-lake facies.

Lack of illite in marginal facies precludes a detrital origin for the illite in more distal facies. Moreover, the way in which composition of mixed-layer clays mimics the zonation of early diagenetic zeolites and feldspars across the playa lake strongly suggests that the clays also formed during early diagenetic alteration of volcanic ash. Distribution of illite is independent of proximity to heat sources and/or depth of burial. We therefore infer a low temperature, near-surface origin for the illite in contrast to the high temperature (>90°C), deep burial conditions required by the Gulf Coast model of illite formation.

U

A NEW NON-TOXIC TECHNIQUE FOR THE CONCENTRATION OF CONODONTS

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The gravimetric concentration of conodonts has traditionally been accomplished through the use of tetrabromethane and methylene iodide. This paper describes results obtained with a new method of gravimetric concentration that uses a non-toxic, water-based magnetic fluid in a Magstream™ separator.

The separator consists of a rotating separation duct surrounded by a cylindrical magnet. Particles to be separated are slurried with the magnetic fluid and fed downward through the duct. An outward magnetic attraction of the fluid drives particles radially inward against an outward centrifugal force

of rotation. Separation is achieved by balancing these forces so that a specific gravity split point is placed between the specific gravities of the particles to be separated.

Conodont concentration was accomplished in two passes. The crushed and appropriately leached samples were first separated at a tetrabromethane equivalent ($G=2.96$) and again at a methylene iodide equivalent ($G=3.32$). Ferromagnetic or strongly paramagnetic minerals were drawn to the outer wall of the separation duct and pinned by the magnet. The concentrated conodonts were washed easily in water. By using this method, hand picking through a large residual sample is either greatly reduced or eliminated.

V

HYDROLOGY OF METEORIC DIAGENESIS -- RESIDENCE TIME OF GROUND WATER IN SMALL, STRIP-ISLAND LENSES.

H. L. Vacher and T. O. Bengtsson (Dept of Geology, Univ of South Florida, Tampa, FL, 33620)

Meteoric diagenesis is a function of the character of the sediment, chemistry of the ground water, and the rate that ground water flushes through the sediment. The latter process can be quantified from the first principles of ground-water hydraulics.

A representative residence time for ground water in an island lens can be defined as the lens volume divided by the total inflows. Potential-theory analysis of a related distributed-recharge, unconfined-flow problem shows that aquifer-average residence time is the weighted mean of all the streamline residence times, where the weighting reflects distribution of recharge. A representative velocity is then given by the geometric mean of the length and average thickness of the flow system divided by the aquifer-average residence time.

Analogous parameters can be calculated for lenses in homogeneous islands by Dupuit-Ghyben-Herzberg procedures. For a 400m-wide Joulter-like cay consisting of Holocene ooids and a 1000m-wide Bermuda-like island consisting of Late Pleistocene calcarenite, the island-average residence times are about 3.2 and 4.8 yrs, respectively, if recharge is .3 m/yr (a Bermudian figure) and effective porosity is 0.2. The representative interstitial velocities are 9.6 and 12.5 m/yr (or 9.6 and 12.5 pore volumes flush through a cu. m. of sediment each yr.)

Flow-net analysis allows determination of how individual-particle residence times, velocities, and ground-water ages are distributed through the lens. The velocities, which vary over 2 orders of magnitude in natural-sized lenses, decrease with depth and increase toward shore. Ground-water ages near the interface close to the outflow are 2 or more residence-time units.

MAJOR AND TRACE ELEMENT SIGNATURES OF LATE TERTIARY PLATFORM DOLOMITES FROM THE BAHAMAS: INDICATION FOR FLUID EVOLUTION

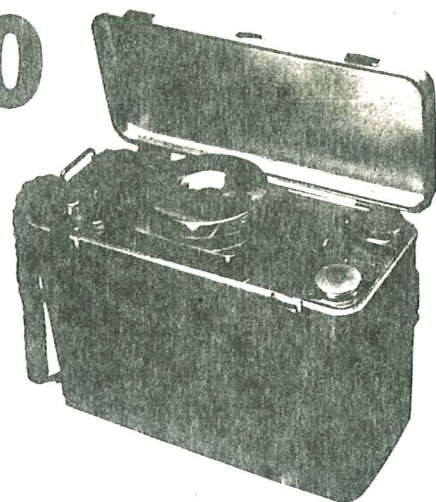
V.C. Vahrenkamp and P.K. Swart (MGG/RSMAS, University of Miami, Miami, FL)

MAGSTREAMTM

MODEL 100

**OFFERS YOU A REVOLUTIONARY
AND DISTINCTLY DIFFERENT
SEPARATION CONCEPT AND
AN ALTERNATIVE TO TOXIC
HEAVY LIQUIDS.**

- FOR PRECISE GRAVIMETRIC SEPARATIONS
- OVER A DENSITY RANGE EXTENDING BEYOND 21 g/cm³



**The MODEL 100 is a rugged
portable separator designed
for field and laboratory use.**

- Multiple Sets of Collectors for Quick Product Removal and Rapid Successive Analyses
- Immediate On-Site Analysis of Sand-Sized Materials
 - Heavy Minerals from Light Minerals
 - Monomineral Fractions from Heavy Mineral Suites
 - Microfossils from Matrix

**FAST, PRECISE, SAFE (Non-Toxic)
EASY-TO-USE AND COST-EFFECTIVE**

EXPAND THE SCOPE AND SAFETY OF YOUR MINERAL ANALYSES!

THE MODEL 100.

Used either in its case or mounted in a laboratory bench top, the Model 100 achieves fast, precise and safe separations over a density range far exceeding that of heavy liquids.

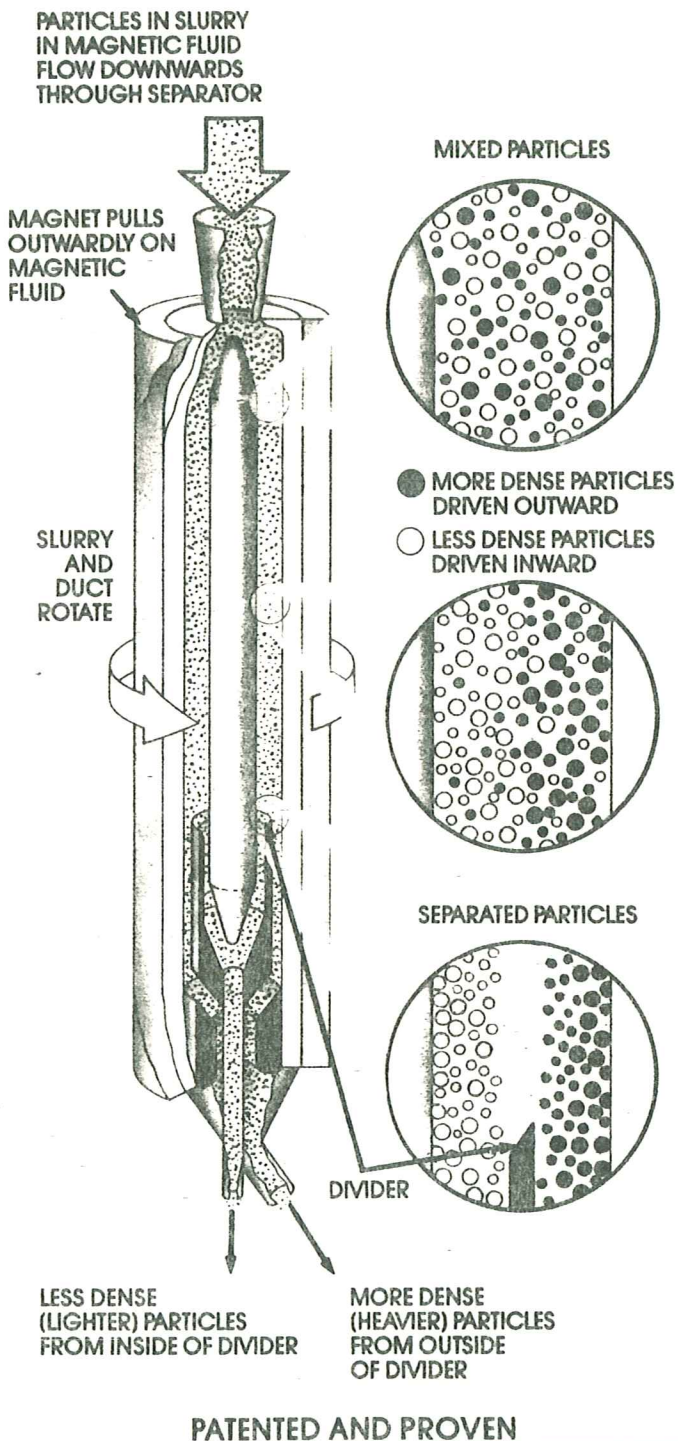


in the field



in the laboratory

HOW MAGSTREAM™ WORKS



For more information on the Model 100 and the entire MAGSTREAM™ line of separators, contact:

MARKETING DIRECTOR—MAGSTREAM™

Intermagnetics General Corporation
New Karner Road, P.O. Box 566,
Guilderland, New York 12084
(518) 456-5456 • FAX: (518) 456-0028 • TLX: 6711205

How Magstream™ is Applied

The density versus magnetic susceptibility diagrams of figure 1 provide a graphic illustration of how available property differences may be exploited for separation. Magstream™ separation bands can be designed as shown in relation to minerals located by gravimetric (density) and magnetic properties on such a diagram. Mineral groupings on opposite sides of the separation bands will report to separate discharge products. For essentially non-magnetic material the separation band is reduced to a precise single density separation split point on the zero susceptibility axis.

For gravimetric or combined property separations, both the slope and the density axis intercept of the band can be adjusted as necessary to exploit available property differences for separation by changing the concentration of the magnetic fluid and/or the speed of separator duct and slurry rotation. For magnetic property separation the duct is not rotated, and the separation bands can be shifted as necessary along the magnetic susceptibility axis by changing fluid concentration (magnetization). The Model 1000E can further effect both adjustments through change of the magnetic field.

Unlike many conventional separation processes, Magstream™ drives particles in opposite directions and does not rely on relative rates of movement to achieve separation. This movement in opposite directions provides an important inherent capability for precise separations independent of particle shape, size or size distribution. In addition, separation conditions may be adjusted to amplify the forces resulting from density and magnetic property differences, enabling effective rates of separation even with small property differentials.

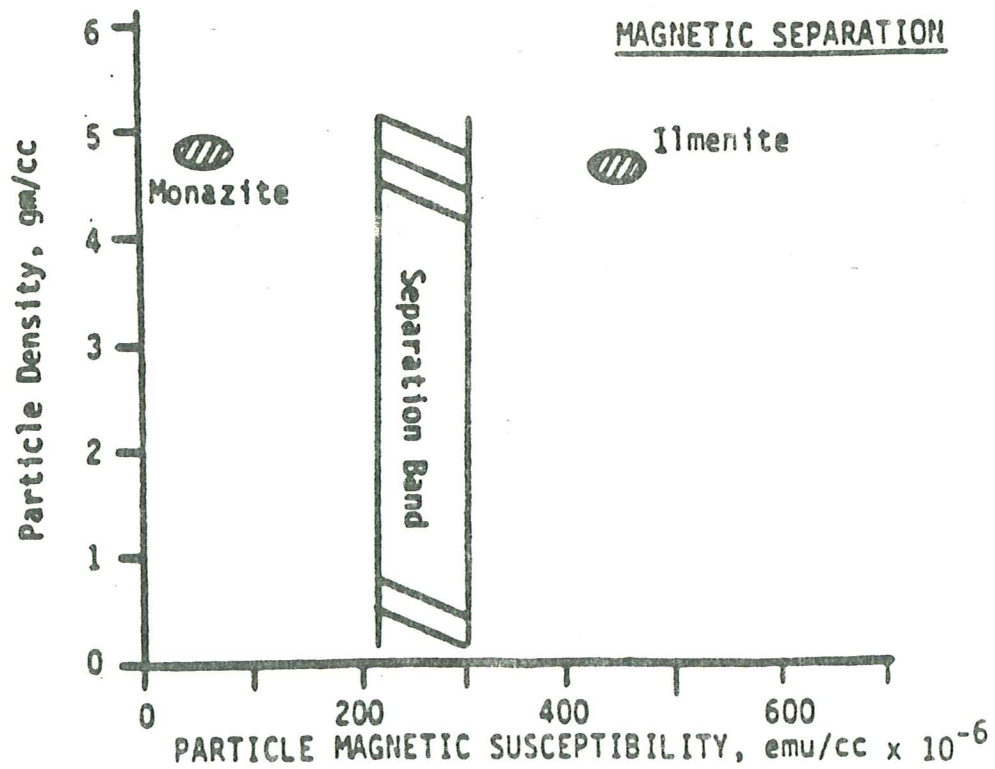
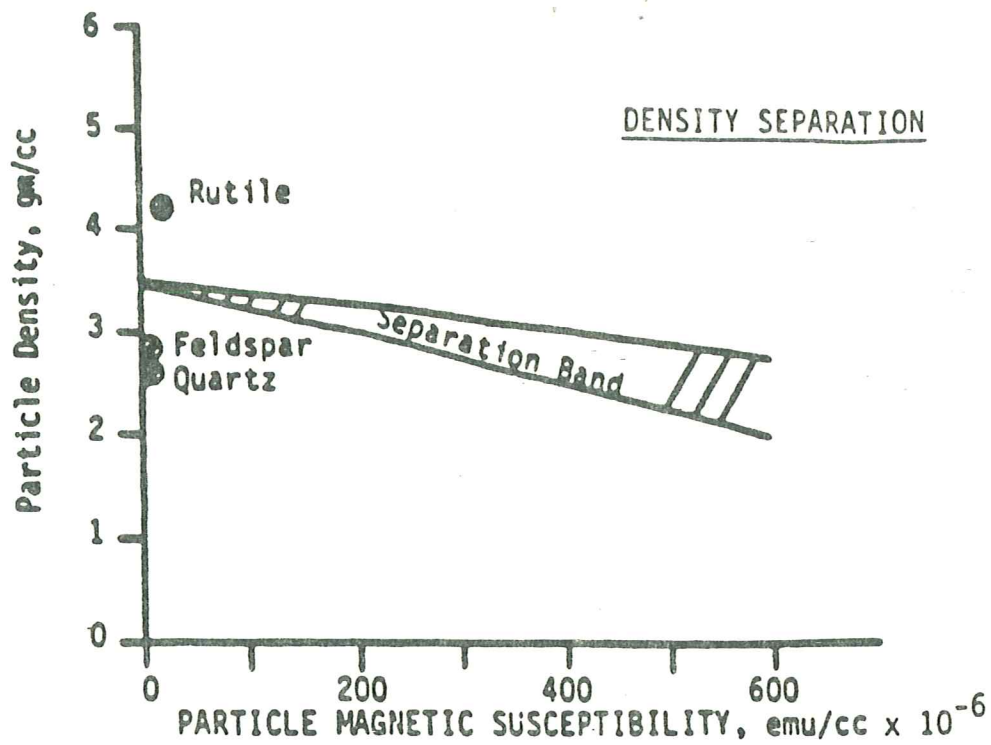


Figure 1 - Typical Magstream™ Separations Displayed on Graphs of Particle Properties

TABLE 1 - Example Magstream™ Applications and Test Results

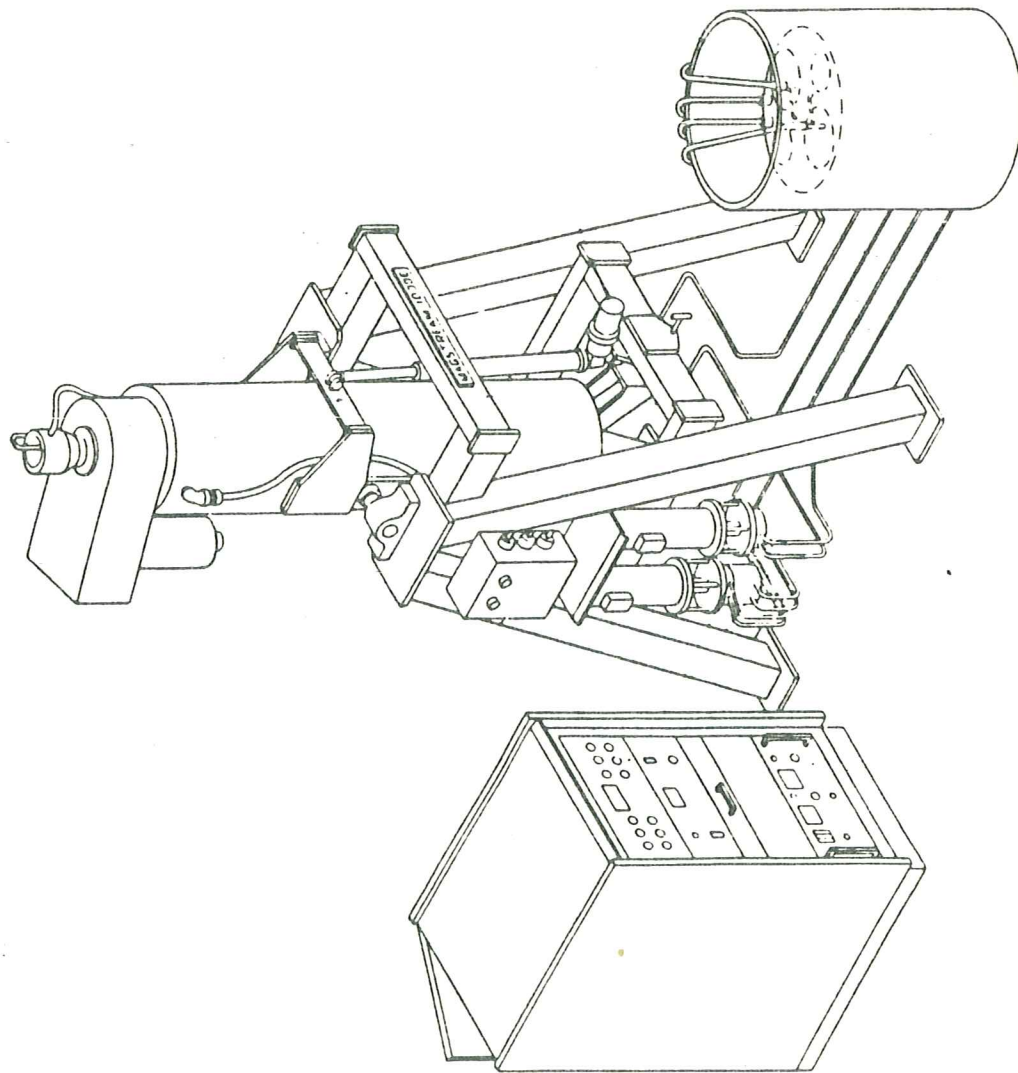
Item No.	Sample Description	Sample Constituents	Separation and Split Point	Separation Results
I.	Dunal Placer (2.73% heavies)	Garnet, magnetite, ilmenite, titanomagnetite, rutile, zircon, pyroboles, tourmaline, staurolite trace heavies, quartz, feldspar sulfides	Single pass, based on density at 2.96 g/cm ³	Heavy mineral grade = 98.73% Heavy mineral recovery = 99.17%
II.	Strand-line Placer (4.07% heavies)	Garnet, pyroboles, titanomagnetite, magnetite, ilmenite, rutile, zircon, trace heavies, quartz, feldspar	Single pass, based on density at 2.96 g/cm ³	Heavy mineral grade = 98.81% Heavy mineral recovery = 99.03%
III.	Genundewa Limestone (conodont bearing carbonate)	Conodonts, calcite, dolomite, minor amphiboles, siderite, pyrite, micrite	Pass #1, based on density at 2.96 g/cm ³ Pass #2, based on density at 3.32 g/cm ³	Conodonts grade = 81.17% Overall conodont recovery = 93.21%

MAGSTREAMTM

From IGC

THE MODEL 1000E

FOR HIGH VOLUME LAB
OR PILOT PLANT USE



- HIGH-THROUGHPUT FLOW-THROUGH SEPARATION SYSTEM FOR LARGE SAMPLES OR CONTINUOUS OPERATION
- FLOOR MOUNTED, WITH POWER OPERATED TILTING SUPPORT FRAME FOR EASY ACCESS
- VARIABLE FIELD FOR VERSATILITY OF USE
- INTEGRAL FLUID RECIRCULATION
- LARGE PRODUCT COLLECTOR/FLUID RESEVOIR
- FULLY INSTRUMENTED WITH SEPARATE CONTROL CABINET
- REMOTE MAGNET COOLING UNIT

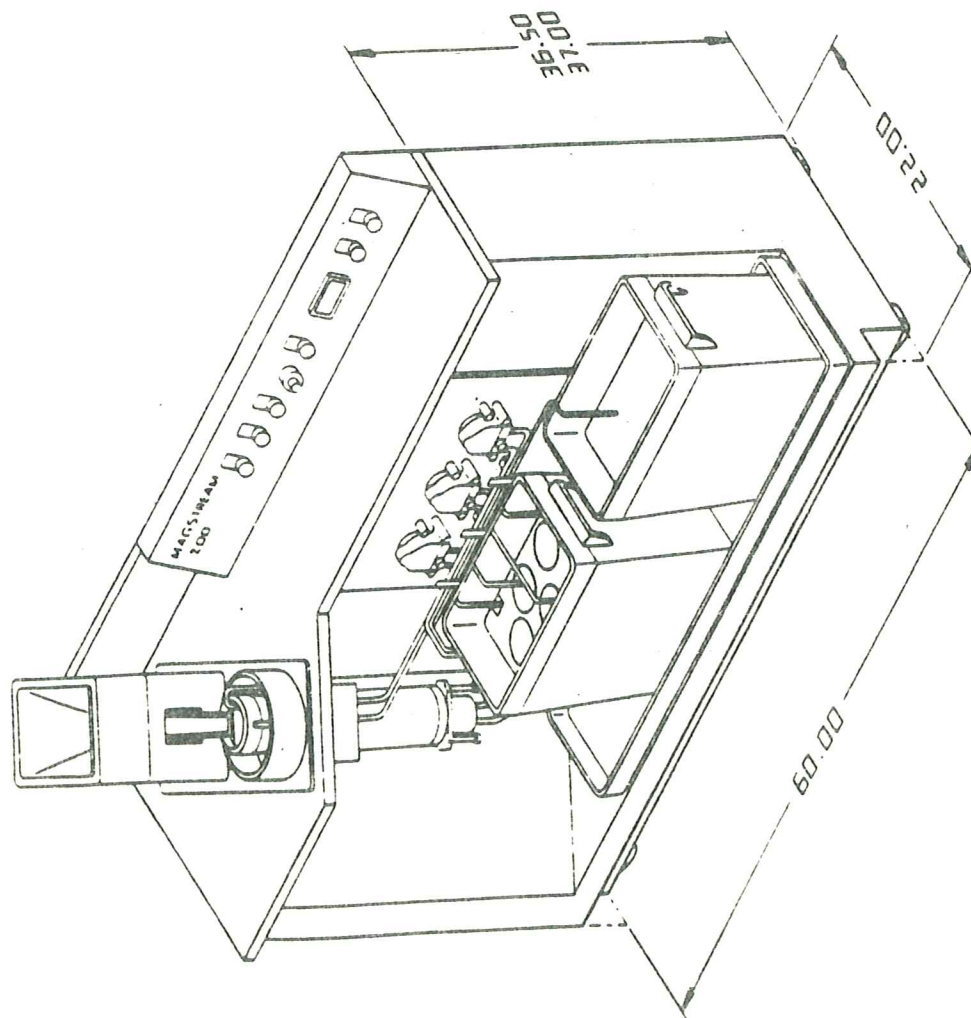
MAGSTREAM™

From IGC

THE MODEL 200

FOR GENERAL LABORATORY USE

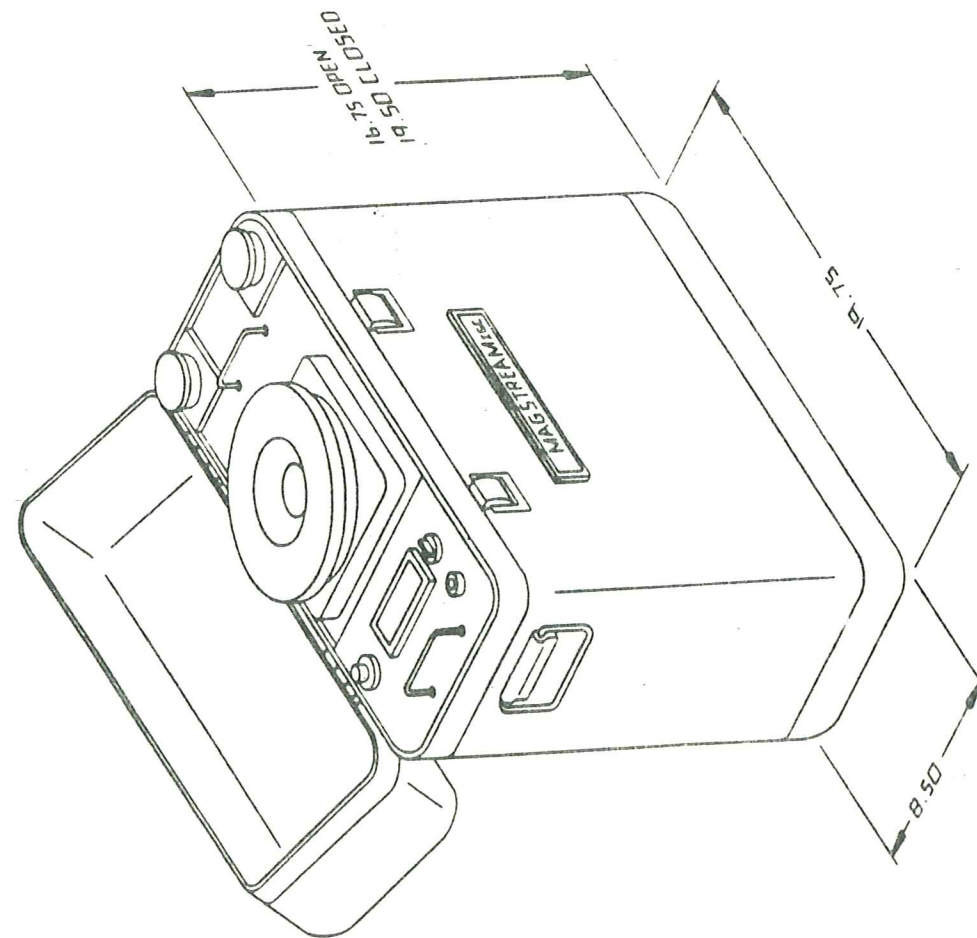
- LAB BENCH STYLED CABINET
- REMOVABLE WHEELS FOR OPTIONAL MOBILITY
- FLOW-THROUGH SEPARATION SYSTEM FOR LARGE SAMPLES OR FINE MATERIALS
- INTEGRAL SAMPLE FEED AND PRODUCT COLLECTION
- FULLY INSTRUMENTED, WITH COUNTER-TOP CONTROL PANEL
- ACCESSORY CUP INSERT SYSTEM FOR THE BATCH SEPARATION OF MULTIPLE SMALL SAMPLES



ENSIONS IN INCHES)

MAGSTREAMTM

From IGC



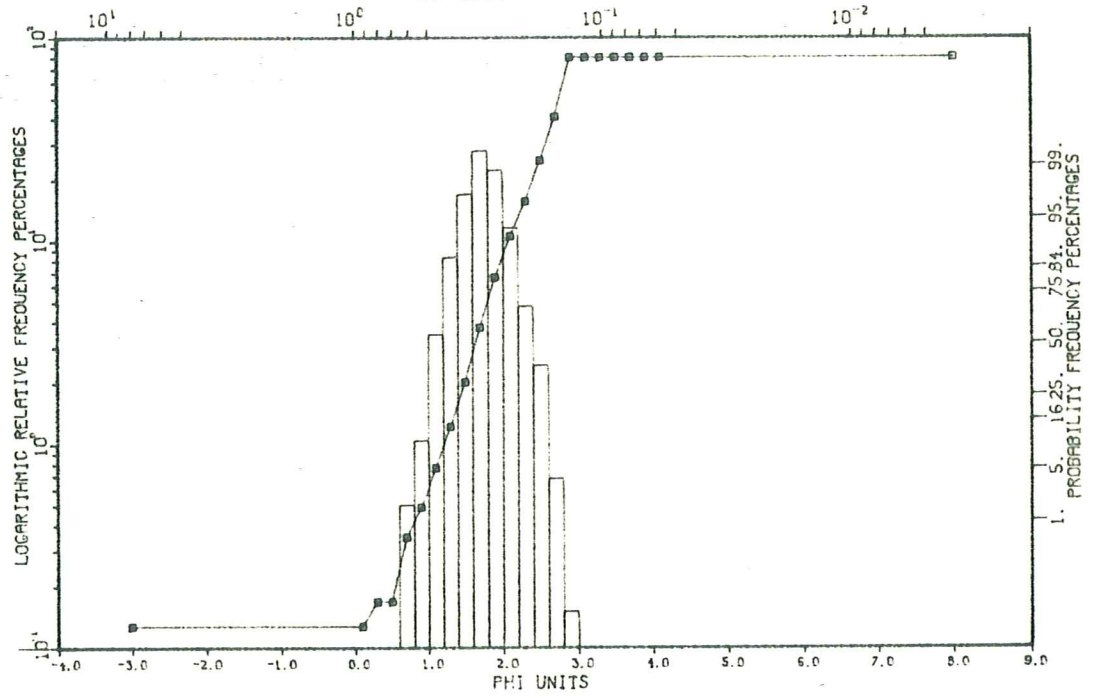
THE MODEL 100 FOR FIELD OR BENCHTOP* USE

- RUGGED INTEGRAL TRANSPORT CASE
- REMOVABLE CUP INSERTS FOR MULTIPLE BATCH SAMPLES
- RAPID SEPARATION OF SAND-SIZED MATERIALS

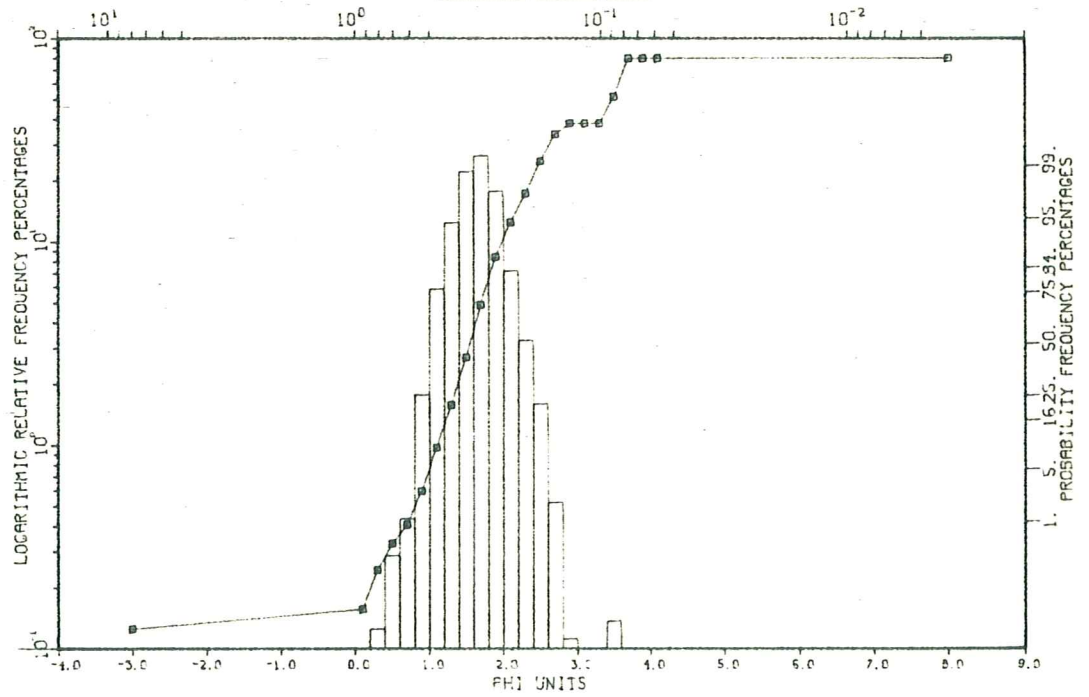
* ALSO CAN BE INSERTED INTO
STANDARD LABORATORY COUNTERTOP

**APPENDIX 3. TEXTURAL PROPERTIES OF SAMPLES FROM SEPT-ILES
AND CAPE BRETON**

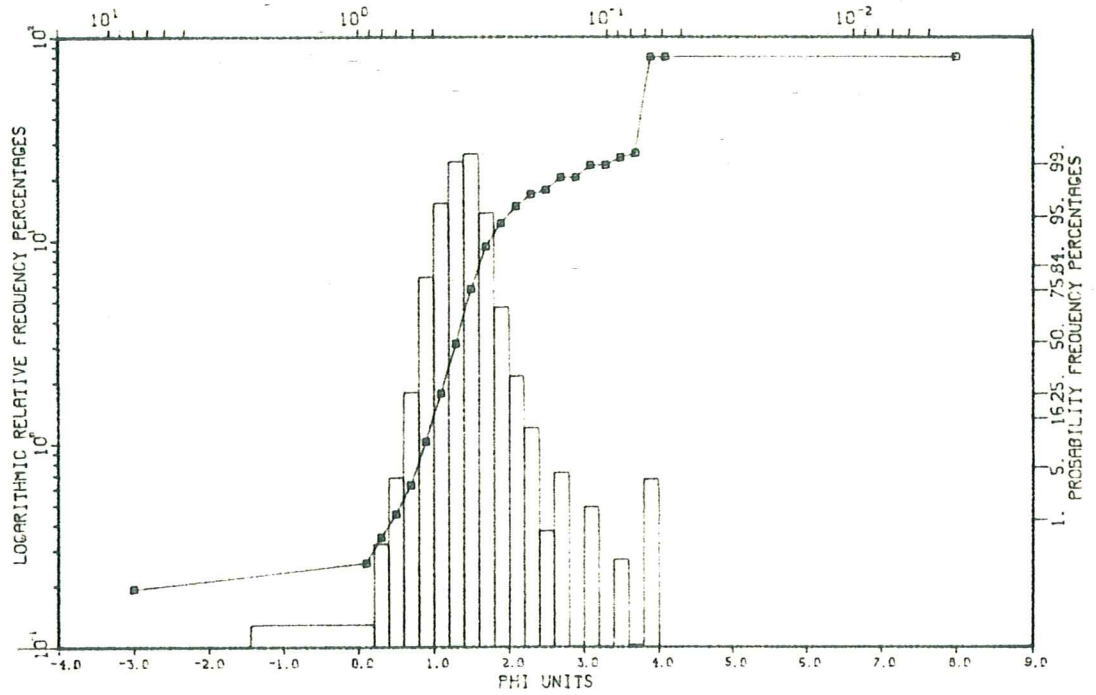
87023- SLG COND. JIM SYVITSKI
 SAMPLE NUMBER- 4745
 MILLIMETER EQUIVALENTS



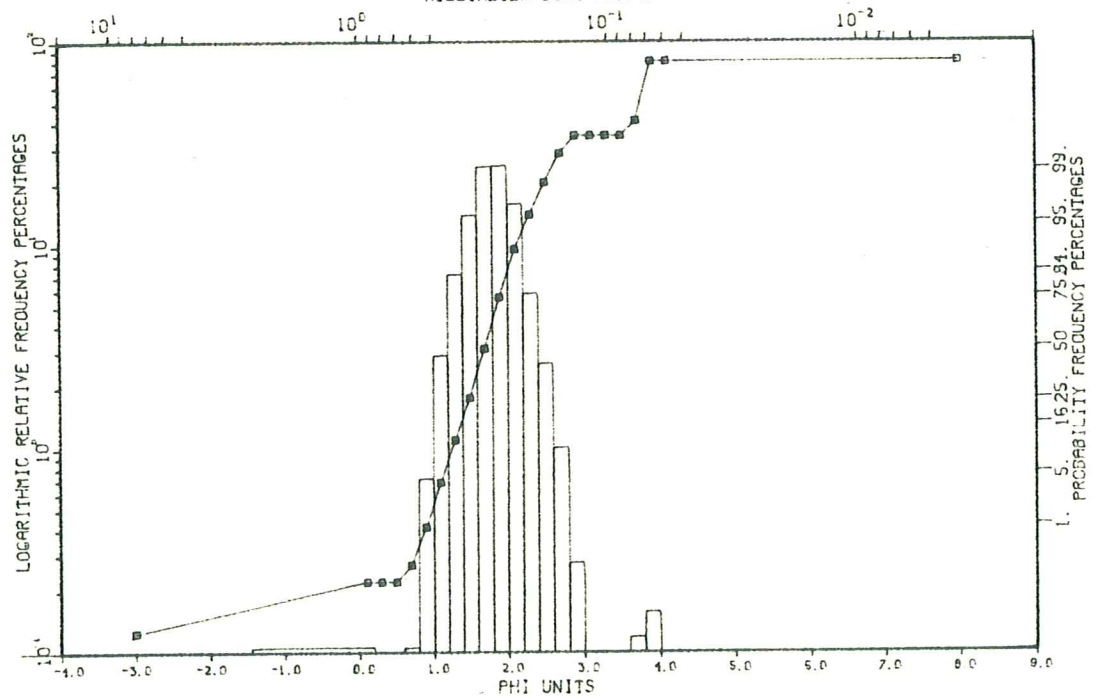
87023- SLG5 BASE OF CLIFF JIM SYVITSKI
 SAMPLE NUMBER- 4747
 MILLIMETER EQUIVALENTS



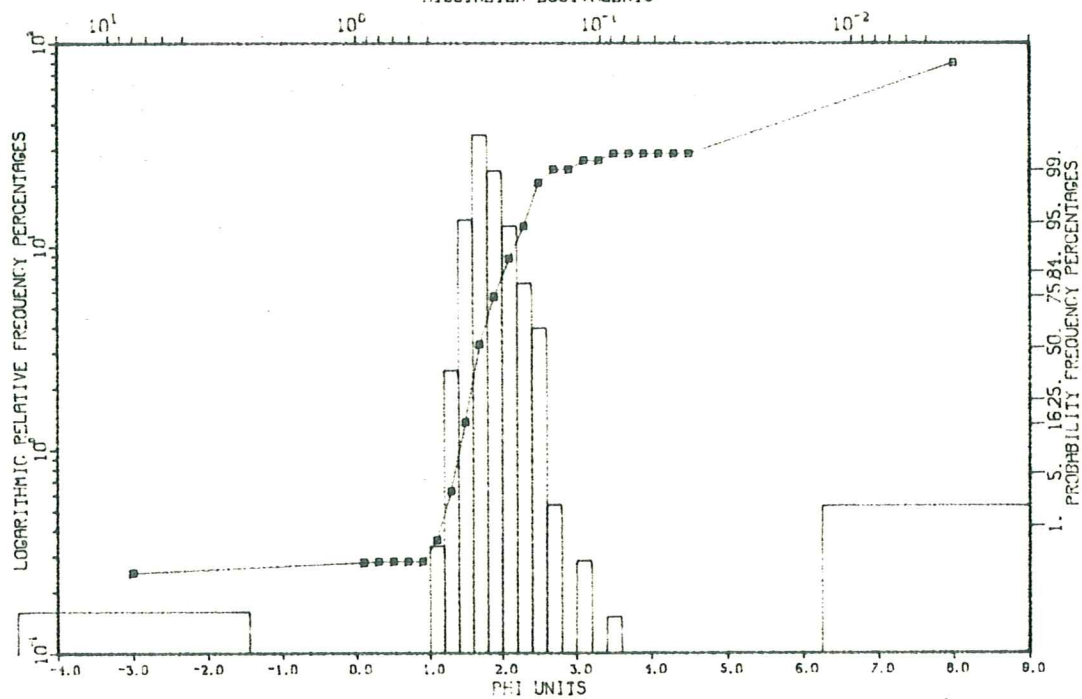
87023- SL8 BASE OF CLIFF 5 CM. JIM SYVITSKI
 SAMPLE NUMBER- 4749
 MILLIMETER EQUIVALENTS



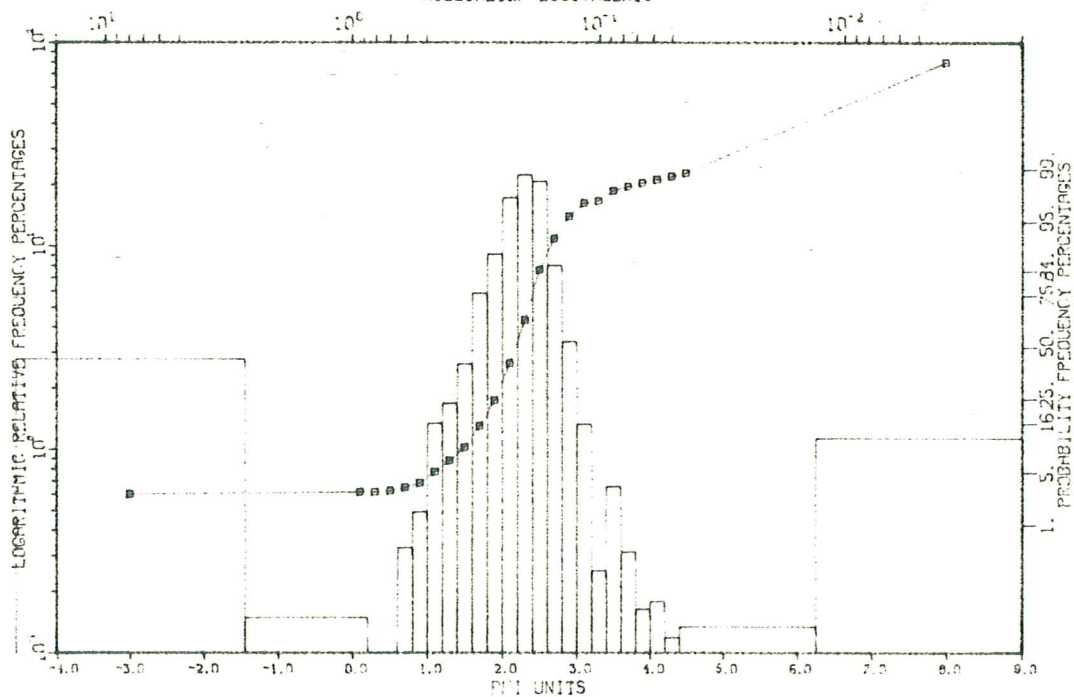
87023- SL62 BASE OF CLIFF JIM SYVITSKI
 SAMPLE NUMBER- 4754
 MILLIMETER EQUIVALENTS



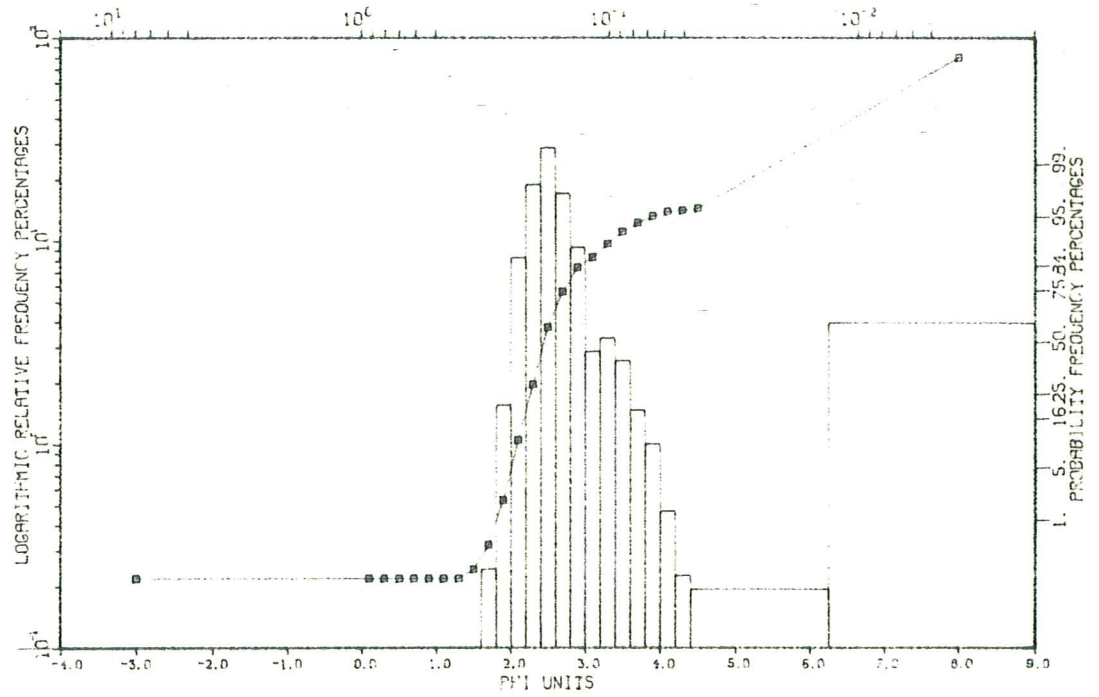
NV 87047-001 JIM SYVITSKI
 SAMPLE NUMBER- 4782
 MILLIMETER EQUIVALENTS



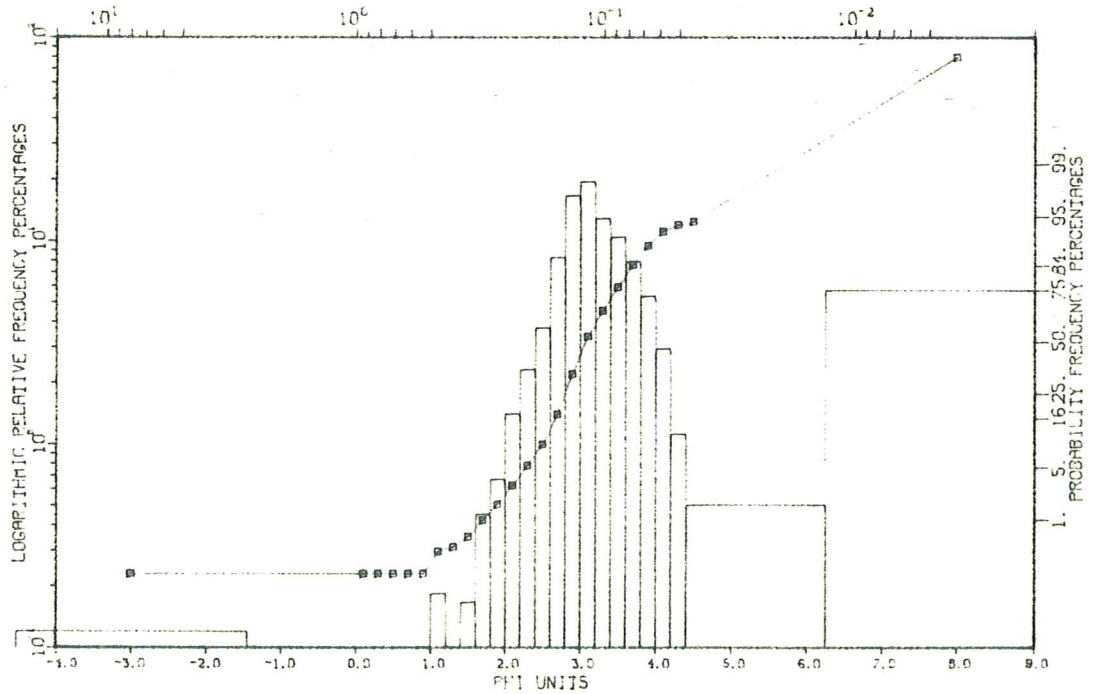
NV 87047-005 JIM SYVITSKI
 SAMPLE NUMBER- 4783
 MILLIMETER EQUIVALENTS



NV 87047-003 JIM SYVITSKI
 SAMPLE NUMBER- 4784
 MILLIMETER EQUIVALENTS



NV 87047-017 JIM SYVITSKI
 SAMPLE NUMBER- 4785
 MILLIMETER EQUIVALENTS



NV 87047-024 JIM SYVITSKI
 SAMPLE NUMBER- 4756
 MILLIMETER EQUIVALENTS

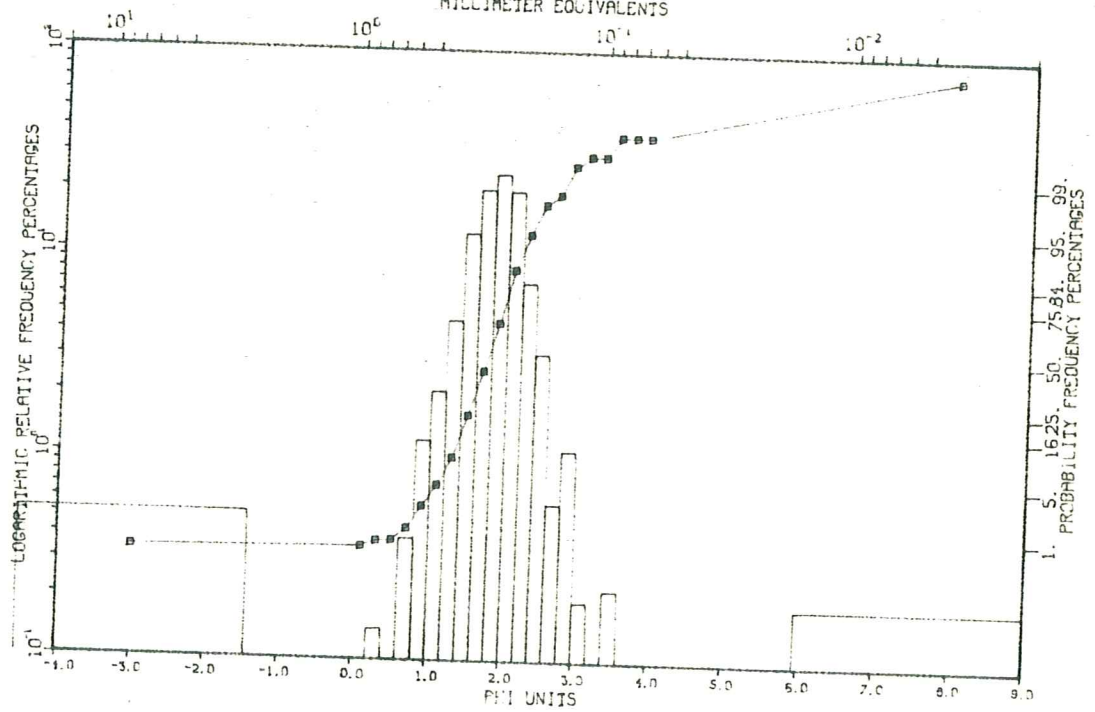


TABLE 2. X-RAY DIFFRACTION RESULTS OF STANDARD MIXES

SAMPLE #	MAJOR MINERAL TYPES	ACCESSORY MINERALS
GAR>63<355 MIC	REASONABLY PURE GARNET, SMALL AMT AMPHIBOLE	KNORRINGITE, ALMANDINE, MANGANOAN
HOR>63<355 MIC	MIXTURE OF KOZULITE AND RIEBECKITE	TOURMALINE, GARNETS (KNORRINGITE, SPESSARTINE, ALMADINE, MANGANOAN), PYROXENE (PIGEONITE), MICA
ILM>63<355 MIC	ILMENITE, RUTILE	ANATASE, ULVOSPINEL, SEPIOLITE, CLINOCHLORE, SANIDINE
MAG>63<355 MIC	MAGNETITE, PERICLASE, JACOBSITE	QUARTZ, GEIKIELITE, BRAUNITE, ACTINOLITE
QTZ>63<355 MIC	REASONABLY PURE QUARTZ	

TABLE 3. PETROGRAPHY OF STANDARD MIXES

STANDARD MIX	DOMINANT MINERAL	OTHER OPAQUES	ACCESSORY MINERALS & GRAINS
GARNET	GARNET -- 98%	1 %	HORNBLende -- 0.5% CASSETERITE -- trace
HORNBLende	HORNBLende -- 95%	5 %	TOURMALINE -- trace IGNEOUS ROCK FRAGMENTS -- trace
ILMENITE	ILMENITE -- 95%	trace	PYROXENE -- 2% RUTILE -- 2% HYPERSTHENE -- trace FELDSPAR -- trace
MAGNETITE	MAGNETITE -- 92%	trace	FELDSPAR -- 2-3% IGNEOUS ROCK FRAGMENTS -- 2% SEDIMENTARY ROCK FRAGMENTS -- 3% MICA -- trace
QUARTZ	QUARTZ -- 99.9%	trace	FELDSPAR -- trace SEDIMENTARY ROCK FRAGMENTS -- trace

